Whangamarino Wetland Hydrology Study

DEPARTMENT OF CONSERVATION

Stage 3: Hydrological Modelling

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Contents

Executive Summary

The Whangamarino Wetland in the Waikato region is a unique and important conservation reserve for flora and fauna, and it represents the second largest raised bog in New Zealand. As a result it is the home to several rare or vulnerable plant species and abundant bird life. Due to its unique values it has been recognised as internationally important under the Ramsar Convention.

With the introduction of the Lower Waikato Waipa Flood Control scheme and hydrodams along the Waikato River, as well as land use changes and intensification within the wider catchment, the flow regime within the wetland has altered. These changes have also resulted in changes to water quality. Changes to water levels and higher nutrient loads have encouraged the growth of invasive plant species into the raised peat dome.

The Department of Conservation (DOC) commissioned Jacobs to develop a hydrological water balance model as a tool to assist with management of the wetland. The objectives of this study were to:

- Develop an understanding of the hydrological functioning of the Whangamarino Wetland and the role that external factors such as flood scheme operation and the Whangamarino weir play in wetland inundation and water level regimes;
- Understand how wetland hydrology would likely change based on hypothetical scenarios relating to modified water management practices or different hydrological conditions.

The approach adapted was a hydrological water balance using a Soil Moisture Water Balance Model to estimate catchment runoff from rainfall, and routing of flow through a GoldSim model. The GoldSim model used a series of logical rules and parameters to convey the flow through the system while allowing for flood control scheme operating rules to be incorporated into the water balance.

Operating rules associated with the Lower Waikato Waipa Flood Control scheme have been incorporated into this model as logic statements. Rules include Lake Waikare target operating levels and gate controls.

The water levels of both Lake Waikare and the Whangamarino Wetland were calibrated to nearby stage recorders producing a very good fit for the calibrated period from 2000 to 2012. Pre 2000 the wetland operated under a different hydrological regime - the original weir having operated for only brief periods between construction in 1994 and failure in 1995. Since 2000, water levels have been relatively constant.

Five different scenarios were run through the calibrated model, in addition to the base situation, with the record extended back to 1966 through use of virtual climate rainfall data. The simulations were:

1) ***Base case:*** Base record extended back to 1966, assuming the current operating regime.

2) ***Lake Waikare modified regime:*** an increase in discharge from Lake Waikare to the wetland while still operating with the flood operating rules; and no discharge from Lake Waikare.

3) ***Land use changes:*** changes to catchment runoff assuming a greater portion of forestry in the upper hills.

4) ***Weir height:*** lower and higher weir heights at the downstream end of the wetland.

5) ***Basin sedimentation:*** to assess how 300,000m^3 and 500,000m^3 of additional sediment may impact on peak levels.

6) ***Whangamarino water level:*** A change was made to the Lake Waikare operating rules requiring discharge out of Lake Waikare into the Whangamarino Wetland (through the Pungarehu Stream) to be stopped when the water level within the Whangamarino Wetland exceeds 4m. Only when the wetland water level recedes below 4m, shall the Lake Waikare discharge resume. This is consistent with the Assessment of Environmental Effects (Rice Resources Limited 1998) for the Lake Waikare discharge, but is not reflected in the Lake Waikare Dam consent (101725). This scenario is discussed in depth in Section 5.3.

Note, these results are based on the current flow regime as per the calibration period from 2001 to 2012. Analyses therefore assume the impact of Whangamarino weir is a permanent feature within the hydrological cycle. Similarly changing land use practices within the catchment, permanent flow from Lake Waikare into the Whangamarino Wetland, and the Lower Waikato Waipa Catchment Control Scheme are considered part of the current environment. It should be noted that none of these features are part of the natural flow regime of the Whangamarino Wetland.

Results were analysed across three different measures: flood frequency analysis, average daily water level (distribution curve), and the proportion of time specific water levels were exceeded.

The most noticeable difference between the scenarios was for the water level distribution curve. This curve is shown below in Figure A. Both the higher and lower weir scenario resulted in reasonable changes to average daily water levels below 4m. The scenario without discharge from Lake Waikare resulted in reduced water levels across the water level distribution curve.

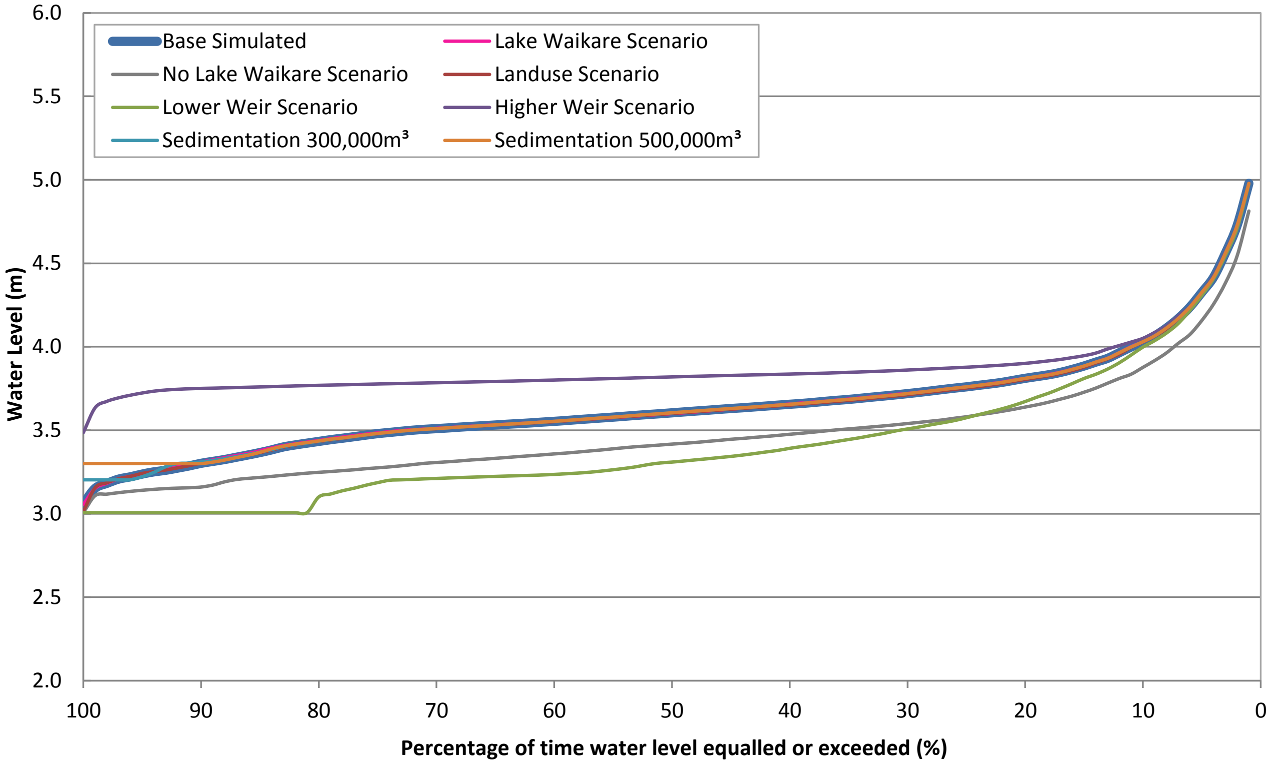

Figure A. Water level distribution curve across the modelled scenarios.

Flood frequency analyses of the simulated scenarios wetland water levels were undertaken. This was to estimate the peak flood water level for a given probability event being equalled or exceeded in any given year. The results showed very little variation across the simulated scenarios, with the exception of the scenario with no Lake Waikare discharge which exhibited lower peak water levels. Results for the 35%, 10% and 1% annual exceedence probabilities are shown below in Table A. Further results are detailed in Section 5.2.

Table A. Estimated annual exceedence probability peak water levels under the different scenarios.

Scenario	Peak Water Level per Return Period (Annual Exceedence Probability)		
	Annual (35%)	10 year (10%)	100 year (1%)
Extended (Base)	4.96	5.52	6.06
Lake Waikare increased discharge	4.96	5.52	6.06
No Lake Waikare discharge	4.79	5.40	6.03
Land use	4.96	5.53	6.06
Weir Lower	4.95	5.52	6.05
Weir Higher	4.97	5.53	6.06
Sedimentation 300,000m3	4.96	5.53	6.06
Sedimentation 500,000m3	4.96	5.53	6.06

The peak water levels during flood events showed very little variation. This is largely because the magnitude of the change is dampened during flood events. Also, it is often during these large events that the Whangamarino control gates are closed or discharge is controlled by factors below the Whangamarino weir (such as the Waikato River water level or conveyance capacity of the downstream channel). Once the gates are closed, variables such as weir height become irrelevant.

A number of data shortfalls were identified in this study, however, the sensitivity analyses and frequency analyses showed little variation to peak flood levels. Further detailed refinements may only result in small improvements. Greater benefit will most likely result from further calibration of the model to extreme events. Currently the model is calibrated to a peak water level at the Whangamarino Falls Rd stage record of 5.6m. This is the 2008 flood. Similarly, calibration to the spatial extent of extreme events would be useful.

The outcome of the calibrated baseline model and model simulations is to assist DOC with management of the wetland. By having a greater understanding of the flood extent, the frequency that parts of the wetland are inundated, and the duration of inundation, will help with the planning and location of fences, monitoring lines and planting etc., as well as with the development of scenarios to protect sensitive areas.

The GoldSim model is a simplified representation of the flow regime and as a calibrated model allows parameters such as the weir height or flood control scheme operating rules to be altered to assess the impact of changes on wetland water levels. The model uses rainfall records from 1966 to present day to allow the running of long-term simulations to assess how relative changes may impact on the duration and extent of flooding. In addition, the model is quick to run so allows the user to test multiple scenarios.

It should be noted that the GoldSim model has not been developed as a hydraulic model or a process model so does not take into account hydraulic parameters such as flow conveyance and velocity, nor how vegetation may impact on conveyance and the flood extent. Model parameter changes should be considered relative changes that provide an indication of how flood levels are impacted. Further detailed analyses of proposed scenarios should be undertaken prior to the implementation of any scenario.

A 2D hydraulic model using the DHI Mike21 software has been developed for a separate project that has run alongside this study. This hydraulic model was developed to help define the flow conveyance to enhance understanding of water quality constituent loads during specific flood events (Jacobs, 2014). This model would be a more appropriate platform to test specific proposed management options within the wetland. In addition, further refinement of the 2D model could be undertaken, such as combining the 2D floodplain with a 1D model of the river channel. This would more accurately reflect the hydraulics of the river channel. The downside of this hydraulic model is model run times are long, therefore it is only practical to use it to assess the impact of changes for given flow events, rather than long-term simulations provided through GoldSim.

To assist Department of Conservation with their management of the wetland, and to reduce peak flood levels (specifically nutrient laden waters reaching the raised peat dome), further scenarios could be developed. These may include changes to the operating rules outside of the Lower Waikato Waipa Flood Control scheme requirements, such as Lake Waikare target water levels and discharge. This may improve understanding of how larger changes to the hydrological cycle may assist with management of the wetland.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to develop a hydrological water balance model as a tool to assist with management of the wetland in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

Analyses in this report relied on water level, flow, rainfall and evaporation data. It has been assumed that this data is true and correct, and it has not been independently verified. The hydrological analysis that supports this report is based on relatively short records and therefore has a degree of uncertainty. The conclusions drawn in this report are based on the literature cited and analyses undertaken.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs's Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party

1. Introduction

1.1 Background

To assist with managing the Whangamarino Wetland, the Department of Conservation (DOC) employed Jacobs to develop a water balance model of the catchment. This model is a conceptual model of the water cycle and was developed to help DOC understand the extent and duration of inundation, and how different management regimes may impact on water levels within the wetland. Ultimately, the model will assist in the hydrological management of the peat bog and invasive flora species.

Water levels in the lower Waikato catchment are managed by Waikato Regional Council to assist in providing flood protection to the lower Waikato region (Waikato Regional Council, 2011). River ‘training’, sand abstraction and possible prevention of sand replacement from the Waikato River hydro dams caused bed and water surface levels in the Waikato River to drop. Between 1958 and 1990 the Waikato river bed level between Meremere and Mercer fell by an average of 1.3 m (Ramsar, 1992).

Due to the resulting change in the hydraulic grade of water between the Whangamarino Wetland and the Waikato River, bed levels in the wetland also fell. This lowered water levels in the wetland since the late 1960’s, and reduced the duration and extent of flood inundation (lower peak water levels) (Ramsar, 1992).

This was thought to pose a significant threat to the wetland ecosystem through the drying of peat bogs and invasion of exotic flora (Blyth, 2011). For this reason a large rock rubble weir was installed at the mouth of the Whangamarino River in 1994 to help restore the minimum water levels in the wetland. After failure in 1995 this was reconstructed in 2000 (with a lower crest at 2.95m RL) and repaired in 2010.

1.2 Objectives

The main objective of this study is to improve understanding of the hydrology of the Whangamarino Wetland, which has been identified as the key driver of the various ecological habitats. This was achieved through development of a water balance model that provides greater understanding of:

- the hydrological functioning of the Whangamarino Wetland;
- the role that external factors such as flood scheme operation and the Whangamarino weir play in wetland inundation and water level regimes; and
- how wetland hydrology would likely change based on hypothetical scenarios relating to modified water management practices or different hydrological conditions.

1.3 Previous Work

This report relates to Stage 3 and 4 of a larger study with the objectives as described above. The project stages are summarised as follows:

- Stage 1a addressed planning of the monitoring options and discussion of available hydraulic modelling approaches.
- Stage 1b addressed installation of equipment and commencement of the monitoring programme.
- Stage 2 was a desktop review of water level and vegetation data, a conceptual model of the water cycle and additional data collection and monitoring requirements.
- Stage 3 (this report) refines the conceptual model developed in Stage 2 populating the model with actual data, as well as calibration, verification and predictive simulations.
- Stage 4 is an external peer review.

Information related to the previous stages can be found in the report:

SKM, 2010. *Whangamarino Wetland Hydrology Study – Preliminary Analyses.* Prepared for Department of Conservation, 19 February 2010.

1.4 Report Layout

This report is laid out in the following sections:

Section 1 provides an introduction and overview of the report.

Section 2 summaries the water cycle and flood control scheme affecting the Whangamarino Wetland.

Section 3 outlines the sources of data used to develop the water balance model and calibration, and assumptions and outstanding gaps in knowledge.

Section 4 documents the water balance modelling framework and modelled hypothetical scenarios.

Section 5 displays results from the analyses and duration/inundation maps.

2. The Whangamarino Flow Regime

2.1 Flow through the Whangamarino Wetland

The Lower Waikato Waipa Catchment Control Scheme (LWWCS) has resulted in an alteration to the natural Whangamarino water cycle. Figure 1 shows the layout of the Whangamarino catchment, and its constructed features, and Figure 2 as a schematic of the current flow regime to help explain how the water cycle has changed.

Prior to LWWCS during normal flow conditions Lake Waikare drained through the Te Onetea Stream. When the Waikato River peaked, flow through the Te Onetea Stream reversed (flowed into Lake Waikare), and any overflow discharged over the Northern Foreshore Spillway into the wetland. At the mouth of the wetland (at the confluence of the Waikato River and Whangamarino River) water could backflow into the Whangamarino catchment which provided natural flood storage until Waikato River levels receded (Wildlands Consultants, 2011).

Under the flood control scheme control gates were installed at the Te Onetea culvert, on the Pungarehu Stream at the Lake Waikare outlet and at the mouth of the Whangamarino River. Flow from the Waikato River into Lake Waikare and Lake Waikare levels became regulated and volumes largely retained within the flood footprint through stopbanks. Consequently discharges from Lake Waikare into the Whangamarino Wetland became controlled.

Under the current scenario the flow regime can be divided into its components and explained as below:

- Runoff from the Matahuru catchment and the area surrounding Lake Waikare drains directly into Lake Waikare where it is stored because of the Lake Waikare control gates then released down the Pungarehu Stream.
- Runoff from the Whangamarino, Reao and Maramarua catchments drains directly into the wetland.
- Within the upper Maramarua catchment is the Mangatangi Dam. Runoff from this catchment is reduced through water abstraction.
- A road causeway crosses the wetland immediately south of the Maramarua River. This is a permeable causeway allowing the slow drainage of flow from the Causeway catchment, usually in a south to north direction.
- A bridge through the upper section of the causeway allows flow from the Kopuku Stream to join the Maramarua Stream. A culvert is located in the causeway near the intersection with Island Block Road to assist in draining flow from the south to the north.
- A flood in the lower Waikato River of approximately a 2% AEP (a 2% chance of an event this size or larger occurring in any given year, or a 1 in 50 year return period) is designed to spill from the Waikato River into Lake Waikare via the Rangiriri Spillway. This occurred during the July 1998 event. The Rangiriri Spillway has been designed to convey 280 m^3/s in a 1% AEP event in the Waikato River (Waikato Regional Council, 2011).

Figure 1. Catchment map of Whangamarino and adjacent catchments.
(see A3 attachment at rear)

Figure 2. Schematic of Whangamarino flow regime.
(see A3 attachment at rear)

2.2 Regulated flows

The LWWCS is controlled through a number of resource consents regulating water levels and flow, which are summarised below. These resource consents have been built into the wetland water balance model as operating rules.

- Where the water level of the Waikato River at the Te Onetea mouth is below RL 7.0 m (Moturiki datum) and below the water level of Lake Waikare, the Te Onetea Gate shall be closed. Where the water level of the Waikato River at the Te Onetea mouth is below RL 7.0 m (Moturiki datum) and above the water level of Lake Waikare, the Te Onetea Gate shall be opened. Where the water level of the Waikato River at the Te Onetea Stream mouth is at or above RL 7.0 m (Moturiki datum), the Te Onetea Gate shall be closed until the water level at the Te Onetea Stream mouth falls below 7.0 m. [Resource consent no. 101716]
- The discharge of water from the Waikato River into the Te Onetea Stream shall not exceed 6 m^3/s at any time. [Resource consent no. 101718]
- Lake Waikare target water levels are given in Table 1. Additional controls are stipulated in Resource consent no. 101725 relating to the required gate opening for rising and falling lake levels. [Resource consent no. 101725]

Table 1. Lake Waikare target water levels.

Period	Control Level	Minimum	Maximum
1 April – 30 September	5.5	5.4	5.6
1 October – 31 December	5.65	5.55	5.75
1 January – 31 March	5.6	5.5	5.7

- Where the Lake Waikare water level is between 5.4 m RL and 5.75 m RL (Moturiki datum) the fish pass sluice gate shall be fully open. Where the Lake Waikare water level is outside of this range the fish pass sluice gate shall be closed. [Resource consent no. 101721]
- The maximum abstraction rate from Lake Waikare for operation of the fish pass shall not exceed 0.9 m^3/s at any time, and shall not be exercised at any time when the level of Lake Waikare is at or below the seasonal control levels. [Resource consent no. 101722]
- The taking of water from Lake Waikare (to the Pungarehu Stream) shall not exceed a rate of 53 m^3/s at any time. [Resource consent no. 101726, 101727]
- Where water levels in the Waikato River are above water levels in the Whangamarino River and are rising, the Whangamarino Gate shall be closed. Where the water level in the Waikato River is below the level of the Whangamarino River and falling, the Whangamarino Gate shall be opened. [Resource consent no. 101729]

In addition to the LWWCS resource consents, DOC hold a resource consent to dam the Whangamarino River below the confluence of the Whangamarino and Maramarua Rivers using a weir. The maximum weir height at the crest should not exceed 3.14 m RL (Moturiki datum). [Resource consent no. 890227].

Runoff from the Maramarua catchment is reduced by extraction from the Mangatangi Dam for water supply purposes. The rate of abstraction varies, typically between 80 million litres per day (0.93 m^3/s) and 125 million litres per day (1.45 m^3/s). The resource consent requires compensation flow into the Mangatangi River (at Workman Road) with a minimum flow of 0.283 m^3/s from December to April, and 0.20 m^3/s from May to November.

3. Data Inputs

3.1 Sourced Data

Data has been sourced from a number of sources for this study. This section describes the different input components, assumptions and exclusions. The model was developed to meet the main objective of the study, which was to improve understanding of the hydrology of the Whangamarino Wetland through a conceptual surface water model of the interactions between the Waikato River and runoff from the Whangamarino catchment. The Lake Waikare and Whangamarino Wetland hydrological system as modelled in the water balance model is represented conceptually in Figure 3.

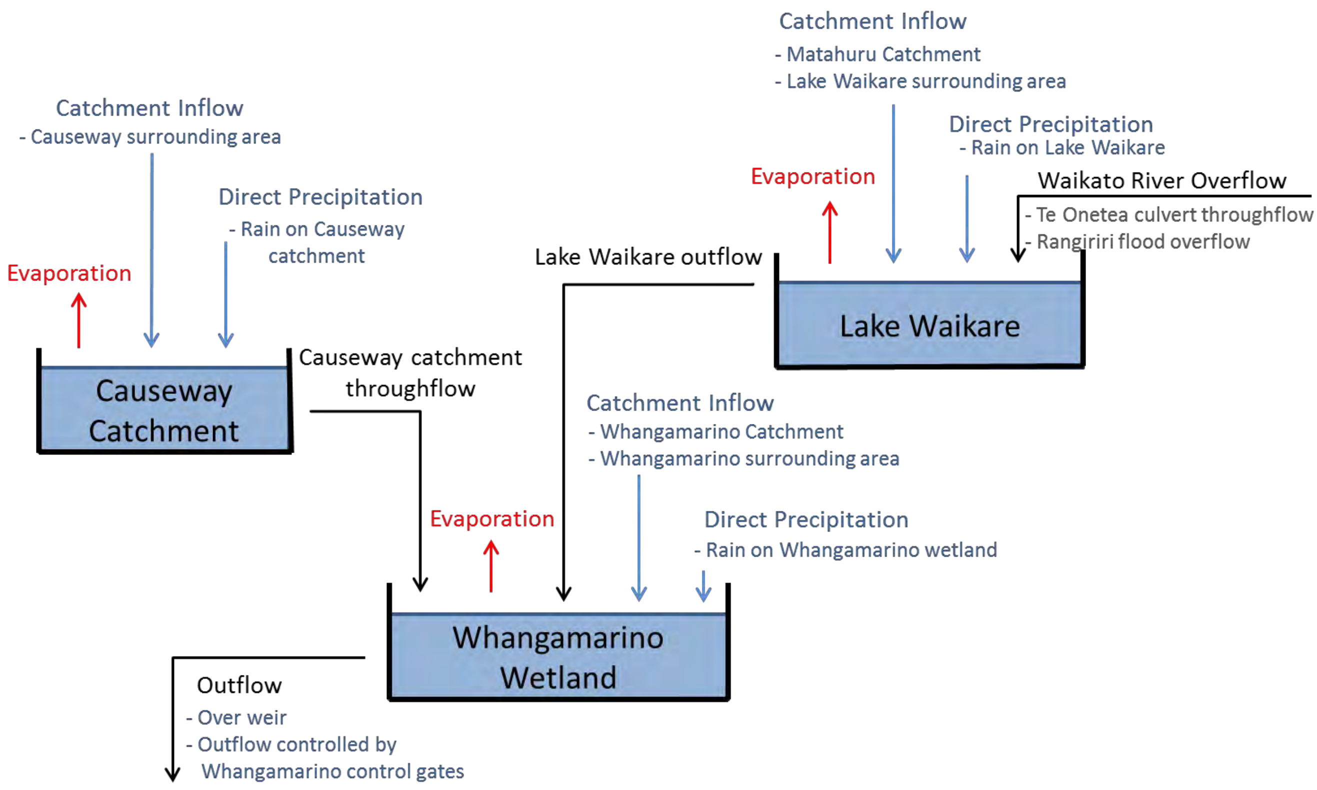

Figure 3. Whangamarino Wetland conceptual water balance model.

The lake and wetland behave as reservoirs with a number of inflows and outflows. Inflow to Lake Waikare includes diversion overflow from the Waikato River, catchment runoff and direct rainfall on the lake. Outflows are lake surface evaporation and controlled releases into Whangamarino Wetland through the gated outlet.

For the purposes of this assessment, the Whangamarino Wetland storage is defined as all surface water stored upstream of the Whangamarino control gates in both the Whangamarino and Maramarua catchments (see Figure 1 for location of catchments). This includes water stored above the surface in both minerotrophic[1] and ombrotrophic[2] regions and within river channels.

Inflow to Whangamarino Wetland includes controlled outflows from Lake Waikare, catchment runoff and direct rainfall on the open water surface and ombrotrophic regions, e.g. bogs. Outflows are open water surface evaporation and outflow at the weir.

[1] Minerotrophic refers to soils and vegetation whose water supply comes mainly from streams or springs.
[2] Ombrotrophic ("cloud-fed") refers to soil or vegetation which receive all of their water and nutrients from precipitation, rather than from streams or springs.

The data sources and components of the water balance model are detailed below.

3.1.1 Surface Water & Storage Areas

There are a number of ponding areas within the catchments in the form of either natural storage areas within the terrain, or specific flood relief ponding areas (for example the ponding zone between Rangiriri and Lake Waikare). For the purpose of this study it is assumed that all rainfall, runoff and overflow within the catchment drain to either Lake Waikare or the Whangamarino Wetland. This assumption is reasonable given the daily timestep of the model, the limitations with estimating the depth-area-volume storage basins, and that inflow and outlet gates are often closed during flood events forming a closed hydrological cycle.

3.1.2 Storage Volume

The LiDAR data for the wetland areas has been filtered to largely remove the impact of vegetation and determine the true storage volume of the wetland (rather than the volume from the tree canopy). Vegetation takes up some of the storage volume, though the exact volume is unknown. A variable bulking factor (based on depth) has been assumed.

In addition to the bulking factor, a wetted area has been added to the surface area component of the depth-area-volume relationship. This was added to assist with calibrating the wetted surface area to the flood extent noted during the 1998 flood.

3.1.3 Groundwater

The impact of groundwater in the GoldSim model has been ignored as it falls outside the scope of this study. The influence of groundwater on a daily water balance is limited as the peat soils within the wetland are perennially saturated and groundwater flow variations within the peat are relatively minor due to the low variation in hydraulic gradient and low permeability of peat. In addition, the groundwater component is an insignificant component of the water balance during flood events, as surface water inputs dominate. The relatively small component of groundwater inputs to the Whangamarino Wetland from the upper catchment is accounted for with the inflow simulated by the Soil Moisture Water Balance Model (SMWBM).

The restiad peat bog, being made up of fibrous organic matter, has a large water content and therefore shrinks and swells in response to changes to the level of the water table. A high rainfall and water table leads to swelling of the bog, whereas dry weather and a low water table leads to shrinkage (Blyth, 2011). The peat bog oscillations have not been considered as part of the simplified representation of the flow regime as these oscillations fall within the limits of accuracy of the wetland depth-area-volume curve and would only affect a small percentage of the available storage volume.

3.1.4 Rainfall and Evaporation

A number of rainfall records were provided for this study. A list of the sites and their record length is provided in Appendix A GoldSim Inputs. No comment files were provided with any of the data, so all values have been assumed to be valid and correct.

Evaporation data was derived from mean monthly evaporation data from the Te Kauwhata M.A.F recorder.

3.1.5 Water Level

A number of water level recorders are used to trigger gate openings and closings within the GoldSim model as well as for calibration of simulated water levels. These recorders include the Waikato River at Rangiriri, the Waikato River at Control Structure Outlet, and Whangamarino at Falls Road. These records are influenced by tides. The daily average level has been used in the simulation. No comment files were provided with any of the data, so all values have been assumed to be valid and correct.

Calibration of Lake Waikare has been based on the Lake Road water level record. Calibration of the Whangamarino Wetland has been based on the Falls Road water level record. At times both recorders are subject to wave runup and back flow caused by flooding within the wetland. To minimise the impact of short term fluctuations the daily average water level has been used in calibration.

3.1.6 Stream Flow

A number of flow records were provided for this study. A list of the sites and their record length is provided in Appendix A GoldSim Inputs. No comment files were provided with any of the data, so all values have been assumed to be valid and correct. Short gaps in the stream flow records have been interpolated (straight-line infilling) to provide a continuous data series.

The flow records at Mangatangi River at SH2, Whangamarino River at Slackline and Matahuru River at Waiterimu Road have been used to calibrate the SMWBM parameters for simulated stream flow from the upper catchments. Both the Slackline and Waiterimu Road flow records have been noted as having potential poor rating curves. These records have been assumed to be correct for this study, though sense has been applied when using them to calibrate runoff from the SMWBM (see Section 4.3).

Within the Maramarua catchment runoff is reduced by a water take from the Mangatangi Dam. Abstraction from the Dam was estimated by calibrating the SMWBM runoff estimate (including abstraction estimates) to the Mangatangi at SH2 recorder. The distribution of flow between the natural record and calibrated record, for the overlapping period 1986-2012 was then compared. The SMWBM had a good fit to the Mangatangi at SH2 flow recorder when a variable abstraction rate and allowance for increases in storage volume during floods was assumed (flow duration curves are compared as part of the calibration in Section 4.3).

3.1.7 Flood Operating Regime

Where possible the flood operating rules as summarised in Section 2.2 have been incorporated into the model. With these rules there is still an element of judgement and human influence to decisions. To model these elements, mathematical equations have been developed. These equations are based on reasonable assumptions and calibrated to the gauged record. A sensitivity analysis has been conducted to determine the impact that different decision making components (most notable Lake Waikare gate operation) have on modelled water levels within the wetland.

The design flow for water over the Rangiriri spillway is up to 280 m^3/s in a 1% AEP event (Waikato Regional Council, 2011). In the Waikato River during the 1998 flood event (approximately a 1% AEP), flow over the Rangiriri spillway was approximately 200 m^3/s (DOC, 2007; Thompson, 2001) with a peak level of 9.05 m RL. Events smaller than a 2% AEP are within the design capability of the Waikato River and should not spill into Lake Waikare (Waikato Regional Council, 2011).

The GoldSim model has been developed whereby if the Waikato River level at Rangiriri is less than 8.8 m RL, no spill flow occurs. If the river level is between 8.8 m and 9.15 m RL, a spillflow of 200 m^3/s and if the river level exceeds 9.15 m RL, then a spillflow of 280 m^3/s. These divisions are based on the design spillway flow and the estimated flow from 1998.

This differs to the modelled levels in Beyá (2005) that estimates peak flow over the spillway of 42 m^3/s (2% AEP), 118 m^3/s (1% AEP) and 299 m^3/s (design). Beyá's levels are based on a mass balance model adjusted to remove the effect of debris blockage at the spillway. Blockage was attributed to the location of a fence which has subsequently been relocated.

3.1.8 Model Limitations and Data Gaps

The SMWBM and GoldSim models have been developed to meet the project objective outlined in Section 1.2 of this report. The models have incorporated known data and information that were available at the time of development. There are data improvements and further research that could be incorporated into future models to enhance the accuracy of results. These are detailed below.

- The purpose of this study is to model the water cycle and assess the impact of the current operating regime and proposed scenarios to help improve understanding of the wetland influences to improve future management. Climate change has not been considered in this study. Understanding the effects of climate change on flood events can be determined if required.
- LiDAR data was sourced from Waikato Regional Council to refine the storage relationship (depth-area-volume) of water within the wetland. Unfortunately data from an area of the wetland largely in the Reao catchment was corrupt. This is an area of approximately 15 km^2. No replacement data is available. To improve the storage relationship, LiDAR would need to be reflown across this area.
- Analyses of the LiDAR data was used to develop the depth-area-volume storage relationship used within the wetland. Understanding the impact of vegetation bulking and the interconnectedness of the terrain would improve the depth-area-volume relationship.
- LiDAR data was unavailable for the Lake Waikare area. Instead the depth-area-volume curve was estimated and calibrated to the Lake Waikare at Lake Road recorder. This relationship could be improved through LiDAR.
- Resolution of the LiDAR point data was processed to a 5 m x 5 m grid. This resulted in very good resolution of the wetland area (which covers approximately 70 km^2) and the development of depth-area-volume curves. However, when mapping peak water levels smaller drainage paths (less than 5m wide) within the wetland are not preserved. In most areas, and in large flood conditions when the wetland basin is full, this will have no impact. Though within the Causeway catchment there is a drainage path less than 5 m wide, from the area of pasture around Coalfields Road, into the Kopuku Stream. This drainage path was not picked up in the resolution of the LiDAR. As a result, mapped water levels within the Causeway catchment appear higher than evidence suggests (M Brady 2013, pers. comm., 29 Apr.). Given the size of the catchment area in respect to the overall model, this will have no significant impact on modelled water levels of the Whangamarino basin. Mapped water levels within the Causeway catchment may appear high.
- Calibration of the Causeway catchment has not been possible due to no water level recorder within this catchment.
- Two significant flood events have occurred during the calibration period: July 2002 and August 2008. The simulated Whangamarino water level had a good fit with the actual recorded water level during both events. However the Lake Waikare simulated level has more variation at the upper end. The model would benefit from further refinement of the upper flood levels should another large flood event occur.
- Rating curves from the three gauging stations have not been assessed for accuracy. Results from the SMWBM calibration question the accuracy of the Whangamarino at Slackline flow record. The SMWBM produces greater flow across the entire flow range. To improve understanding of this difference, the rating curve would need to be reviewed. As the site closed in 1992 current gaugings would not be comparable.
- Rangiriri ponding zone and Lake Waikare ponding zones have not been explicitly defined within the GoldSim model (this is the ponding area between the Waikato River and Lake Waikare resulting from spilling over the Rangiriri spillway). In the GoldSim model, which is a daily model of the water balance, ponding of this area is incorporated into the Lake Waikare storage equation. On a daily timestep, the effect of this is negligible.
- It has been difficult to gauge the rock weir installed at the downstream end of the Whangamarino Wetland. Both Waikato Regional Council and Scottech have reported difficulties in getting an accurate measure of flow. This is attributed to a number of reasons including the permeable weir structure, variable river bed and weed, and during high flow water entering the Whangamarino River downstream of the weir from across the floodplain. The weir rating curve estimated in the GoldSim model has been estimated though consideration of the WRC gaugings, WRC 1D model of the Waikato River, Scottech gauging, and calibration to the Falls Road record. Further enhancement could be made to this model if an improved rating curve is developed.
- In all GoldSim scenarios the initial storage volume of Lake Waikare and the Whangamarino Wetland were the same. However, in the higher weir scenario or sedimentation scenarios, the initial water level would be expected to be higher in reality. As the initial water level was unknown, for consistency, the initial storage volume was kept the same for all scenarios.

4. Conceptual Water Balance Model

The SMWBM and GoldSim software was selected to model the conceptual water balance of the Whangamarino catchment. The Whangamarino model is a simplified representation of the flow regime, and as a calibrated model enables the user to test at a high level a raft of different scenarios that may be used to assist with managing the wetland ecosystem.

This conceptual water balance model refines the model build process undertaken in Stage 2 of this project. The previous studies and report are outlined in Section 1.3. Changes to the model undertaken as part of Stages 3 and 4 are discussed in this report.

The refined conceptual model has involved the separation of the Whangamarino Wetland into two basins: the Whangamarino basin and the Causeway basin. The Whangamarino basin incorporates most of the wetland; it receives outflow from Lake Waikare, catchment inflow from the upper catchments of SH2 and Slackline and the lower catchments of Reao and Maramarua, as well as direct precipitation falling on the wetted area.

The Causeway basin has been separated from the total area as flow to the south of the Causeway road is impeded by this structure. The Causeway is a permeable elevated road constructed to connect the Kopuku coal mine to the Meremere Power Station. A culvert at the downstream end of the Causeway assists in draining this catchment.

The Causeway catchment is modelled as flowing into the Whangamarino catchment. In reality there may be times when water may backflow depending on the spatial and temporal distribution of rainfall in the catchments (and releases of flow from Lake Waikare).

4.1 SMWBM

The Soil Moisture Water Balance Model is used to estimate runoff from the catchments. It is a lumped parameter model used to generate streamflow time series from catchment rainfall by simulating soil moisture storage, attenuation and losses through time. The calibration parameters are detailed in Table 2. The calibrated model incorporates rainfall, catchment land use and soil infiltration characteristics adjusting the key parameters so that the simulated time series generated for gauged catchments compare satisfactorily with the observed flows. This forms the catchment inflow component to the GoldSim model.

Table 2. Key SMWBM parameters and units.

Model Parameter	Description	Units
ST	Depth of water stored in the soil zone	mm
FT	Maximum rate of percolation to groundwater	mm/day
Zmax	Maximum soil infiltration rate	mm/hr
PI	Depth of water stored in the vegetation canopy	mm
POW	Power of the soil moisture – percolation equation	-

Due to differences in land use in the upper catchments and the variation in rainfall across the area, the catchment runoff has been revised for this study. The upper catchment area has been split into three subcatchments based on the natural topography and calibrated to flow gauges within each catchment. The calibration period varied for each catchment to coincide with the period of flow data. Based on catchment similarity the model parameters were transposed to the surrounding lower catchments and used to generate streamflow time series for the full period of rainfall data.

Where local rainfall records adjacent to the catchment were available, these were used to calibrate the SMWBM parameters. Virtual rainfall from the NIWA Climate Database was then applied to enable a long-term time series record to be generated. The virtual rainfall record provides simulated rainfall time series from 1960 to present for any location across New Zealand at a 5km^2 grid. The locations of the virtual rainfall records adopted for this study are shown in Appendix B.

4.2 Calibration

Calibration of the SMWBM is discussed in Section 4.3, and calibration of the GoldSim model is discussed in Section 4.4.

4.3 Calibration to flow recorders (SMWBM)

The SMWBM was used to develop simulated runoff records for each of the upper catchments to provide continuous flow records from 1966 to present. Key model parameters were adjusted to reach a good calibration between simulated runoff and actual runoff as recorded by flow gauges within the respective catchments. These parameters were adjusted based on catchment characteristics and reasonable parameters for the area. Table 3 details the records used for calibration.

Table 3. Flow records used for calibrating catchment runoff within the SMWBM.

Modelled Catchment	Site	Record Length
Maramarua	Mangatangi at SH2	1986-2012
Matahuru	Matahuru at Waiterimu Rd	1984-2012
Whangamarino	Whangamarino at Slackline	1980-1992

Within the Maramarua catchment, runoff is reduced by a water take from the Mangatangi Dam. Typical catchment characteristics were used to estimate runoff from the Maramarua catchment, the record was then adjusted to account for abstraction from the dam and compensation flows to the River, calibrated to the Mangatangi at SH2 flow record.

Both the Matahuru catchment and the Maramarua catchment calibrated well to the gauged record. The Slackline calibration, while showing a good hydrological response, tends to over predict flows within all spectrums of the flow duration curve. This tends to suggest a catchment rainfall or flow gauging (underreporting) error. However, the implications of the flow potentially being over predicted is minimal as peak water levels within the wetland have been calibrated to the Falls Road water level record. Other variables, such as the depth-area-volume curve may compensate for any differences. Figure 4 to Figure 6 plot the observed flow distribution against the simulated flow distribution for the three upper catchments.

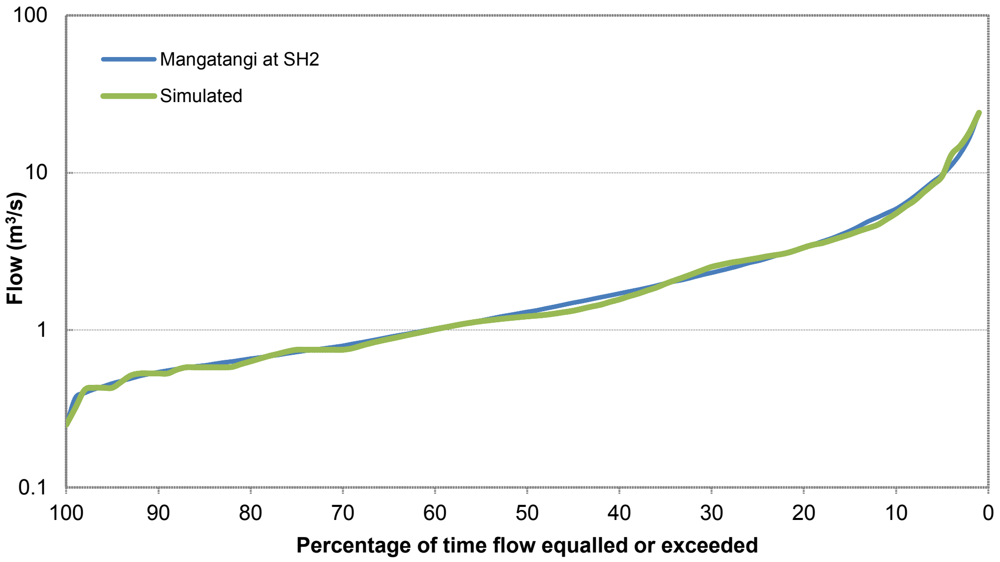

Figure 4. Observed and simulated flow distributions for Mangatangi at SH2.

The simulated flow from the SMWBM for the Maramarua catchment has been adjusted to allow for abstraction from the Mangatangi Dam for water supply purposes and the compensation flow required in the receiving River. The resulting flow distribution curve has a good fit to the gauged record.

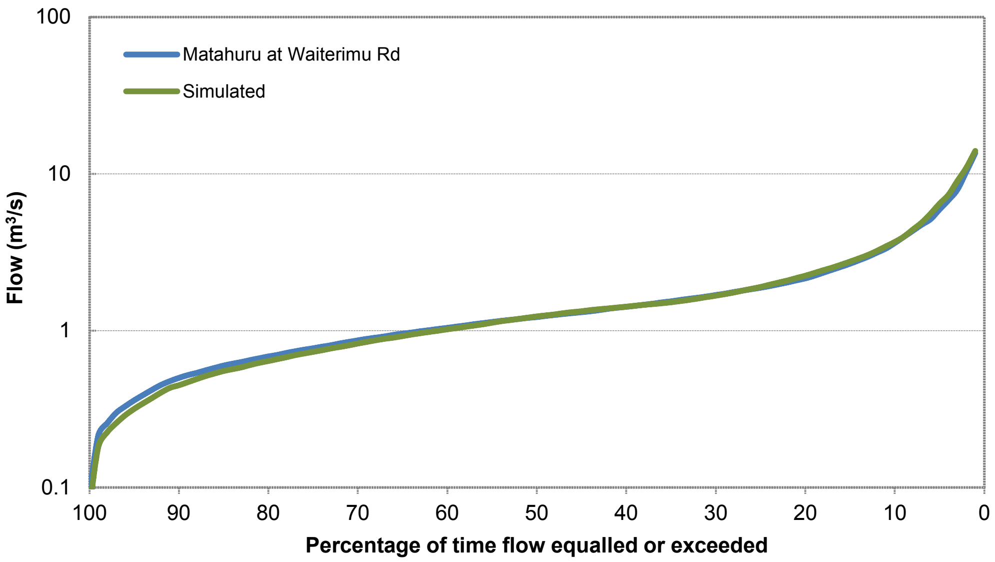

Figure 5. Observed and simulated flow distributions for Matahuru at Waiterimu Rd.

The simulated flow from the SMWBM for the Matahuru catchment has a good fit to the gauged record.

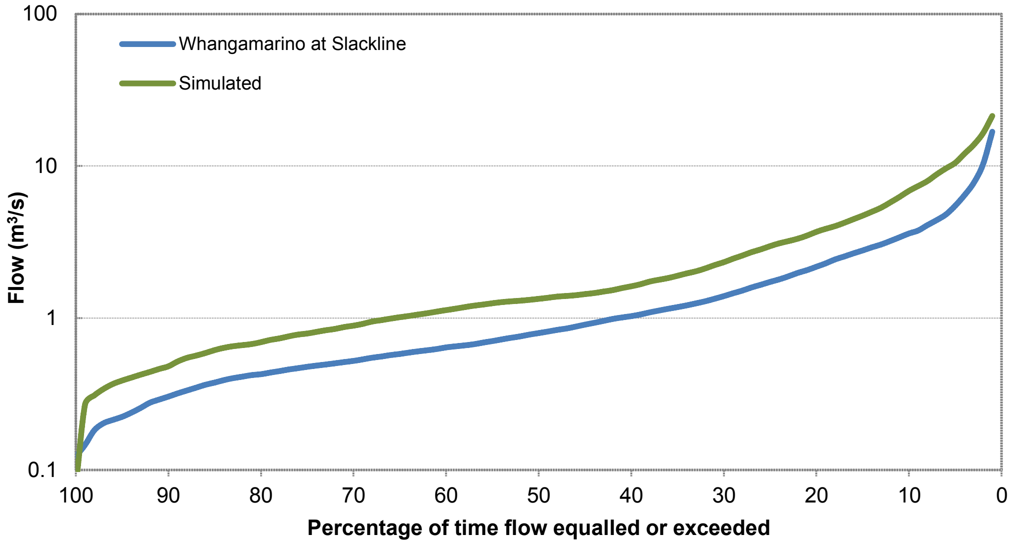

Figure 6. Observed and simulated flow distributions for Whangamarino at Slackline.

The simulated flow from the SMWBM for the Slackline catchment has a poor fit to the gauged record with the simulated record giving higher flows across all distributions. A number of scenarios were tested in the SMWBM to try to improve the fit while maintaining sensible catchment characteristics for the land use and soil properties, as well as to the adjacent catchments. Reducing the rainfall by 60% improved the calibration, however there is no justification to reduce the rainfall and the resulting mean annual precipitation was significantly too low for the Waikato region.

As a result of the sensitivity runs and knowledge of the area it is believed that the Slackline flow data is under recorded. Given that this area is subject to backflow from the Whangamarino Wetland, rating the river would have been difficult. The rating curve has not been reviewed as part of this study.

4.4 GoldSim Model

4.4.1 Calibration to Stage Recorders

Calibration of the GoldSim model was based on the period from 2000 to 2012. This is the period following repair of the rock weir where water levels within the wetland stabilised around an average of 3.6 m RL at the Falls Road recorder.

The GoldSim model has been calibrated to stage recorders within the catchment. The Lake Waikare component of the GoldSim model is compared to Lake Waikare at Lake Road, and the Whangamarino component of the GoldSim model is compared to Whangamarino at Falls Road. Plots of each record across the calibrated period (2001 – 2012) are shown in Figure 7 and Figure 8, for Lake Waikare and Whangamarino, respectively. There is no recorder within the Causeway catchment to calibrate this area against.

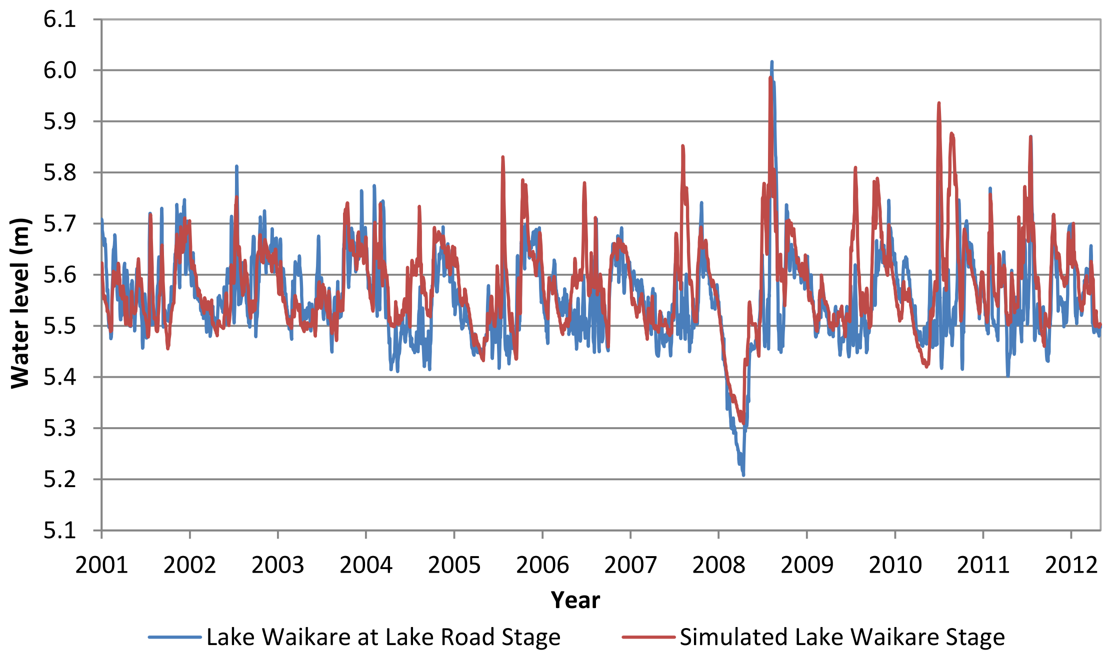

Figure 7. Calibration of Lake Waikare water level.

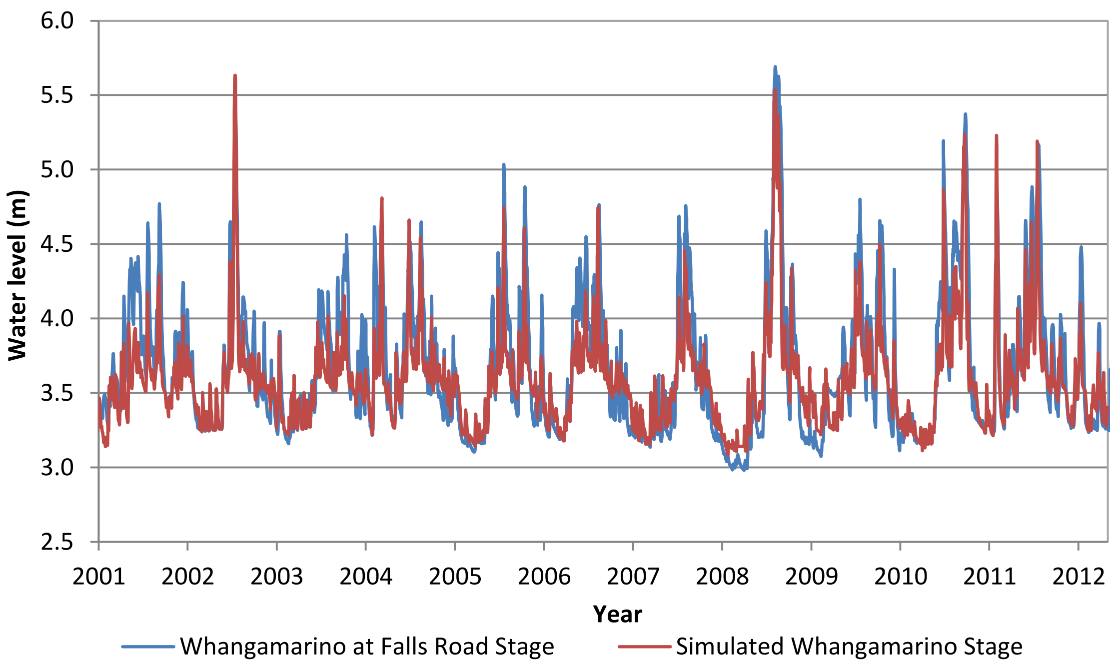

Figure 8. Calibration of Whangamarino Wetland water level.

Figure 7 and Figure 8 show a very good fit between the actual record and the simulated record. There is slightly more variation in the Lake Waikare calibration, particularly at the lower stage levels and during the 2008 drought. During the drought the simulated water level was slightly higher than the actual water level. Subsequently this trend is also present in the Whangamarino stage record. This correlation could be improved through Lake Waikare LiDAR data, particularly if it was flown during a time of drought.

In addition to the drought, the average lake level in Figure 7 appears to trend slightly lower from 2004 to 2008. This could be attributed to a number of causes including a change in the operating regime of the lake (within the Flood Rules), climate variability (i.e. interdecadal pacific oscillation), or a change in the stage record. Further refinement of Lake Waikare could be possible if further information becomes available.

Calibration of the Whangamarino Wetland gave a very good fit across the full range of calibrated water levels. Large floods or droughts above or below these levels are not calibrated and are based on a best estimation.

It should also be noted that a number of variables in the GoldSim model can be altered for calibration, for example, the depth-area-volume curve, the weir relationship, inflows etc. The best estimates for these variables were made based on the available information, and then adjustments were made for calibration.

4.4.2 Calibration to Historical Data

As calibration of the depth-area-volume relationship, historical data from the 1998 flood event was obtained. From the Munro (1998) report *The Waikato Regional Flood Event of 9-20 July 1998*, the area of flooding of the Whangamarino Wetland swelled from its normal 17km^2 to 67km^2, and the Wetland water level peaked at 5.75m. Though the 1998 event is outside the calibration period as the hydraulic regime of the wetland was different (the rock weir had failed), the extent of flooding in this large event is useful to provide an indication of flood extents. The expected extent of flooding in the GoldSim model for an event of the same depth would result in a very similar surface inundation of approximately 70km^2.

Frequency analysis of the 1998 event in the Waikato River (at Rangiriri) placed this event between a 2% and a 1% AEP and triggered spillflow over the Rangiriri spillway. Based on the GoldSim model, this event in the Whangamarino Wetland would result in a peak water level of 6.13m and a return period exceeding a 1% AEP. This difference is attributed to the physical changes made to the weir in 2000.

Two significant flood events occurred during the calibration period: July 2002 and August 2008. Both of these events are plotted in Figure 9 and Figure 10 comparing the simulated event to the actual Falls Road stage record. Both simulated records show a good fit to the actual stage record.

The 2002 event was the larger of the two in the Waikato River. Munro estimated the return period of it (in the Waikato River) at approximately a 5% AEP (Munro, 2002). Based on the GoldSim model, this event in the Whangamarino Wetland yielded a return period of between a 10% and a 5% AEP.

These results are comparable given that the Whangamarino catchment is only a small part of the larger Waikato River catchment and spatially affected by different rainfall events.

Frequency analysis of the Whangamarino Wetland at Falls Road is not comparable as the Falls Road record was influenced by the physical changes to the weir height (whereas the GoldSim model assumes the current weir configuration across the entire record length).

Model results were also compared to September 2010 flood event results. Blyth (2011) estimated that the September 2010 flood had an annual recurrence interval of 1 in 3.3 years. The fit of the modelled results to the actual results were not as good as the 2002 and 2008 flood events and this was likely due to high antecedent water levels going into the September 2010 event (Figure 11).

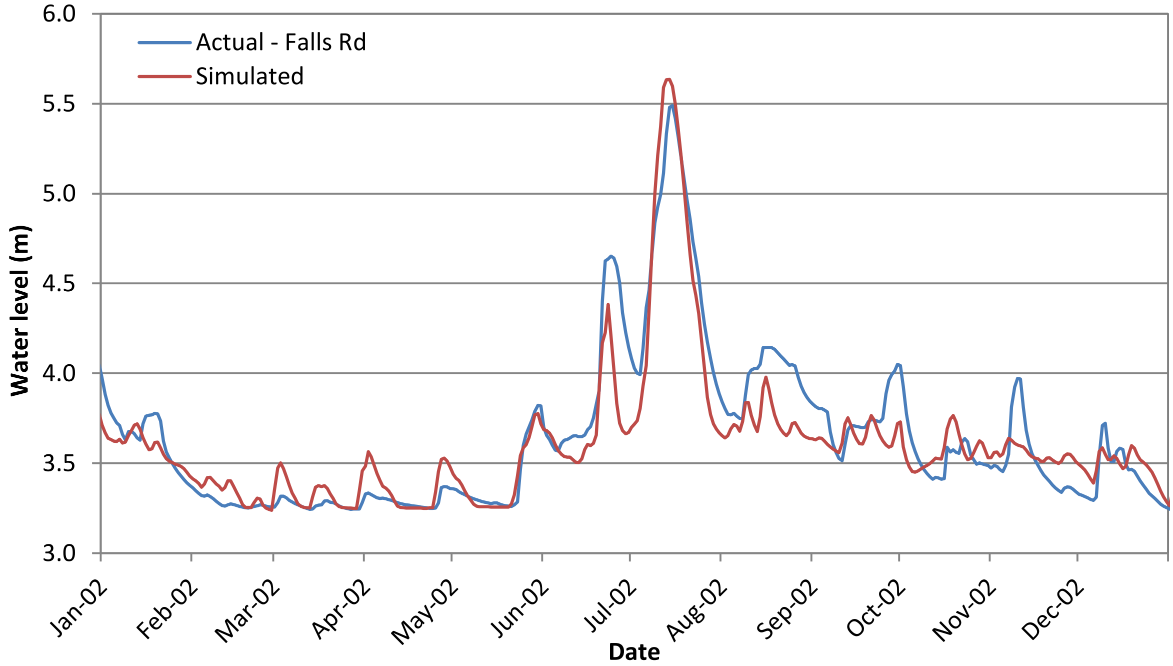

Figure 9. Simulated versus actual Falls Rd stage record for 2002.

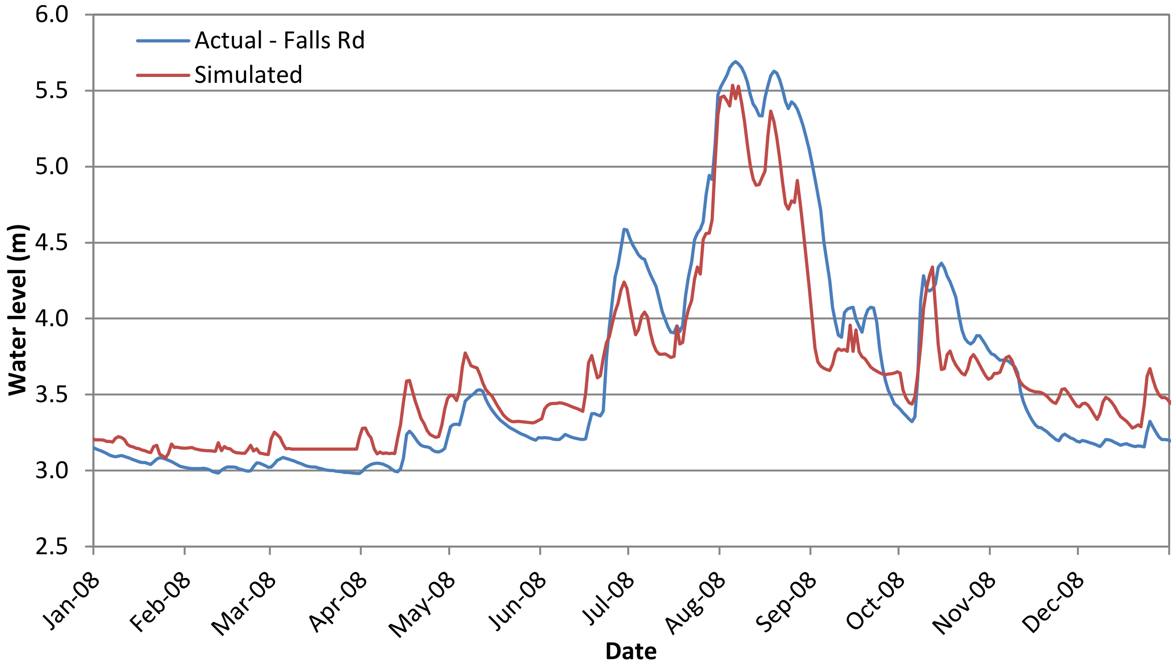

Figure 10. Simulated versus actual Falls Rd stage record for 2008.

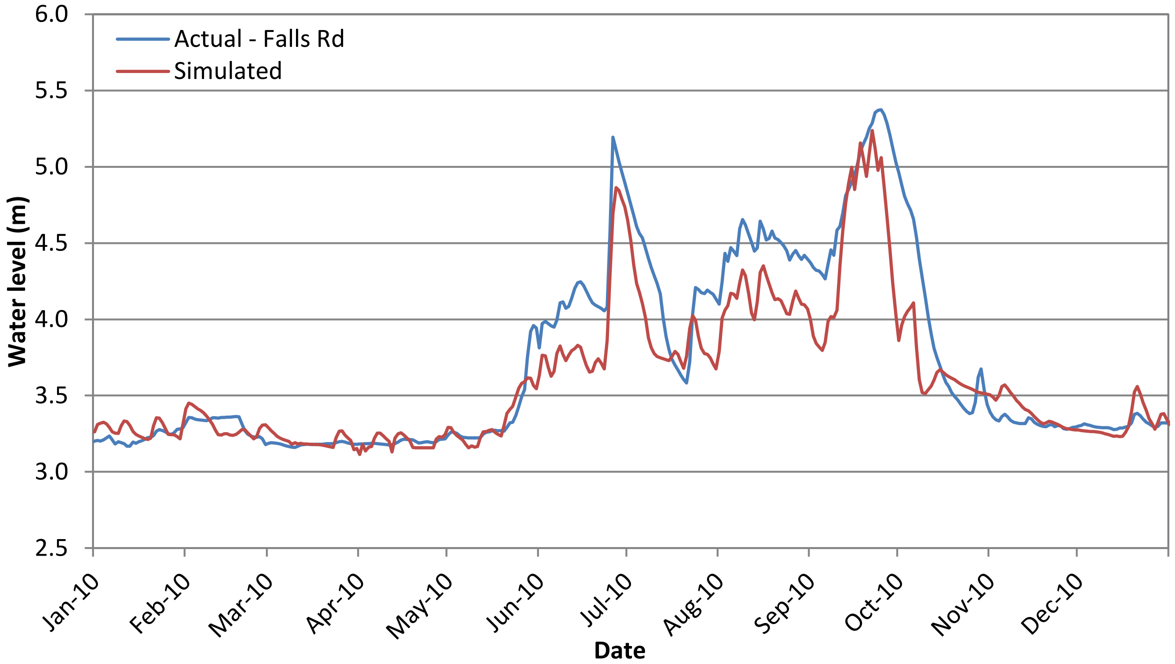

Figure 11. Simulated versus actual Falls Rd stage record for 2010.

5. Results

5.1 Model Scenarios

A number of scenarios were modelled using the calibrated GoldSim model. These scenarios are listed below. For consistency, in all scenarios the initial storage volume of Lake Waikare and the Whangamarino Wetland were the same. Likewise all other model parameters other than those being adjusted for the given scenario were maintained.

1) Extended (base) record

Using the virtual rainfall data the calibrated model was run from 1966 to 2012, based on the current operating regime.

2) Lake Waikare modified regime

Two Lake Waikare scenarios were undertaken. The first involved changes to the operating regime of Lake Waikare while still operating within the existing flood control rules. This involved discharging more flow at water levels between the minimum and maximum seasonal target water level thereby lowering the typical lake level and allowing greater storage capacity during floods.

The second scenario involved blocking all Lake Waikare discharges into the wetland. This was to help assess what impact Lake Waikare has on flood levels and whether this may help DOC manage sensitive ecosystems within the wetland.

3) Land use changes

Changes were made to the SMWBM variables to represent greater forestry in the upper catchment and how this may influence runoff and wetland water levels. The idea being that through the planting of additional forests in the upper catchment, runoff may be reduced. The Matahuru catchment was unchanged but the forestry cover within Mangatangi catchment at SH2 (194.5 km^2) and the Whangamarino catchment at Slackline (131.6 km^2) was changed from no forestry cover to forestry cover over the whole catchment.

4) Weir height

A lower and a higher weir height scenario were modelled to understand how changes may impact on peak wetland water levels. The scenarios assume the weir was lowered by an amount and raised by an amount. The baseline weir stage-discharge relationship was developed through consideration of stream gaugings and model calibration. The modelled weir height and the altered weir heights may not relate to actual levels. The scenarios show how changes to the weir may impact on water levels.

5) Basin sedimentation

Two sedimentation scenarios were considered: sedimentation of 300,000m^3 lining the wetland, and sedimentation of 500,000m^3. The sedimentation volume was derived based on the Waikato Regional Council report developed for their resource consent [101727] and provided to Department of Conservation (WRC, 2012). Their report estimates approximately 157,000m^3 of sediment has accumulated in the wetland (largely in the Pungarehu Stream, mineralised wetland and Whangamarino River) between 2005 and 2012. The scenarios evaluate how long- term sediment build up may influence the Wetland’s water levels.

As the water balance model is a simplification of the overall water cycle, it has not been possible to direct sedimentation to the most likely areas where it will occur. Instead the depth-area-volume curve was adjusted to fill the lowest areas with sediment first, up to the given volume stated volume. Based on the depth-area-volume curve relationship, at a water level of 4m in the wetland, 300,000m^3 sedimentation represents approximately 4% of the available storage volume, and 500,000m^3 represents approximately 7% of the available storage volume.

6) Whangamarino water level:

This scenario involved adjusting the Lake Waikare operating rules to assess whether changes to the lake operation may reduce flood levels in the wetland. Specifically the change was when the water level within the Whangamarino Wetland exceeded 4m then discharge out of Lake Waikare into the wetland (through the Pungarehu Stream) shall be stopped until the water level in the wetland recedes below 4m. This scenario is outlined in depth in Section 5.3.

Note, all reported values and analyses were developed at the time of writing using the most appropriate information available. Subsequent to running the model and analysing results new information came to light regarding flow through the Te Onetea culvert. The logger on this culvert is believed to overestimate flow, when compared to spot gaugings. The recorded flow from the logger was used to develop the relationship for inflow from the Waikato River into Lake Waikare. This therefore overestimates inflow into Lake Waikare. This new information has not been incorporated into the scenarios,though it is expected that it would result in only minor changes to results.

The above scenarios resulted in changes to the inflow and outflow volumes entering and leaving the wetland. These changes are summarised in Table 4. The inflow to the wetland is comprised of Lake Waikare discharge, runoff from the wetland catchments (the lowland surrounding the wetland, and rainfall directly on the wetland), runoff from the Maramarua and Whangamarino upper catchments, and throughflow beneath and through the causeway from the Causeway catchment. The outflows are evaporation and flow from the wetland back into the Waikato River. The values are average daily inflows and outflows so have been calculated across the simulated record (1966-2012) as an average based on the number of days of record.

Table 4. Summary of average daily inflow and outflow volumes from simulation scenarios.

Scenario	Inflow (m^3/d)	Outflow (m^3/d)
Base Simulation*	1,750,000	1,750,000
Lake Waikare increased discharge	+1,000	+1,000
Lake Waikare no discharge	- 800,000	-373,000
Land use Scenario	-21,000	-21,000
Lower Weir Scenario	-33,000	+175,000
Higher Weir Scenario	+10,000	+116,000
Sedimentation 300,000m^3	0	+108,000
Sedimentation 500,000m^3	0	+118,000

* Using the revised Te Onetea inflow estimates the base simulation is expected to result in daily inflows into the Whangamarino Wetland in the order of 1,380,000m^3/d.

Inflows to the wetland and outflows from the wetland differ in each scenario. In the Lake Waikare increased discharge into the wetland scenario, the inflow and outflow from the wetland is marginally increased. This is most likely due to the limited impact of altering Lake Waikare discharge within the operating rules.

The scenario with no discharge from Lake Waikare has a much greater impact on wetland inflows and outflows. Given that the inflows are substantially less than the outflows, overtime this will result in drying of the wetland, unless other parameters within the wetland start to compensate for this change.

The land use scenario through planting of forestry in the upper catchment has resulted in a reduction of both the inflows and outflows from the wetland.

Lowering of the weir height has resulted in less inflow and greater outflow in comparison to the baseline scenario. Under this scenario the average minimum water level of the wetland will be lower than in the baseline scenario. Therefore there will be a greater number of days when the water level in Waikato River is greater than the water level in the Whangamarino Wetland and consequently a greater number of days when the

Whangamarino control gates and the Lake Waikare outlet gate are required to close. There are typically greater outflow from the wetland due to the weir height being lower than present.

Conversely with a higher weir height, the Whangamarino control gates are closed less frequently so there will be more occasions when inflow from Lake Waikare outlet is able to occur, and more occasions when the water level in the Wetland is greater than the water level in the Waikato River, therefore flow is able to discharge.

Both the sedimentation scenarios result in greater discharge as the available storage volume is reduced. There is no resulting change to inflow volumes.

5.2 Contribution of Different Water Sources to Water Budget

The table below (Table 5) outlines the contribution of different catchments to the water budget in the Whangamarino Wetland during the base simulation scenario with revised Te Onetea inflow estimates.

Table 5. Contribution of different water sources to the water budget at Whangamarino Wetland. This table outlines the percentage of flow volume at the downstream point of the catchment. See Appendix B for the catchment locations.

Water source	Percentage of flow volume (%)
Whangamarino River	23.0
Lake Waikare including Matahuru catchment	16.8
Maramarua River	24.7
Eastern	11.0
Western	5.7
South	3.4
South-Western	7.8
Northern	7.8
Total	100

5.3 Resulting Water Levels

Daily average water levels results from each scenario were compared to understand their relative influence on water levels within the wetland. Three analyses were undertaken:

- Frequency analysis of the wetland water level to estimate the mean annual flood peak (2.33 year annual recurrence interval (ARI) or 35% AEP, the 1 in 10 year ARI (10% AEP) and the 1 in 100 year (1% AEP).
- Water level distribution curve to understand how the average daily water levels are affected under different scenarios.
- Count of the number of days given water levels are exceeded and their average duration, to assist in the management of flood events.

5.3.1 Frequency Analysis Results

Flood frequency analyses were undertaken on wetland water levels to understand how peak flood levels may differ across scenarios. These analyses were conducted using the record length from 1966 to 2011 across the maximum annual data set. The Log Pearson Type III best fitted the Whangamarino water level data. The estimated peak levels are displayed in Table 6, the frequency analysis plots are displayed in Appendix C Frequency Analysis Plots.

Table 6. Peak Water Level Frequency Analysis.

Scenario	Peak Water Level per Return Period (Annual Exceedence Probability)		
	Annual (35%)	**10 year (10%)**	**100 year (1%)**
Extended (Base)*	4.96	5.52	6.06
Lake Waikare increased discharge	4.96	5.52	6.06
No Lake Waikare discharge	4.79	5.40	6.03
Land use	4.96	5.53	6.06
Weir Lower	4.95	5.52	6.05
Weir Higher	4.97	5.53	6.06
Sedimentation 300,000m^3	4.96	5.53	6.06
Sedimentation 500,000m^3	4.96	5.53	6.06

* Using the revised Te Onetea inflow estimates the base simulation is expected to result in daily inflows into the Whangamarino Wetland in the order of 1,380,000m^3/d.

The peak flood levels across all scenarios (excluding the scenario where there is no discharge from Lake Waikare) are very similar. Given that the maximum change between the base model and the scenarios results in a -2% to +0.6% change in inflow volumes, and a -1% to +10% change in outflow volumes (Table 6); and during flood events outflow from the wetland is typically tail water controlled from below the Whangamarino weir, little variation between peak events is expected.

The difference between the scenario with no discharge from Lake Waikare and the base model is a -46% change in inflow volume, and a -21% change in outflow volume (Table 6). The peak water levels for this scenario have also been dampened due to the cessation of flow from Lake Waikare.

The base flood levels across the three return period events are mapped in Figure 12. Only the base simulation has been mapped as the there is little variation between results (excluding the scenario where there is no Lake Waikare discharge). Figure 13 shows the flood levels across the monitoring transect line from Blyth (2011). This transect has been used in previous water quality and flood studies. The mapped flood extents correlate well with the inundation distances estimated by Blyth (2011). Blyth estimated that the September 2010 flood had an annual recurrence interval of 1 in 3.3 years, with the flood event impacting on water level regimes up to 1.4 km from the Whangamarino River. Figure 13 illustrates a comparison between the transect lines, and estimated flooding from Blyth (2011) and the simulated flood extents.

Figure 12. Flood extents under the base scenario.
(see A3 attachment at rear)

Figure 13. Peak water levels across the Whangamarino Wetland transect.
(see A3 attachment at rear)

5.3.2 Water level distribution curve

Figure 14 compares the distribution of average daily water levels. The average daily water level forms the y-axis, while the percentage of time that a given water level is exceeded forms x-axis. The curves show that 100%

of the time, the water level across all scenarios is greater than 3.0m, and less than 1% of time the water level exceeds 5.0m.

The curves show that the scenarios largely impacted on the lower water levels. This is where the percentage change in inflows and outflow is a greater proportion of the total daily flow. Under flood scenarios, the change in inflows and outflows is minor. Changes to the weir height and stopping the discharge from Lake Waikare had the most significant effect. The water levels in the scenario with no Lake Waikare discharge are significantly lower than the base simulation.

The lower weir scenario, as well as both sedimentation scenarios show the wetland water level not dropping below a given height. For the lower weir scenario, this is the approximate height of the weir. When the water level in the wetland equals the weir height, the only outflow from the wetland is evaporation. Evaporation is such a minor component of the water balance, this outflow is not noticed.

In regard to both sedimentation scenarios, sedimentation was assumed to fill the shallowest depressions of the depth-area-volume curve first, thereby filling the terrain and removing the available storage volume from the lowest water levels. As a result the wetland water levels cannot drop below this filled level.

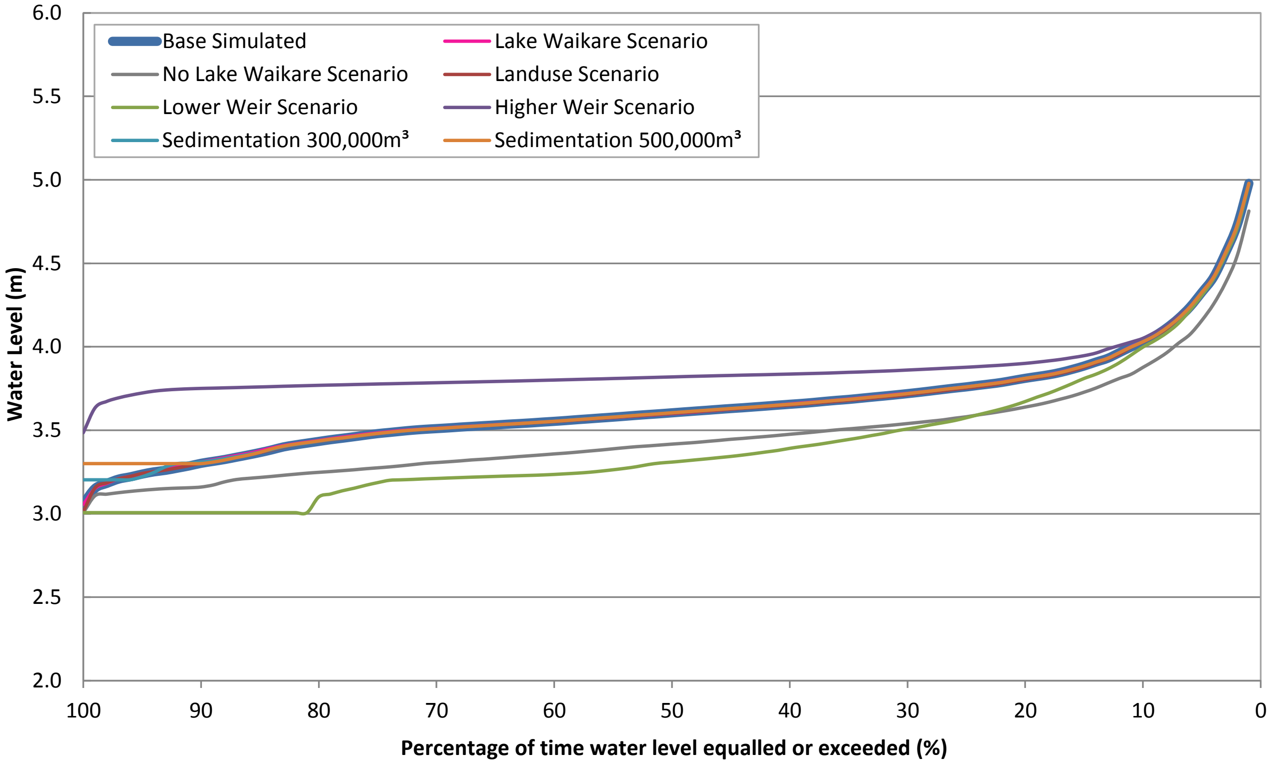

Figure 14. Water level distribution curve.

5.3.3 Count of Days

To assist with the management of flood events, the number of days that water levels exceed given values is compared. Table 7 counts the total number of days across the record (16801 days total from 1966 to 2011) while Table 8 summarises the average duration (days), that these events exceeded given water levels. As this is based on the extreme flood events, there is little difference between values with the exception of the scenario with no Lake Waikare discharge occurring.

Table 7. Count of Peak Water Level Flood Inundation across the simulated record, 1966-2011.

Scenario	Number of Days Simulated Water Level Exceeds…		
	4.96 m Annual (35%)	5.52 m 10 year (10%)	6.05 m 100 year (1%)
Extended (Base)*	180	27	3
Lake Waikare increased discharge	179	27	3
No Lake Waikare discharge	106	12	0
Land use	181	27	3
Weir Lower	176	28	3
Weir Higher	180	28	4
Sedimentation 300,000m3	180	27	3
Sedimentation 500,000m3	180	27	3

Table 8. Average Event Duration (days per event), 1966-2011.

Scenario	Average Duration of days when Simulated Water Level Exceeds…		
	4.96 m Annual (35%)	5.52 m 10 year (10%)	6.05 m 100 year (1%)
Extended (Base)*	5.1 days (35 simulated events)	6.8 days (4 simulated events)	3.0 days (1 simulated event)
Lake Waikare increased discharge	5.3 days (34 simulated events)	6.8 days (4 simulated events)	3.0 days (1 simulated event)
No Lake Waikare discharge	3.8 days (28 simulated events)	6.0 days (2 simulated events)	0 days (0 simulated events)
Land use	5.2 days (35 simulated events)	6.8 days (4 simulated events)	3.0 days (1 simulated event)
Weir Lower	4.8 days (37 simulated events)	5.6 days (5 simulated events)	3.0 days (1 simulated event)
Weir Higher	4.9 days (37 simulated events)	5.6 days (5 simulated events)	4.0 days (1 simulated event)
Sedimentation 300,000m^3	5.1 days (35 simulated events)	6.8 days (4 simulated events)	3.0 days (1 simulated event)
Sedimentation 500,000m^3	5.1 days (35 simulated events)	6.8 days (4 simulated events)	3.0 days (1 simulated event)

5.4 Whangamarino water level

To assist with improving management of the wetland, an additional scenario was run whereby a change was made to the Lake Waikare operating rules requiring discharge out of Lake Waikare into the Whangamarino Wetland (through the Pungarehu Stream) to be stopped when the water level within the Whangamarino Wetland exceeds 4m. Only when the wetland water level recedes below 4m, shall the Lake Waikare discharge resume. This is consistent with the Assessment of Environmental Effects (Rice Resources Limited 1998) for the Lake Waikare discharge, but is not reflected in the Lake Waikare Dam consent (101725). The water level results from this run (called the Gate Closure Rule Scenario) are compared to the base simulation. Figure 15 displays the water level distribution curve. This shows that under the gate operating rule, peak water levels are decreased, however, the water levels between 3.5 and 4.0 m are higher than they would be under the base simulation.

There is minimal difference from the base simulation in the inflows and outflows in the Whangamarino Wetland. On average there is 1,745,000 m^3/d of inflow and outflow from the wetland under the Gate Closure Rule scenario. This represents an approximate average decrease of 5,000 m^3/d in inflow and outflow compared to the base simulation model.

The peak flood levels are lower under the Gate Closure Rule (Table 9). Table 10 and 11 show that peak water levels above 4.96m have decreased in frequency under the Gate Closure Rule. This is due to the stopping of inflow into the wetland from Lake Waikare at wetland water levels greater than 4m.

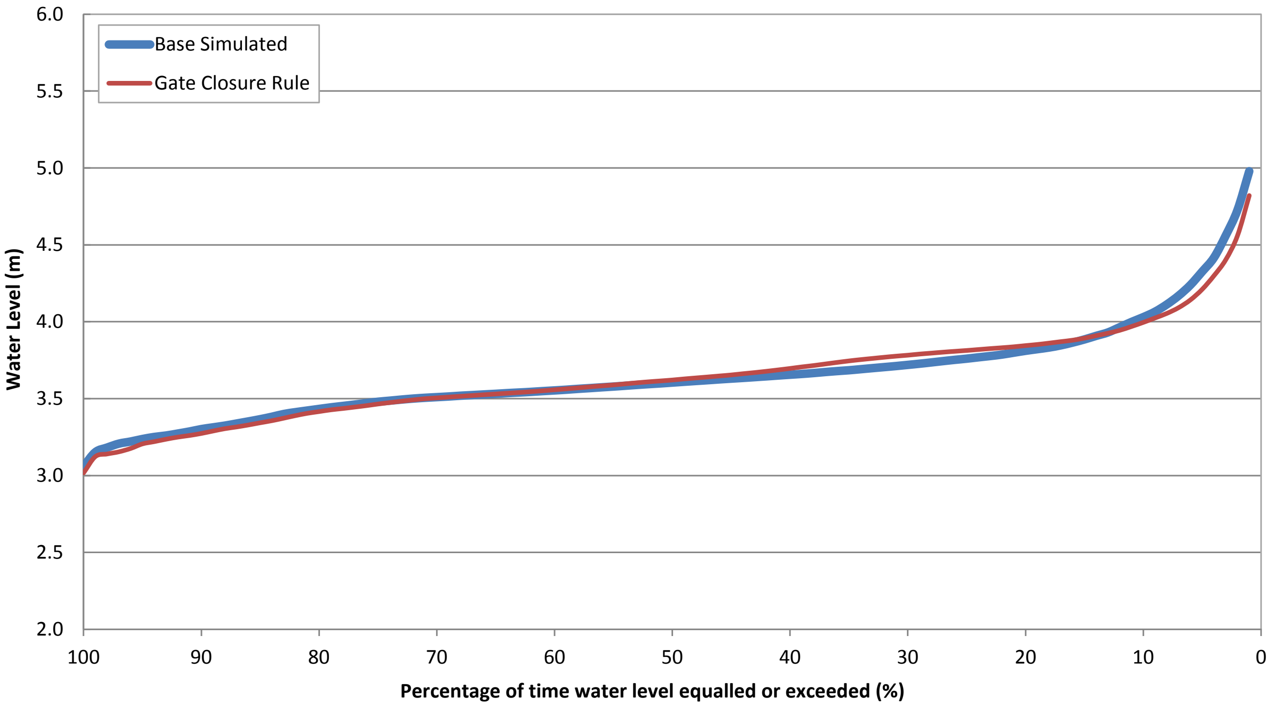

Figure 15. Water level distribution curve. Base scenario vs Gate Closure Rule scenario.

Table 9. Peak Water Level Frequency Analysis. Base scenario vs Gate Closure Rule scenario.

Scenario	Peak Water Level per Return Period (Annual Exceedence Probability)		
	Annual (35%)	10 year (10%)	100 year (1%)
Extended (Base)*	4.96	5.52	6.06
Gate Closure Rule	4.81	5.42	6.06

Table 10. Count of Peak Water Level Flood Inundation across the simulated record, 1966-2011. Base scenario vs Gate Closure Rule scenario.

Scenario	Number of Days Simulated Water Level Exceeds…		
	4.96 m Annual (35%)	5.52 m 10 year (10%)	6.05 m 100 year (1%)
Extended (Base)*	180	27	3
Gate Closure Rule	107	13	0

Table 11. Average Event Duration (days per event),1966-2011. Base scenario vs Gate Closure Rule scenario.

Scenario	Average Duration of days when Simulated Water Level Exceeds…		
	4.96 m Annual (35%)	5.52 m 10 year (10%)	6.05 m 100 year (1%)
Extended (Base)*	5.1 days (35 simulated events)	6.8 days (4 simulated events)	3.0 days (1 simulated event)
Gate Closure Rule	4.0 days (27 simulated events)	6.5 days (2 simulated events)	0 days (0 simulated events)

6. Conclusion and Recommendations

The GoldSim model was developed to improve understanding of the hydrological functioning of the Whangamarino Wetland and the role that external factors play in wetland inundation. It was also developed to understand how hypothetical scenarios relating to modified water management practices or hydrological situations may impact on peak water levels.

Improvements were made to the conceptual model developed under a previous project to include the Lower Waikato Waipa Flood Control Scheme operating rules, and calibration to rainfall and flow records. The operating rules, as specified through the relevant resource consents were incorporated into the model as logic rules.

Good calibration results were achieved for both Lake Waikare and the Whangamarino Wetland. Calibration of the Whangamarino at Slackline flow record was poor, with differences suggesting a poor rating curve. As the flow site is closed, it was not possible to check. Calibration of the Northern bog forming the Causeway catchment was not possible as there is no stage record with known datum.

Calibration with historical events showed a reasonable fit, though this calibration was only possible for the period from 2000 to 2012. Prior to 2000 the wetland operated under a different hydrological cycle pre the reconstruction of the rock weir.

Results from Section 5 suggest that of the different scenarios run, the most noticeable change occurred to the water level distribution curve. Both the higher and lower weir scenario resulted in reasonable changes to average daily water levels. The scenario of where there was no Lake Waikare discharge significantly reduced water levels within the wetland and the frequency of peak water levels were also reduced.

The peak water levels during flood events showed very little variation across most scenarios. This is largely because the magnitude of the change is dampened during flood events. Also, it is often during these large events when the control gates are closed. Once the gates are closed, variables such as weir height become irrelevant as flow cannot discharge from the wetland, and the gate becomes the controlling factor.

6.1 Application of model in wetland management

This GoldSim model can be used to determine what scenarios have the most impact on wetland water levels. The model indicates that changes in the operating regime of Lake Waikare can have a large impact on the water levels within the wetland. The discharge from Lake Waikare keeps water levels in the wetland approximately 0.2m higher than they would be without discharge from Lake Waikare.

It also indicates that the weir height, while having a large effect on wetland water levels, does not influence the peak wetland water levels. As discussed above, this is due to the flood gates becoming the controlling factor of peak water level height.

The Gate Closure Rule scenario indicates that the frequency of peak water levels can be decreased through management of the Lake Waikare flood gate. Flood events and therefore peak water levels are responsible for depositing sediment and nutrients into the most sensitive areas of the wetland, therefore decreasing the frequency of these events would help to protect the wetland.

Preventing discharges into the Whangamarino from Lake Waikare when the water level exceeds 4m was identified as a management method in the Assessment of Environmental Effects (Rice Resources Limited 1998) for the Lake Waikare discharge and damming, however this management method is not reflected in the Lake Waikare Dam consent (101725), and therefore has not been implemented. The GoldSim analysis indicates there would be a benefit of implementing this management method.

6.2 Recommendations

Section 3.1.8 identified a number of areas where there are still gaps in knowledge and where if warranted improvements could be made. However, results have shown that at peak flood levels, these minor improvements may have little impact on the outcome. Sensible decisions should be made to determine whether all gaps should be resolved.

Priority should be placed on improving the calibration range, and calibration to the spatial extent. Likewise running further scenarios for management purposes would be helpful to understand how the hydrological regime can be altered to enhance the wetland. Specifically, this may include:

- ***LiDAR data for Whangamarino Wetland***

New LiDAR data to replace the corrupt data through the centre of the wetland. This would improve the understanding of the spatial extent of flooding through this reach.

- ***Further calibration of water levels within Lake Waikare, the Whangamarino Wetland and the spatial extent of flooding.***

Currently the calibrated range for Lake Waikare is from 5.2m to 6.0m and Whangamarino Wetland is from 3.0m to 5.6m. Should a flood event outside of this range occur, the model could be checked and adjusted to provide great confidence in extreme flood estimations.

Similarly, if a large flood event occurred, the spatial extent could be pegged or photographed, and used for calibration of the flooding extent.

- ***Development of further scenarios for wetland management***

Results in Section 5 (Table 6) showed very little difference in the peak water level of extreme events. However, it is these extreme events that are changing the ecological balance within the wetland through the deposition of sediment and nutrients to the peat bogs. Further scenarios could be developed to understand whether changes can be made to the Lower Waikato Waipa Flood Control Scheme that may result in a reduction in peak flood levels.

7. References

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CLIENT
Department of Conservation

PROJECT
Whangamarino Hydrology Report: Stage 3

SCALE	PROJECT CODE
1:145,000 @ A3	AE04239
PROJECT MANAGER	DRAWN
CAL/CS	CS
PROJECT DIRECTOR	DATE
MS	10/12/2014

Catchment Map of the Whangamarino Wetland

FIGURE 1

JACOBS SPATIAL
Carlaw Park
12-16 Nicholls Lane
Parnell, Auckland
Tel +64 9 928 5500
Fax +64 9 928 5501

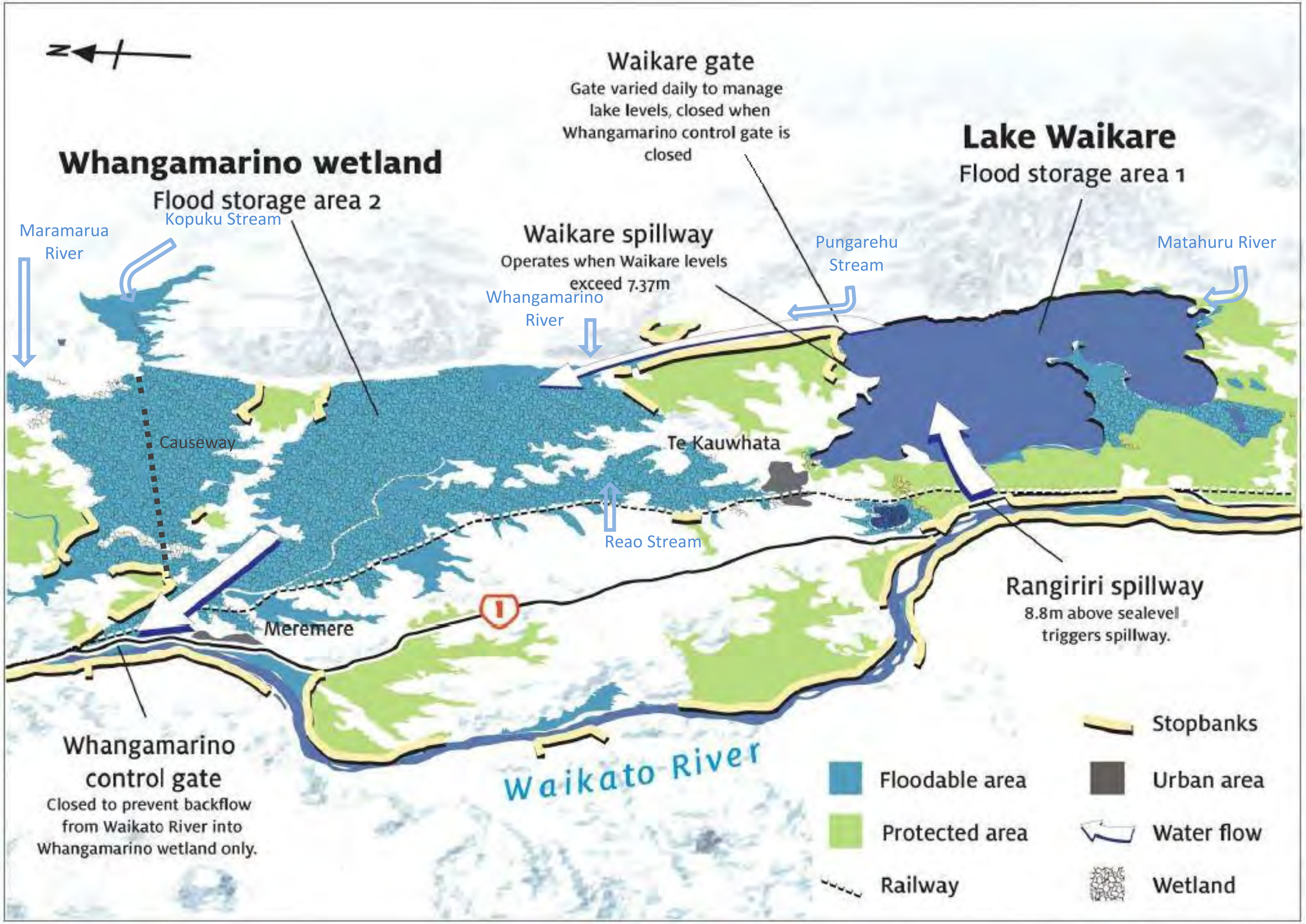
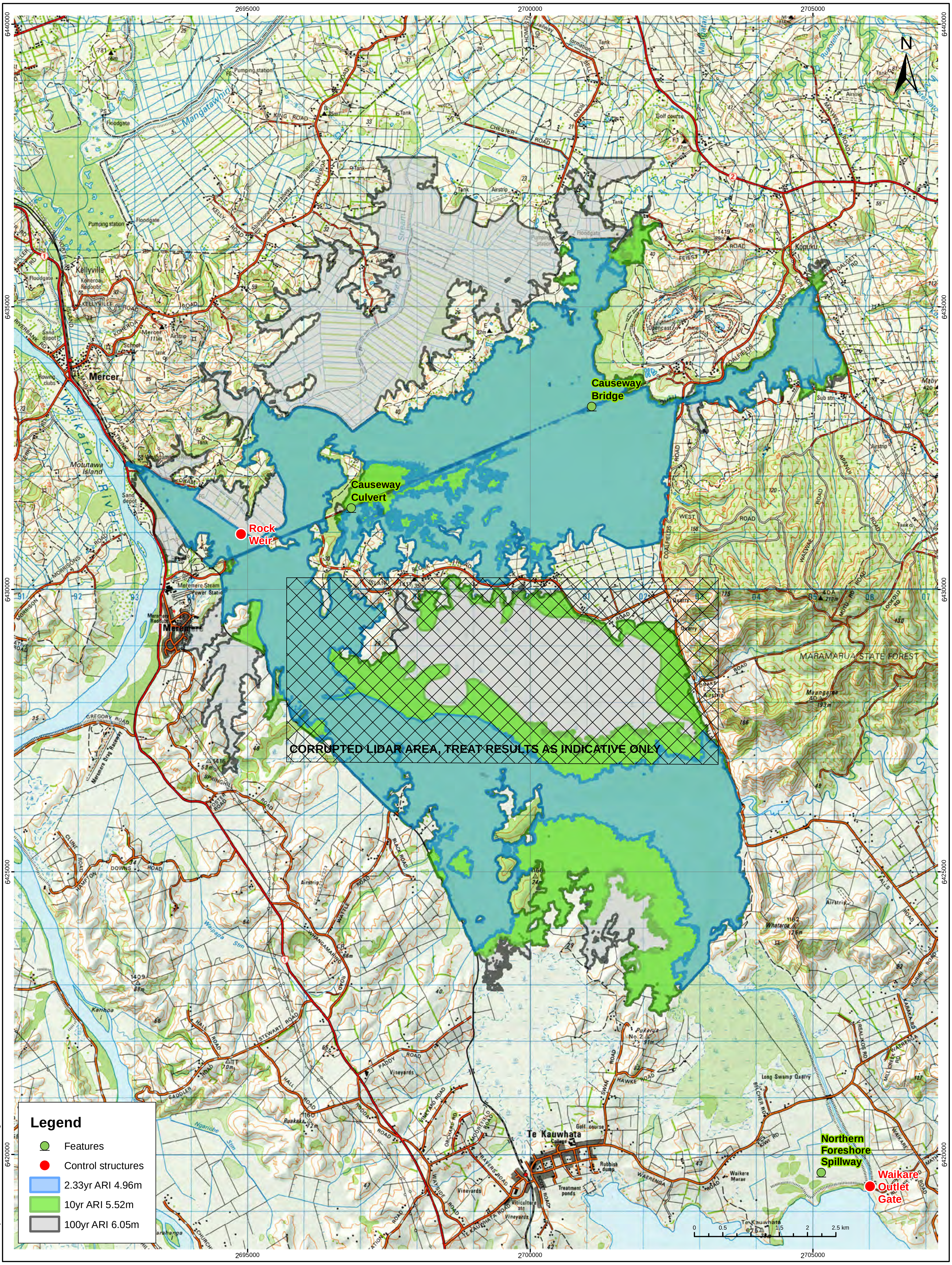


Figure 2. Schematic of Whangamarino Flow Regime.
Source Adapted from WRC, 2011.



CLIENT Department of Conservation	
PROJECT Whangamarino Hydrology Report: Stage 3	
SCALE 1:60,000 @ A3	PROJECT CODE AE04239
PROJECT MANAGER CAL/CS	DRAWN CS
PROJECT DIRECTOR MS	DATE 10/12/2014

Flood Extents
2.33 year, 10 year and 100 year ARI

FIGURE 12

JACOBS SPATIAL
Carlaw Park
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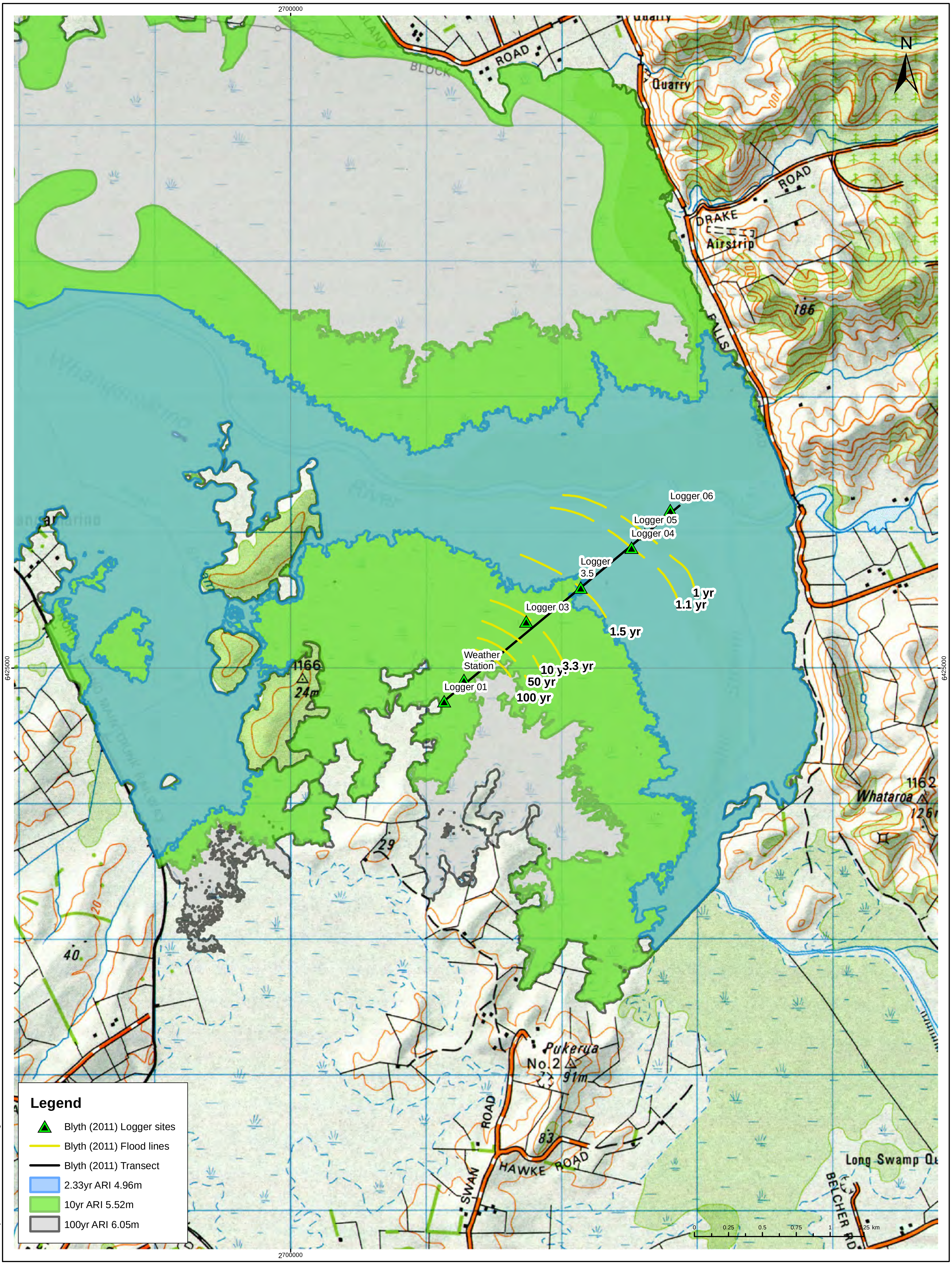

CLIENT Department of Conservation	
PROJECT Whangamarino Hydrology Report: Stage 3	
SCALE 1:25,000 @ A3	PROJECT CODE AE04239
PROJECT MANAGER CAL/CS	DRAWN CS
PROJECT DIRECTOR MS	DATE 14/12/2014

Flood Extents Across Transect Line
2.33 year, 10 year and 100 year ARI

FIGURE 13

JACOBS SPATIAL
Carlaw Park
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Parnell, Auckland
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Appendix A. GoldSim Inputs

Gauged Records

Data	Site	Source	Record Length
Rainfall	Mangatawhiri Rainfall	Cliflo database: Mangatawhiri Agent site 2066	1/1/1986-31/5/2012 Daily 9am NZST
Rainfall	Lake Waikare Rainfall	Cliflo virtual climate station 30820	1/1/1960 – 25/6/2012 Daily
Rainfall	Whangamarino Rainfall	Cliflo virtual climate station 29201	1/1/1960 – 25/6/2012 Daily
Water Level	Waikato River at Rangiriri	WRC	1/4/1965 – 31/5/2012
Water Level	Lake Waikare at Lake Road	WRC	27/5/1981 – 31/5/2012
Water Level	Whangamarino at Falls Road	WRC	25/6/1964 – 31/5/2012
Water Level	Waikato River at Control Structure Inlet	WRC	22/4/1992 – 31/5/2012 (1 day ave, 00:00)
Water Level	Waikato River at Control Structure Outlet	WRC	13/12/1980 – 31/5/2012 (1 day ave, 00:00)
Flow	Te Onetea	WRC	2/5/2005 – 3/8/2005
Flow	Mangatangi at SH2	WRC	20/05/1986 – 30/05/2012
Flow	Whangamarino at Slackline	WRC	8/12/1967 – 1/4/1992
Flow	Matahuru at Waiterimu Rd	WRC	13/7/1984 – 30/5/2012
Evaporation	Te Kauwhata M.A.F	Cliflo	1/11/1982 – 30/11/1990

Te Onetea Culvert Flow

Rangiriri Water Level (m)	Flow (m^3/s)
4.00	0
5.40	0
5.50	1.9
5.60	3.5
5.80	5.5
6.00	6.4
6.20	8.0
6.50	11.0
6.99	16.0
7.00	0
10.00	0

Lake Waikare Depth Area Volume Curve

Depth	Area (km^2)	Volume (km^3)
4.5	0	0.0
4.6	30	1.5
4.7	31	4.6
4.8	32	7.7
4.9	33	11.0
5.0	34	14.3
5.1	35	17.8
5.2	36	21.3
5.3	37	25.0
5.4	38	28.7
5.5	39	32.6
5.6	40	36.5
5.7	41	40.6
5.8	42	44.7
5.9	43	49.0
6.0	44	53.3
6.1	45	85.5
6.2	45	117.8
6.3	45	150.0
6.4	45	250.0
6.5	45	400.0

Lake Waikare Outlet Flow (m^3/s)

	Month											
Level	1	2	3	4	5	6	7	8	9	10	11	12
3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.4	0.0	0.0	0.0	0.9	0.9	0.9	0.9	0.9	0.9	0.0	0.0	0.0
5.5	0.9	0.9	0.9	0.9	0.9	5.2	5.2	5.2	5.2	0.0	0.0	0.0
5.55	0.9	0.9	0.9	12.1	12.1	12.1	12.1	12.1	12.1	0.9	0.9	0.9
5.6	5.7	5.7	5.7	12.7	12.7	12.7	12.7	12.7	12.7	0.9	0.9	0.9
5.65	13.3	13.3	13.3	18.7	18.7	18.7	18.7	18.7	18.7	5.9	5.9	5.9
5.7	13.9	13.9	13.9	19.5	19.5	19.5	19.5	19.5	19.5	13.9	13.9	13.9
5.75	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	14.5	14.5	14.5
5.8	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
5.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9
6	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7
6.1	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5
6.2	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
6.3	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
6.4	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1
6.5	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1
7	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6	44.6
7.369	52.9	52.9	52.9	52.9	52.9	52.9	52.9	52.9	52.9	52.9	52.9	52.9
7.37	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
7.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
8	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0

Whangamarino Wetland Depth Area Volume Curve

Depth	Area (km^2)	Volume (hm^3)
3.0	9.69	0.00
3.1	10.49	0.00
3.2	12.61	0.05
3.3	16.38	0.33
3.4	19.72	0.87
3.5	22.03	1.61
3.6	23.64	2.59
3.7	24.35	3.55
3.8	25.06	4.59
3.9	26.18	5.88
4.0	27.52	7.15
4.1	30.34	9.08
4.2	33.46	10.84
4.3	35.53	12.89
4.4	37.16	15.11
4.5	38.41	17.48
4.6	39.43	19.95
4.7	40.43	22.53
4.8	41.43	25.21
4.9	42.46	27.99
5.0	43.71	30.88
5.1	45.65	33.89
5.2	46.94	37.10
5.3	47.92	40.46
5.4	50.21	44.51
5.5	52.35	48.29
5.6	59.93	53.14
5.7	62.59	63.29
5.8	63.20	68.16
5.9	63.60	74.55
6.0	66.91	91.15
6.1	67.12	96.13
6.2	72.41	119.54
6.3	73.97	129.76
6.4	74.11	134.78
6.5	74.27	139.83

Causeway Depth Area Volume Curve

Depth	Area (km^2)	Volume (hm^3)
4.0	0	0
4.1	0	0
4.2	2.00	0.00
4.3	2.00	0.00
4.4	2.00	0.00
4.5	2.00	0.00
4.6	2.00	0.00
4.7	2.00	0.00
4.8	2.02	0.00
4.9	2.10	0.01
5.0	2.30	0.03
5.1	2.64	0.07
5.2	2.78	0.16
5.3	3.20	0.34
5.4	3.84	0.61
5.5	5.21	1.61
5.6	6.68	2.14
5.7	8.24	2.83
5.8	9.42	3.66
5.9	10.00	4.57
6.0	10.16	5.53
6.1	10.20	6.48
6.2	12.26	9.48
6.3	12.28	10.45
6.4	12.29	11.41
6.5	12.31	12.38

Causeway to Maramarua Throughflow

Volume (hm^3)	Discharge (m^3/s)
0	0
0.6	0.3
0.8	0.3
0.9	0.3
1.1	0.3
1.3	0.3
1.6	0.5
1.9	0.5
2.3	0.6
2.7	0.7
3.1	0.8
3.6	1.0
4.1	1.5
4.6	202
5.3	362
6.1	728
7.0	870
8.1	1036
9.3	1247
10.7	1657
12.2	2100
13.7	3800

JACOBS

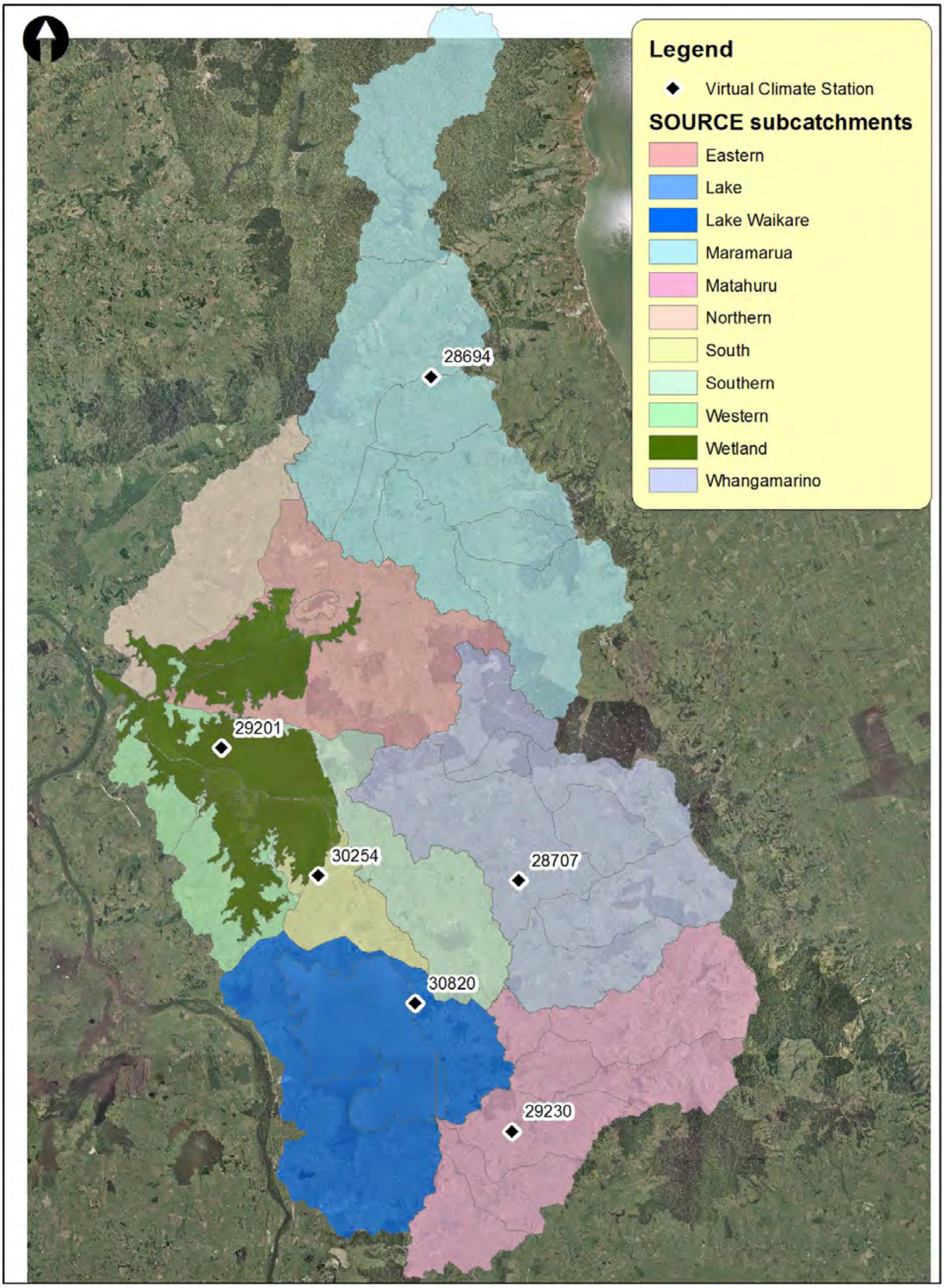
Monthly Evaporation

Month	Evaporation (mm/day)
1	4.3
2	3.7
3	2.8
4	1.6
5	0.9
6	0.6
7	0.7
8	1.1
9	1.8
10	2.8
11	3.4
12	4.1

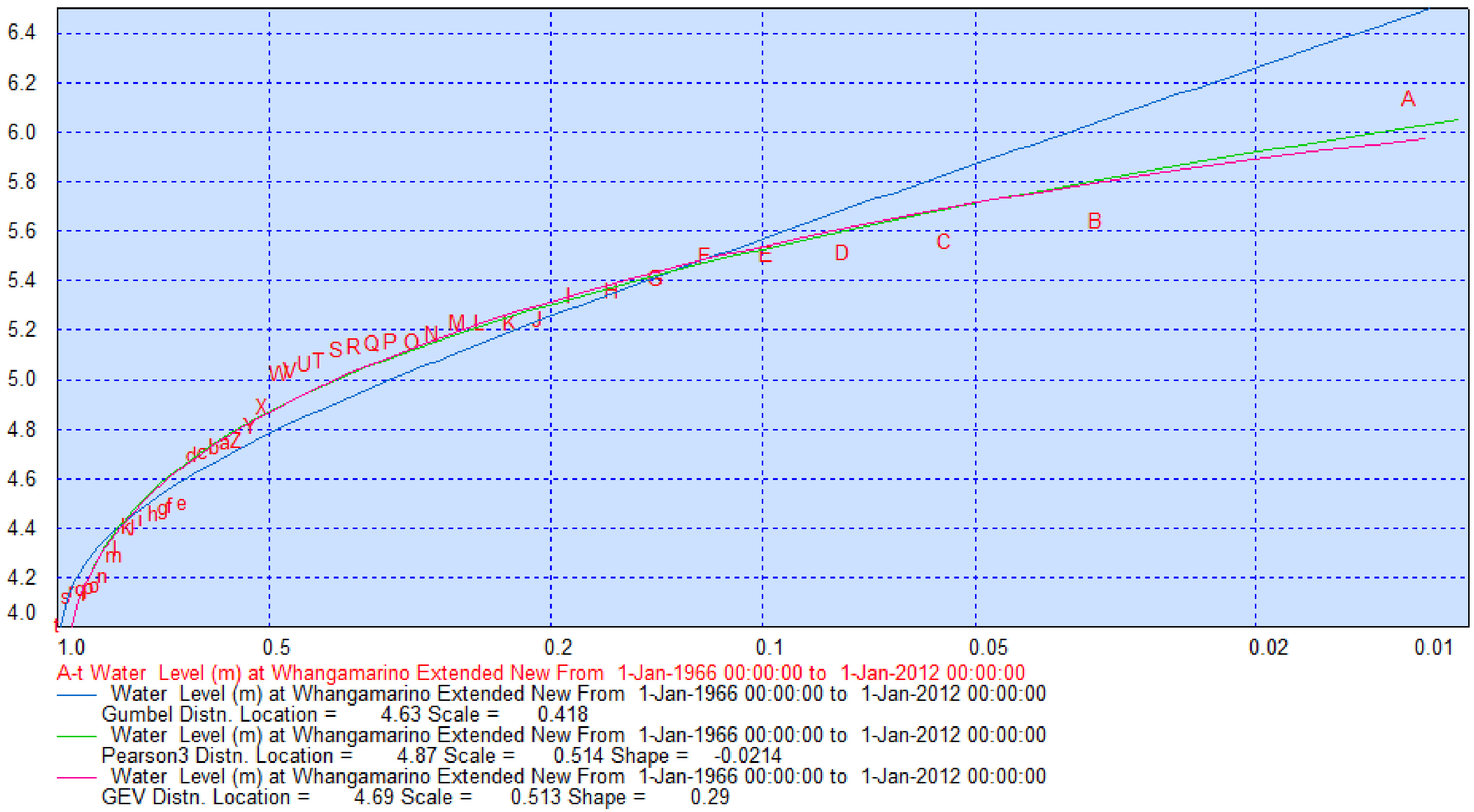
Whangamarino Weir Rating Curve

Stage (m)	Flow (m^3/s)
0.00	0
1.00	0.3
2.00	0.3
2.25	0.3
2.50	0.3
2.75	0.3
3.00	0.9
3.25	3.1
3.50	9.0
3.75	26
4.00	49
4.25	65
4.50	75
4.75	80
5.00	85
5.25	88
5.50	90
5.75	92
6.00	94
7.00	100

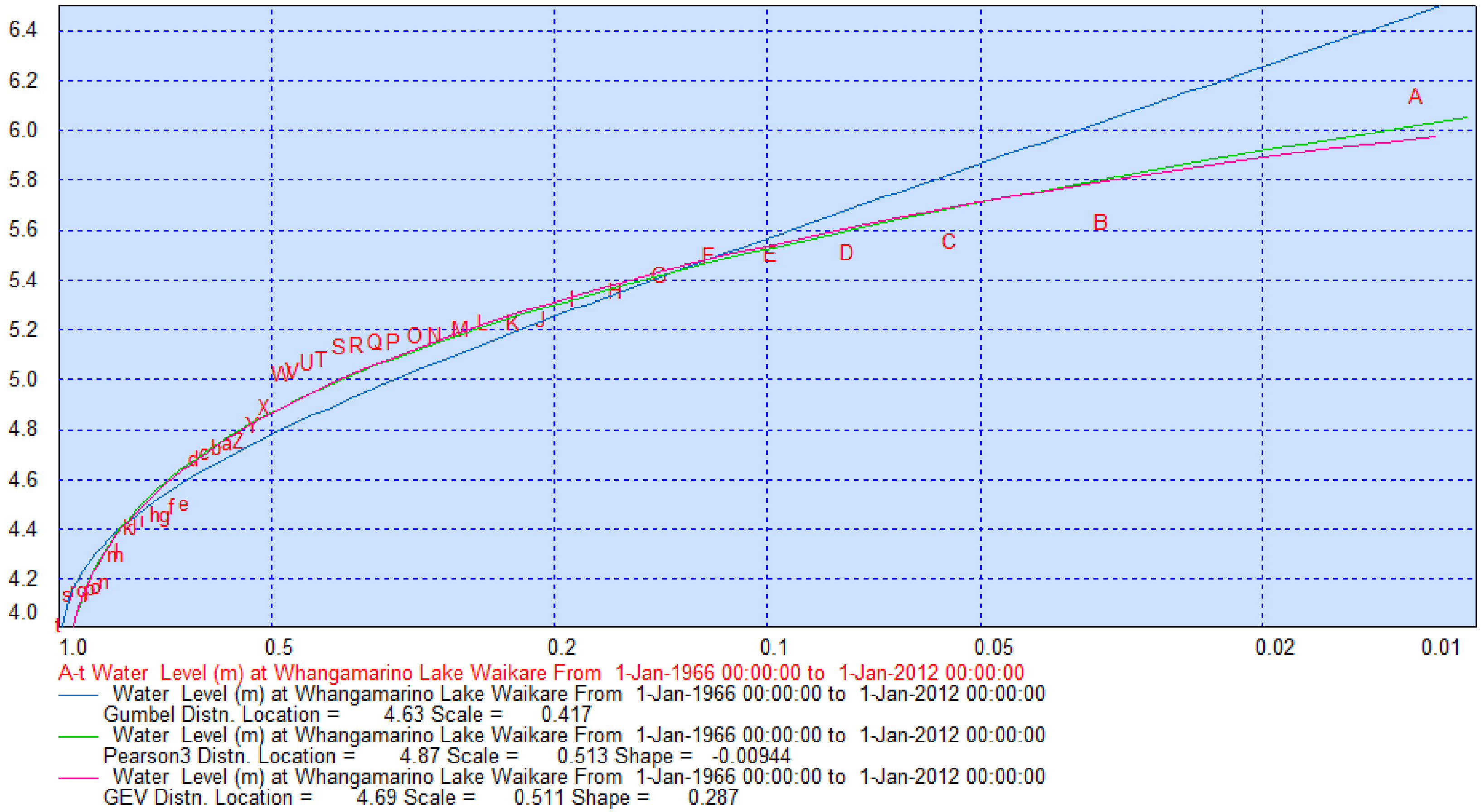
Appendix B. Catchments and Virtual Climate Station Locations



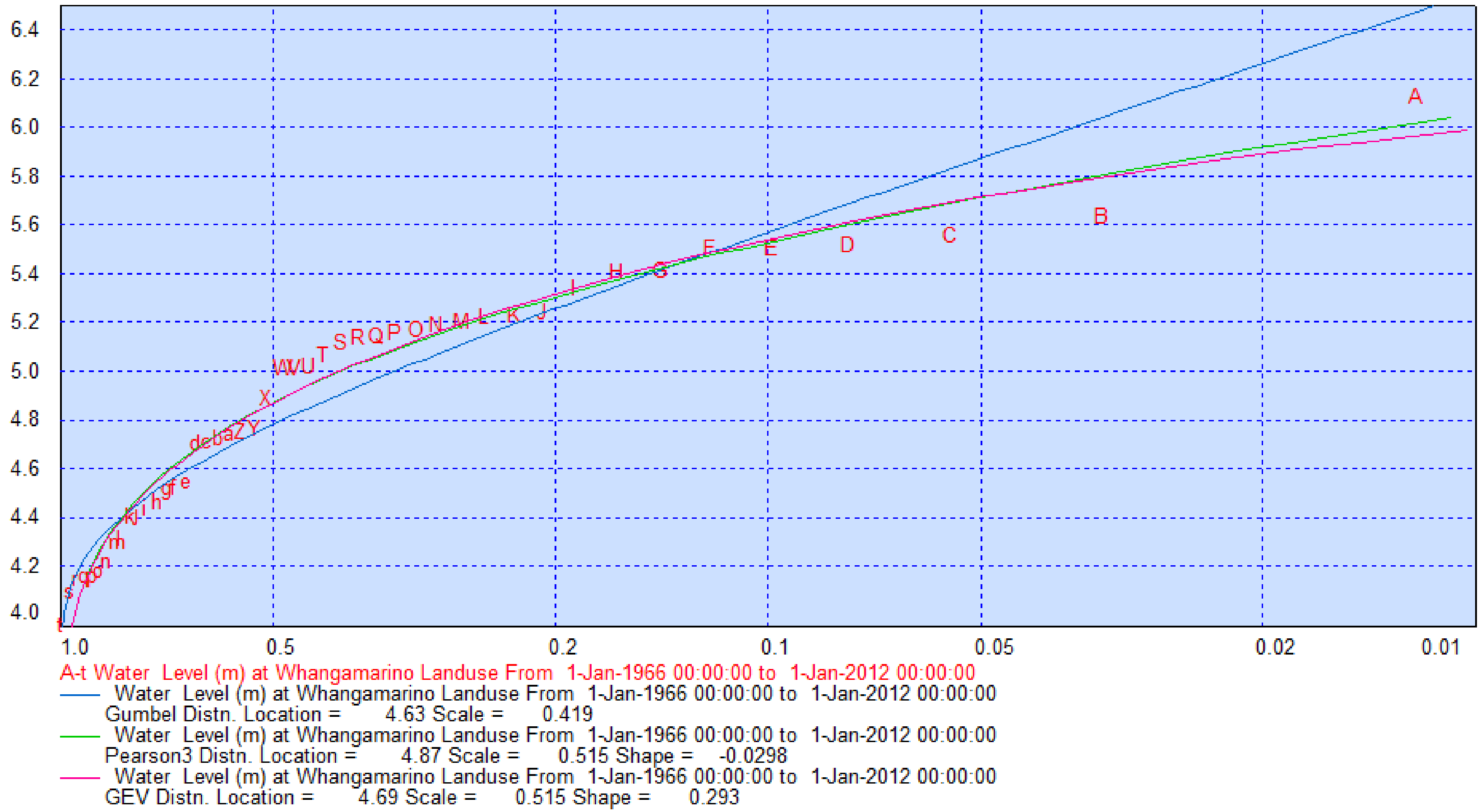
Appendix C. Frequency Analysis Plots



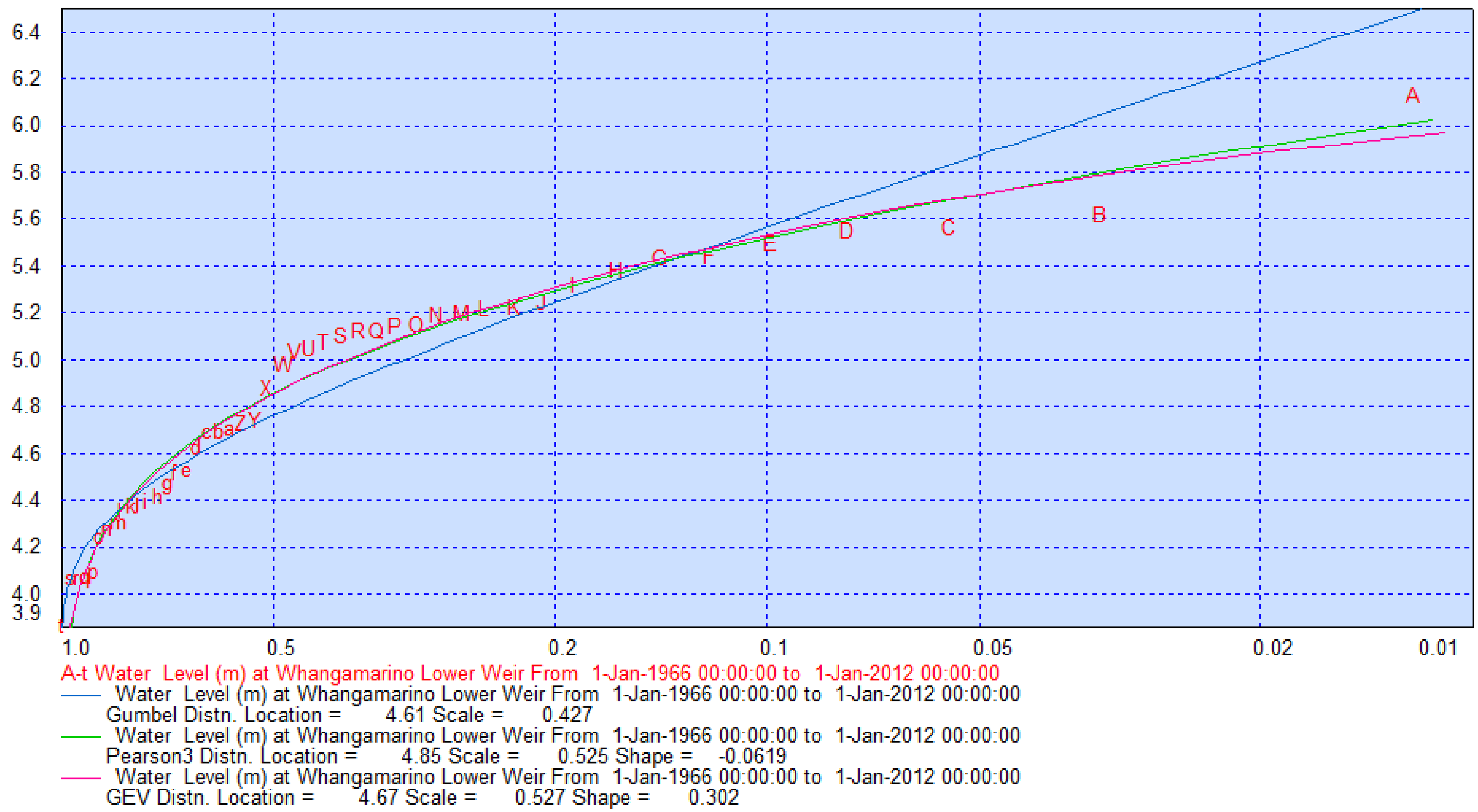
- **Figure C1. Frequency distribution plot of Whangamarino annual maximum water levels under the Extended scenario (best fit: Log Pearson Type III)**



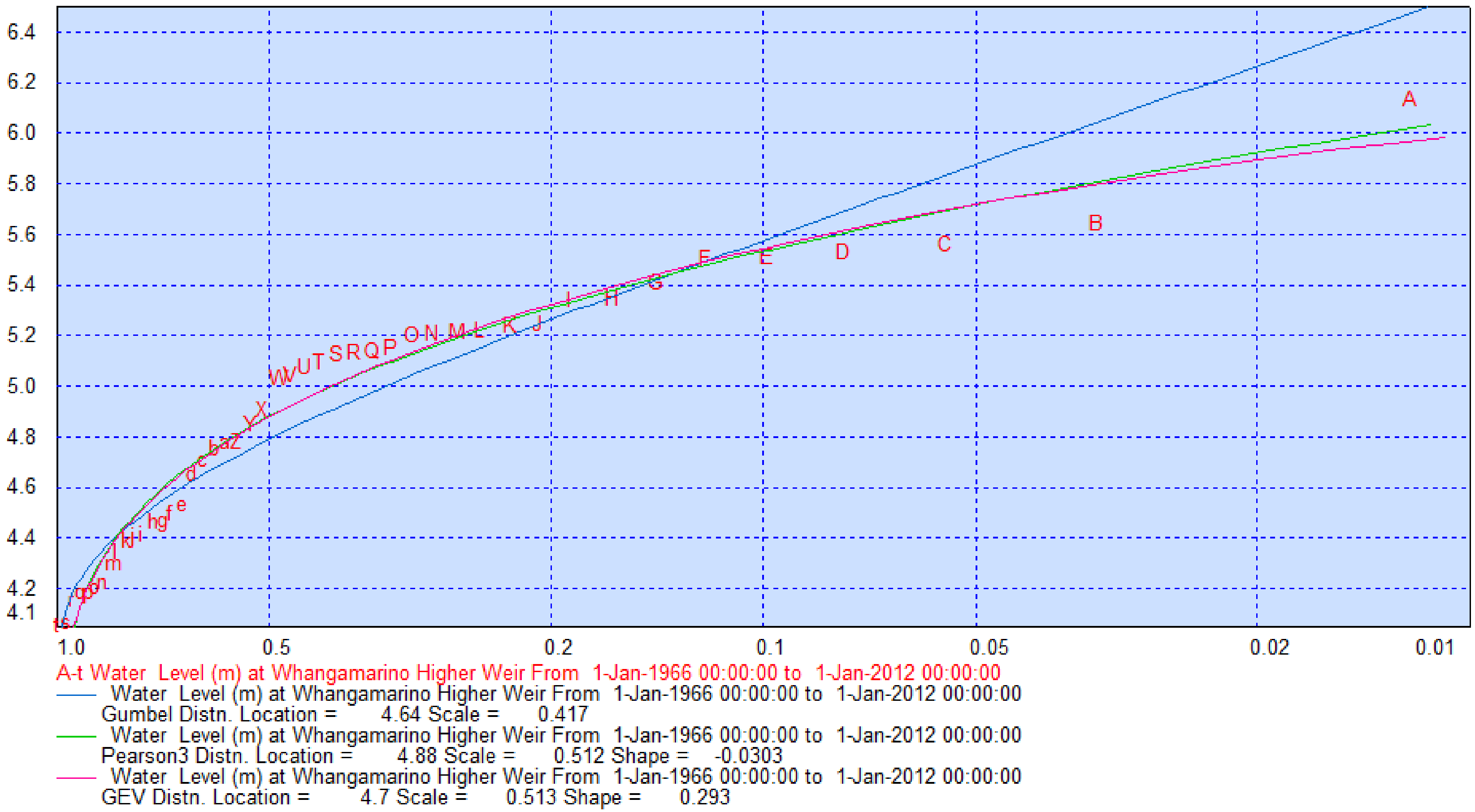
- **Figure C2. Frequency distribution plot of Whangamarino annual maximum water levels under the Lake Waikare scenario (best fit: Log Pearson Type III)**



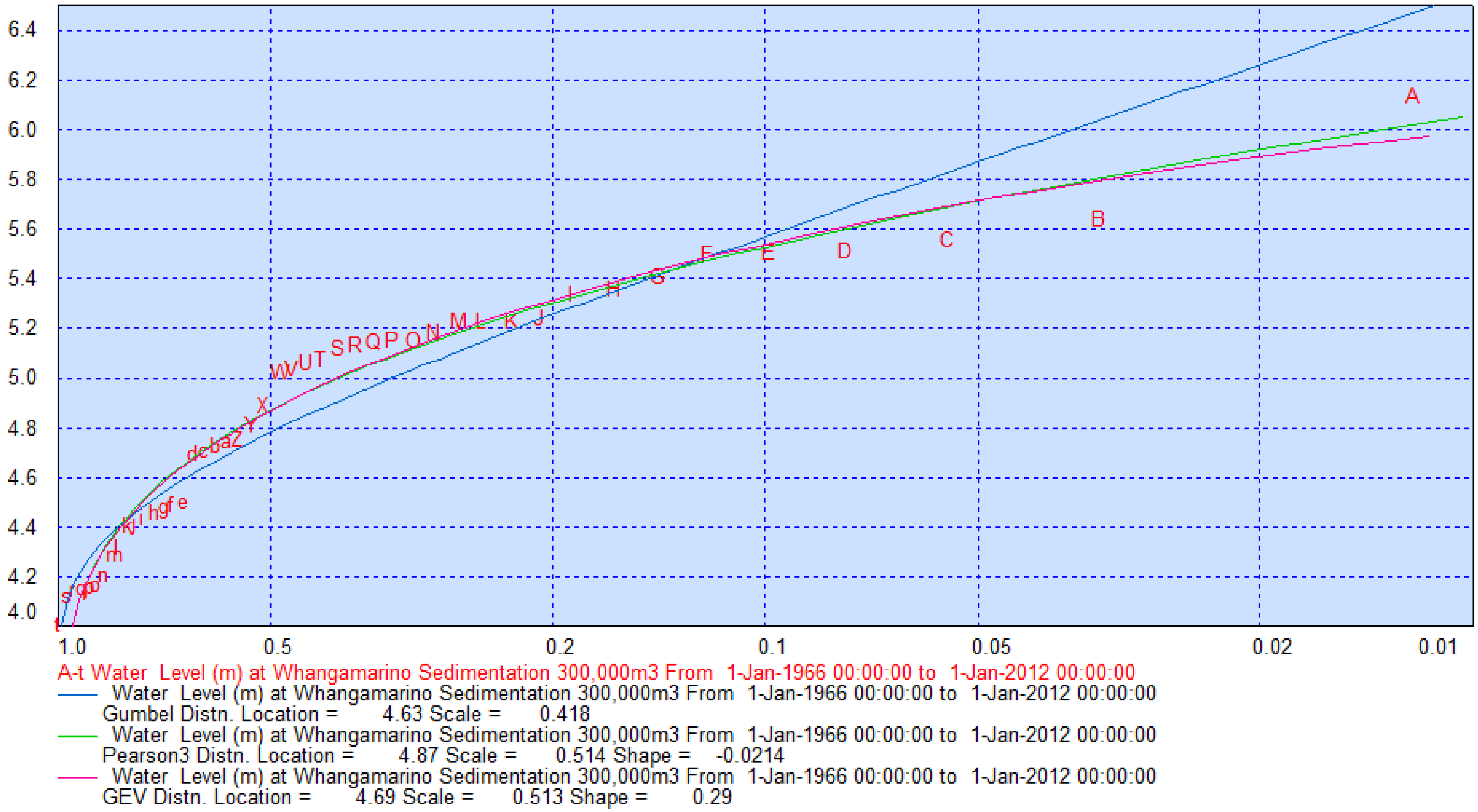
- **Figure C3. Frequency distribution plot of Whangamarino annual maximum water levels under the Landuse scenario (best fit: Log Pearson Type III)**



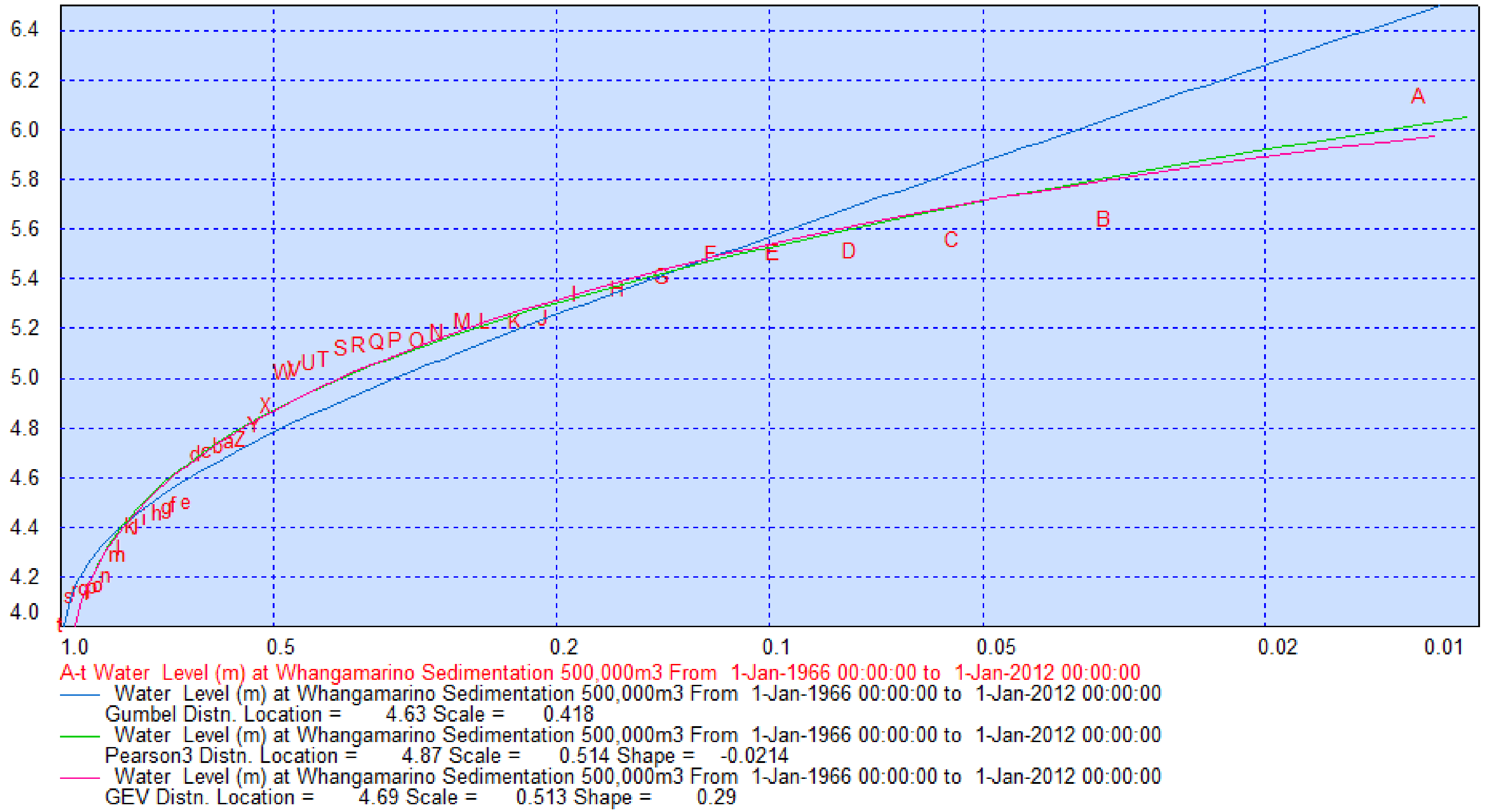
- **Figure C4. Frequency distribution plot of Whangamarino annual maximum water levels under the Lower Weir scenario (best fit: Log Pearson Type III)**



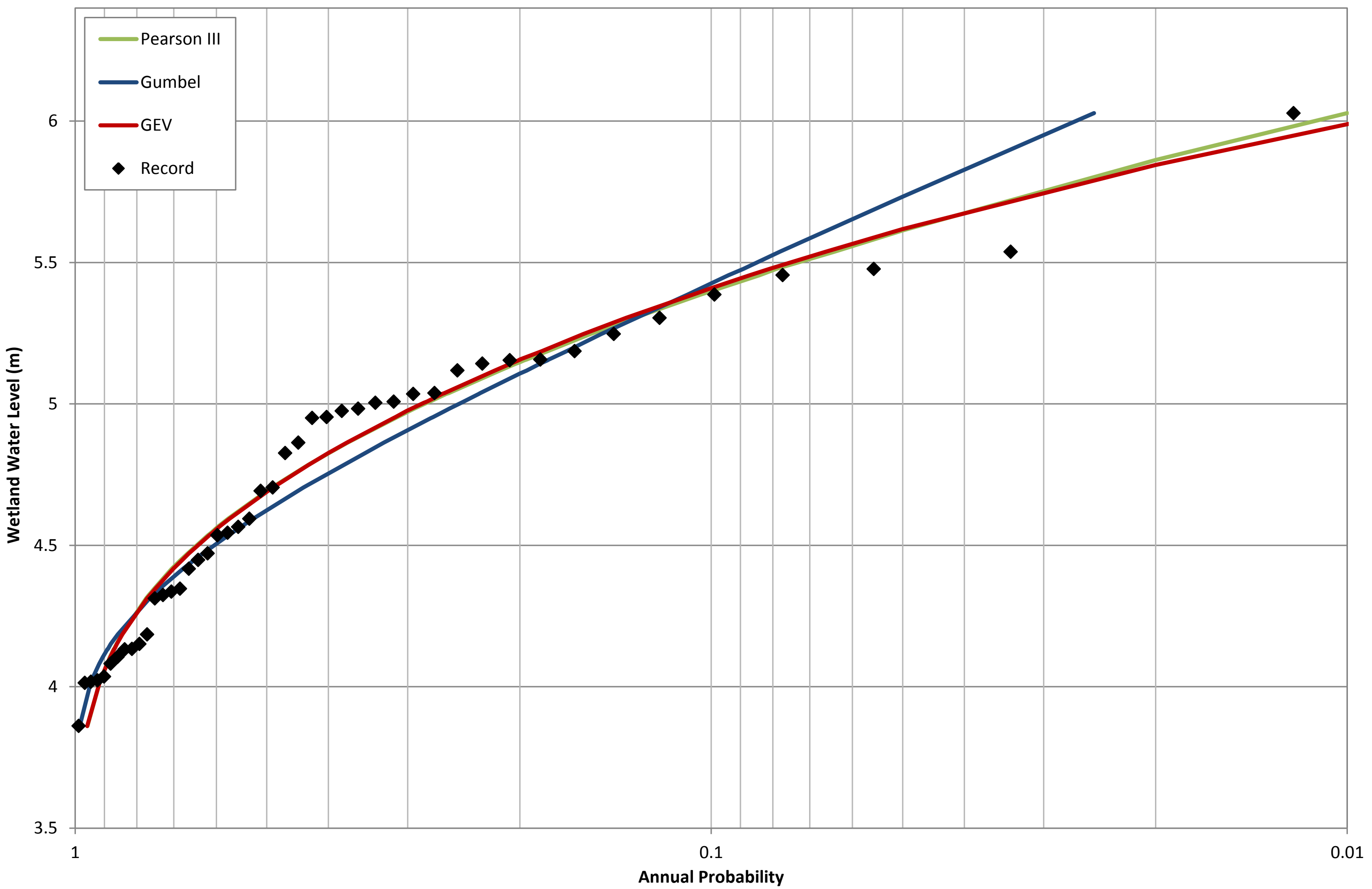
- **Figure C5. Frequency distribution plot of Whangamarino annual maximum water levels under the Higher Weir scenario (best fit: Log Pearson Type III)**



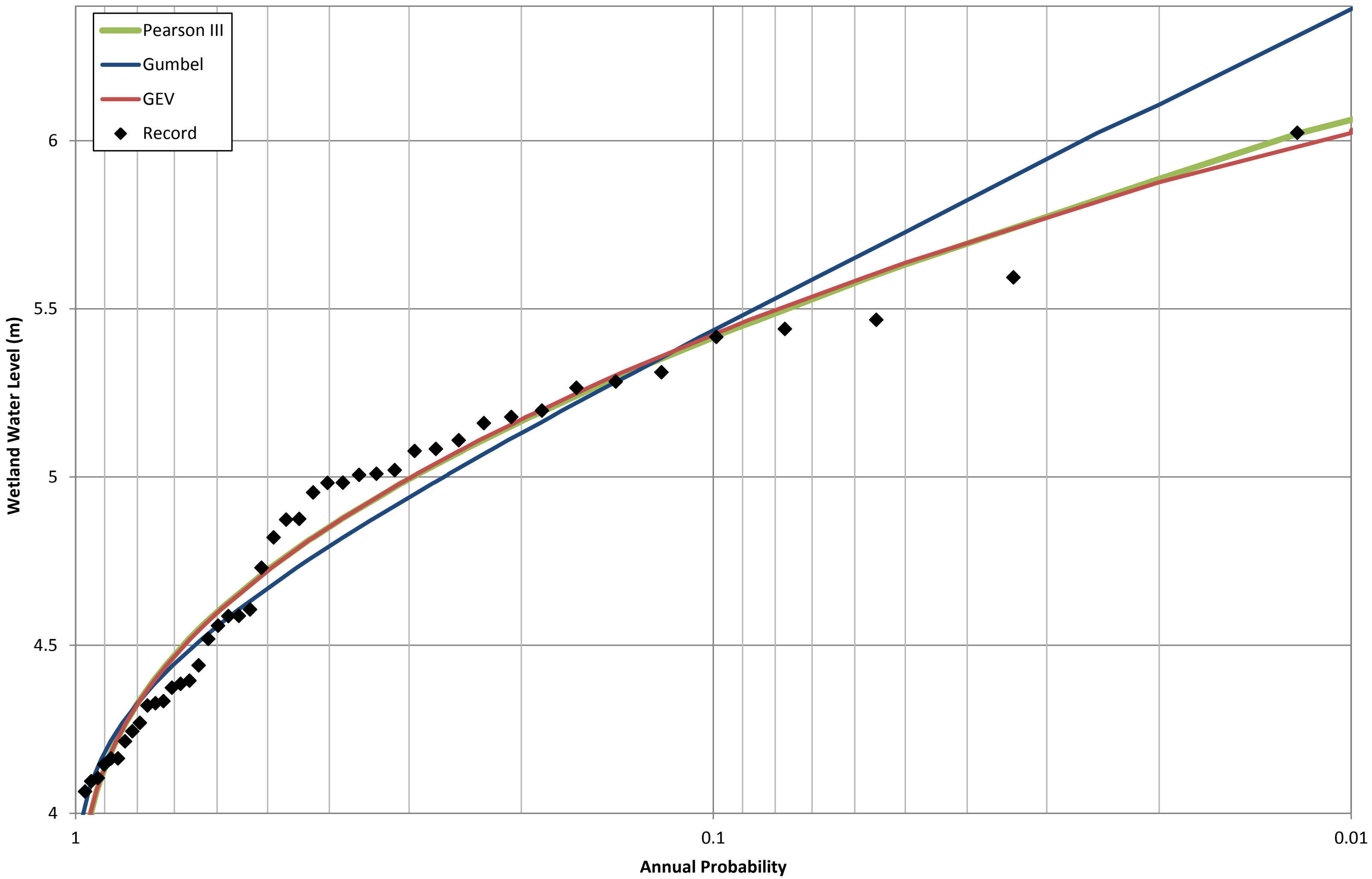
- **Figure C6. Frequency distribution plot of Whangamarino annual maximum water levels under the Sedimentation 300,000m³ scenario (best fit: Log Pearson Type III)**



- **Figure C7. Frequency distribution plot of Whangamarino annual maximum water levels under the Sedimentation 500,000m³ scenario (best fit: Log Pearson Type III)**



▪ **Figure C8. Frequency distribution plot of Whangamarino annual maximum water levels under the No Lake Waikare Discharge scenario (best fit: Log Pearson Type III)**



- **Figure C9. Frequency distribution plot of Whangamarino annual maximum water levels under the Lake Waikare Gate Closure Rule scenario (best fit: Log Pearson Type III)**