University of Southern Queensland

Faculty of Health, Engineering and Sciences

Predictions for the Hydrological Performance of the Parua Stream Dam

A dissertation submitted by

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Abstract

Engineers rely heavily on empirical methods for the design of Dams and associated outlet structures. Over-estimating parameters can lead to increased costs and under-estimating parameters can lead to safety concerns. Previous investigations revealed that the Parua Stream Dam was designed using the Rational Method, with a catchment area less than one third the actual size of the catchment. It has also been proposed to harvest a number of pine plantations which has the potential to increase runoff. This presents a concern for the safety of the dam and the outlet structures in a significant storm event.

This dissertation aimed to assess the performance of the existing dam and outlet structures in order to provide information that could be used if remedial works are required. This was achieved by monitoring rainfall and water level data and calibrating TP-108 parameters in HEC-HMS to construct a more accurate model of the catchments response to rainfall. This has also allowed an evaluation of the regional TP-108 method and the method of gauging catchments to calibrate model parameters.

The investigation revealed that the TP-108 method over-predicted runoff due to initially classifying the soils of the Waipapa Group as group C soil, instead of a group A soil. The Calibrated models achieved a much better fit when compared to TP-108 models and the final calibrated parameters achieved an acceptable level of fit, when verified against all storm events. The spillway breached in all simulation runs for the 1% Annual Exceedance Probability (AEP) events based on historic and climate change rainfall scenarios and existing and post pine tree harvest cover conditions. This confirmed the dam has inadequate performance with respect to the original design specifications and New Zealand Society on Large Dams, Dam Safety Guidelines (NZSOLD, 2015).

The project identified several potential errors and limitations when using a model to represent catchment behaviour. It also presents recommendations to minimise these potential errors through more accurate topographic data, discharge monitoring of outlet structures and site-specific infiltration testing.

The project demonstrates acceptable levels of fit can be achieved through calibrated models using gauged data; however additional storm data is required to verify the results of the project.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Callum Smith

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1 Introduction

One of the most important areas of civil engineering is hydrology and water management. The hydrological process is a relatively well-known concept in engineering science. It has become more important in recent years due to the implications of a growing population, climate change and the increase in urban development (McGrane 2016, p. 2295). These implications present complexities in being able to accurately predict catchment behaviour in response to rainfall. Being able to predict catchment behaviour allows the design of suitably sized hydraulic structures, predictions on the extent of flooding, management of water resources and predicting the effects that modifying a catchment will have on outlet structures or downstream developments (Volpi & Fiori 2014, p. 855).

The peak discharge and volume of runoff are usually the most important elements needed in hydraulic design of outlet structures and dams (Hayes & Young 2006, p. 2). There are many different methods used to model a catchment to predict the peak discharge and runoff in response to varying rainfall events. These include gauging a catchment to monitor the response of the catchment and other simplified methods that involve empirical formulas used to estimate different hydrological parameters.

The consequences of using the wrong parameters can have devastating effects as illustrated with the Belci Dam Failure in 1962, in Romania. The dam spillway design was based off rain gauge data that was over 10 years old. There were several events that displayed higher peak discharges compared to predictions in the initial design calculations. This resulted in the breaching of the spillway. These events led to new and higher calculations of the estimated peak discharge for the dam, for a 1% Annual Exceedance Probability (AEP) event. Consequently, the spillway was never re-designed to account for the higher predicted discharges. As a result, there was a rainfall event that resulted in the breach of the spillway and subsequent failure of the dam (Sharma & Kumar 2013, p. 2-3). On the other hand, if over conservative parameters are used, dams can be over-engineered which results in unnecessary construction expense to the owner, especially for small dams where the potential failure impact is low.

The method of gathering actual data provides a more accurate representation of the catchment behaviour; however it involves significant time and cost to undertake. Empirical methods provide a quick and cost-effective method to estimate the catchment behaviour but the prediction may be significantly inaccurate (Gricke & Smithers 2013, p. 1935-1936). There are numerous different empirical methods used to calculate hydrological parameters. Each method is specific to certain catchment types, regions and the local engineering standards. This presents difficulty for the designer to choose the most appropriate and accurate method for the particular design catchment.

1.1 Project Background

Parua Stream in New Zealand has a small earth embankment dam located along its flow path. The dam has been in service for the past 16 years as an attenuation reservoir with the potential for future water supply for stock and irrigation. The dam contains a low-level concrete culvert and a concrete lined emergency spillway as outlet structures. Specific details on the dam and structures are discussed in more detail in Section 3.2.2 and shown in Plans in Appendix C.

The catchment contains a number of areas of Radiata Pine forest that are ready to be harvested. Due to the potential change in the physical nature of the catchment, the dam has recently been the subject of initial assessments by others to assess the expected change in the hydrological behaviour of the catchment. The initial assessments identified a number of concerns regarding the original dam design which are discussed further in Section 2.9.

Although there have been no known events resulting in the dam overtopping, the outcomes of the initial assessment present a concern around the safety of the dam. The main concern is that the dam outlet structures were designed using an incorrect catchment area in the original Rational Method calculations. This has identified a risk that the dam is likely to overtop in a more frequent rain event than the 1% AEP event, used in the original design.

It is anticipated that remedial works, if required, will incur significant costs. Therefore, it is considered appropriate to conduct a high-level hydrological analysis of the dam catchment to obtain a more accurate estimate of the catchment hydrological behaviour and the dam and outlet structure performance.

Due to insufficient local data the dam catchment can only be modelled using empirical methods acceptable with local engineering standards. Region specific empirical formulas that are used to calculate parameters like time of concentration and initial abstraction are limited. This has highlighted the need to obtain gauge data from the catchment in order to calibrate these parameters so a more accurate model of the catchment can be constructed. This will allow a more accurate analysis of the dam performance under varying rainfall events and for different cover conditions.

1.2 Project Aim

The aim of the project is to assess the performance of the existing dam and outlet structures using calibrated HEC-HMS model parameters, determined from measured rainfall and water level data for existing land cover conditions and conditions after the harvesting of forestry blocks.

1.3 Objectives

The objectives of the project include:

- Research and adopt gauging methods, using current best practice.
- Critically review and construct an empirical model with appropriate formulas used to calculate hydrological parameters, using standard best practice.
- Run a model using real rainfall data to generate a predicted change in reservoir levels over the time of the rainfall event and compare this to the observed changes in reservoir levels, for the same rainfall event.
- Calibrate model parameters based on the observed reservoir levels with measured rainfall data and adopt the best fit parameters over a number of larger rainfall events.
- Perform a qualitative and statistical performance analysis and determine the final calibrated parameters to be used.
- Run the calibrated model for a 1% AEP event based on historic rainfall and a future climate change scenario (RCP 6.0 predicted for the period 2081-2100), for both cover conditions.
- Assess the performance of the dam and outlet structures by evaluating the predicted maximum elevation and discharge for all 1% AEP simulations.
- Evaluate the appropriateness of using uncalibrated empirical models and the limitations in both calibrated gauged models and uncalibrated empirical models.

1.4 Expected Outcomes

The project has been developed to provide information on the predicted dam performance for a variety of current and future cover conditions and rainfall predictions. The anticipated outcomes include:

- Information on calibrated hydrological parameters for the catchment.
- Information on the extent of dam overtopping for a 1% AEP.
- Information to use as the basis of remedial works, if required.
- Insight into the limitations and/or benefits of using calibrated hydrological parameters to model catchment behaviour.

2 Literature Review

2.1 Introduction

A review of relevant literature from previous research, textbooks, design standards and design documents related to the project is provided here. This chapter defines catchment hydrology and identifies the design methods and parameters used in the original dam design. Previous investigations of the project site are examined, as well as current standards and guidelines for hydraulic design of small earth embankment dam outlet structures. Specific hydrological modelling methods, current environmental monitoring standards for collecting gauged data in a catchment and previous literature involved with calibrating and assessing the performance of hydrological models are also reviewed. The literature review will allow the design of an appropriate methodology to achieve the aims and objectives of the project.

2.2 Catchment Hydrology

A catchment (drainage basin or watershed) is a topographically bound area that collects rainfall and directs it to a stream or channel and eventually out of the catchment, usually into the sea (Peters 1994, p. 207). Catchments can be made of a series of smaller sub-catchments that contribute to the main catchment. Each catchment and sub-catchment is dynamic, meaning that the hydrological response can vary for the catchment with respect to time (Pathiraja *et al* 2016, p. 3350). This is what makes analysing and predicting catchment behaviour so difficult.

There are a number of factors or parameters influencing the behaviour of a catchment. These parameters determine the quantity of rainfall that discharges from the catchment as runoff, and what quantity is stored, evaporated or infiltrated into the ground (USGS 2021a). These parameters form the basis for hydrological models and are used to assess the catchment response to rainfall. The parameters can be categorised into meteorological and physical parameters.

2.2.1 Meteorological Parameters

Meteorological parameters are associated with rainfall and evaporation. These parameters are extremely variable, and are discussed in further detail below.

Rainfall Intensity, Duration and Frequency (IDF)

Rainfall intensity is the average rainfall rate (mm/hr) for a specific rainfall duration and frequency, with duration being the length of a storm event (min or hr) and frequency is the likelihood of the event reoccurring (Vyver 2015, p.1451-1452). Intensity, duration, frequency curves are used to predict rainfall intensities for storm events with varying durations and frequencies. An example IDF curve is shown in Figure 2.1.

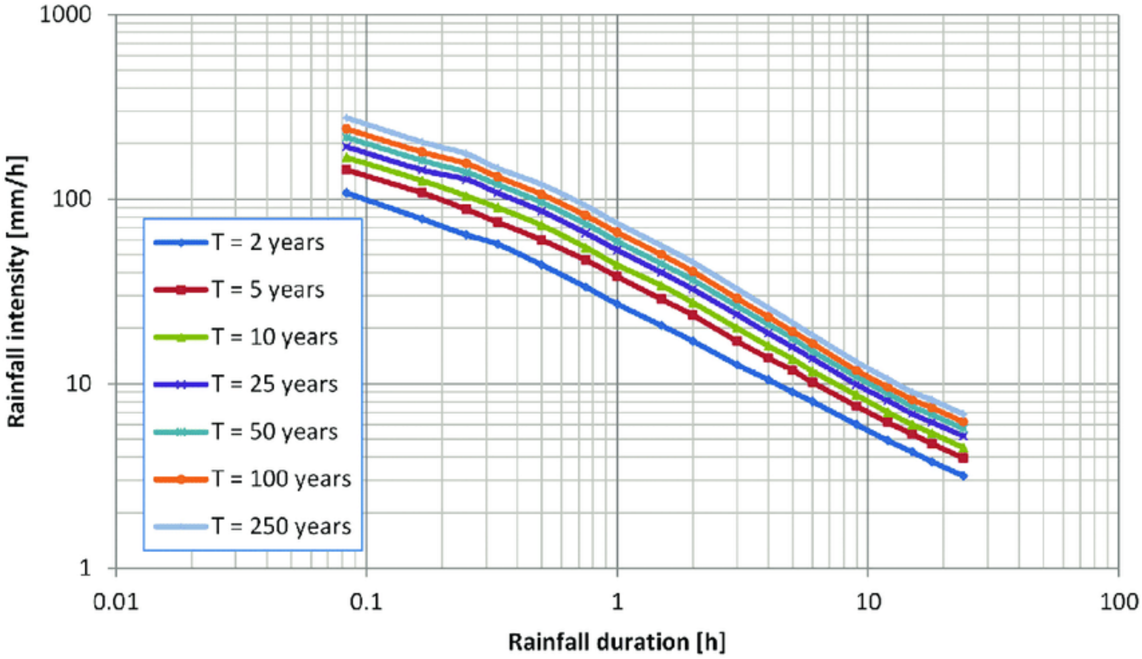


Figure 2. 1. Intensity Duration Frequency Curve

(Bezak et al 2018, p.5).

The IDF curve in Figure 2.1 displays a typical trend for how rainfall intensity varies depending on duration and frequency. Figure 2.1 shows how rainfall intensities tend to be higher for shorter duration and less frequent events. IDF curves are important in being able to determine a rainfall intensity to be used for a specific design storm, when the time of concentration is known or can be accurately estimated.

Rainfall Depth

Rainfall depth is the total amount of precipitation that falls in a given storm event. It is usually expressed as a depth and can be converted to a volume by multiplying the depth by area over which it has rained. There are also depth, duration, frequency (DDF) curves, similar to IDF curves. These allow rainfall depths to be used in engineering design, for different design storms.

Evopotranspiration

Evapotranspiration is a combination of evaporation, being the rate at which water transfers from a liquid to a vapour or gas, and transpiration being the process in which plants extract water from the soil through their roots and lose water as vapour through their leaves (USGS, 2021b). It is dependent on solar radiation, temperature, relative humidity, atmospheric pressure and wind (Almedeij 2012, p.1-2). These variables are dynamic depending on the time of year and time of day. Evapotranspiration can have an impact on the hydrology of a catchment as it can reduce the quantity of surface and groundwater storage meaning there is potentially more retention volume available in storm events. Reservoirs that have large surface areas within a catchment can lose considerable volumes of water through the process of evaporation. Catchments containing significant areas of forest and trees can lose large volumes of water through transpiration.

2.2.2 Physical Parameters

The physical parameters of a catchment are what contribute to the rainfall becoming runoff, when the rainfall reaches the surface of the catchment. These parameters can also be dynamic and variable throughout the catchment.

Catchment Area

The catchment area is usually expressed in square metres or square kilometres (m^2, km^2) or in hectares (ha). The movement of surface water is influenced by gravity, where it flows from an area of higher elevation to lower elevation. This principle means that the topography of a catchment defines the extent of the catchment area, with catchment boundaries usually separated by higher elevations like ridge lines. The larger the catchment area the more potential rainfall volume can fall and contribute to the peak discharge at the outlet (Bedient *et al* 2008, p.8).

Land Cover

The catchment surface can be made up of a number of different cover types. These can vary from grass to vegetation, trees, rock, gravel, concrete, decaying organic matter and more. Each cover type responds differently when it comes into contact with surface water by influencing the rate of runoff. Impervious surfaces like concrete contribute to significantly higher runoff rates for the same rainfall as pervious surfaces like grass and vegetation (Bedient *et al* 2008, p.98). Trees can also further slow down the runoff rate as the canopy acts as an extra barrier between rainfall and the ground surface. Land cover is continually changing and even the variations in grass length can impact the rate of runoff in a catchment (Montaldo *et al* 2020 p.1305).

Surface Slope

The slope of the main channel in the catchment and the slopes of the overland flow paths influence the rate of runoff. The slope is usually expressed as the rate of change of elevation along the distance of the flow path (Bedient *et al* 2008, p.97). Steeper slopes lead to higher velocities of flow and lower times of concentrations, which can increase the runoff rates. Higher slopes can also decrease the soil infiltration rate which increases runoff rates (Nassif & Wilson 1975, p. 548). Slopes vary within a catchment and along channels. This means that defining this parameter is very difficult, and accurate delineation from topographic maps can be challenging and inaccurate.

Soil Type

The type of soil can influence the rate of infiltration and ultimately the rate of runoff in a catchment. Different soil types have different infiltration rates. Soils like heavy clays are almost impermeable, allowing very little infiltration and more rainfall will runoff or pond. Sands and gravels, on the other hand, are very permeable and a large proportion of rainfall is able to infiltrate into the ground where it moves through the catchment at a much slower rate, compared with surface flow (Pitt *et al* 2001, p. 3). Soil types can vary throughout a catchment especially if the catchment has a large area. The fluctuations in soil moisture can have a considerable impact on rainfall runoff, and are largely dependent on the type of soil, time of year and frequency of rainfall events (Pathiraja *et al* 2016, p.3351).

Channels and Reservoir Characteristics

The channels and reservoirs in a catchment contribute to the runoff rate in a catchment through the process of storage and attenuation. Both channels and reservoirs have the ability to store runoff for a certain period of time before the storage capacity is reached where outflow will be equal to the inflow. Before the storage capacity is reached the discharge can be controlled through outlet structures like culverts and weirs. This allows the discharge rate of the reservoir/channel to be reduced to a rate less than the inflow, with the remaining inflow volume being stored. This process is called attenuation, which can reduce the peak discharge and time to peak in a catchment (Montaldo *et al* 2004, p.545).

2.3 Catchment Gauging

There are many reasons to gauge a catchment including flood analysis, water management and to design hydraulic structures. The size and complexity of the catchment, the proposed design and local standards will determine the gauging system to be used.

The following project requires the gauging of the Parua Stream catchment. In order to adopt the most appropriate methodology for the project it is important that hydrological gauging equipment and standards for catchments are assessed.

2.3.1 New Zealand Environmental Monitoring Standards

Land, Air, Water Aotearoa (LAWA) have completed a project called the National Environmental Monitoring Standards (NEMS), to provide consistent standards on how environmental data should be collected throughout New Zealand (LAWA, 2021). The following standards have been summarized in Table 2.1 and 2.2 below and were used as the basis of equipment selection, site selection and data collection for the project.

NEMS Rainfall Recording (NEMS, 2017)

NEMS Rainfall Recording is specifically aimed at what equipment is acceptable for obtaining rainfall data, where the equipment should be placed and how to calibrate and validate the gauges. The standard sets out minimum requirements for equipment type and placement that ensure the data meets specific quality criteria.

The standard includes a site matrix and a rainfall data quality matrix that provides a quality code for the proposed equipment set up. The combined score should be less than 3 in order to achieve a quality code of QC600. This ensures data is collected using standard best practice and meets the national standards.

The quality code is scored in relation to achieving the following requirements:

Table 2. 1: NEMS Rainfall Recording Standard Requirements

(NEMS, 2017)

Metadata *Section 1.1*		Metadata shall be recorded for sites and measurements.
Stationarity *Section 1.2*	Stationarity shall be maintained.	

Site Topography *Section 2.1*	Slope of land	Slope less than 19° Site not on a roof
Exposure *Section 2.2*	Wind effects	Site shall not be subject to median average annual wind speeds > 3m/s
Obstructed Horizon *Section 2.3*	All gauges	No obstruction present within a 2:1 ratio of distance to height
Required Gauges *Section 3.1*	All gauges	Primary reference gauge and intensity gauge are present
Distance Between Gauges *Section 3.2*	Primary reference gauges and intensity gauges	Between 600 mm and 2000 mm
Verification of Gauges	Primary reference gauges Section 3.3.1	Gauge complies with requirements for verified primary reference gauges
	Intensity gauges Section 3.4.1	Gauge complies with requirements for verified intensity gauges
Primary Reference Gauges *Section 3.3*	Resolution	Can be read to 1-mm resolution
	Orifice diameter	127–203 mm
	Height	305 mm ± 20 mm *or* ground level with anti-splash grid installed
Intensity Gauges *Section 3.4*	Resolution	≤0.5 mm
	Orifice diameter	127–203 mm
	Height	285–600mm *or* ground level with anti-splash grid installed

Timing of Measurements *Section 3.6*	Totalising interval	Maximum period ≤ 60 s *or* event recording
	Accuracy *Section 4.1.2*	Deviation no greater than 60 s from New Zealand Standard Time
	Time zone	Express time as New Zealand Standard Time (NZST). *Do not use New Zealand Daylight Time (NZDT).*
Site Inspections *Section 4.1.1*	Frequency	Minimum once every 3 months
Data Validation *Section 4.1.3.2*	Deviation – intensity gauge vs. primary reference gauge	The deviation of the intensity gauge to the primary reference gauge does not exceed ±10% of the primary reference gauge reading *or* 5 mm where less than 50 mm of rain has fallen.
Processing of Data		All changes shall be documented. All data shall be quality coded as per the Quality Codes flowchart.

NEMS Water Level (NEMS, 2019)

NEMS Water Level is specifically aimed at what equipment is acceptable for obtaining water level data, where the equipment should be placed and how to calibrate and validate the equipment. The standards set out minimum requirements for equipment type and placement that ensure the data meets specific quality criteria.

The requirements of the standard are summarized in Table 2.2 below:

Table 2. 2: NEMS Water Level Standard Requirements

(NEMS, 2019)

Units of Measurement			Express units in: • metres (m), or • millimetres (mm).
Resolution			1 mm
Timing of measurements	Maximum recording interval	Rivers and lakes	5 min
		Groundwater	15 min
		Sea	1 min
	Averaging	Rivers, lakes and groundwater	Instantaneous value *Note: Averaging must be defined and justified in the accompanied metadata stating comparison results with instantaneous and why this averaging period was used.*
		Sea	• 1 min (average), and • 1 Hz sampling interval (minimum)
	Resolution		1 s
Accuracy	Rivers and lakes		The greater of: • ± 3 mm, or • 0.2 % of effective stage.
	Sea and groundwater		The greater of: • ± 10 mm • 0.2% of effective stage.
Stationarity	Stationarity of record shall be maintained.		

Timing of Measurements (con.)	Accuracy	Rivers, lakes and groundwater	± 90 s
		Sea	± 20 s
	Time Zone		Express time as New Zealand Standard Time (NZST). *Note: Do not use New Zealand Daylight Time (NZDT).*
Supplementary Measurements	Barometric Pressure		Required for unvented pressure transducers. Note: Barometric pressure data is a useful supplement for the analysis of groundwater and sea level.
	Measurement Statistics		Any supplementary data stream shall be defined in the metadata.
	Salinity		Required for pressure transducers in estuarine environments.

Validation Methods	Sensor test	Required pre-deployment.
	Primary reference measurement	Nearest 1 mm with estimate of uncertainty.
	Inspection of Recording Installations	Perform sufficient inspections to ensure the collected data, are of known and acceptable uncertainty, and free from bias, both in level and time.
Calibration	Frequency	Where relevant follow manufacturer's specifications. Annually for pressure transducers.
	Method	Where relevant follow manufacturer's specifications.
	Primary reference gauge	Reduced level of recording zero demonstrated constant over time to ± 3 mm.

Metadata	Scope	Metadata (Annex G) shall be recorded for all measurements.
Quality Assurance		Quality assurance requirements are under development.
Processing of Data		All changes from raw record shall be documented in the metadata. All data shall be quality coded as per Quality Codes flowchart.

2.3.2 Water Level Measuring Devices

The Water Level standard highlights several different measuring devices that are suitable for monitoring the water level in reservoirs. These include;

Staff Gauges

A staff gauge is a simple measuring device that is fixed over the depth of the water body being measured. It allows for instantaneous water level measurements, control checks with other devices and sets the zero level for recording the water level.

Electric Plumb Bob

An Electric Plumb Bob is a device that works by completing an electric circuit and initiating a buzzer or light when the plumb bob comes in contact with the water. This allows the user to read the measurement directly from the tape that the plumb bob is connected to. The main application is usually to measure the water in a stilling well.

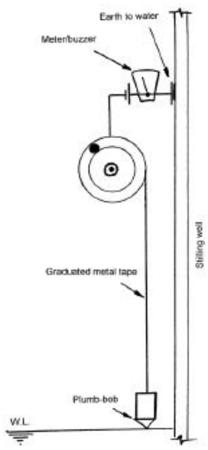


Figure 2. 2. Electric Plumb Bob Example

(NEMS, 2019)

Shaft Encoder

The Shaft Encoder works by recording the relative rise and fall of the float (water level) that is connected via a pulley to a counterweight. It requires a stilling well and can be connected to a data logger.

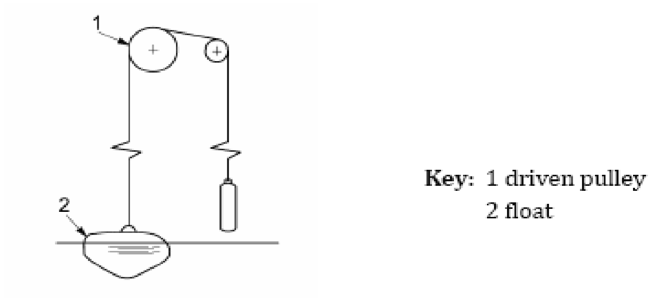


Figure 2. 3. Shaft Encoder Example
(NEMS,2019)

Pressure Transducers

Pressure Transducers work on the principle of converting pressure from the atmosphere and water acting on the sensor into an electrical signal. These sensors usually do not require a stilling well and can be connected to a data logger for recording changes in water level. Most of these sensors have automatic compensation for changes in atmospheric pressure and water density, due to changes in temperature.

Gas Purge Sensors

Gas Purge Sensors measure the changes in water level via a small tube that has gas constantly flowing through it. As the water level changes the backpressure in the tube is measured and is proportional to the water pressure over the orifice of the tube.

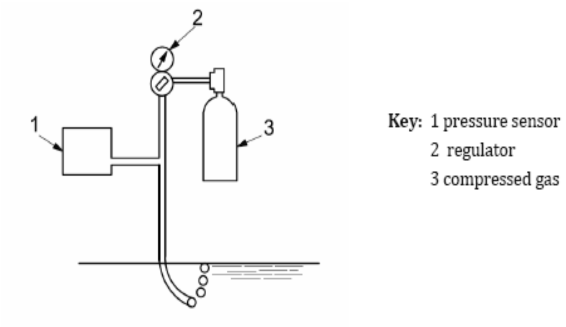


Figure 2. 4. Gas Purge Sensor
(NEMS, 2019)

Acoustic Transceivers

The Acoustic Transceivers measure the time it takes for an acoustic sound wave to return from the water surface to the receiver. This time can be converted to distance and allows the measurement of the change on water level. Sensors can be mounted in the air or in the water. The air sensors typically have lower accuracies and the accuracy depends largely on knowing the air temperature during recording and being able to place the transceiver as close as possible to the water surface.

The water sensors do not require a stilling well but are also sensitive to changes in water temperature.

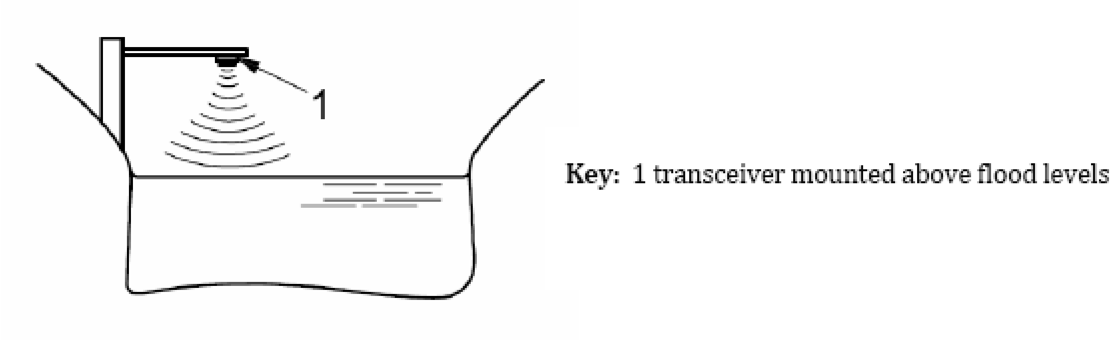


Figure 2. 5. Air Path Acoustic Transceiver
(NEMS, 2019)

Data Loggers

Most electrical measuring devices will automatically transmit the recorded data to an internal data logger or to a telemetry system. This allows data to be collected and monitored without removing the device and also allows the user to see if there are any potential errors occurring in data collection.

2.3.3 Site Selection

There are many factors that should be taken into account when choosing a site to set up the equipment. These are dependent on the type of equipment and the type of water body that is being measured.

All sites should take into account:

- Access and legal requirements when setting up, monitoring and removing measuring devices.

- Potential hazards and mitigation measures.
- Hydraulic properties of the site, whether a stilling well is necessary and that the largest possible flood will be able to be measured.
- Environmental effects.
- Resource consent requirements.
- Durability and stationarity of the site.
- Positioning to allow power supply or solar panels.

The water bodies that are relevant to the project include:

Lake/Reservoir Stations

- Should be sheltered from waves.
- Located in a position to record the lowest possible level while still not too far away from an area where the data logger is positioned and accessible.

Reference Levels

In order to monitor and validate the measured water levels and equipment, there should be survey controls put in place at the site.

The stage height of the water should have a vertical datum that it can be referenced to throughout the measuring period. There should also be a minimum of three permanent benchmarks set up on site to check station movement and allow correction.

The levels to be taken with reference to the datum include:

- Staff Gauge zero.
- Inverts of the existing culvert inlet and outlet, the existing spillway inlet and the dam top.

Calibration and Verification

Verification checks should be undertaken at a maximum of three-month intervals. The water level should be logged with reference to the staff gauge over a known time. This should be checked against the logged value on the sensor for the same time period in order to develop the sensor offset to the referenced staff gauge level. This value can be checked in site monitoring checks to ensure stationarity and accuracy of the sensor.

2.4 Earth Embankment Dam Standards and Guidelines

A number of design guidelines have been identified and reviewed that are relevant to the project. These guidelines identify recommendations around hydrologic and hydraulic design for dam structures,

2.4.1 New Zealand Dam Safety Guidelines (NZSOLD, 2015)

The main guideline specific to New Zealand Engineers, is the New Zealand Society of Large Dams (NZSOLD) "Dam Safety Guidelines" (NZSOLD 2015). This guideline provides recommendations for the steps to take when designing dams. The NZOLD, 2015 Guidelines have been reviewed in order to determine the best approach to assess the performance of the existing dam and outlet structures.

This is an extensive document that covers a number of modules including legal aspects, hazard classification, design, construction, safety management, emergency plan and lifecycle management.

This review will focus mainly on the legal requirements, hazard classification and design aspects of the guideline which are relevant to the project.

NZSOLD 2015 Module 1 – Legal Requirements

This module highlights the legislative obligations in relation to New Zealand Dams. The guideline addresses the liability on the dam owner if any dam failure occurs and impacts on downstream properties or environments.

One important requirement is that the dams need to be classified to reflect the potential impact of the dam failure. These classifications are to be addressed every 5 years or whenever modifications on the dam can result in changes to the downstream effects. This is particularly relevant due to the proposed change in land cover conditions for the project catchment.

The module indicates that there are many legal requirements for dam owners to follow. This is important to the current project as the original design has raised questions on the safety of the dam. This places the owner and potentially the original design engineer in a position of liability if the dam was to fail.

NZSOLD 2015 Module 2 – Consequence Assessment and Dam Potential Impact Classification

The guideline provides a Dam Classification System otherwise known as the Potential Impact Classification (PIC). This system is related to the potential impacts if the dam was to fail. The adopted PIC should be based off a dam break analysis to determine the potential impacts of the hypothetical dam break on downstream people, property and the environment.

With the results of the dam break analysis the damage level and the potential loss of life can be assessed. This is what the PIC is based on and can either be low, medium or high. Table 2.3 displays the PIC for potential damage and loss of life:

Table 2. 3: Determination of Potential Impact Classification
(NZSOLD, 2015)

Assessed damage level	**Population at risk (PAR)**			
	0	**1 to 10**	**11 to 100**	**More than 100**
Catastrophic	High potential impact	High	High	High
Major	Medium potential impact	Medium/High	High	High
Moderate	Low potential impact	Low/Medium/High	Medium/High	Medium/High
Minimal	Low potential impact	Low/Medium/High	Low/Medium/High	Low/Medium/High

A dam break analysis is outside the scope of the project and without a proper dam break analysis the PIC of the existing dam at Parua Stream cannot be determined. For the purpose of the project it has been assumed the PIC of the dam is low.

NZSOLD, 2015 Module 3 – Investigation Design and Analysis

Module 3 gives a summary of the performance requirements dams should have based on the PIC level. Table 2.4 is useful to observe the different requirements based on dam PIC:

Table 2. 4: Recommended Performance Criteria for Dams

(NZSOLD, 2015)

Hazard	Performance Criteria	PIC		
		Low	Medium	High
Wind and Waves	Adopted freeboard for embankment dams should be the largest of the following three freeboard requirements:			
	Freeboard at maximum normal reservoir level	Wind set up and wave run up for the highest 10% of waves caused by a sustained wind speed, which is dependent on the fetch, with an AEP of greater than 1 in 100.		
	Freeboard at intermediate flood levels	Freeboard should be determined so that it has a remote probability of being exceeded by any combination of wind generated waves, wind set up and reservoir level occurring simultaneously.		
	Freeboard at maximum reservoir level during inflow design flood impact	The greater of (a) 0.9m or (b) the sum of the wind set up and wave run up for the highest 10% of waves caused by a sustained wind speed, which is dependent on the fetch, with an AEP of 1 in 10;		
Flood	Inflow Design Flood (IDF)	1 in 100 AEP to 1 in 1,000 AEP	1 in 1,000 AEP to 1 in 10,000 AEP	1 in 10,000 AEP to Probable Maximum Flood (PMF)
Earthquake	Operating Basis Earthquake (OBE)	1 in 150 AEP		
	Safety Evaluation Earthquake (SEE)	50^{th} percentile level for the Controlling Maximum Earthquake (CME) if developed by a deterministic approach, then at least 1 in 500 AEP ground motion but need not exceed the 1 in 1,000 AEP ground motion.	50^{th} percentile to the 84^{th} percentile level for the CME id developed by a deterministic approach, and need not exceed the 1 in 2,500 AEP ground motion developed by a probabilistic approach.	84^{th} percentile level for the CME id developed by a deterministic approach, and need not exceed the 1 in 10,000 AEP ground motion developed by a probabilistic approach

Table 2.4 shows the recommended dam performance, in terms of design flood, is based on the PIC level. For a low PIC it is recommended to adopt a 1% to 0.1% AEP and with high

PIC dams it is recommended to adopt a 0.01% AEP to the Probable Maximum Flood (PMF). This makes sense, as a dam with high impact potential from dam failure should not have the potential to ever overtop and fail.

The guidelines state that "Specialist hydrological support for the estimation of flood flows" should be sought when designing a dam of any PIC level.

The guidelines state that it is difficult to determine estimations of flood frequencies higher than 1% AEP. For catchments less than 10km² in area, rainfall/runoff modelling using rainfall frequency estimates and a temporal distribution of uniform pattern is acceptable to predict the flood hydrograph.

The guideline also specifies that for Low PIC dams, "the Rational Method in conjunction with a triangular shaped hydrograph or other regional flood estimation approaches and rainfall/runoff routing" are appropriate solutions to use in flood frequency analysis. For Medium and High PIC dams, "two or more recognised hydrological methodologies and appropriate judgment" are required for flood frequency analysis.

Table 2. 5: Recommended Minimum Inflow Design Floods

(NZSOLD, 2015)

PIC	**Population at risk (PAR)**	**Potential Loss of Life**	**AEP of IDF**
Low	0 to 10	0	1 in 100 to 1 in 1,000
Medium	0 to 10	0	1 in 1,000
	0 to 10	1	1 in 2,500
	11 to 100	0 to 1	1 in 10,000
High	No Limits	0 to 1*	1 in 10,000
	No Limits	>10*	PMF

(*) If the Potential loss of life is between 1 and 10, the minimum IDF should be determined on a pro rata basis between the 1 in 10,000 AEP event and the PMF.

The guideline recommends Table 2.5 is used to determine the inflow design floods for the analysis of existing dams. It is also recommended that if the catchment contains a reservoir capable of storing flood flows, a hydrograph for the flood event should be determined in order to assess the peak water level and outflow from the reservoir.

2.4.2 Hawkes Bay Regional Council - Small Dam Design (Shaver, 2009)

The Far North District Council (FNDC) and Northland Regional Council (NRC) provide no specific standards or guidelines applicable to small earth embankment dams; however other districts in New Zealand do provide guidelines for small dams.

The Hawkes Bay Regional Council (HBRC) has provided a small dam design guideline, specifically for use within the Hawkes Bay Region. Although this region is outside the area of the project site, it provides useful information other North Island Councils are specifying to use for the design of similar structures.

The HBRC have highlighted the lack of concern regarding small dams in the New Zealand legislation and standards. NZSOLD (2015) puts more emphasis into medium and high PIC dams. This is understandable because if the low-risk dams fail there are minimal impacts, so why do we need such stringent guidelines? HBRC has addressed this concern by creating guidelines to be used for small dams, with the following recommendations regarding outlet structures:

Principal Spillway Design

Shaver (2009) specifies that the principal spillway should be greater than 150mm in diameter and greater than 300mm below the invert of the emergency spillway. The capacity of the principal spillway should be able to discharge long duration flows without the emergency spillway discharging while conveying a 10-year storm.

Emergency Spillway

The emergency spillway should be able to convey the 100 year storm with a non-erosive velocity to a downstream point that does not endanger the dam wall. The minimum freeboard from the invert of the emergency spillway to the crest of the dam should be at least 600mm (Shaver 2009, p. 19-20).

Nowhere in the guideline does it specify the hydrological methods that should be used in order to determine the 10 year or 100 year storm discharge that the spillways are to be designed for.

2.4.3 United States Department of the Interior (USDI) - Design of Small Dams

The USDI have provided a technical publication that relates specifically to small dams (USDI, 1987).

Sizing Hydraulic Features

The USDI (1987) gives a comprehensive methodology that should be followed in order to determine the design flood hydrograph that is to be used in design of the hydraulic structures and storage reservoirs.

The publication indicates there are different design flood hydrographs that should be used depending on the potential impacts of failure. Similarly to the NZSOLD guideline, the PMF is to be used in cases where a loss of life is highly likely. A specific frequency hydrograph may be used if downstream hazards can be deemed as negligible.

The publication acknowledges the fact that many designs are required where there is no stream flow data. For these cases synthetic flood hydrographs need to be developed using estimations for various parameters like infiltration, cover conditions and lag time.

Where spillway design is concerned, the recommendation is to determine a combination of reservoir capacity, freeboard and spillway discharge capacity to accommodate the selected inflow design flood. This allows the design discharge requirement of the spillway to be determined. The spillway type and size can be designed once this discharge is known.

2.4.4 Dam Guidelines Conclusion

The guidelines reviewed in this section mainly highlight the fact that a dam should be designed on a case-by-case basis. No two dams can be considered the same and dams should be designed based on the hazard classification.

The methods referred to for hydrological analysis included rainfall/runoff (hydrographs) and NZSOLD (2015) also includes the rational method as being appropriate.

Although there are no specific guidelines for the Northland Region, the NZSOLD, 2015 guidelines provide appropriate recommendations in terms of the design and analysis of all dams in New Zealand. These recommendations should be considered in the review of methods to be used in analysing the existing dam performance.

2.5 Review of Empirical Modelling Methods

Section 2.2 highlights the complexities of catchment hydrology and the many different dynamic parameters that contribute to runoff generated from rainfall. It is not practical for engineers to gauge every catchment when designing simple structures in small catchments. This has led to the development of various models that are used to represent the catchments response to rainfall based on observations from existing gauged catchments and hydrological experiments.

The project requires the Modelling of the Parua Stream Dam catchment using empirical methods. This section will review empirical methods to model the hydrological response of a catchment in order to adopt the most appropriate model for the project.

Section 2.4 gives a background on New Zealand guidelines that indicate the design flood and methods that should be used to provide a flood frequency analysis. Two of these methods include the Rational Method and a Runoff/Routing method which are both investigated in the following sections. This allows validation for the method that is chosen to assess the performance of the existing dam associated with the current project.

2.5.1 The Rational Method

The Rational Method has been used since the late 19th century and is a simple model that predicts the peak discharge in a catchment based on Equation 2.1 below from Pennington 2012:

$$q = \frac{CIA}{F} \qquad (2.1)$$

where:

q=Peak Discharge (m^3/s)

F=Unit Conversion Factor (360 for SI units)

C=Runoff Coefficient (Dimensionless)

A=Catchment Area (ha)

I=Rainfall Intensity for the Duration Equal to the Time of Concentration (mm/hour)

Equation 2.1 is a commonly used method that is defined in the New Zealand Building Code Standard for Surface Water (NZBC: E1) as an acceptable solution to be used country wide where the territorial authority does not have more accurate data from sophisticated hydrological Modelling of the catchment (MBIE 2000, p. 11). The equation in NZBC:E1 for the rational method is the same as Equation 2.1 and uses 360 as the constant for F.

The Rational Method in NZBC:E1 allows the peak discharge to be predicted for various rainfall intensities in a catchment of constant area with a constant runoff coefficient. With the catchment area being fixed there are only two parameters, the runoff coefficient and rainfall intensity, that need to be determined to calculate the peak discharge.

Runoff Coefficient (C)

Equation 2.1 indicates that the product of rainfall intensity and catchment area contributes directly to the peak discharge (Pennington 2012, p. 2). Theoretically, the product of these two parameters would be the peak discharge if the catchment was entirely made up of impervious surfaces, containing no evaporation or losses. Section 2.1 highlighted the many processes that occur as rainfall interacts with the catchment surface. This means that less than 100% of rainfall will reach the catchment outlet and contribute to the peak discharge.

The runoff coefficient represents the ratio of rainfall to runoff and is usually determined by the soil type, land cover and slope (MBIE 2000, p. 12). Due to the fact that the runoff coefficient involves a number of dynamic physical parameters it can be difficult to choose an accurate value for the entire catchment based on empirical values provided. In order to estimate a more realistic runoff coefficient for a catchment, a weighted runoff coefficient can be calculated based on the Equation 2.2. This weighted coefficient takes into account varying runoff coefficients for different areas in the catchment.

$$C = \frac{\sum C_i A_i}{A_c} \tag{2.2}$$

where:

C=Runoff Coefficient (Dimensionless)

Ci=Runoff Coefficient for a particular land use

Ai=Area of land that applies to Ci

Ac=Catchment Area

Different regions have various cover and slope combinations available to determine the empirical runoff coefficients that should be used. These are usually provided in the standard that is defining the method, as is the case in NZBC:E1.

It is important to note that the runoff coefficients provided in the empirical method defined by NZBC:E1 assume the ground conditions are saturated. This would mean that the values are conservative and could potentially over predict the peak discharge. This adds a factor of safety as there is the potential that a period of intense rainfall could occur directly after a period of prolonged rainfall.

Rainfall Intensity

The rainfall intensity that is usually adopted for design is based off intensity, duration and frequency tables for the specific area. A designer will adopt a frequency event based on design standards and determine the time of concentration in order to find the rainfall intensity that will be used for design.

The important aspect of this parameter is that it assumes the rainfall duration is equal to the time of concentration (MBIE 2000, p. 12).

Time of Concentration

The time of concentration (t_c) is generally defined as the time it takes for a rain drop to travel from the most distant point in the catchment to the outlet (Grimaldi *et al* 2010, p. 217).

Gerike and Smithers (2013) highlighted the fact that there are many different methods available to estimate the time of concentration of a catchment and many different definitions. Each method can provide considerably different values for t_c, leading to large variations in peak discharges that are used to design hydraulic structures. Figure 2.6 displays the different definitions of time of concentration on a combined hydrograph and hyetograph.

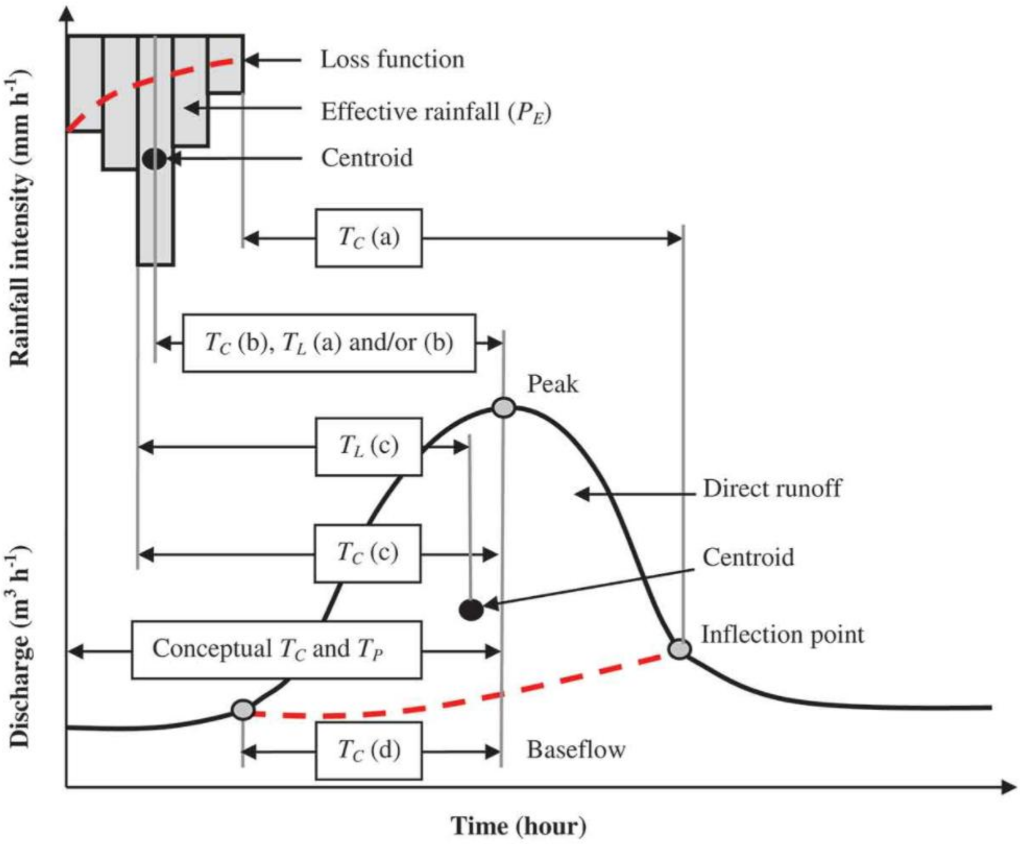


Figure 2. 6. Combined Hydrograph and Hyetograph Displaying Different Time of Concentration Definitions

(Gerike & Smithers 2013, p.1940)

The definitions from Gerike and Smithers, (2013) that relate to Figure 2.6 are:

a. "the time from the end of effective rainfall to the inflection point on the recession limb of the total runoff hydrograph, i.e. the end of direct runoff; however, this is also the definition used by Clark (1945) to define T_L;"

b. "the time from the centroid of effective rainfall to the peak discharge of total runoff; however, this is also the definition used by Snyder, (1938) to define T_L;"

c. "the time from the maximum rainfall intensity to the peak discharge; or"

d. "the time from the start of total runoff (rising limb of hydrograph) to the peak discharge of total runoff."

Figure 2.6 illustrates the conflicting definitions for time of concentration available in literature. The actual definition and value that is used will be based on the definition given in the method that is chosen to model the catchment. Gerike and Smithers (2013) concluded that it is important to avoid using time parameter estimations based on empirical methods without applying local correction factors obtained through catchment gauging.

Rational Method NZBC:E1 Time of Concentration (MBIE 2000, p.13)

The time of concentration formula is specified in the NZBC:E1 for rural New Zealand catchments to use with the NZBC:E1 rational method and is shown below.

$$tc = 0.0195\left(\frac{L^3}{H}\right)^{0.395} \tag{2.3}$$

where:

tc=Time of Concentration (minutes)

L=Length of Catchment(m) measured along the flow path

H=Rise from bottom to top of catchment

NZBC:E1 applies the equal area method if the catchment has areas of varying slopes. If this is the case *h* is used instead of *H* and is shown in Figure 2.7.

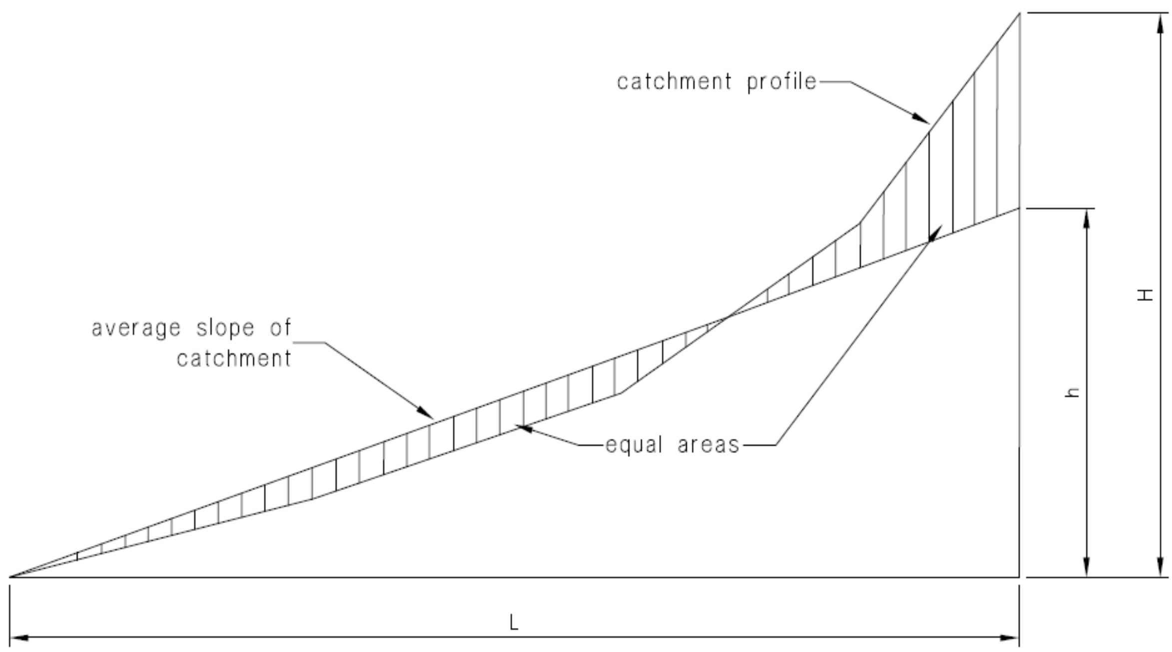


Figure 2. 7. Equal Area Method to Determine h Value.

(MBIE 2000, p.17)

Rational Method Assumptions

In order to provide a level of confidence in using the Rational Method to predict catchment behaviour, the following assumptions need to be made (Hayes & Young 2006, p.7):

1. "Precipitation is uniform over the entire basin,
2. Precipitation does not vary with time or space,
3. Storm duration is equal to the time of concentration,
4. Design storms of a specified frequency produce the design flood of the same frequency,
5. Basin area increases roughly in proportion to increase in length,
6. Time of concentration is relatively short and independent of storm intensity,
7. Runoff coefficient does not vary with storm intensity or antecedent soil moisture,
8. Runoff is dominated by overland flow, and
9. Basin storage effects are negligible."

Limitations of the Rational Method

The main limitation in using the Rational Method is that it is mainly based on calculating the peak discharge. Pennington (2012) has highlighted a number of common errors where the Rational Method is used for purposed other than calculating the peak discharge.

One of the most common errors is that it is used to produce a hydrograph to be used in flood routing analysis (Pennington 2012, p.4). This error is due to the fact that it is very unlikely for a rainfall event to have a uniform rainfall intensity and duration equal to the catchments time of concentration. In assuming this, a hydrograph like the one shown in Figure 2.8 would be produced to estimate runoff volumes.

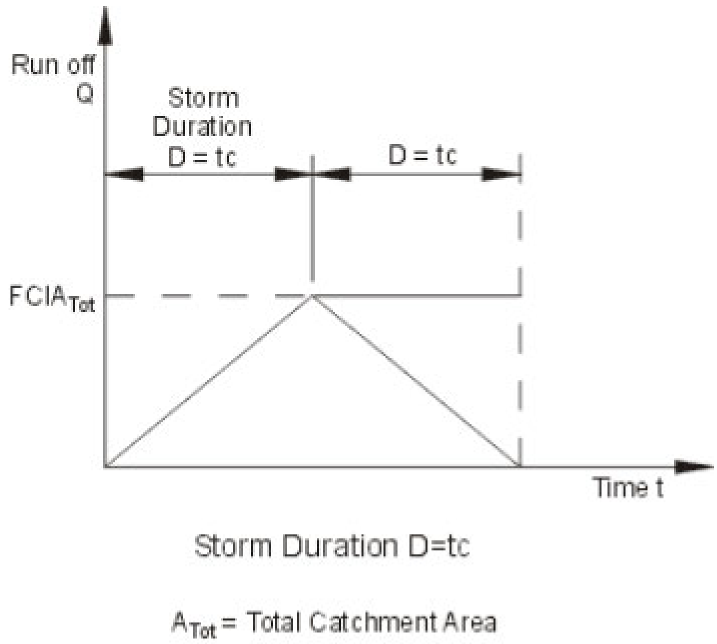


Figure 2. 8. Rational Method Hydrograph Example
(Mainroads Western Australia, 2019)

This approach should be avoided as it is likely to underestimate detention volumes (Pennington 2012, p.7). This contradicts the NZSOLD (2015) guideline that specifies the Rational Method triangular hydrograph as an appropriate method.

Appropriateness of Rational Method to Assess Dam Performance

The importance of the Rational Method is that it provides a predicted peak discharge at the catchment outlet. This is useful to size outlet structures in the initial design phase of a hydraulic design. The method should not be used to assess the hydrological response in a catchment where the effects of storage and flood routing need to be considered. It may be useful as a check against modelled flows.

2.5.2 Soil Conservation Science Method (SCS) – Rainfall/Runoff

Another method that is widely accepted and specified for use in Northland, New Zealand is the Auckland Regional Councils Technical Publication-108 (TP-108) (ARC, 1999). This method applies localised parameters to the United States Soil Conservation Service Technical Release No. 55 (TR55), more commonly known as the SCS Curve Number Method.
The TR55 method and TP108 are based on the following equation (USDA, 1986):

$$P = Q + I_a + F \tag{2.4}$$

where:

Q=Runoff (mm)

P=Rainfall (mm)

Ia=Initial Abstraction (mm)

F=Actual retention after runoff begins (mm)

The equation defines rainfall being equal to runoff and the losses in the catchment. The losses can be separated into initial abstraction (Ia) and actual retention after runoff begins (F). The initial abstraction is defined as "all losses occurring before runoff begins" (ARC 1999, p.6). This is essentially the amount of rainfall that gets intercepted in the catchment by depressions in the topography, vegetation, evaporation and infiltration. The actual retention accounts for the depth of rainfall that does not contribute to runoff, excluding the initial abstraction. This is related to soil infiltration and is dependent on soil type and cover conditions of the catchment (ARC 1999, p.6-7).

Initial Abstraction (*Ia*)

The TR55 method approximates the Ia as being:

$$I_a = 0.2S \tag{2.5}$$

Based on data from local catchments, the TP108 method has specified that a constant initial abstraction depth of 5mm for pervious areas and 0mm for impervious areas is more appropriate for the region.

During wetter months it is likely that subsequent rainfall events will result in a decrease in the initial abstraction value. This could be related to increased ponding in the catchment. This would result in runoff occurring at rainfall depths less than in dry conditions and should be considered when analysing the observed water level data, if there is any variability in the initial abstraction values.

For catchments with varying areas of pervious/impervious surface types, the initial abstraction can be calculated using the following equation (ARC 1999, p.9):

$$I_a = 5mm \times \left(\frac{A_{perv}}{A_{tot}}\right) \tag{2.6}$$

Theoretical Maximum Potential Soil Retention (*S*)

As rainfall depth increases the actual retention *(F)* is thought to increase to a theoretical maximum potential retention *(S)*. Once this point is reached, all subsequent rainfall will contribute to direct runoff. The ratio of the actual retention to the theoretical maximum potential retention is assumed to be equal to the ratio of direct runoff to rainfall minus the initial abstraction shown in Equation 2.7.

$$\frac{F}{S} = \frac{Q}{P-I_a} \tag{2.7}$$

The relationship between rainfall, runoff, initial abstraction and soil retention from Equation 2.4 can be seen in Figure 2.9.

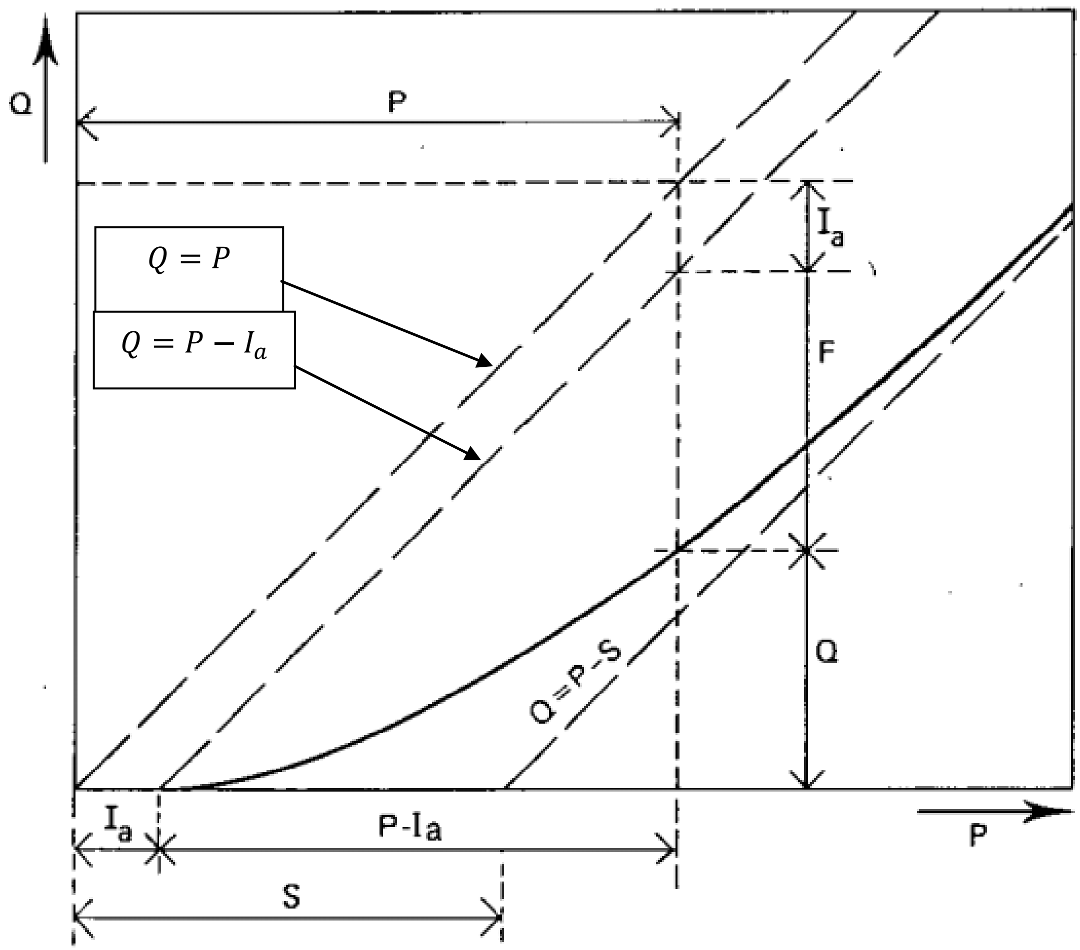


Figure 2. 9. Relationship between Rainfall, Runoff, Initial Abstraction and Soil Retention.
(Panda, 2021)

Figure 2.9 displays initial abstraction occurring at the beginning of the rainfall with no runoff (bold line) generated. After the initial abstraction phase, runoff begins and is largely influenced by the maximum potential soil retention (S). As the rainfall continues the maximum potential soil retention is reached and the runoff begins to trend more linearly, based on the relationship in the following equation:

$$Q = P - S \tag{2.8}$$

Equation 2.4 and Equation 2.7 can be combined to form Equation 2.9 which is defined in TR55 as the SCS runoff equation (USDA 1986, p. 2-1).

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \tag{2.9}$$

where:

Q=Runoff (mm)

P=Rainfall (mm)

Ia=Initial Abstraction (mm)

S=Potential maximum retention after runoff begins (mm)

Curve Number (CN)

The curve number is based on the maximum soil retention and is based on soil type, cover type, treatment and, hydrologic condition and can relate rainfall to runoff as shown in Figure 2.10.

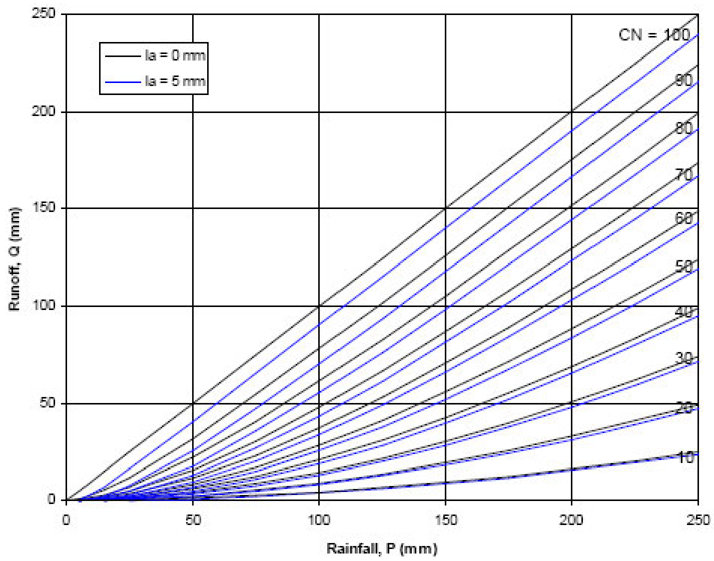


Figure 2. 10. Relationship between CN Number, Rainfall and Runoff

(ARC 1999, p.7)

Figure 2.10 illustrates how the varying curve numbers represent different proportions of runoff with respect to rainfall. A curve number of 100 represents an impervious area where all rainfall will contribute to runoff, whereas a curve number of 0 represents an area where the retention potential in the catchment is greater than the potential maximum rainfall and no rainfall will contribute to runoff.

For a catchment with varying CN, a weighted CN should be used based on the same principle as the weighted runoff coefficient example in Equation 2.2. Table 2.8 below gives an example of some specific CN values for a given soil type, cover type and hydrological condition that are specified to be used in the TP108 method.

Table 2. 6: Example CN Values

(ARC, 1999)

Cover description		Curve numbers for hydrologic soil group-			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay.		30	58	71	78
Brush-brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods-grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads-buildings, lanes, driveways, and surrounding lots.		59	74	82	86

The S value can be calculated once the CN has been determined from the following equation (USDA 1986, p.2-1):

$$S = \frac{1000}{CN} - 10 \qquad (2.10)$$

Once the *S* value, rainfall depth and initial abstraction have been determined, the runoff depth can be calculated from Equation 2.9.

SCS Time of Concentration Method

The time of concentration for the SCS method is defined as "the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed" (USDA 1986, p.3-1).

The SCS CN Method bases the time of concentration on the flow path of the catchment from the most distant point to the outlet. It uses flow velocities and length of flow to determine the travel time for each different flow segment and combines the travel times together to determine the overall time of concentration of the catchment (USDA 1986, p.3-1).

The TP108 method specific to the Auckland Region uses an empirical equation used to calculate the time of concentration that is based off 14 measured catchments in the Auckland region and is shown in Equation 2.11 (ARC 1999, p.12):

$$t_c = 0.14CL^{0.66}\left(\frac{CN}{200-CN}\right)^{-0.55} S_c^{-0.3} \tag{2.11}$$

where:

tc=Time of Concentration (hrs)
C=Channelisation Factor allowing for effects of urbanization on runoff velocities
CN=Weighted Curve Number for the catchment
Sc=catchment slope (m/m) calculated using the equal area method

The time of concentration is important in the SCS and TP108 methods, to develop the unit peak discharge for the catchment, which is the peak discharge per square metre per millimetre of runoff. This parameter is used to calculate the peak discharge of the catchment based on the area and runoff depth.

SCS Unit Hydrograph

The SCS unit hydrograph is a dimensionless hydrograph that allows the user to determine the catchment runoff once the peak flow and time to peak are determined (ARC 1999, p.11).

We can see in Figure 2.11 that the time to peak *(tp)* is given as time *(t)/tp=1* and the peak flow *(qp)* is given as *flow/qp=1*. We can apply dimensions to the hydrograph by multiplying the *t/tp* by the *tp* and the *q/qp* by *qp*.

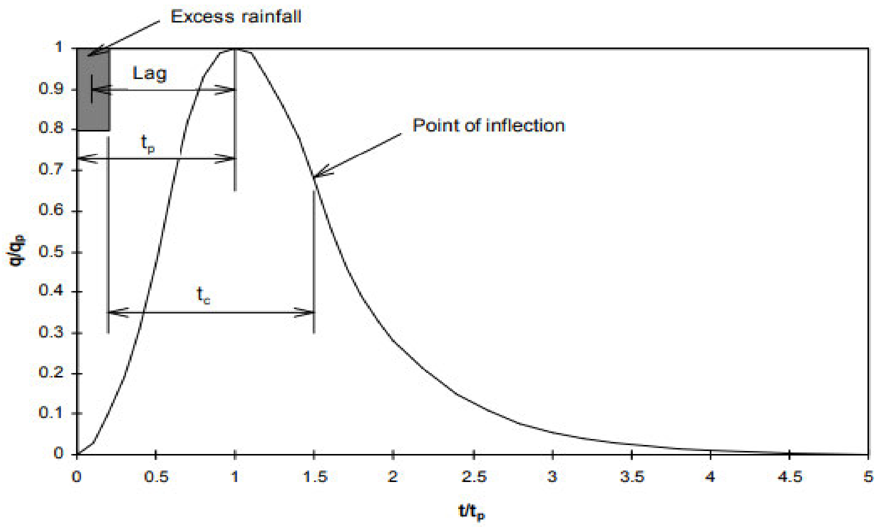


Figure 2. 11. SCS Unit Hydrograph

(ARC 1999, p.11)

Design Rainfall

The design rainfall used in the TP-108 method is based on local conditions and observed storm data for a 24-hour temporal rainfall event, with higher rainfall intensities occurring in the middle of the storm event (ARC 1999, p.4). The frequency event should be adopted based on design standards that are required.

An example of the Auckland temporal 24 hour storm is shown in Figure 2.12 below

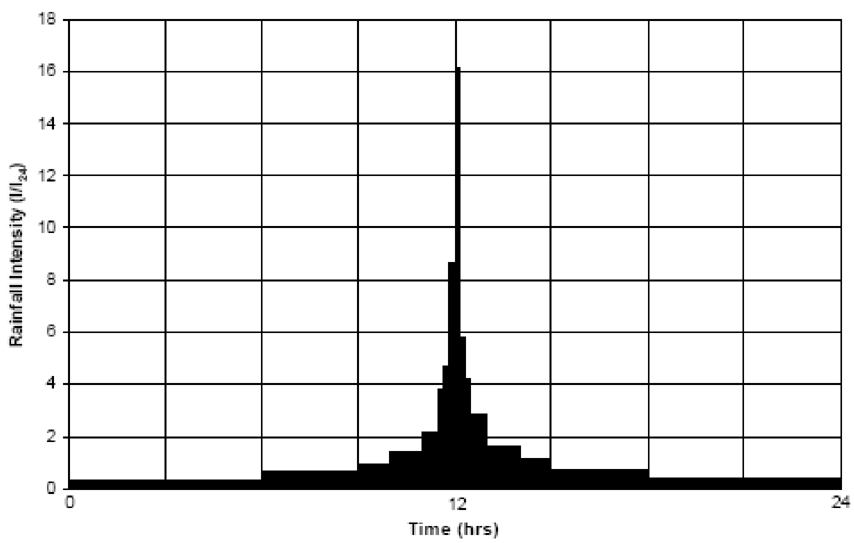


Figure 2. 12. 24 Hour Design Storm for the Auckland Region

(ARC 1999, p.4)

The design rainfall to be used in the TP108 method is limited by one style of storm event that is shown in Figure 2.12. The actual distribution of rainfall in a given storm event may be a lot different to the suggested one in Figure 2.12.

2.5.3 Empirical Model Method Conclusion

Based on the review of the Rational Method and the SCS Curve Number Method, it is clear that the most appropriate method to use for analysing the performance of the existing dam and outlet structures is the SCS Curve Number Method. In particular, the regional version specified in TP108 should be used, as it has been developed based on observations in the closest region to the project site.

This method takes into account the flood routing influences of the reservoir. The same approach using the Rational Method triangular hydrograph is expected to contain higher errors.

The SCS Curve Number Method is also compatible with HEC-HMS computer software. This allows increased efficiency of computations and allows for comparison and calibration with observed data (USACE, 2021).

2.5.4 Modelling Outlet Discharge

The reservoir associated with the current project contains a low elevation culvert outlet and a higher elevation spillway. These outlet structures will be taken into account in Modelling and evaluation of the catchment response to rainfall.

The theory of Reservoir Routing is based on the conservation of mass (Bedient *et al* 2008, p.257):

$$I(Inflow) - Q(Outflow) = \frac{\Delta S}{\Delta T}(Rate\ of\ change\ in\ storage) \quad (2.12)$$

Knowing the elevation-storage volume relationship of the reservoir, we can calculate the inflow hydrograph based on the following equation:

$$\frac{\Delta S}{\Delta T} + Q = I \quad (2.13)$$

In order to model the inflow, we need to know the discharge hydrograph for the reservoir based on the outlet structures.

Culvert Discharge

There are a number of different flow conditions that can potentially occur in a culvert and it is difficult to predict the culvert flow type and the most restricting condition. The United States Department of Transportation Federal Highway Administration Publication NO. FHWA-HIF-12-026 (Schall *et al* 2012, p. 1.17) explains that inlet control "occurs when the culvert barrel is capable of conveying more flow than the inlet can accept" and outlet control "occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept".

Each different condition will have a different flow rate. This is with respect to the headwater depth above the invert of the culvert and is governed by different empirical equations that have been formulated from extensive lab testing. Two different approaches used to determine the headwater discharge relationship for culverts are summarized below.

Schall *et al, (*2012) Discharge-Headwater Relationship

Inlet Control

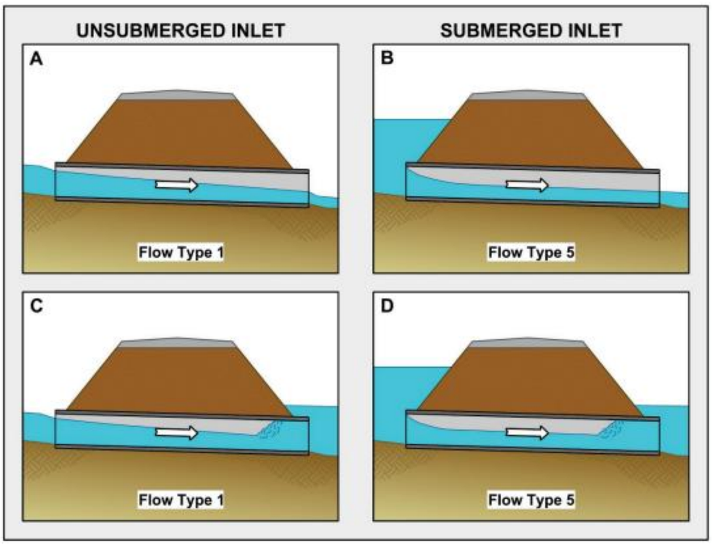


Figure 2. 13. Example of Culvert Inlet Conditions

(Schall et al 2012, p.3.2)

An important feature of inlet control conditions is that the culvert is only ever flowing part full. When the inlet is submerged critical flow occurs at the inlet as seen in B and D in Figure 2.14.

Culverts shown as C and D in Figure 2.14 display a hydraulic jump occurring in the culvert as a result of submerged outlets. If the tailwater depth was to continue increasing due to downstream effects, the hydraulic jump would travel toward the inlet. Once the pipe is flowing full the culvert would be flowing under outlet conditions.

Schall *et al (*2012) specifies that the discharge for unsubmerged inlet conditions can be modelled for the change in headwater elevations based on the Weir Equation shown below:

$$\frac{HW_i}{D} = \frac{H_c}{D} + K\left[\frac{K_u Q}{AD^{0.5}}\right]^M + K_s S \qquad (2.14)$$

where:

HWi=Headwater depth above inlet control section invert (m)

D=Interior height of culvert

Hc=Specific head at critical depth (m)

K,M=Constants from Tables in Standard

Q=Discharge (m³/s)

S=Culvert barrel slope (m/m)

A=Full cross sectional area of culvert barrel (m²)

Ku=Unit conversion (1.811 SI)

Ks=Slope correction -0.5 (+0.7 mitered inlets)

S=Potential maximum retention after runoff begins (mm)

When $Q/AD^{0.5} = 2.21$ inlet submerged conditions apply and the orifice equation is used to model flow as shown below (Schall *et al* 2012, p.A.2):

$$\frac{HW_i}{D} = c\left[\frac{K_u Q}{AD^{0.5}}\right]^2 + Y + K_s S \qquad (2.15)$$

where:

C, Y=Constants from Tables in Standard

Outlet Control

Outlet control conditions can occur based on the scenarios shown in Figure 2.15:

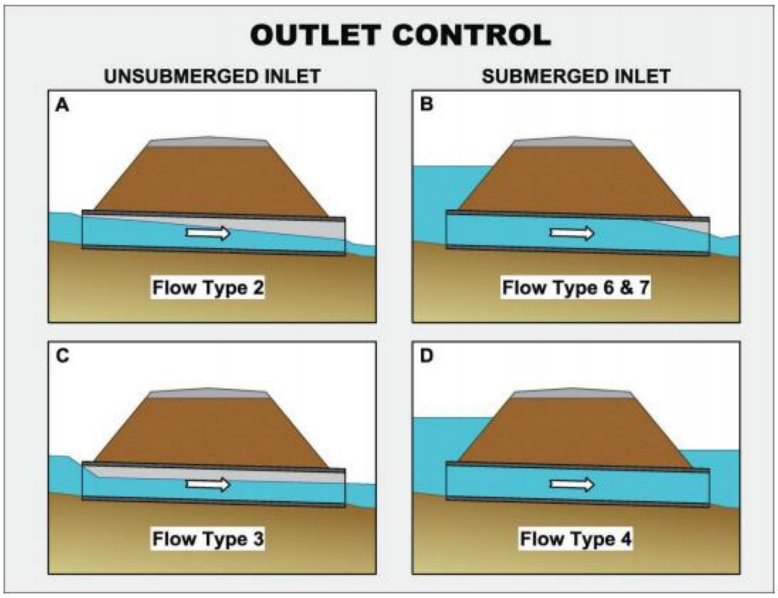


Figure 2. 14. Example of Culvert Outlet Conditions

(Schall et al 2012, p.3.8)

Outlet conditions occur with the culvert flowing part full or full. For submerged inlet conditions the discharge is calculated based on energy balance, which is "the total energy required to pass the flow through the culvert barrel and is made up of the entrance loss, the friction losses through the barrel and the exit loss" (Schall *et al* 2012 p.3.9). These losses can be expressed by Equation 2.16 and Figure 2.16.

$$H = 1 + k_e + \left[\frac{K_u n^2 L}{R^{1.33}}\right]\frac{V^2}{2g} \tag{2.16}$$

where:

H=Headwater depth

ke=Entrance loss coefficient

n=Manning roughness coefficient for a culvert with uniform material on the full perimeter

Ku=19.63 (SI units)

R=Hydraulic Radius of culvert barrel (m)

V=velocity in the barrel (m/s)

g=Acceleration due to gravity (m/s²)

L=Length of culvert (m)

The velocity can be calculated by rearranging Equation 2.16 to Equation 2.17.

$$V = \sqrt{\frac{H \times 2g}{(1+k_e)+\frac{(K_u \times n^2 \times L)}{R^{1.33}}}} \qquad (2.17)$$

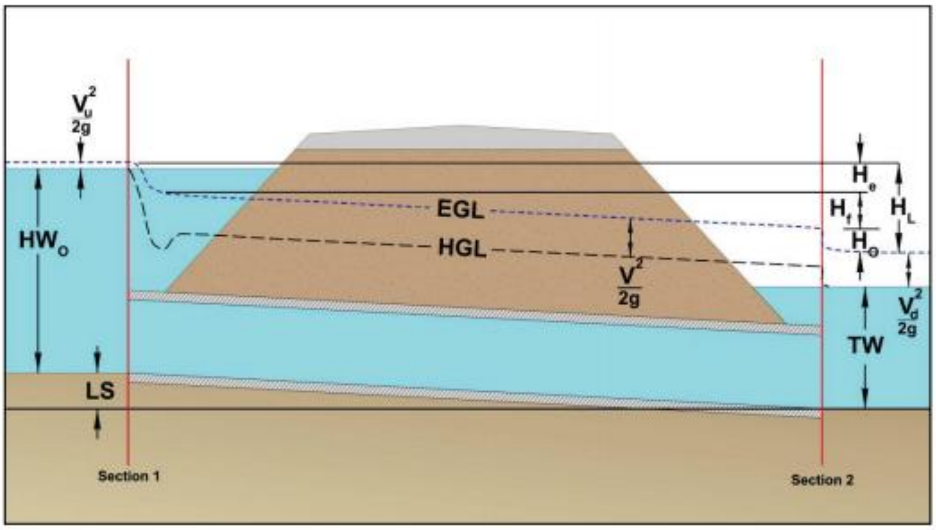


Figure 2. 15. Example of Energy Loss in a Culvert (Outlet Conditions)
(Schall et al 2012, p.3.11)

Figure 2.16 illustrates the energy losses occurring through a culvert under outlet conditions, when flowing full. We can see that with an unchanged culvert condition, the energy losses and downstream velocity will not change for a change in headwater depth. This will lead to the same change in tailwater depth, as the headwater depth increases.

ENV2103, (2017) Discharge-Headwater Relationship

Inlet Control-Inlet Submerged

This culvert condition assumes that the headwater depth is greater than 1.2 times the culvert diameter. For this condition the culvert inlet is said to behave as an orifice and the head-discharge relationship can be obtained by the orifice equation (*ENV2130 Hydraulics1: Course Notes* 2017, p. 289):

$$Q = 0.6 \times \frac{\pi D^2}{4} \sqrt{2g(y_{HW} - 0.6D)} \qquad (2.18)$$

where:

Q=Discharge (m³/s)

g=Acceleration due to gravity (m/s²)

yHW=Head water depth (m)

D=Culvert diameter (m)

This equation has been derived assuming approach velocities are small and the specific energy is approximately equal to the headwater depth. It also assumes a coefficient of contraction at the inlet and a coefficient of discharge are both equal to 0.6.

Critical Flow

Critical flow occurs for a certain discharge when the specific energy is at a minimum relative to the depth (ENV2103 2017, p.248). If the flow depth increases given the same discharge the flow turns to subcritical. If the flow depth decreases with the same discharge, the flow is defined as supercritical. For supercritical and subcritical flow, higher energy is required to convey the same discharge as critical flow depth as seen in Figure 2.17.

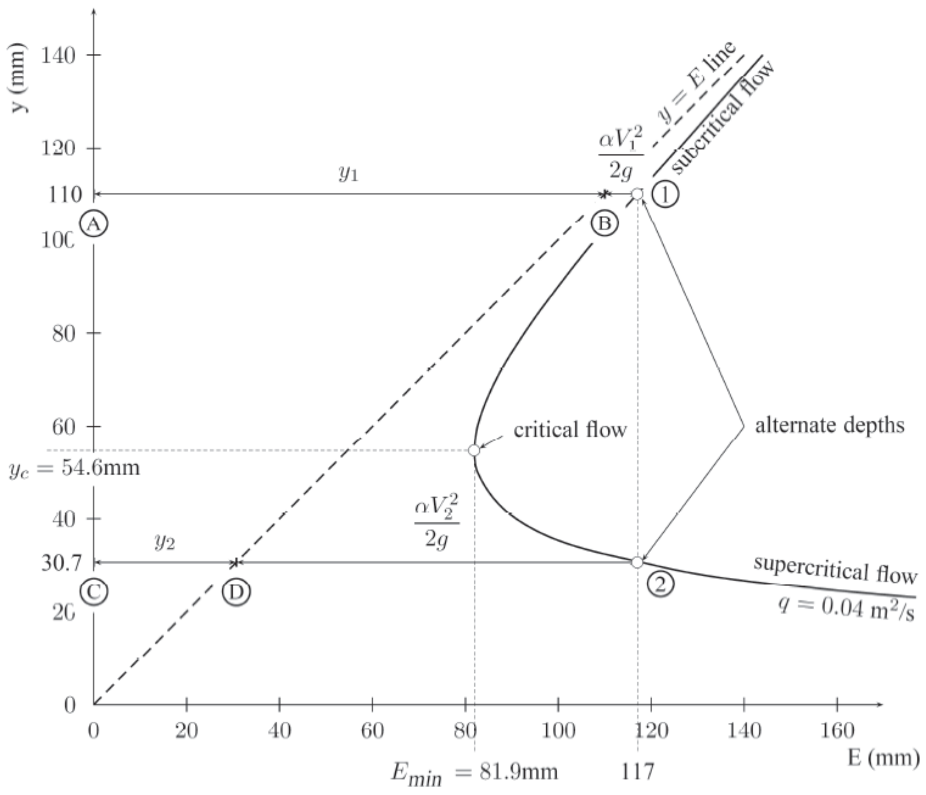


Figure 2. 16. Specific energy diagram for constant discharge

(ENV2103 2017, p.247)

The critical slope is the slope that allows the critical depth of flow to pass through the culvert. For the same discharge, a deviation away from critical slope will induce subcritical or supercritical flow.

Inlet Control-Inlet Unsubmerged (Critical flow condition)

For this type of culvert flow, critical flow occurs just inside the inlet. We can use Equation 2.17 to calculate critical flow in the culvert:

$$\frac{\alpha Q^2 B}{g A^3} = 1 \tag{2.19}$$

where:

Q=Discharge (m^3/s)

g=Acceleration due to gravity (m/s^2)

A=Cross section flow area (m^2)

B=Top width of flow (m)

The parameters to be used in Equation 2.19 can be seen in Figure 2.18. We can calculate B from Equation 2.20, θ from Equation 2.21 and A from Equation 2.23.

$$B = Dsin\theta \tag{2.20}$$

$$\theta(radians) = \cos^{-1}\left(1 - \frac{2y}{D}\right) \tag{2.21}$$

$$A = \frac{D^2\theta}{4} - \frac{D^2 sin\theta}{4} + \frac{Dysin\theta}{2} \tag{2.22}$$

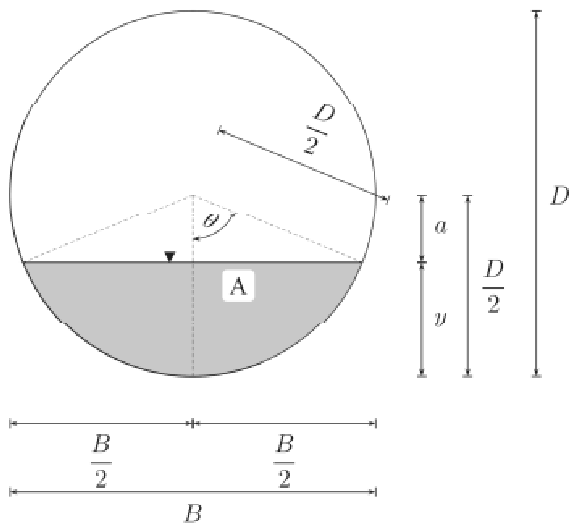


Figure 2. 17. Pipe Geometry – Part Full Flow

(ENV2103 2017, pp.291)

By knowing the culvert diameter and the depth of flow in the culvert we can calculate the cross-sectional area of flow and the top width of flow in order to calculate the discharge, based on Equation 2.19.

Outlet Control-Inlet and/or Outlet Submerged

For this condition the culvert is thought to be under full flow conditions. The energy equation can be applied to determine the culvert discharge shown in Equation 2.23.

$$Q = A * \sqrt{\frac{y_{HW} - y_{TW} + S_{oL}}{\frac{n^2 L}{R^{\frac{3}{4}}} + \frac{K_e + 1}{2g}}} \qquad (2.23)$$

Equation 2.23 takes into account frictional loss and entrance loss in the culvert to determine flow rate.

The three different head discharge relationships that are specified from ENV2103 (2017) course notes provide a good basis for Modelling culvert discharge based on different water elevations in the reservoir.

Spillway and Dam Top Discharge

The discharge from spillways and the dam top can be Modelled using the trapezoidal weir equation that is specified in Auckland Regional Council Technical Publication TP10 (ACR 2003, p.5-13).

$$Q = 0.57(2g)^{0.5}\left(\frac{2}{3}Lh^{\frac{3}{2}} + \frac{8}{15}Zh^{\frac{5}{2}}\right) \qquad (2.24)$$

where:

Q=Discharge (m³/s)

g=Acceleration due to gravity (m/s²)

L=Length of weir (m)

h=flow depth at upstream side of weir (m)

Z=Horizontal/Vertical side slope (m/m)

The discharge can be calculated for varying flow depths in relation to the elevation of the reservoir water level.

2.6 HEC-HMS Modelling Software

There are a number of computer software that allow the user to model catchment behaviour in response to rainfall events. These models vary in complexity and the methods used to analyse the catchment. HEC-HMS is a rainfall runoff modelling software freely available through the United States Army Corps of Engineers (USACE).

HEC-HMS allows the choice of different methods to be used to model runoff, including the SCS Curve Number Method that has been highlighted in Section 2.5.2. It allows the use of Geographic Information Systems (GIS) to speed up the process of defining catchment parameters (USACE, 2021).

Sahu *et al,* (2020) concluded in their review that HEC-HMS is a good option for rainfall-runoff modelling. It can be calibrated easily with observed rainfall and runoff data and has a wide range of uses in hydrology. It can also be used to determine boundary conditions for inputs into other 2-D software like HEC-RAS to speed up computations.

2.6.1 Reservoir Routing

HEC-HMS allows reservoir routing to model reservoir storage and attenuation. This is particularly useful to model the project catchment. It is also useful to create an elevation storage relationship for the reservoir based on the change in volume for different water level elevations.

2.6.2 Outlet Discharge

HEC-HMS also allows the Modelling of outlet structures. The flow conditions of the culverts are modelled for inlet and outlet control for the varying headwater depths. The computations in HEC-HMS compute the energy required to produce a given flow rate. The most restrictive condition is what determines the flow condition used in the final computation (USACE, 2021).

Spillways and dam tops can be modelled using the standard broad crested weir equation or a user specified discharge for a given elevation. The spillways and dam tops require the length, invert elevation and a discharge coefficient. HEC-HMS recommends a discharge coefficient of 2.6 to be used.

2.6.3 Base-flow Modelling

There are a number of different options to include the base-flow of a catchment. Although the TP-108 publication does not specify the consideration of base-flow, it is an important parameter to consider in obtaining a model that provides a good fit to observed data. Some of the methods that could be considered to help with the model calibration include (USACE, 2021):

Constant Monthly

This method sets a constant monthly discharge from the catchment. This can account for groundwater flow coming into the reservoir that is representative of the constant stream flow that can occur at the outlet between rainfall events.

Linear Reservoir

This method conserves mass by routing the losses through "linear reservoirs". The linear reservoirs have a specified initial base-flow and a fraction that determines how much of the loss is routed through the linear reservoir. If the fraction is equal to 1, then all of the loss gets routed through the reservoir and no loss recharges the aquifer. There is a storage coefficient which represents the response time of the base-flow. HEC-HMS allows three separate linear reservoirs to be used to model the different base-flow. More rapidly responding interflow can be represented by a linear reservoir with a smaller storage coefficient. Slower responding base-flow can be represented by another linear reservoir with a much larger storage coefficient.

Recession

The recession method specifies an initial base-flow and a recession constant that determines the rate at which the recession limb of the hydrograph recedes after rainfall.

2.6.4 Time-Series Data

HEC-HMS allows the import of time series data like precipitation gauge and stage gauge data. This data can be set as observed data and as specified hyetographs in the meteorological model. This is useful to allow observations between modelled and observed outputs for the same rainfall event.

2.6.5 Model Calibration

HEC-HMS provides a method to calibrate the initial parameters used in a simulation model against observed rainfall and runoff data. The method required to calibrate a model is shown in Figure 2.19.

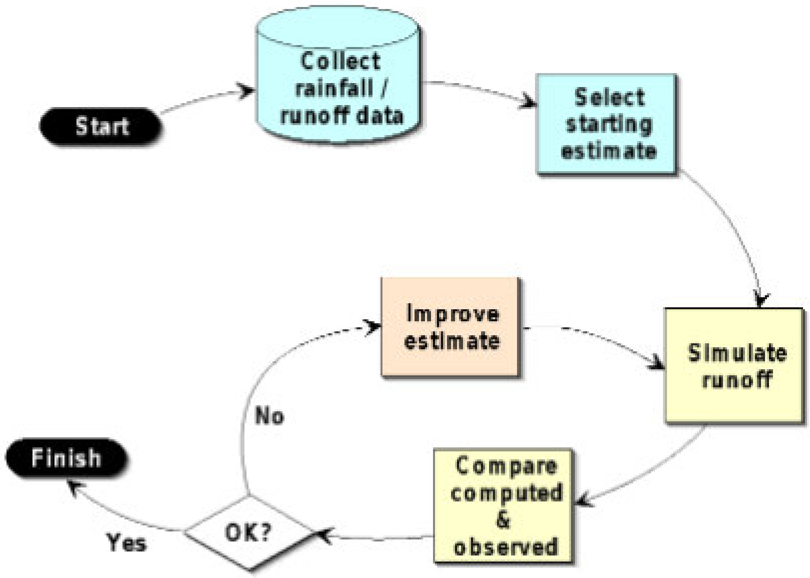


Figure 2. 18. Calibration Process

(USACE, 2021)

The typical procedure computes a 'goodness-of-fit' between the observed and computed hydrograph by identifying parameters measured by an 'objective function'. The objective functions available are:

- Sum of absolute errors

$$Z = \sum_{i=1}^{NQ} |q_o(i) - q_s(i)| \tag{2.25}$$

- Sum of squared residuals

$$Z = \sum_{i=1}^{NQ} [q_o(i) - q_s(i)]^2 \tag{2.26}$$

- Percent error in peak

$$Z = 100 \frac{q_s(peak) - q_o(peak)}{q_o(peak)} \tag{2.27}$$

- Peak-weighted root mean square error

$$Z = \left\{ \frac{1}{NQ} \left[\sum_{i=1}^{NQ} \left(q_o(i) - q_s(i) \right)^2 \left(\frac{q_o(i) + q_o(mean)}{2q_o(mean)} \right) \right] \right\}^{0.5} \tag{2.28}$$

where:

Z=objective function

NQ=number of computed hydrograph ordinates

qo(i)=observed flows

qs(i)=calculated flows

qo(peak)=observed peak

qo(mean)=mean of observed flows

qs(peak)=calculated peak

The aim of the calibration processes it to obtain parameters that result in the minimum objective function. In order to obtain these 'optimised parameters' the program performs a trial and error search procedure where an initial trial parameter is selected, then the parameter is changed a number of times until the error is minimised. This can be achieved by a Univariate-Gradient Algorithm in which successive corrections to the parameter estimate are made until the parameter reaches a value where the objective function is at its lowest. Multiple parameters can be optimised at once. For this process the parameters are successively optimised one at a time with the others kept constant (USACE, 2021).

The optimize parameter function is useful in optimizing parameters based on stream flow discharge hydrographs. Unfortunately, there is no function that allows parameters to be automatically optimized between observed and modelled reservoir elevations. The process provides relevant theory on a good procedure to following when considering calibrating parameters and assessing the fit of a model.

2.7 Assessing Model Performance

2.7.1 Quantitative Assessment

Section 2.6.5 highlights several statistical performance predictors that allow the quantitative assessment of model performance or a "goodness of fit" between models and observed data.

Ritter and Carpena (2012), outlined that "model performance assessment should include at least one absolute value error indicator, one dimensionless index for quantifying the goodness-of-fit and a graphical representation of the relationship between model estimates and observations". The Ritter and Carpena (2012) study provides a method that accounts for the range of data relative to the error. This is important when comparing a small error in a small dataset to a large error in a much larger data set. It provides formulas to calculate the number of times the observations variability is greater than the mean error (n_t), shown in Equation 2.29. From this, the Nash Sutcliffe Efficiency (*NSE)* Coefficient can be calculated using on Equation 2.30.

$$n_t = \frac{SD}{RMSE} - 1 \tag{2.29}$$

$$NSE = 1 - \left(\frac{1}{n_t+1}\right)^2 \tag{2.30}$$

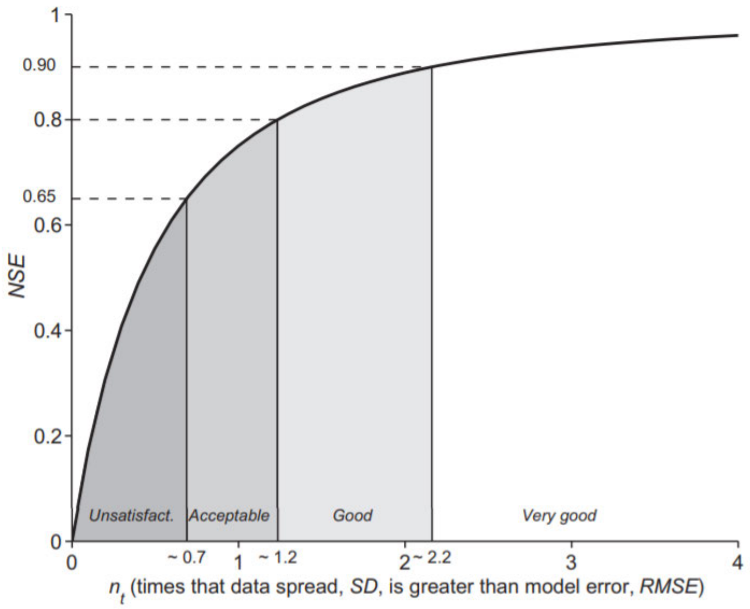


Figure 2. 19. Index of Goodness-of-Fit from Statistical Assessment

(Ritter and Carpena 2012, p.35)

Figure 2.20 illustrates the required *NSE* and n_t to achieve the various levels of fit that are suggested by Ritter and Carpena, *2012*. A very good fit would have a NSE greater than 0.9 with a n_t greater than 2.2.

2.7.2 Qualitative Assessment

The graphical representation of the model fit that is mentioned in Section 2.7.1 is achieved through a visual inspection. This method is considered very straight forward and approximate and is a qualitative method that can be subjective to the person inspecting the data. This process relies on a good level of experience to determine the appropriateness of the fit

(Crochemore *et al* 2014, p.414-415). A qualitative assessment should be included in conjunction with a quantitative assessment, as specified by Ritter and Carpena, (2012).

2.8 Original Parua Stream Dam Design

The original design calculations and drawings are provided in Appendix C. The original hydrological and hydraulic design of the outlet structures has been summarised below.

2.8.1 Catchment Modelling Method

The catchment areas were divided into three separate catchments using a topographic map that included a dam catchment, an initial downstream watercourse catchment (watercourse 1) and another more distant downstream watercourse catchment (watercourse 2).

The calculation of the predicted peak flows for the catchments based on 1% and 10% AEP events were specified using the Rational Equation from NZBC:E1, shown in Equation 2.31.

$$Q = \frac{CIA}{360} \tag{2.31}$$

where:

Q=Peak Flow Rate (m³/s)

I=Rainfall Intensity (mm/hour)

A=Catchment Area (ha)

The initial Rational Method equation parameters and calculated peak flow rates are shown in Table 2.7:

Table 2. 7: Rational Method Calculation Summary

Catchment	Area (ha)	Runoff Coefficient (C)	Flow Rate (1% AEP) (m^3/s)	Flow Rate (10% AEP) (m^3/s)
Dam	20	0.4	3.12	1.9
Watercourse 1	6.5	0.4	1.0	0.6
Watercourse 2	8.5	0.4	1.3	0.8

There were no details provided on the methodology of calculating the runoff coefficients. However the runoff coefficients are likely to have come from the empirical Rational Method process.

2.8.2 Culvert Design

The Culvert outlet was designed based on the initial downstream watercourse capacity for a 10% AEP event. The capacity of the downstream watercourse was calculated using the Mannings Equation for open channel flow shown in Equation 2.29:

$$Q = A\left(\frac{1}{n} \times R^{\frac{2}{3}} \times S^{0.5}\right) \tag{2.32}$$

where:

Q=Flow Rate (m³/s)

A=Flow Area (m²)

n=Manning's Roughness Coefficient

R=Hydraulic Radius (m)

S=Channel Slope (m/m)

The Mannings Equation parameters and calculated peak flow rates for the downstream watercourse are shown in Table 2.8.

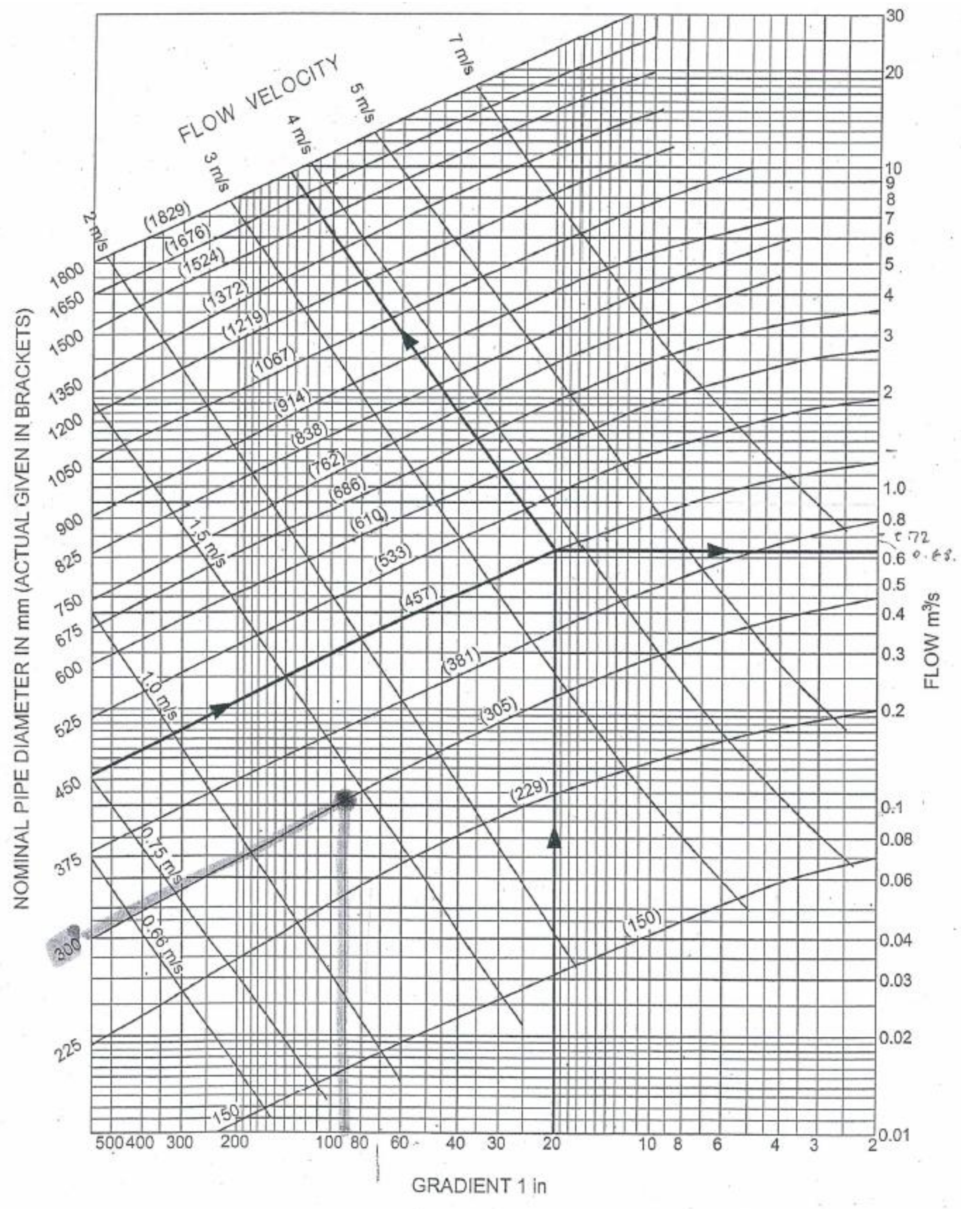
Table 2. 8: Mannings Equation for Downstream Watercourse

Slope (m/m)	Flow Area (m²)	Hydraulic Radius (R) (m)	Mannings Roughness Coefficient (n)	Peak Flow Rate (m³/s)
0.02	0.4165	0.2384	0.028	0.8088

The capacity of the downstream water course was calculated to be 0.8088m³/s. The peak flow rate calculated in Table 2.7 for Watercourse 1 in a 10% AEP event was 0.6m³/s. The designer adopted a culvert size that attenuated flows so the downstream watercourse capacity was not exceeded in a 10% AEP event. This means the allowable flow through the culvert and into the downstream watercourse 1 is:

$$0.8088 - 0.6 = 0.2088 m^3/s \tag{2.33}$$

The designer adopted a 300mm concrete culvert with a 1.11% grade. Using Figure 2.21, the flow rate for this culvert was determined to be 0.103m³/s, allowing 0.11m³/s of excess flow rate available in the watercourse. Figure 2.21 shows that a 375mm culvert at 1.11% is under 0.2088m³/s. This size of culvert may have been a more appropriate size as it would allow more discharge from the reservoir, without the downstream watercourse flooding.



Example: A 450 internal diameter pipe with a gradient of 1 in 20 will have a flow of 0.63 m³/s at a velocity of 3.75 m/s

Figure 2. 20. Culvert Flow Determination

(Original design)

2.8.3 Spillway Design

The spillway was designed using the peak flow rate calculated for a 1% AEP event. The spillway was sectioned into three parts based on the proposed channel slope and desired flow velocity.

The initial spillway slope used was 0% and was designed using the Trapezoidal Weir Equation (Equation 2.31) from Auckland Regional Council Technical Publication 10 (ARC, 2003).

$$Q = 0.57(2g)^{\frac{1}{2}}\left(\frac{2}{3}Lh^{\frac{3}{2}} + \frac{8}{15}Zh^{\frac{5}{2}}\right) \qquad (2.34)$$

where:

Q=Peak Flow Rate (m³/s)

g=Acceleration due to gravity (9.81m/s²)

L=Length of weir

h=depth of flow upstream of the weir

Z=Horizontal/Vertical Side Slopes

The Trapezoidal Weir Equation parameters and calculated peak flow rates calculated for the spillway are shown in Table 2.9:

Table 2. 9: Equation for Trapezoidal Weir

Peak Flow Rate (m^3s)	**Depth of Flow (h) (m)**	**Horizontal/Vertical Side Slopes (m/m)**	**Length (L) (m)**
3.12	0.5	1	4.8544

Looking at the design plans in Appendix C the spillway was designed at a depth of 1m from the depth of the spillway invert to the crest of the dam. The required freeboard was not included in the calculations. It could be assumed from the calculations that the design used a 0.5m freeboard. The actual length was specified in design drawings as 3.257m, which is less than the calculated value in Table 2.9. Using the length calculated in Table 2.9, a flow rate of 3.12m³/s is achieved with a 0.5m freeboard to the dam crest.

The second spillway section was based off a channel slope of 12.5% and was designed using the Mannings Equation (Equation 2.32) to determine a flow depth and velocity for the 4.8544m spillway length. This was calculated as:

Flow Velocity = 5.9383m/s

Flow depth = 0.106m

The third section used the Mannings Equation for a 12.5% slope, 3m length and varying roughness coefficients to include a section with large rocks embedded into the concrete channel. The results are shown in Table 2.10:

Table 2. 10: Mannings Equation for 3m Section of Spillway

Channel Type	Peak Flow Rate (m^3s)	Horizontal/Vertical Side Slopes (m/m)	Length (L) (m)	Mannings Roughness Coefficient (n)	Depth of Flow (h) (m)	Flow Velocity (m/s)
Concrete Channel	3.12	1	3	0.013	<u>0.1417</u>	<u>7.0106</u>
Concrete Channel with Large Rocks	3.12	1	3	0.04	<u>0.2782</u>	<u>3.4214</u>

Table 2.10 highlights the effect of placing large rocks in the channel to reduce the flow velocity and increase the flow depth. This may have been designed to reduce the erosion potential where the concrete channel transitions back to natural ground.

2.8.4 Reservoir Retention Capabilities

The design specified a reservoir working volume of 6000m³ and a total retention volume of 9000m³. This indicates that when the water level is at the invert of the culvert there is 6000m³ of reservoir water volume available and when the water level is at the spillway invert there is 9000m³ of reservoir water volume available.

The designer calculated the total discharge volume from the culvert for various durations. These volumes were added to the retention volume to give a maximum runoff volume allowed for the various duration storm events before the invert of the spillway is reached.

The designer calculated the rainfall depths required to achieve the total retention volume for the given duration storm event using a rearranged form of Equation 2.31 shown below in Equation 2.35:

$$I = \frac{V \times 100}{A \times C} \tag{2.35}$$

where:

I=*Total Rainfall Depth (mm) over Storm Duration*

V=*Total Retention Volume* (m^3)

C=*Runoff Coefficient*

A=*Catchment Area* (m^2)

The runoff coefficient was altered to 0.5 to account for the change in cover conditions due to the proposed construction of the dam. This change in runoff coefficient allows for the increase in water surface area, which is considered to be impervious.

The maximum retention volumes, rainfall depths and frequencies are shown in Table 2.11:

Table 2. 11: Culvert Discharge and Maximum Retention Volumes for Various Storm Durations

Duration (hours)	Culvert Discharge Volume (m^3)	Retention Volume (m^3)	Total Retention Volume (m^3)	Maximum Total Rainfall Depth over Duration (mm)	Associated Frequency Event (AEP %)
1	371	9000	9371	93.7	2
6	2225	9000	11225	112.3	2.5
12	4450	9000	13450	134.5	5
24	8899	9000	17899	179	5

It was assumed that the designer used Depth-Duration-Frequency tables available from the National Institute of Water and Atmospheric Research (NIWA), High Intensity Rainfall Design System (HIRDS) to obtain the associated frequency event for the calculated rainfall depths.

2.9 Previous Dam Investigations and Analysis

2.9.1 2019, Initial Dam Investigation (by Others)

Initial investigations into the dam in 2019 were conducted to assess the safety of the dam given the proposal to harvest areas of Pine Forest. Independent hydrological analysis using the Rational Method, calculated the parameters as:

Table 2. 12: Comparison of Rational Method Parameters

	Catchment Area (ha)	Runoff Coefficient (C)	Runoff Coefficient (after theoretical tree harvest)	Rainfall Intensity (mm/hr) (1% AEP)	Rainfall Intensity (mm/hr) (10% AEP)
2019	70	0.44	0.47	57.3	37.4
Original Design	20	0.4	N/A	140.4	87

It can be seen in Table 2.12 that there is quite a variation in a number of parameters used in the NZBC:E1 Rational Method calculations. The 2019 catchment area was calculated as over three times the original design area. The 2019 runoff coefficient is relatively similar; however, the time of concentration must be significantly different as the 2019 rainfall intensities are based on a time of concentration of 190 minutes. It was later identified that this was an incorrect time of concentration. Although not specified, the time of concentration used in the original design is more consistent with rainfall intensities based on a 10-minute time of concentration, from NIWA HIRDS data.

The peak flows based on the parameters calculated in the 2019 investigation and the original design are displayed in Table 2.13 below:

Table 2. 13: Rational Method Calculation Summary

	AEP (%)	Peak Flow Rate – Current Conditions (m^3/s)	Peak Flow Rate – Post tree harvesting Conditions (m^3/s)
2019	**10**	3.4	4.0
	1	5.2	6.2
Original Design	**10**	1.93	N/A
	1	3.12	N/A

The variations in the Rational Method Equation parameters present an expected difference in the calculated peak flows of the catchment. The 2019 calculations indicate peak flows are potentially higher than original design calculations that were used for outlet design. This was the case even though an incorrect time of concentration was used.

2.9.2 2020, Subsequent Investigation

Due to the discrepancies between the parameters used in the calculations, the catchment area and time of concentration were investigated to determine if there were more appropriate methods available to obtain these parameters.

The catchment area was delineated using the most recent (2018) Light Detecting and Ranging (LiDAR) Digital Elevation Model (DEM). The catchment area was confirmed to be 70.3 hectares.

It was found that there was an error in the initial time of concentration used. A more appropriate method taken from NZBC:E1 was used to calculate the time of concentration and it was found to be approximately 14 minutes. This led to an investigation on what time of concentration should be used. It was concluded that there are very limited Rational Method time of concentration formulas applicable to the region and catchment type. A number of time of concentrations were calculated using different methods obtained from literature. These values ranged from 9 minutes to 77 minutes. Peak flows for three different times of concentrations for a 1% AEP were calculated, with the results shown below:

Table 2. 14: 9-minute Time of Concentration Results

(2020)

Scenario	Intensity (mm/hr)	Peak Flow (m^3/s)
RCP8.5 100-yr	195	16.0
RCP6.0 100-yr	176.4	14.5
Historic	144	11.8

Table 2. 15: 14-minute Time of Concentration Results

(2020)

Scenario	Intensity (mm/hr)	Peak Flow (m^3/s)
RCP8.5 100-yr	166.4	13.6
RCP6.0 100-yr	150.4	12.3
Historic	123	10.1

Table 2. 16: 31-minute Time of Concentration Results

(2020)

Scenario	Intensity (mm/hr)	Peak Flow (m^3/s)
RCP8.5 100-yr	129.6	10.6
RCP6.0 100-yr	117.2	9.6
Historic	96	7.9

The peak flows are shown to be considerably higher than original design calculations and initial hydrological assessments. The time of concentration variations also highlight a need to measure a more accurate representation of the catchments time of concentration.

2.9.3 Implications from Previous Investigations

The previous investigations of the Parua Stream Dam have presented the following implications:

- There are limited empirical models available to the region.
- Catchment parameters need to be determined to predict a more accurate representation of catchment response to rainfall.

- The dam outlet structures may be under designed compromising the safety of the dam.
- Remedial works may need to be undertaken to allow the harvest of forestry blocks.

2.10 Literature Review Conclusion

The original design contains calculation errors leading to potentially under designed outlet structures. The safety of the dam is in question and remedial works are likely to be required. Previous investigations have identified difficulties in adopting suitable empirical parameters to use for hydrological models.

NZSOLD (2015) states that; “the hydrological analysis of any dam requires specialist hydrological support for the estimation of flood flow”, that “rainfall/runoff modelling using rainfall frequency estimates and a temporal distribution of uniform pattern is acceptable to predict flood hydrographs” and that the “Rational Method in conjunction with a triangular shaped hydrograph is an appropriate model” for low PIC dams. The Rational Method is considered to contain high errors when used for flood routing and the SCS-CN method was identified as the most appropriate method to model the Parua Stream Dam catchment.

Due to the complexity of catchment hydrology, catchment gauging can be performed to measure rainfall and water level data. Gauging the catchment allows the observation of the rainfall and runoff characteristics of the catchment and calibration of empirical parameters in HEC-HMS.

Calibrated parameters need to produce reservoir elevations that represent a good fit to the observed reservoir elevations so that a reasonable representation of catchment response can be modelled for the theoretical storm events. This will allow the assessment of the predicted performance of the dam and outlet structures and provide information to be considered for the most economical remedial solution, if required.

3 Methodology

The literature review has highlighted the requirements to achieve the aims and objectives of the project. This chapter will identify the processes followed in the completion of this project.

The project was broken down into a catchment gauging and monitoring stage and a catchment modelling and data review stage.

3.1 Catchment Gauging and Monitoring

The catchment gauging and monitoring stage involved selection of gauging equipment, placement of equipment, collection of data and validation of data.

3.1.1 Data Required

The most appropriate equipment to gauge the catchment was selected based on the following data required for analysis.

Rainfall

The rainfall data required included both depth and intensity. This means a RIMCO rainfall intensity gauge with a tipping bucket and a primary storage gauge were used. The intensity gauge included an HOBO event logger, allowing the recording of each time the tipping bucket fills with 0.2mm of rainfall, in order to calculate the rainfall intensities in millimetres per minute. The storage gauge allowed the total depth of rainfall to be measured over a known time period and be compared to the total cumulative depth recorded by the intensity logger, so as to validate the accuracy of the tipping bucket gauge.

Water Level

Due to the multiple inlets into the dam reservoir and the time constraints associated with gauging the main stream and setting up a rating curve, it was decided that the option to gauge the main stream was not practical for this project. It was decided to monitor the rainfall runoff into the dam based on the stage height of the reservoir. This allows for the entire catchment to contribute to the inflow, and also allows for catchment base-flow, reservoir routing and culvert and spillway discharge to be accounted for.

3.1.2 Equipment Selection

The equipment was selected in accordance with NEMS Rainfall Recording (NEMS, 2017) and NEMS Water Level (NEMS, 2019) standards and after conversation with The

Environmental Collective (ENVCO) confirming the selected equipment complies with the necessary New Zealand Standards. Specifications for the chosen equipment are included in Appendix E.

Staff Gauges

The water level to the top of the spillway from the recording zero level is approximately 4m. This depth required 4 staff gauges at 1m length to be set up on the upstream side of the dam. The bottom of the lowest staff elevation was set at recording level zero. The staff gauges required a minimum 15cm overlap.

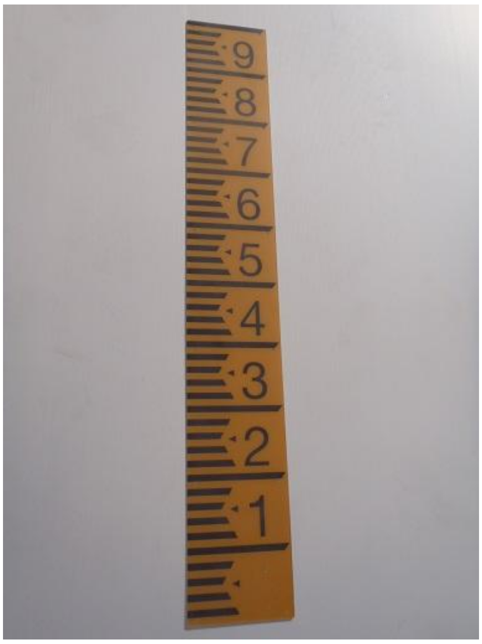


Figure 3. 1. Chosen Staff Gauge
(ENVCO, 2021)

Primary Rain Gauge

The primary rain gauge was a storage rain gauge used to validate the intensity gauge. It has a stainless-steel rim and was set up based on the NEMS Rainfall Recording Standard.

Rainfall Intensity Gauge and Data Logger

The rainfall intensity gauge was a RIMCO -7499-STD tipping bucket rain gauge. This intensity gauge complies with the NEMS Rainfall Recording standard and complies with the highest potential quality.

Figure 3. 2. RIMCO-7499-STD Tipping Bucket Rain Gauge
(ENVCO, 2021)

The intensity gauge was connected to a HOBO Pendant Event Logger. That automatically records the time when the internal tipping buckets fill 0.2mm of rainfall. The HOBO Pendant Event Logger is powered by a small battery and the data can be easily downloaded on site via a USB download cable.

Figure 3. 3. HOBO Pendant Event Logger
(ENVCO, 2021)

Water Level Measuring Device and Data Logger

The type of water level measuring device was chosen based on the simplicity of set up, accuracy of the device and advice from ENVCO, based on the site area. It is a battery powered pressure transducer sensor that includes an internal data logger.

The device is a PT2X Self Logging Smart Sensor that measures the change in pressure due to the change in water level. It works based on the following equation (NEMS 2019):

$$h = \frac{P}{pg} \tag{3.1}$$

where:

P=Pressure

g=Acceleration due to gravity (m/s^2)

p=density of water (1000kg/m^3 at 4°C)

h=water level (m)

The PT2X Smart Sensor comes with a vented cable to ensure that changes in atmospheric pressure are automatically compensated in the data recording. The PT2X also has a temperature recorder to compensate for the change in water density with temperature changes. The sensor is self-logging and automatically records changes in water level with respect to time. Data can be downloaded via a USB port connected by a cable to the logger. The device comes with Aqu4plus software used to export the data to EXCEL as a .csv file

3.1.3 Equipment Placement

The equipment was placed in accordance with NEMS standards. Figure 3.4 displays the locations of each item of equipment used in the project and a topographic plan is shown in Appendix D.

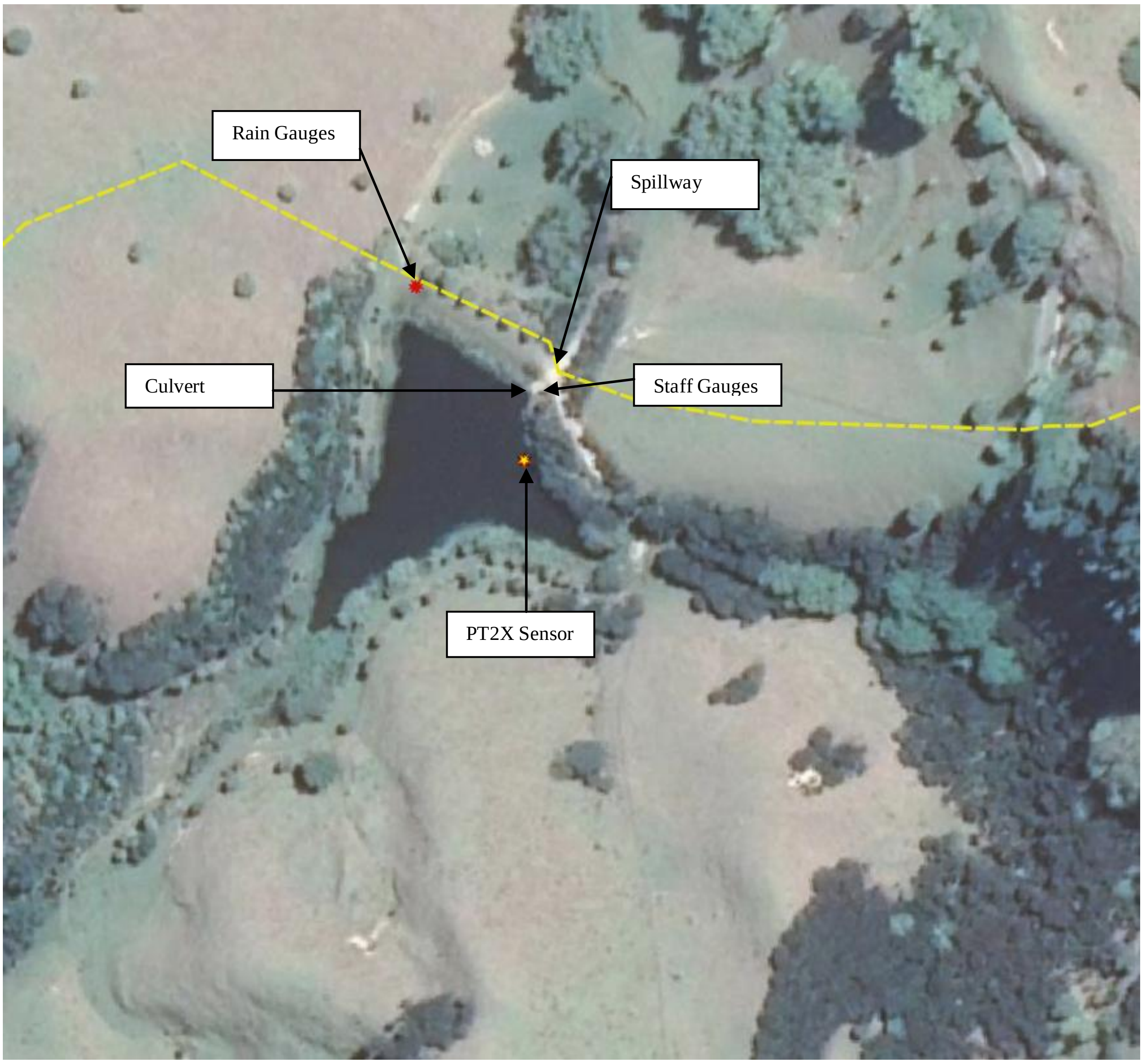


Figure 3. 4. Locations of Gauging Equipment

(Locations of equipment are approximate, north up the page, not to scale)

Reference Levels

The three required benchmarks were placed use a Trimble Geo7X GPS. The vertical datum is referenced to the recording zero level at bottom of the lowest staff gauge and the benchmarks. The benchmark closest to the water level logger was set at the elevation in terms of One Tree Point 1964 local vertical datum. A dumpy level was used to set up the staff gauges so that they overlap correctly and so that the staff gauge zero reading is referenced to the vertical datum. The elevations of all benchmarks, inverts and the recording zero were taken using a dumpy level.

When the PT2X recording begins, the water level is calibrated to the water level reading from the staff gauge, within the Aqua4plus software. This sets the water level for the PT2X as the same as the staff gauge water level. This provided a simple way to calculate the water level in terms of the vertical datum.

Staff Gauges

There were a total of four 1m staff gauges set up with a 150mm overlap as shown in Figure 3.5.

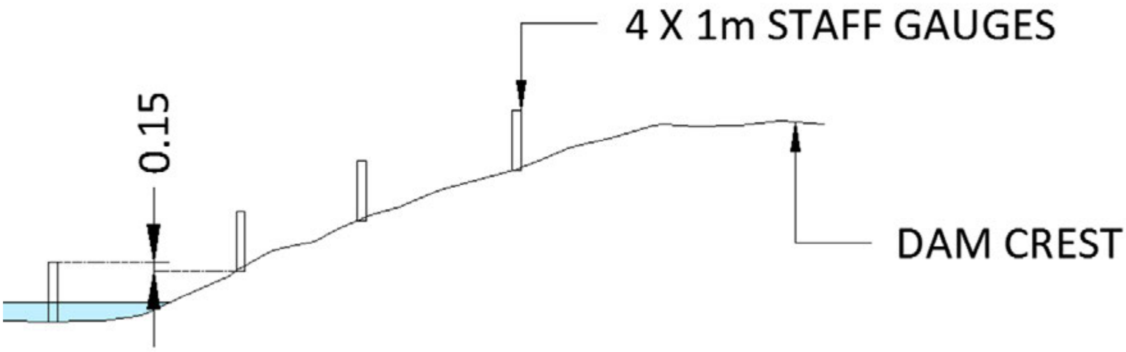


Figure 3. 5. Example of Staff Gauge Set Up

The staff gauges were fixed to treated timber posts and referenced to the vertical datum and benchmarks.

Rainfall Gauges

The rainfall gauges have been set up in the location shown in Figure 3.4 and Appendix D. The positions were taken using the Trimble Geo7X to ensure they kept stationarity during the recording period. The position was chosen to account for exposure, shielding and slope requirements set out in the NEMS standard. The reference gauge and intensity gauge have been positioned 1200mm apart. The Quality Code Matrix for the rain gauge site set up is included in Appendix F. The final score was 1, meaning the quality of the site selection and set up is defined as QC600 (NEMS, 2017). QC600 represents a quality that ensures data has been collected using best possible practice at the time of recording and the data is considered to be a good representation of the parameter that is monitored (NEMS, 2017).

Exposure

The location has a mean annual average wind speed between 3 and 4m/s. This is slightly above the requirements set out in the NEMS Rainfall Recording Standard and is defined as moderate exposure. Moderate wind exposure adds one point to the Quality Code Matrix. This was the only point that the site selection acquired. The maximum quality QC600 was still achieved despite being the equipment being positioned in a moderate wind exposure zone. It was considered to construct a wind break around the Rain Gauges that would also act as a barrier to stock. It was agreed with the property owner that stock would remain out of the equipment area for the duration of the dam monitoring period. The wind break was also going to obstruct the property owner's movement across the dam. It was for these reasons a wind break was not constructed and more emphasis was placed on Rain Gauge validation between the Intensity gauge and the Primary Reference Gauge.

Topography

To check that the potential site meets the topographic requirements, Geographic Information System software (QGIS) was used. The Digital Elevation Model (DEM) provided by the NRC that was flown in 2018 was clipped at a 200m radius from the proposed rain gauge location. The maximum and minimum elevations were extracted from the clipped DEM. The average slope of the site including its 200m surrounds was calculated at an average slope of 8.8°. This slope is under the 19° limit.

Obstruction

Potential obstructions were identified from the most recent aerial image provided by Google Earth and as part of a site walkover.

There were no potential obstructions identified near the proposed site location closer than twice the height of the obstruction.

3.1.3.1 Water Level Measuring Device and Data Logger

The position of PT2X sensor needed to take into account the potential of impact of floating debris, drawdown effects of the outlet structures, and the potential for waves to give erratic fluctuations in water level data. Figure 3.4 shows the position of the device which has taken into account all of the constraints.

In order to provide protection to the device from floating debris and waves the device was fixed to a PVC pipe secured into the ground with a number of steel pickets. The PVC pipe was secured to the steel pickets with bolts and has a number of 2mm wide slits in the pipe to allow water into the pipe. The sensor was secured to the PCV pipe with zip ties. The vented cable will be protected from debris by being zip tied to smaller steel pickets along the bottom of the reservoir.

3.1.4 Site Monitoring and Data Collection

NEMS standards require the equipment to be inspected and verified at a minimum of three-month intervals. Rain gauges are not to deviate over 10% of totals for more than 50mm of rainfall collected or more than 5mm for totals less than 50mm. These verified readings can be seen in Appendix H. Water level devices are verified based on the manufacturer's specifications which set an allowable error of plus or minus 3mm. Verification and site monitoring will occur based on Table 3.1 below with the data collected at the same time as the site visits.

Table 3. 1: Site Monitoring Plan

Site Visit	Description
1	On set up of equipment
2	After first rainfall event
3	After a significant rainfall event
4	If there are any unexplained inaccuracies or discrepancies in the data
5	Every 3 months after last site visit
6	Upon removal of equipment

3.2 Catchment Modelling

The catchment modelling stage occurred concurrently with the data collection stage.

3.2.1 Site Locality and Details

In order to adopt the most appropriate model type and catchment parameters, the site setting and conditions were identified.

The dam is located on the Parua Stream, to the east of Wainui Road, which forms the western extent of the catchment and the ridgeline above Matauri Bay, forming the eastern extent of the catchment. The dam is some 72m long and approximately 6.0m high.

The dam's catchment covers most of the upper half of a small valley formed by the Parua Stream and is approximately 70.3 hectares in area. The stream appears to have predominantly cut into the terrain, followed by filling of the subsequent valley with colluvium and alluvial sediments. Downstream of the dam and nearer the coast, the streambed becomes recent coastal deposits of sand, likely underlain by mud.

The locality of the site is shown in Figure 3.6.

Figure 3. 6. Locality Plan

Dam location is shown with yellow triangle in the image, north is up the page (LINZ, 2021).

Table 3. 2: Site Details

Item	Description
Site Address	2105 Wainui Road, Kaeo
Property Area	1,235,566 m, 21,235,566 m2
Territorial Authority	Far North District Council, Northland Regional
Zoning	Rural Production at dam & General Coastal downstream of dam

Geology

The 1:250,000 geological map, Geology of the Whangarei Area (Edbrooke & Brook, 2009) indicates that the catchment is underlain by the Waipapa Group, comprising massive to thinly bedded lithic, volcaniclastic metasandstone and argillite with tectonically enclosed basalt and chert.

3.2.2 Dam and Outlet Structures

Design documents

The original dam design documents, refer Appendix C, show the dam as being a homogeneous earth fill dam with 1V:3H upslope and downslope embankments. The source of the fill material appears to be from the spur-ridge above the right abutment, as shown in Figure 3.7.

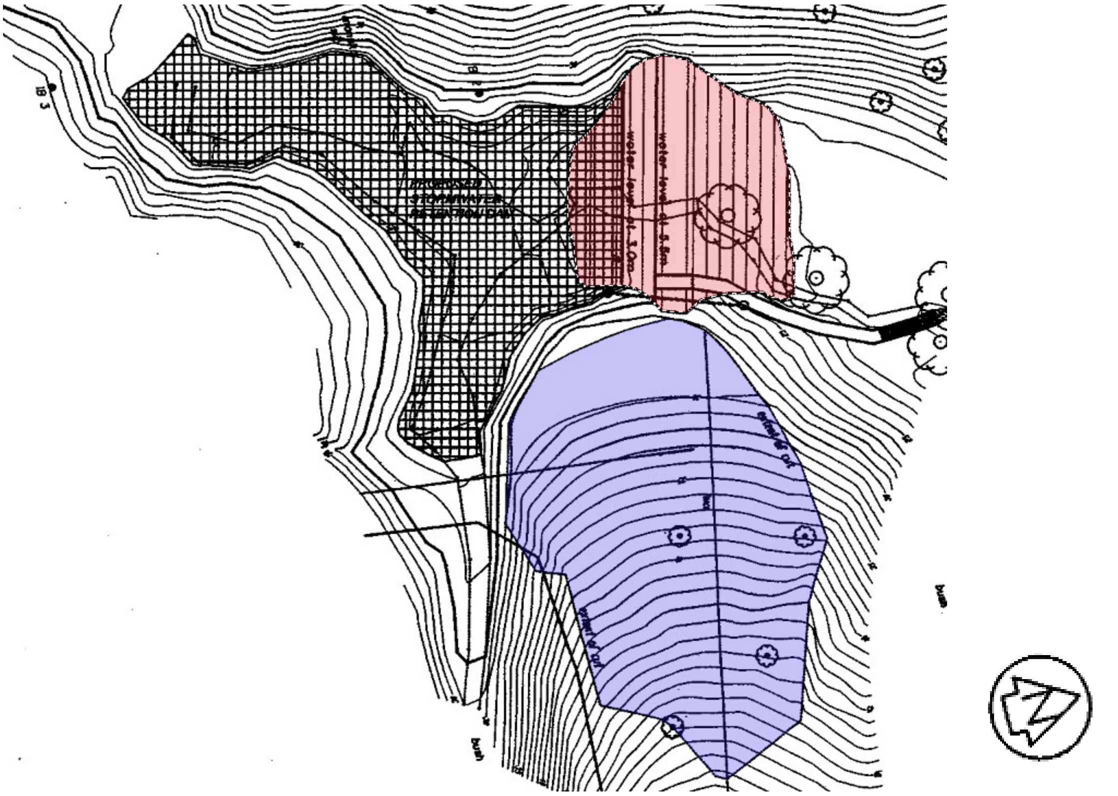


Figure 3. 7. Cut Fill Plan

Design drawing modified by Others to show areas of design cut and fill (Initial Investigation 2019)

The design documents show a normal reservoir water depth of 3.0m maintained by a low-level outlet consisting of a small wing-walled inlet structure discharging through a 300mm Reinforced Concrete Rubber Ring Jointed (RCRRJ) pipe, refer Sheet 3/4 in Appendix C. The emergency spillway begins with a 3.082 wide concrete weir that transitions into a 3.4m wide square-end concrete chute located on the fill embankment. Approximately halfway down the right abutment the chute's founding material transitions from fill material to original ground. The chute continues on original ground narrowing to 3.3m wide, becoming 'amoured' before having 200mm sized rocks grouted into the chute for the last 15m of the chute. The chute terminates with a 5m long 'poly propylene' lined channel in original ground with 300mm rip-rap. The weir is level at the crest and where it transitions into the concrete chute entrance. The concrete chute steepens to 1V:8H for the remainder of its length. The low-level culvert pipe is designed with a 1V:86H gradient.

Previous Observations

Water Levels

During the 15-year service life of the dam there have been no known observations of the spillway invert being reached. Rainfall gauge data for the duration of the service life of the dam in the area was unable to be sourced, to get an understanding on the severity of previous events.

Base Flow

It is understood through site observations and discussion with the property owner that the water level in the reservoir has never dropped below the invert of the culvert in the winter months. This is important in order to set up boundary conditions for the elevation-volume data and for consideration of a base flow to include in the HEC-HMS model.

3.2.3 Spatial Data

The co-ordinate system used in the project was New Zealand Geodetic Datum 2000 (NZGS2000) with the Mount Eden 2000 meridional circuit.

The elevation data is all referenced to One Tree Point 1964 (OTP 1964) vertical datum.

Surface Model

The 1m grid LiDAR DEM provided by NRC was imported into Civil3D to create a surface model of the catchment. Close inspection of the surface revealed an artefact on the reservoir banks. The DEM was overlain by the aerial image to reveal the artefact was created by a fallen tree extending into the reservoir. The surface was modified to remove this artefact and create a more accurate representation of the actual surface model.

The dam embankment and spillway were surveyed using a Trimble Geo7X GPS. A surface of the dam and spillway was created and pasted to the modified catchment surface.

A user defined contour was created at 1m above the crest of the dam to represent a potential maximum flood height. The larger surface of the catchment was clipped to the user defined contour and across the middle of the dam. This gave the final surface model that represents the reservoir to be used in model. The final topographic surface of the dam embankment and all spatial data can be seen in Appendix D.

Elevation Volume Relationship

The Stage Storage tool in Civil3D was used with the surface model to create an elevation volume table based on 0.01m contour intervals. This tool uses an average end area method to calculate the change in volume based on the difference in area between the contours. It is an approximate method that is likely to incur a certain amount of error. The 1m DEM used to construct the surface is also likely to have a certain error associated with the spatial data. This error was considered in the evaluation of the model.

Dam and Spillway Cross Sections

Cross sections of the dam and spillway were created from the surface model. This provided input data to use in HEC-HMS.

Longest Flow Path Long Section

The longest flow path was drawn in QGIS and the shapefile imported into CIVIL3D. The polyline from the shapefile was converted into an alignment to create a surface profile of the flow path. The length of the flow path and slope, from the equal area method defined in TP108, was obtained from the section profile.

3.2.4 HEC-HMS

To develop an understanding of the performance of the dam and outlet structures, an appropriate hydrological model was constructed in HEC-HMS. A number of different steps were involved in setting up the model, which are described in the following sections.

Determining Catchment Parameters

Catchment Delineation

The contributing catchment was delineated based on a visual assessment of the 1m DEM. In addition, contours and aerial imagery analysis provided input into assessing the catchment extent. The catchment was calculated to be 70.3 hectares in area which was consistent with the 2019 and 2020 investigations.

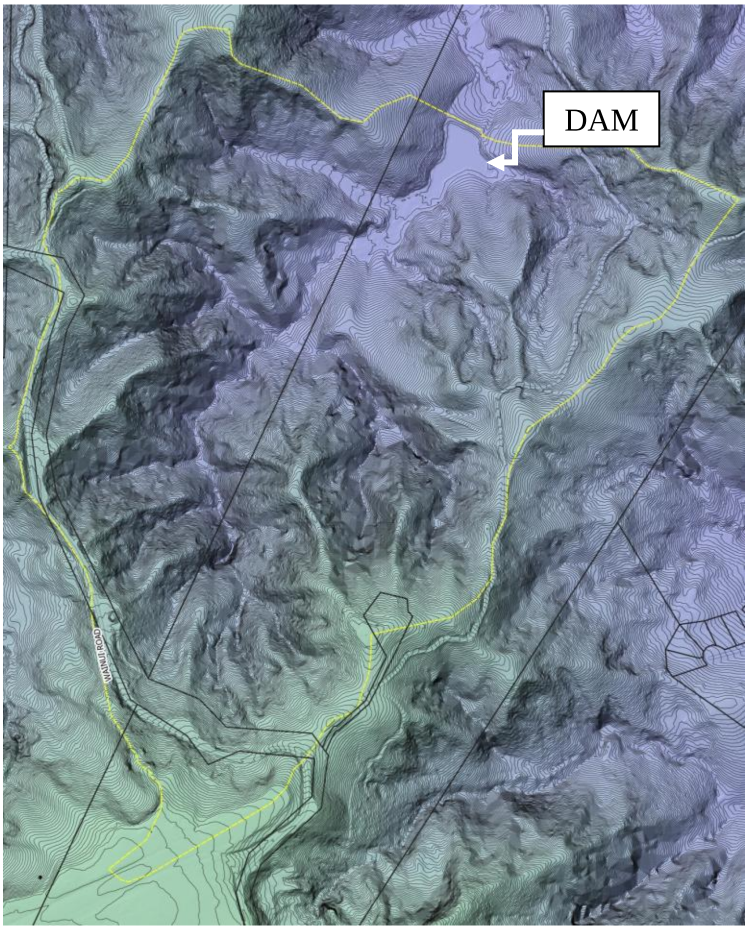


Figure 3. 8. Catchment Area

Dam location with catchment extent shown with yellow dashed line, contours are shown at 1m intervals with blue shading lower elevations and green shading higher elevations, north is up the page. DEM courtesy of NRC, 2018.

Weighted Curve Number

In order to calculate the weighted curve number, the most recent geo-referenced aerial image was imported into CIVIL 3D that contained the surface of the catchment. The 1:250,000 geological map, "Geological maps of the Whangarei Area" (Edbrooke and Brook 2009) was used to determine the initial soil type as a Type C soil. The Waipapa Group typically consists of a deep weathering profile with heavy clay residual soils. This is consistent with TP108 for weathered mudstone and sandstone of Group C. Polygons of different cover type and condition were constructed around the various areas to calculate the weighted curve number for the catchment. The classifications of varying curve numbers from TP108 for varying soil types that were determined included:

Table 3. 3: Curve numbers typical for Auckland conditions (from TP108)

(ARC 1999, p.9)

Land Use	Group A Soil	Group B Soil	Group C Soil
Bush, humid-climate, not grazed	30	55	70
Pasture, lightly grazed, good cover	39	61	74
Sealed Roads/Impervious[1]	98	98	98
Pine trees[2]	30	55	70

1. Other impervious areas include the dam reservoir, roofs and paved areas around houses.
2. The pine trees were given the same CN as "Woods in good condition", from TP-108.

The curve number for the areas covered by pine trees after the trees are harvested were taken from Appendix B in TP108 as "Recently Regraded" with a CN taken from the soil group that was determined as the most appropriate for the catchment, after calibration.

The percent of impervious area was calculated from area determined to be Sealed Road/Impervious Areas.

Time of Concentration

The time of concentration was calculated along the longest flow path in the catchment using the Equation 2.9. The lag time which is required in HEC-HMS is specified by USDA (2010):

$$Lag\ time\ (T_L) = 0.6 \times T_C \qquad (3.2)$$

Initial Abstraction

Initial abstraction is specified as being 5mm for impervious catchments. The initial abstraction was modified depending on the percent impervious cover based on Equation 2.6.

Base-flow

The TP-108 method does not specify to include base-flow for modelling. Therefore, no base-flow was used for the initial model runs.

The Linear Reservoir base-flow modelling method was used in the calibrations to account for the base-flow and interflow occurring in the catchment. This required an estimation of the initial discharge which was adjusted until the water level in the reservoir, prior to the rainfall, was matched to the observed water level.

Modifying Gauge Data for HEC-HMS

The raw data that was downloaded from both data loggers needed a certain amount of modification to make the time series “regular” enough to be compatible with HEC-HMS.

Rainfall Data Modification

The raw rainfall data was able to be exported into EXCEL with columns corresponding to the date, the time of the tipping bucket event and the depth (0.2mm). The minimum time interval required in HEC-HMS is 1 minute. The “MROUND” function in EXCEL was used to round the time to the nearest minute. The “IF” function was used to sum the rainfall depths for the same time values, to get the depth/minute over the rainfall events. This data was exported into a free software called HEC-DSSVue. This allowed the conversion of irregular time series data to regular data, using the “Math Functions” tool. A table was created with the date and time for every minute of the storm event, with the associated depth/minute of rainfall. Times where there was no tipping bucket event were set to zero mm/minute of rainfall. The data was directly copied into HEC-HMS as a “Specified Hyetograph”. The depths associated with different times were verified in HEC-HMS with values in the raw data to ensure the data had been imported into HEC-HMS correctly.

Reservoir Elevation Modification

The water level data was exported into EXCEL where it was displayed in columns as a date, time and water level with reference to the staff gauge levels. The staff gauge water levels were converted to the vertical datum by adding the recorded level to the recording zero elevation determined by the topographic survey. The PT2X data logger recorded the water level every ten seconds. HEC-HMS requires a minimum one-minute interval between data recordings. The raw data was modified by averaging the elevations over thirty seconds before and after the one-minute interval. The “OFFSET” function was used in EXCEL to filter the date/time and elevations into the minute intervals that were required. These values were verified by checking the averages for a number of different time intervals throughout the recording. The modified data was exported directly into HEC-HMS as a “Stage Gauge” for the specified recording interval.

Model Setup

A number of different models were created, based on the recording period of the data and the different rainfall/cover scenarios. For this project only one sub-basin and one reservoir were used to model the catchment. The following steps were followed to set up a typical HEC-HMS model:

1. Open HEC-HMS version 4.8.
2. Select new project (Ctrl + N) and name as Parua Stream Dam (with date of recording period) making sure the units are metric.
3. Components → Basin Model Manager
    - Name the Basin Model Manager and create.
    - Select the Basin Model Manager in the top left window.
    - On the tool pallet at the top, select a Sub Basin  name and insert into Basin Model.
    - On the same tool pallet select Reservoir  name and insert into Basin Model.
    - Right click on the Sub Basin and select "Connect Downstream" and click on the Reservoir.
4. Components → Paired Data
    - Select Elevation-Storage as the data type and name the component and create.
    - Select "Paired Data" in the left window and the Elevation-Storage icon.
    - Specify units as 1000M3
    - In the Table Tab, paste the elevation storage table created in Civil3D.
5. Components → Time Series Data
    - Select Precipitation Gages under Data Type, name and create.
    - In the left window, select the time series data "Precipitation Gauge and set Data Source to Manual Entry, Units to Incremental Millimetres and Time Interval as 1 Minute.
    - Select the extension below the Precipitation Gauge in the left window and enter the recording interval.
    - In the Table Tab, paste the modified rainfall data or hypothetical nested storm data for the specified recording period.
6. Components → Time Series Data
    - Select Stage Gages under data type, name and create.
    - In the left window, select "Stage Gages" and set Data Source to Manual Entry, Units to Metres and Time Interval to 1 Minute.
    - Select the extension below the Stage Gauge in the left window and enter the recording interval.
    - In the Table Tab, paste the modified Reservoir Elevation data for the specified recording period.
7. Components → Meteorological Manager
    - Name and create.
    - Select in the left window and specify the Precipitation as "Specified Hyetograph".

- Select the Basins Tab and set the Include Subbasins to “Yes”.
- Select the “Specified Hydrograph” icon and set the gauge to the precipitation gauge required from the time series data.

8. Components → Control Specifications
    - Name and create
    - In the left window, select the icon and enter the time parameters of the event that is being modelled and enter the time interval as 1 Minute.
9. Sub-Basin Parameters
    - Click on the Sub-Basin in the window to the left. In the Sub-Basin Tab enter the sub-basin area in km^2 as 0.703. Enter the Loss Method as “SCS Curve Number”. Enter the transform method as “SCS Unit Hydrograph”. Keep the other methods as “None” or set base-flow to Linear Reservoir for calibrated simulations.
    - Under the Loss Tab, enter the Initial abstraction as the required value. Enter the calculated Weighted Curve Number. The impervious area was kept as 0%.
    - In the Transform Tab, enter the Lag Time calculated using Equation 3.2 and keep the Graph type as Standard (PRF 484).
10. Reservoir Parameters
    - Click on the Reservoir in the window to the left. Specify the Method as “Outflow Structures”, the storage method as “Elevation-Storage”, the elev-sto function to the Paired Data Component, the Initial Condition as the water level at the start of the Control Specification Period, the main tailwater as “Assume None”, time step method as “Automatic Adaptation”, 1 Outlet, 1 Spillway and 1 Dam Top.
    - Under the Options Tab, select Observed Stage and Pool Elevation as the Stage Gauge.
    - Select the Outlet folder in the left window and specify as “Culvert Outlet”, Direction “Main”, Solution Method, “Automatic”, Shape, “Circular”, Chart “1: Concrete Pipe Culvert”, Scale “1: Square Edge Entrance with Headwall” then enter the parameters determined from the topographic survey for length, inlet elevation and the entrance and exit discharge co-efficient as 1.0.
    - Select the Spillway folder and specify the Method as “Broad Crested Weir” and set the parameters from the topographic survey for the spillway length. Set the discharge coefficient to 2.6.
    - Select the Dam Top folder and specify the Method as “level dam top” and the invert from the topographic survey data. Set the discharge coefficient to 2.6.
11. Compute → Create Compute → Simulation Run
    - Name and next
    - Specify Basin Model, Meteorological Model and Control Specifications and Finish.
12. Run Simulation
    - In the left window select the Compute Tab.
    - Right click the required simulation run and select “Compute”
    - Once 100% complete select the Results Tab and analyse the required tables or graphs.

Hypothetical Rainfall Event

The design rainfall depths for all hypothetical storm events have been taken based from the National Institute of Water and Atmospheric Research (NIWA), High Intensity Rainfall Design System version 4 (HIRDSv4). The design storm predictions come in a range of climate change scenarios for different periods. The New Zealand Standards, that are used by for the Far North District Council, specify that an allowance for climate change should be used in design (New Zealand Standards, 2010). The current project adopted design rainfall intensities based on historic rainfall scenarios and using a climate change RCP6.0 for the period 2081-2100. This allowed a comparison between a more relevant scenario for the original design to a scenario that is adopted as more recent best practice.

A 24-hour nested storm with a temporal pattern was created in Excel from NIWA HIRDs Version 4 data for the area. Rainfall depths for the 1% AEP storm were obtained from the depth duration frequency Tables 3.4 and 3.5.

Table 3. 4: NIWA HIRDSv4 DDF Table (From Historic Data)

(NIWA, 2021)

AEP (%)	10 min	20 min	30min	60 min	120 min	360 min	720 min	1440 min
50	10.5	16.3	20.8	30.7	43.7	70.7	90.8	112
10	16	24.9	31.8	47	66.9	108	140	172
2	21.6	33.7	43	63.7	90.8	148	190	235
1	24	37.5	48	71.1	101	165	213	263

Table 3. 5: NIWA HIRDSv4 DDF Table (Climate Change Scenario RCP6.0 2081-2100)

(NIWA, 2021)

AEP (%)	10 min	20 min	30 min	60 min	120 min	360 min	720 min	1440 min
50	12.6	19.6	25	36.9	52.1	81.9	103	125
10	19.4	30.2	38.6	57	80.6	127	161	195
2	26.3	41.1	52.5	77.7	110	175	221	267
1	29.3	45.9	58.6	86.8	123	196	248	300

The storm rainfall intensities were broken into 5-minute intervals so the data could be easily entered into HEC-HMS. The highest intensities were applied to the middle of the storm event, giving a temporal rainfall pattern like the one shown in Figure 2.12.

3.3 Identifying Rainfall Events

Small rainfall events, where the reservoir level did not exceed the obvert of the primary culvert, were not considered significant enough to model. This was because of the extremely high sensitivity of the model parameters when trying to calibrate the models with observed data. The impacts of these small events were also deemed insignificant when considering the aims of the project. The water level data was examined in EXCEL to inspect when the water level exceeded the obvert of the primary culvert, over the various recording periods.

3.4 Calibration and Analysis

3.4.1 Initial Calibration

The initial calibration was achieved using the raw observed rainfall and water level data for each storm event. Parameters like time of concentration and initial abstraction could be established from observed data.

Time of Concentration

The time of concentration was defined as the time for rainfall to travel for the most distant point of the catchment to the outlet. It was taken by the difference in time (in minutes) between the point of highest rainfall intensity to the point of the greatest change in reservoir volume/minute.

Initial Abstraction

An Initial Abstraction was calculated as the depth of rainfall before a change in reservoir elevation occurred for each storm event.

3.4.2 HEC-HMS Calibration

The calibrated parameters were input into HEC-HMS to run the calibrated model against the observed data. The curve number and linear reservoir base-flow were the remaining parameters that were adjusted to get the best fit model.

3.4.3 Model Performance Evaluation

Quantitative Assessment

Once the Modelling for each storm event was completed, the percent error in peak reservoir elevation (Equation 3.3), the root mean square error (Equation 3.4), the Nash Sutcliffe

Efficiency Coefficient (*NSE)* (Equation 2.30) and the number of times the observations variability is greater than the mean error (n_t) (Equation 2.29) were calculated to assess the performance of the calibrated models. Figure 2.20 was used to determine the index of the goodness of fit for each calibrated model.

$$\%\ Error\ in\ Peak = 100 \times \frac{p_i - o_i}{o_i} \tag{3.3}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(p_i - o_i)^2}{n}} \tag{3.4}$$

where:

pi=Modelled Level

oi=Observed Level

n=Number of observations

Qualitative Assessment

The figures containing the observed data and the calibrated model were used to assess the level of fit, qualitatively. This included observations on the differences between models. This method helped identify the parameters that needed changing for the calibrations.

3.4.4 Determination of Final Catchment Parameters

The criteria for the final parameters included:

- Must not under predict the reservoir elevation for any storm events.
- Must achieve “Acceptable”, based on Figure 2.20, for all events.

These criteria provide an assurance that the runoff is less likely to be under predicted.

Each storm event was modelled using the final calibrated parameters and the Model Performance Evaluation method was completed again. The results from the performance evaluation were used to verify the final parameters used for modeling the 1% AEP hypothetical storm events.

4 Results

4.1 Introduction

The results of the catchment gauging and modelling are presented in this Chapter. The Chapter includes the result from the following Sections:

- Spatial Data Analysis.
- Catchment Parameters for HEC-HMS
- Observed Data and Storm Identification
- TP-108 Models vs Observed data
- Initial Calibration and Performance
- Final Parameter Determination and Final Calibrated Models
- 1% AEP Simulations

4.2 Spatial Data Analysis

Outlet Structures

Table 4. 1: Outlet Structure Details

Item	Value
Spillway Length	3.082 m
Dam Top Length (minus Spillway)	72.908 m
Culvert Length	33.926 m

Elevation Data

Elevation data required as inputs into HEC-HMS includes:

Table 4. 2: Elevation Data

Item	Elevation (m OTP Vertical Datum)
Upstream Culvert Invert	24.912
Upstream Culvert Obvert	25.212
Downstream Culvert Invert	24.524
Spillway Invert	27.828
Dam Top Invert	28.007
Elevation-Volume Data	See Appendix D Table D.1
Benchmark 1	28.574

Longest Flow Path Long Section and Equal Area

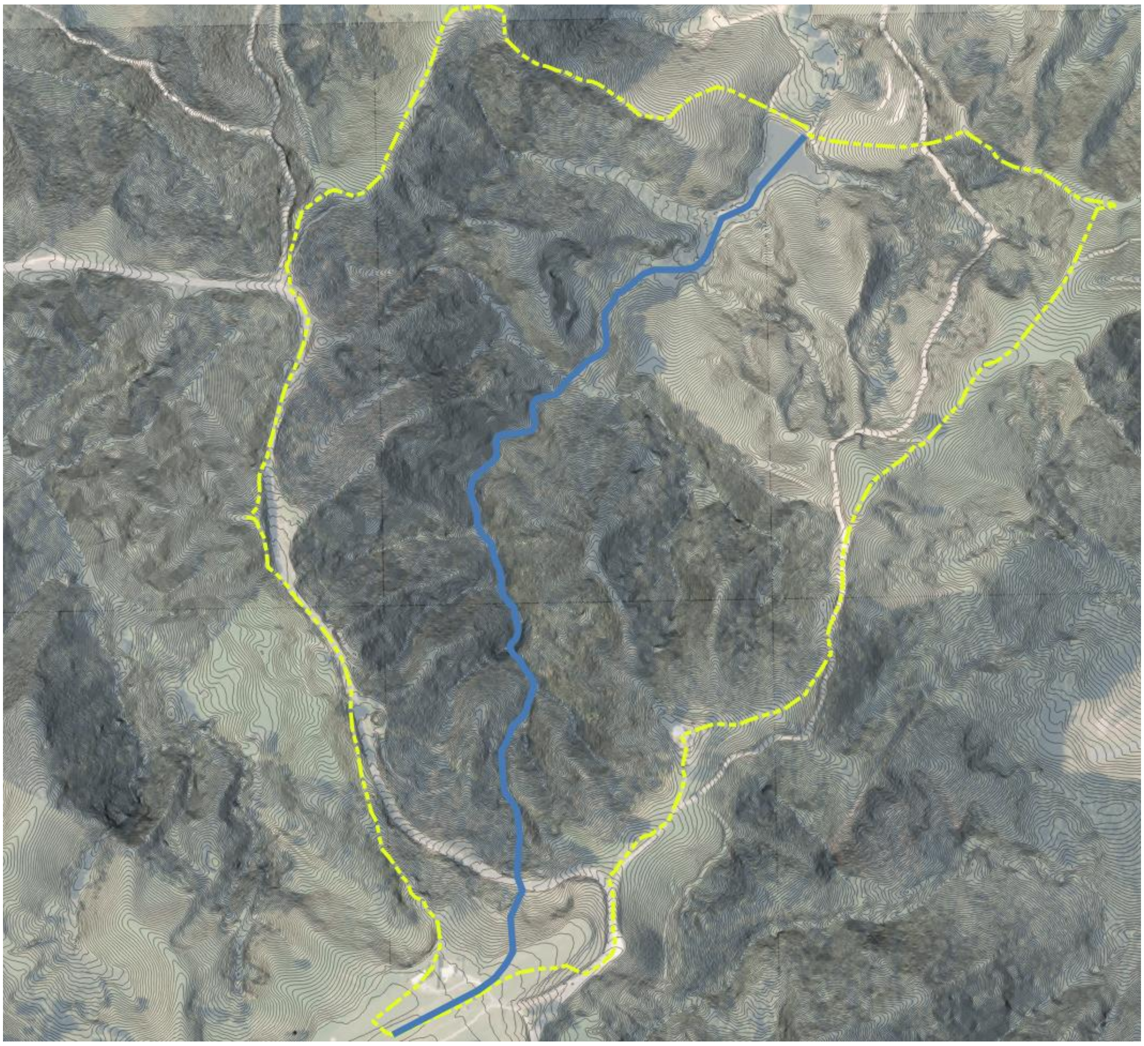


Figure 4. 1. Longest flow path

Catchment area shown by dashed yellow line, flow bath in blue. NRC 1m contours on LINZ aerial image. North up the page, not to scale.

The longest flow path from QGIS is shown in Figure 4.1. The long section and equal area evaluation can be seen in Appendix D. The parameters calculated from the equal area method are:

Table 4. 3: Longest Flow Path Parameters

Parameter	Value
Length of flow path	1467 m
Equal Area Slope	0.086 m/m

4.3 Catchment Parameters for HEC-HMS

4.3.1 Initial Abstraction

The total impervious area of the catchment was calculated as 0.3%. This was considered negligible based on the catchment area. This value resulted in adopting an initial abstraction value of 5.0 mm.

4.3.2 Weighted Curve Number

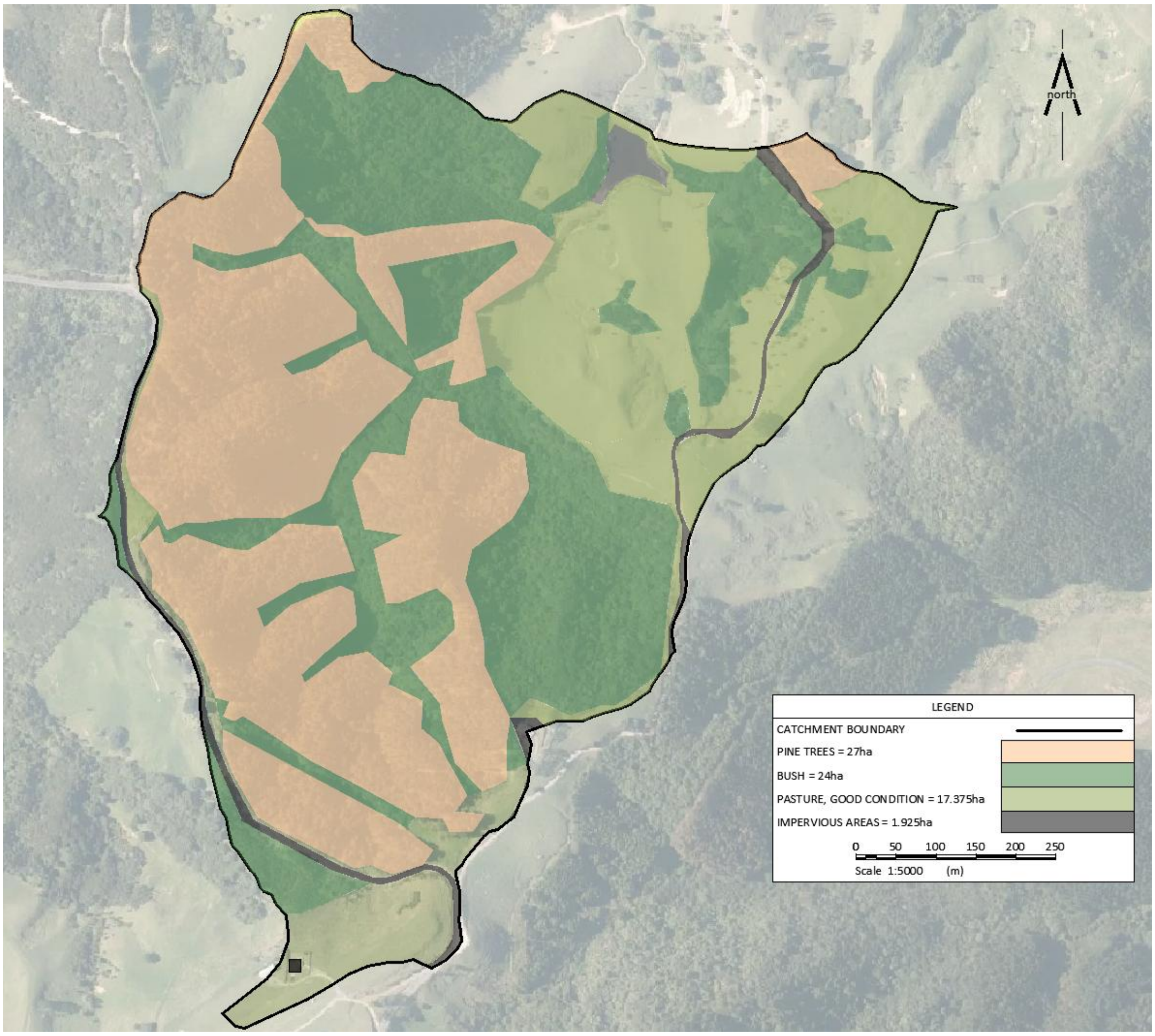


Figure 4. 2. Catchment Cover Conditions used for calculating the Weighted Curve Number

The weighted curve number for existing conditions was calculated as 71.756 as seen in Table 4.4:

Table 4. 4: Weighted Curve Number (Existing conditions)

Land Use	Group C Soil CN	Total Area (ha)	CN*Area(ha)
Bush, humid-climate, not grazed	70	24	1680
Pasture, lightly grazed, good cover	74	17.375	1285.75
Sealed Roads/Impervious Areas	98	1.925	188.65
Pine trees	70	27	1890
Total		70.3	5044.4
CN*	**71.756**		

The weighted curve number used for post pine tree harvest was determined after final calibration using the Curve Number Tables in TP-108 based on the calibrated weighted curve number for existing conditions. This can be seen in Section 4.7.

4.3.3 Time of Concentration

Equation 4.1 displays the time of concentration using parameters calculated in Section 4.2 and Table 4.3. The time of concentration was calculated as 49.470 minutes.

$$T_c = 0.14 \times 1467.1^{0.66} \times \left(\frac{71.756}{200-71.756}\right)^{-0.55} \times 0.086^{-0.3} = 49.470\, minutes \qquad (4.1)$$

The lag time using equation 3.2 was found to be 29.682 minutes.

$$T_L = 0.6 \times 49.470 = 29.682\, minutes \qquad (4.2)$$

4.4 Observed Data and Storm Identification

4.4.1 Observed Water Level and Rainfall Data

Water Level Data

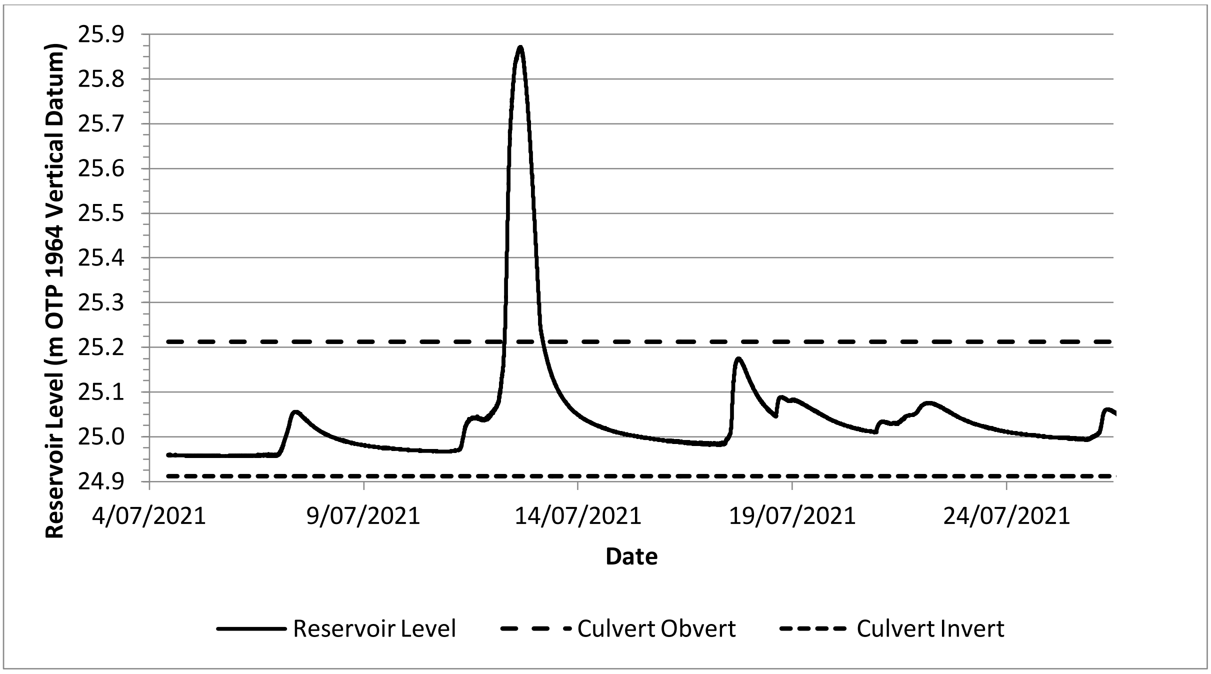


Figure 4. 3. Reservoir levels from 04/07/2021 to 27/07/2021

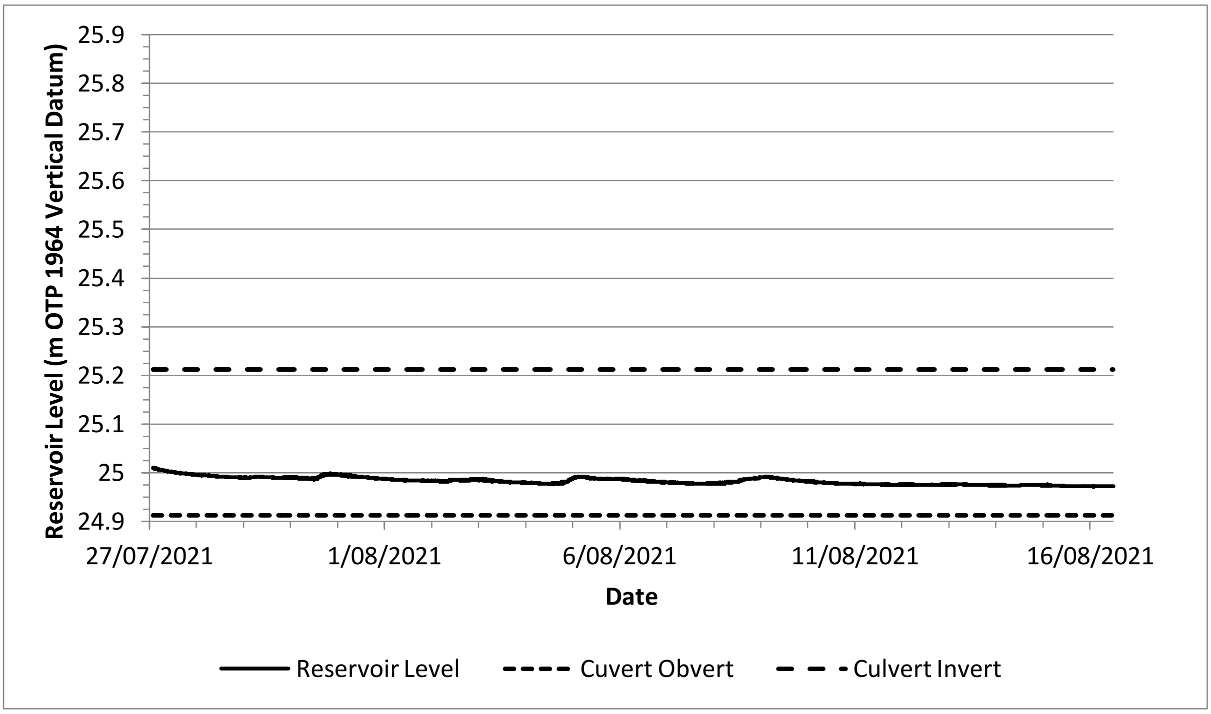


Figure 4. 4. Reservoir levels from 27/07/2021 to 17/08/2021

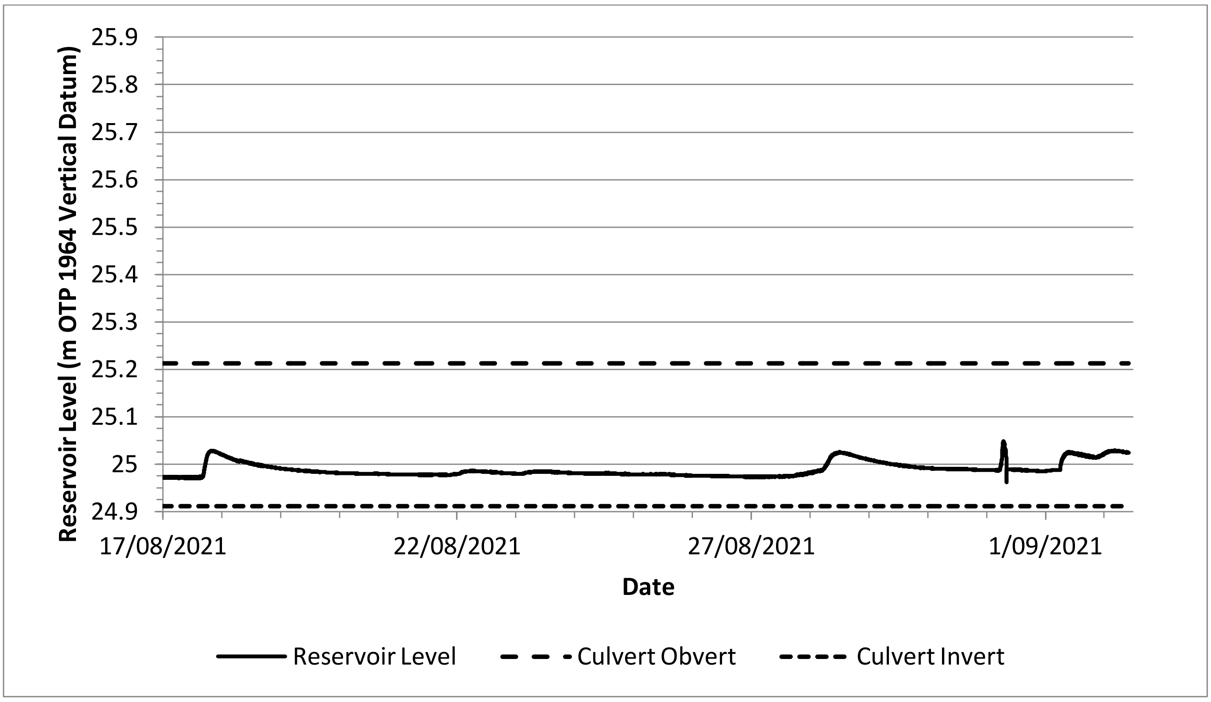


Figure 4. 5. Reservoir levels from 17/08/2021 to 02/09/2021

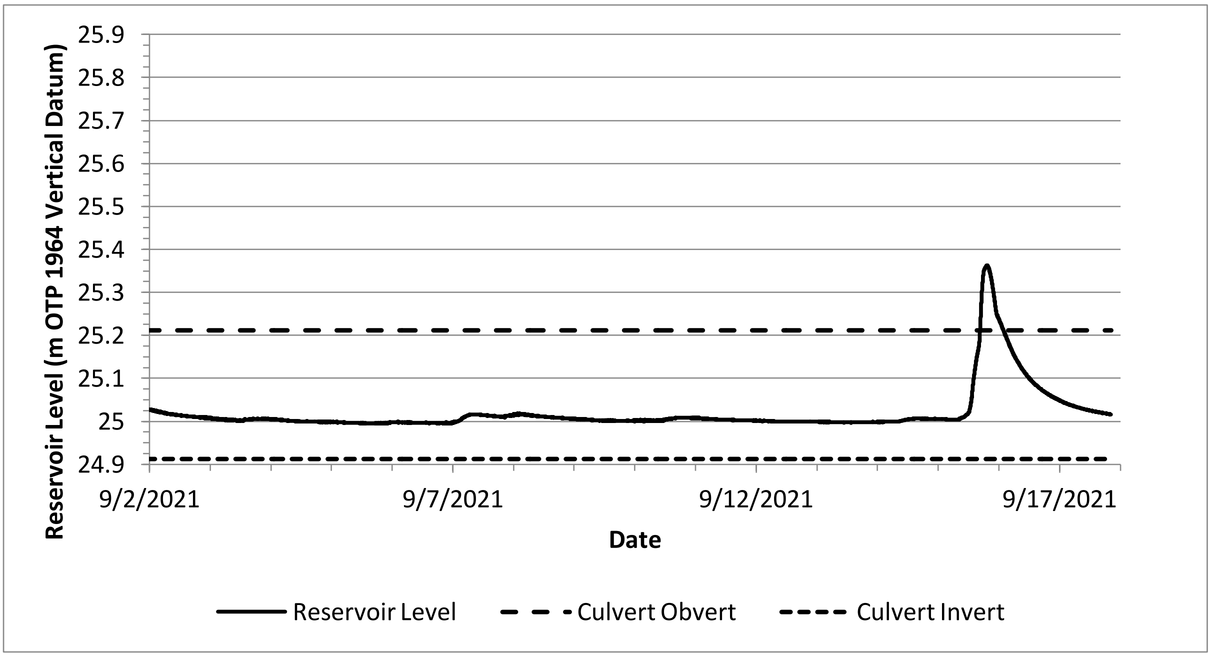


Figure 4. 6. Reservoir levels from 02/09/2021 to 17/09/2021

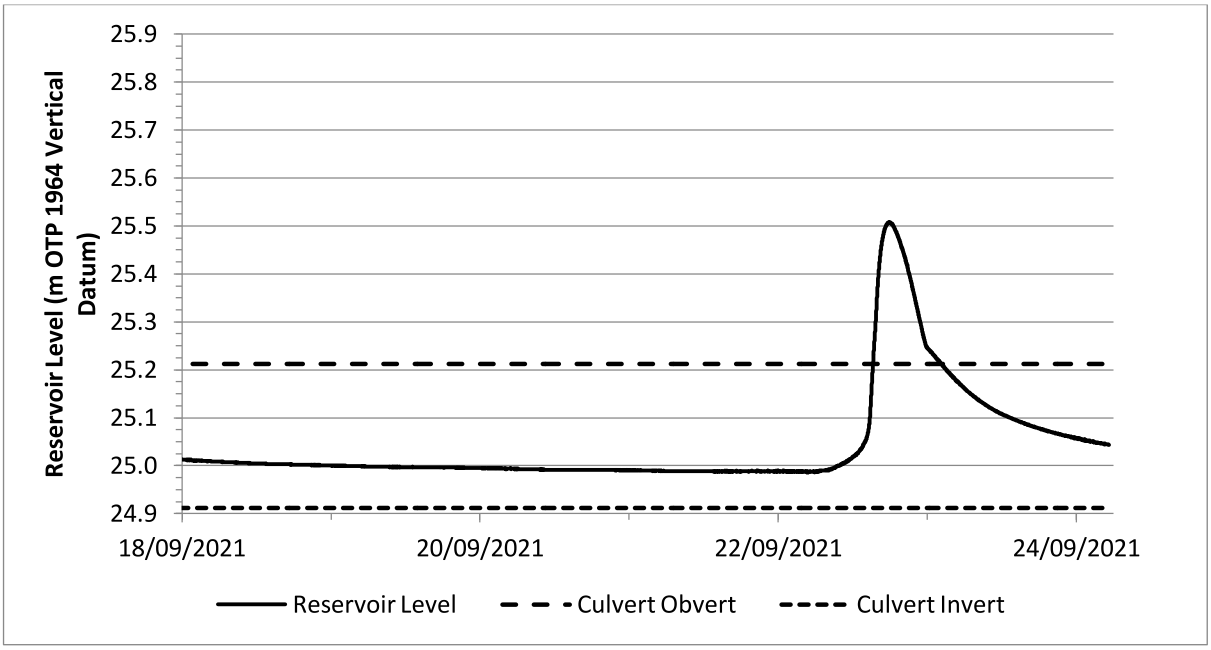


Figure 4. 7. Reservoir levels from 18/09/2021 to 24/09/2021

Rainfall Data

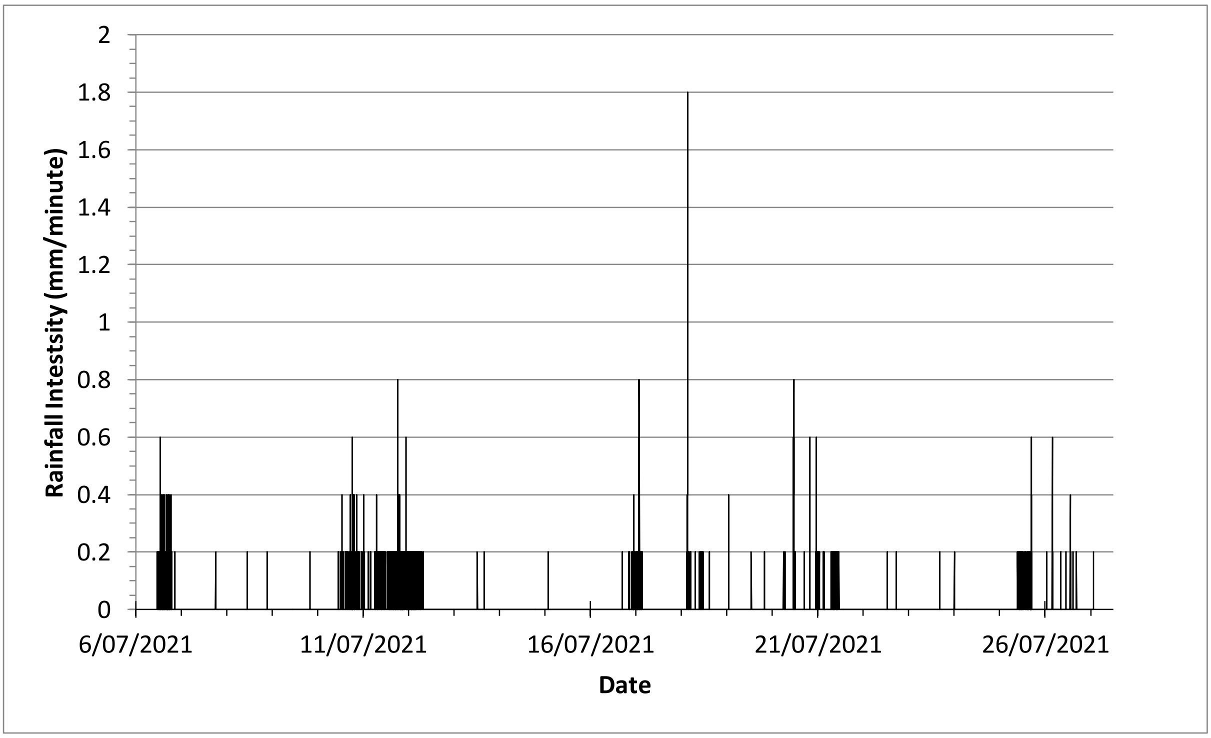


Figure 4. 8. Rainfall depth (mm/minute) from 06/07/2021 to 27/07/2021

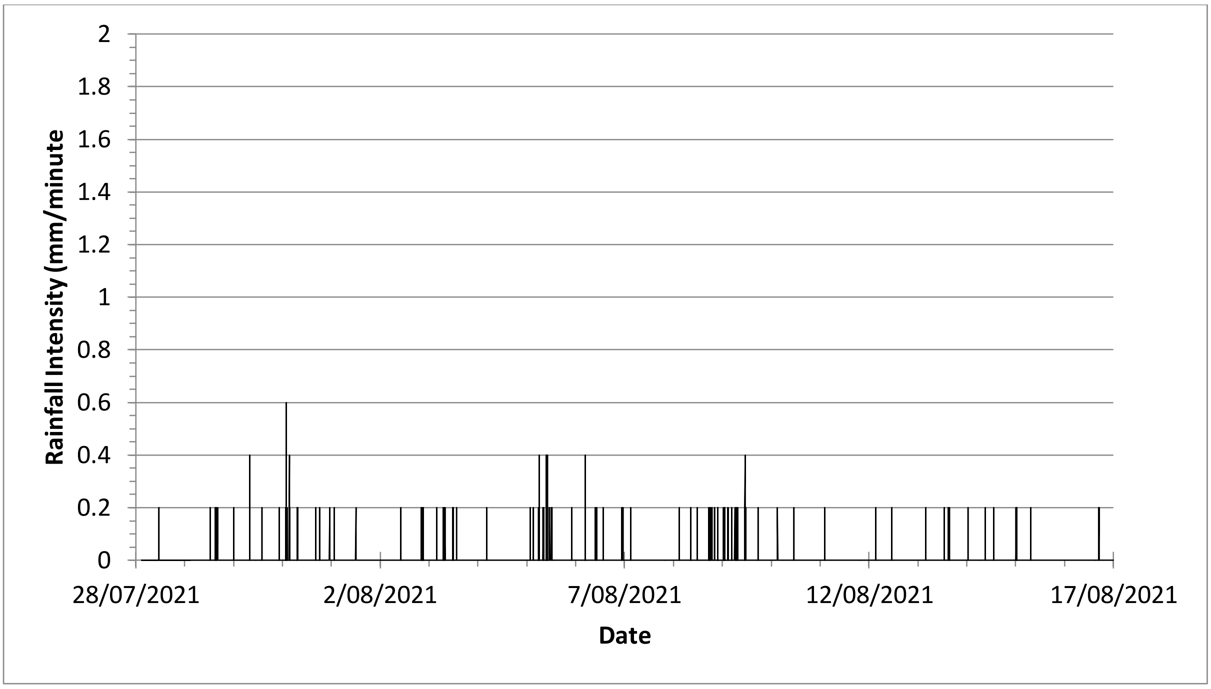


Figure 4. 9. Rainfall depth (mm/minute) from 28/07/2021 to 17/08/2021

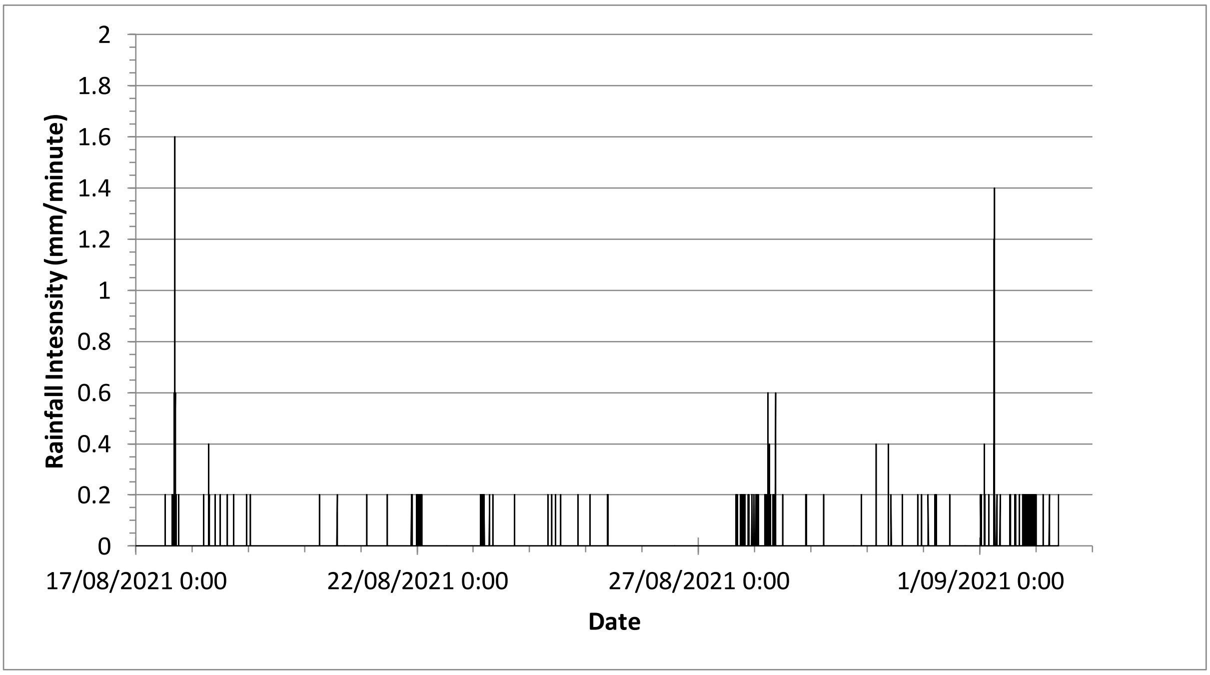


Figure 4. 10. Rainfall depth (mm/minute) from 17/08/2021 to 02/09/2021

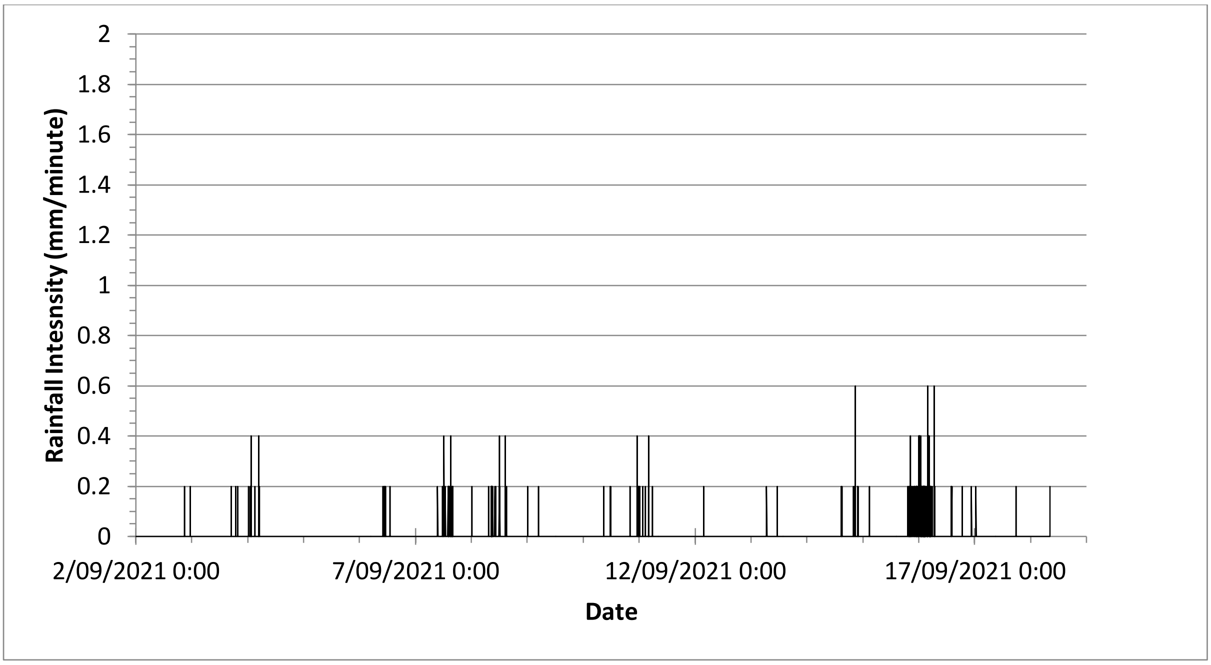


Figure 4. 11. Rainfall depth (mm/minute) from 02/09/2021 to 18/09/2021

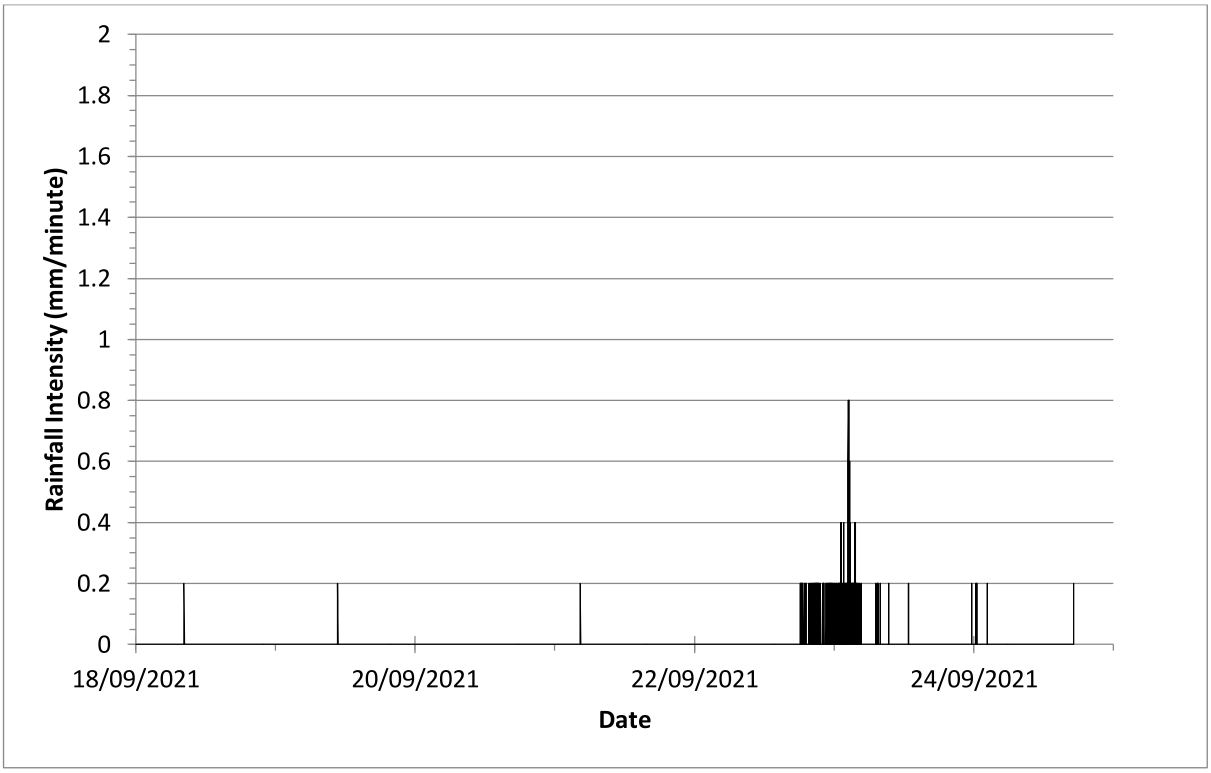


Figure 4.12 Rainfall depth (mm/minute) from 18/09/2021 to 24/09/2021

4.4.2 Storm Events

Table 4. 5: Storm Events Identified for Analysis

Storm Event	Start Date	Start Time	End Date	End Time	Initial Soil Conditions	Total Rainfall From 21 days Prior to Storm
12th July	10/07/2021	10:00	15/07/2021	20:00	Dry to Moist	68.5mm
16th September	15/09/2021	10:00	18/09/2021	08:00	Moist to Wet	126.5mm
23rd September	22/09/2021	18:12	23/09/2021	09:23	Moist to Wet	117mm

4.4.3 Initial Soil Conditions

The soil conditions observed the start of July were dry to moist with only 68.5 mm of rainfall recorded three weeks before the 12th of July storm event.

The is soil conditions in September were noticeably more saturated and recorded depths were 126.5 mm for the 16th of September event and 117 mm for the 23rd of September event.

The rainfall data used to assess these initial conditions is included in Appendix G and was taken from Northland Regional Council Rainfall Data from the closest station “at Towai at Weta” (NRC 2021). This station is approximately 5.5 km to the west of the dam reservoir.

4.5 TP-108 Models vs Observed Response

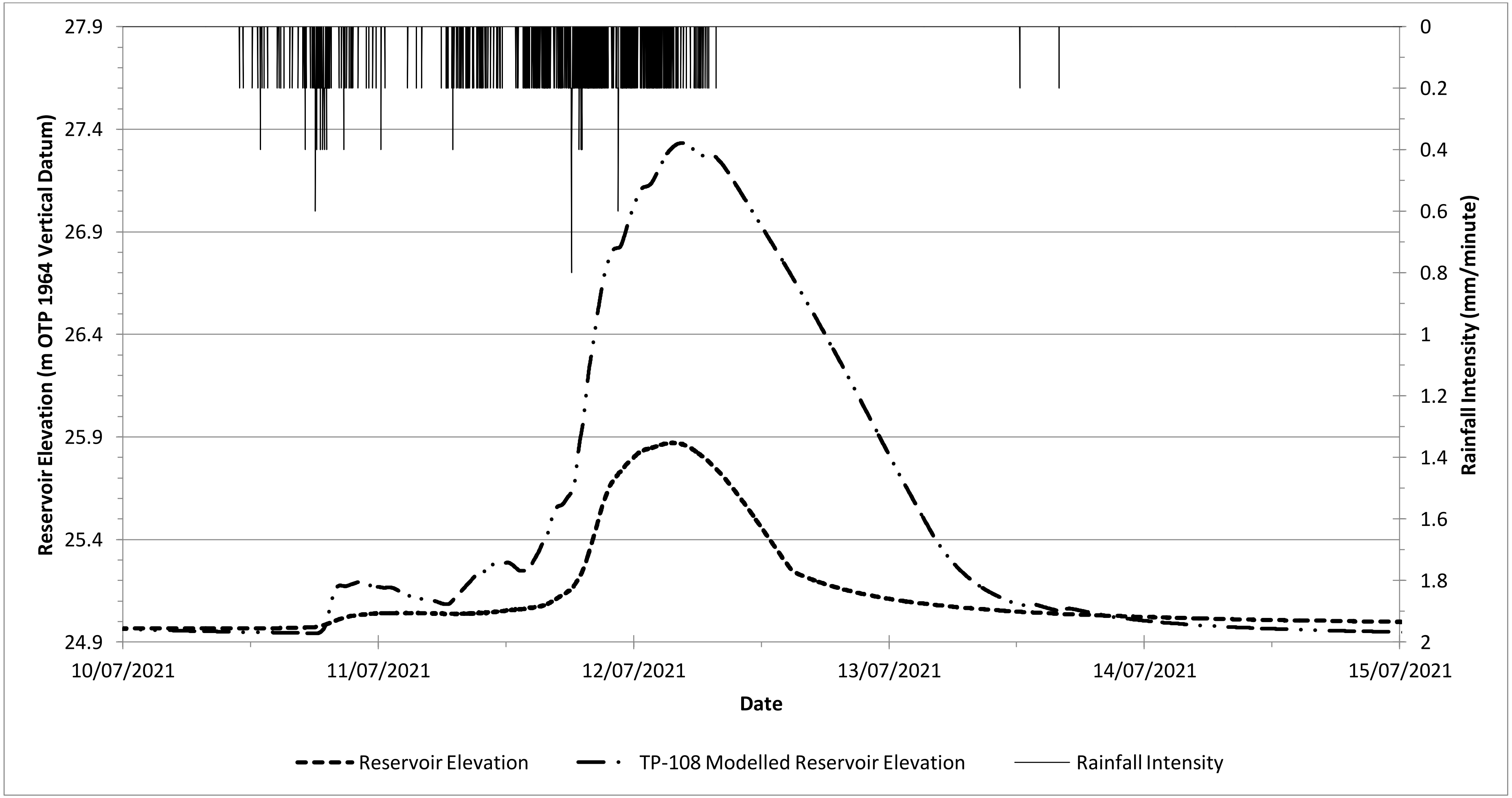


Figure 4. 12. Modelled Reservoir Elevation using TP-108, Observed Elevation and Rainfall Intensity for the 12th July Storm Event

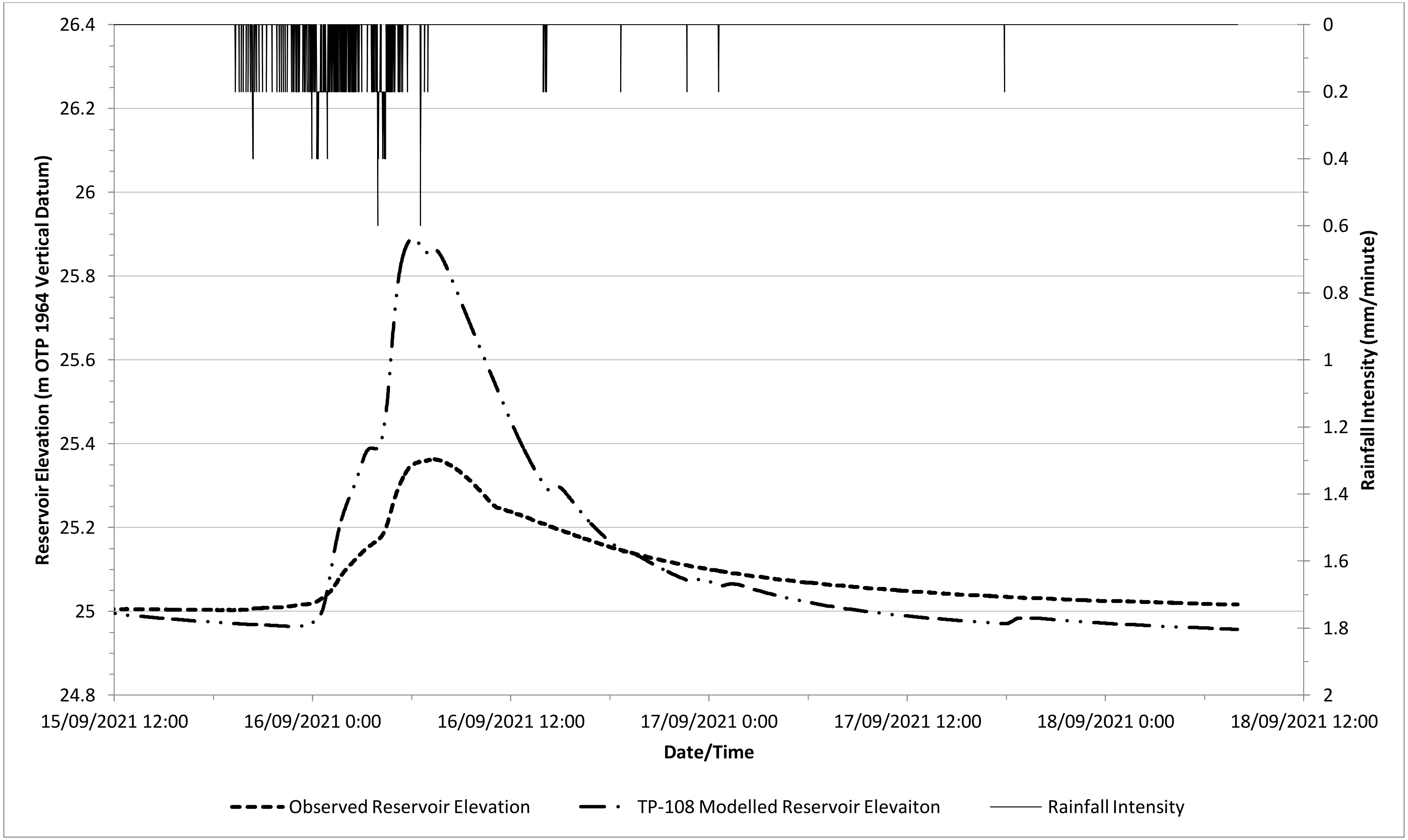


Figure 4. 13. Modelled Reservoir Elevation using TP-108, Observed Elevation and Rainfall Intensity for the 16th September Storm Event

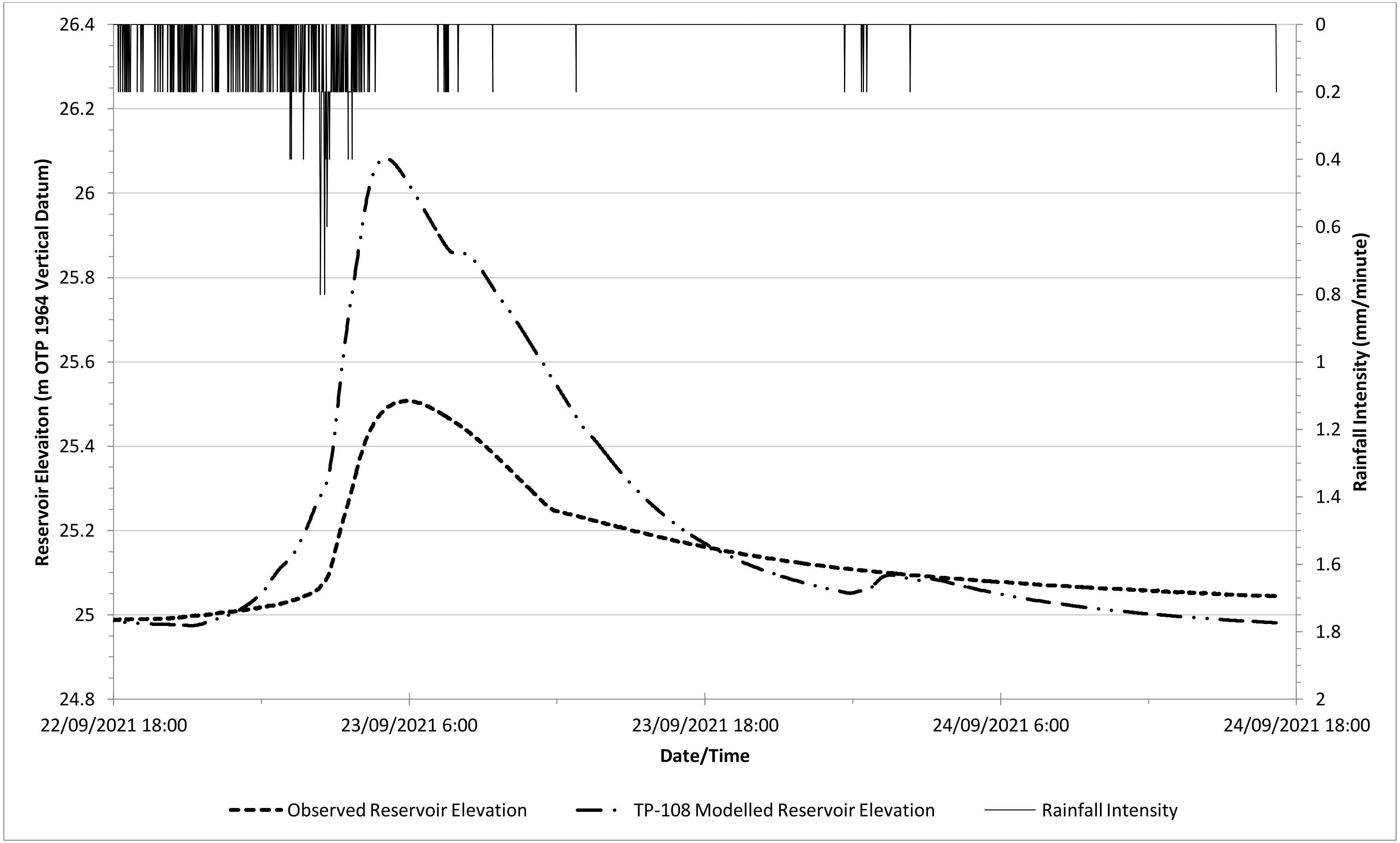


Figure 4. 14. Modelled Reservoir Elevation using TP-108, Observed Elevation and Rainfall Intensity for the 23rd September Storm Event

4.6 Initial Calibration

4.6.1 Initial EXCEL Calibration

The initial calibrations for the time of concentration and initial abstraction were performed in EXCEL.

The results of the initial calibration for each storm event are shown in Table 4.6.

Table 4. 6: Initial EXCEL Calibration

	12th July	**16th September**	**23rd September**
Time of Concentration	86 minutes	45 minutes	48 minutes
Lag Time (for HMS)	51.6 minutes	27 minutes	28.8 minutes
Initial Abstraction	4.8mm	1.6mm	2.8mm

4.6.2 HEC-HMS Trial and Error Calibration

The parameters displayed in Table 4.6 were used in HEC-HMS for the corresponding storm event. The curve number and linear reservoir parameters were input for the 12th July storm event and modified along with slight changes to Table 4.6 parameters to achieve an observed and statistical best fit.

Once the best fit was achieved for the 12th July event the curve number and linear reservoir parameters were used as a baseline for the 16th September event and the same process was followed to achieve the best fit for this event and then the 23rd of September event.

The results of the best fit parameters and model performance evaluation are shown in Table 4.7

Table 4. 7: HEC-HMS Calibration

Parameter	Storm Event		
	12th July	**16th September**	**23rd September**
Time of Concentration	75 minutes	75 minutes	75 minutes
Lag Time (for HMS)	45 minutes	45 minutes	45 minutes
Initial Abstraction	4.8mm	2.0mm	3.0mm
Weighted Curve Number	35.5	37.2	41.2
Linear Reservoir 1 Initial Discharge (m^3/s)	0	0	0
Linear Reservoir 1 GW1 Fraction	0.035	0.06	0.06
Linear Reservoir 1 GW1 Coefficient (hours)	10	8	8
Linear Reservoir 2 Initial Discharge (m^3/s)	0.0028	0.006	0.005
Linear Reservoir 2 GW2 Fraction	0.055	0.04	0.065
Linear Reservoir 2 GW2 Coefficient (hours)	80	80	80
% Error in Peak Reservoir Level (%)	0.11	0	1.92
RMSE	0.0270	0.0083	0.0163
n_t	7.96	8.79	4.26
NSE	0.988	0.990	0.964
Figure 2.19 Index	Very Good	Very Good	Very Good
Predicted Reservoir Level Peak ≥ Observed Peak	Yes	Yes	Yes
Visual Inspection	Good Fit	Very Good Fit	Very Good Fit

4.6.3 HEC-HMS Calibrated Models

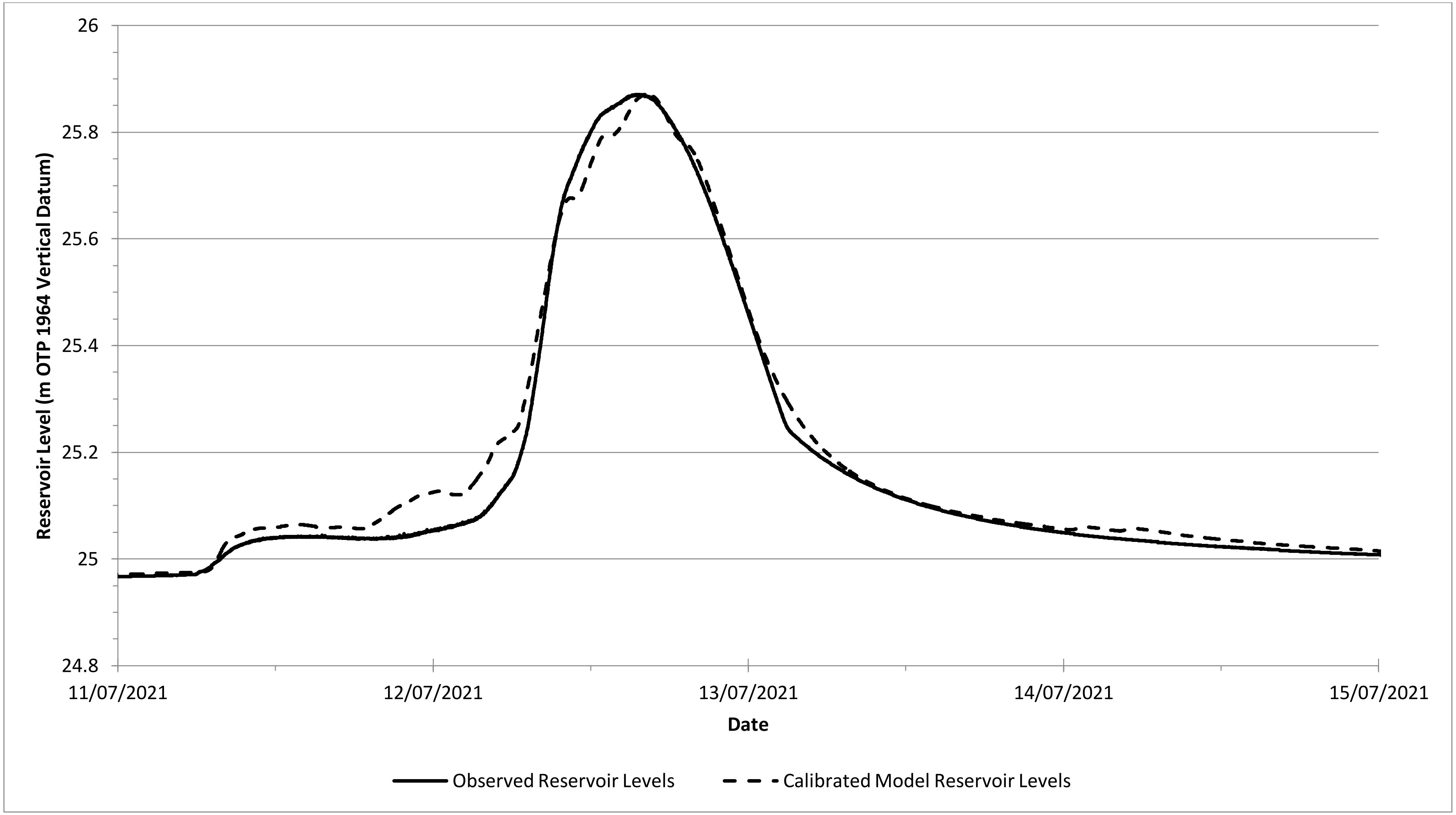


Figure 4. 15. Best-Fit Calibrated Model Reservoir Levels vs Observed Reservoir Levels for the 12th July Storm Event

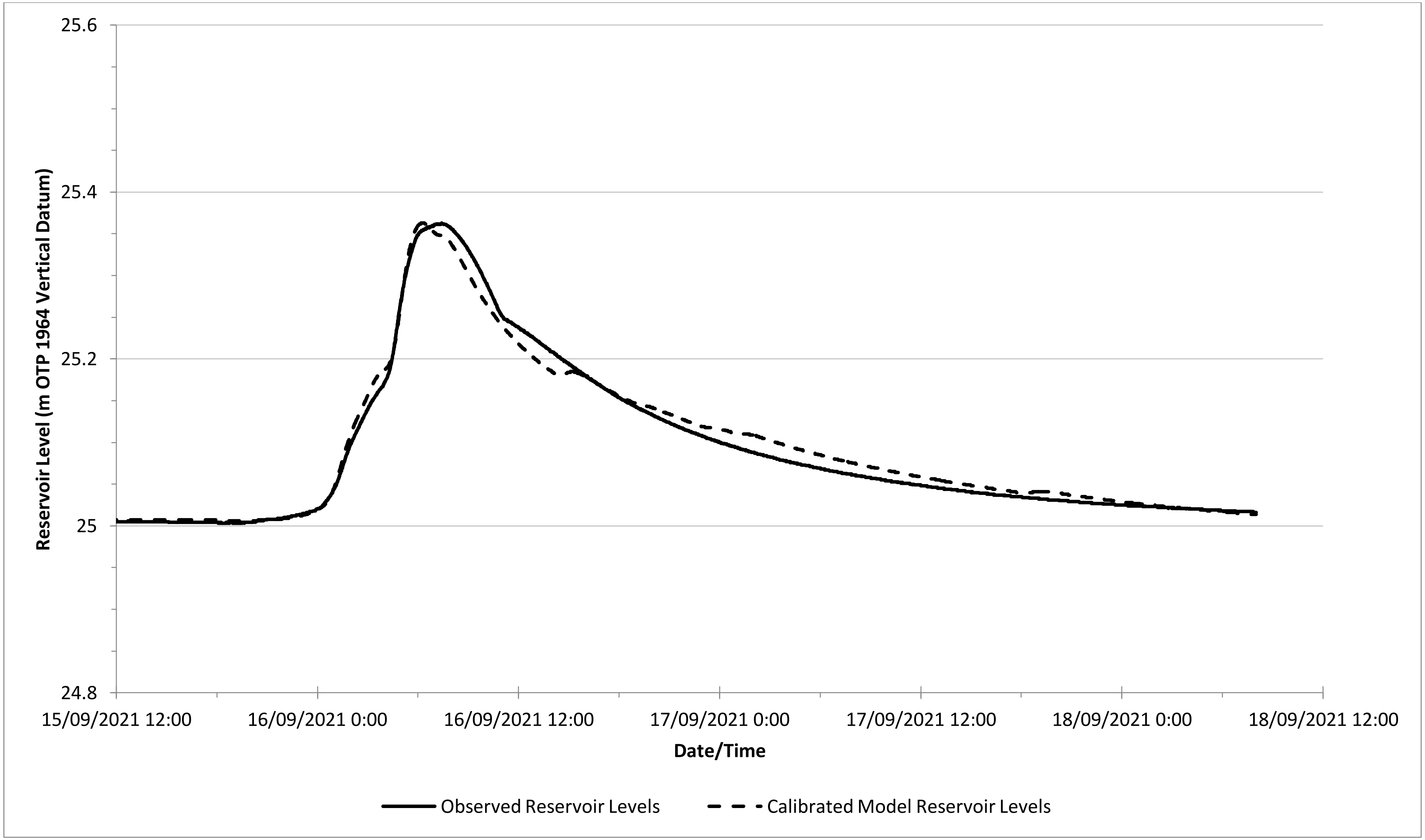


Figure 4. 16. Best-Fit Calibrated Model Reservoir Levels vs Observed Reservoir Levels for the 16th September Storm Event

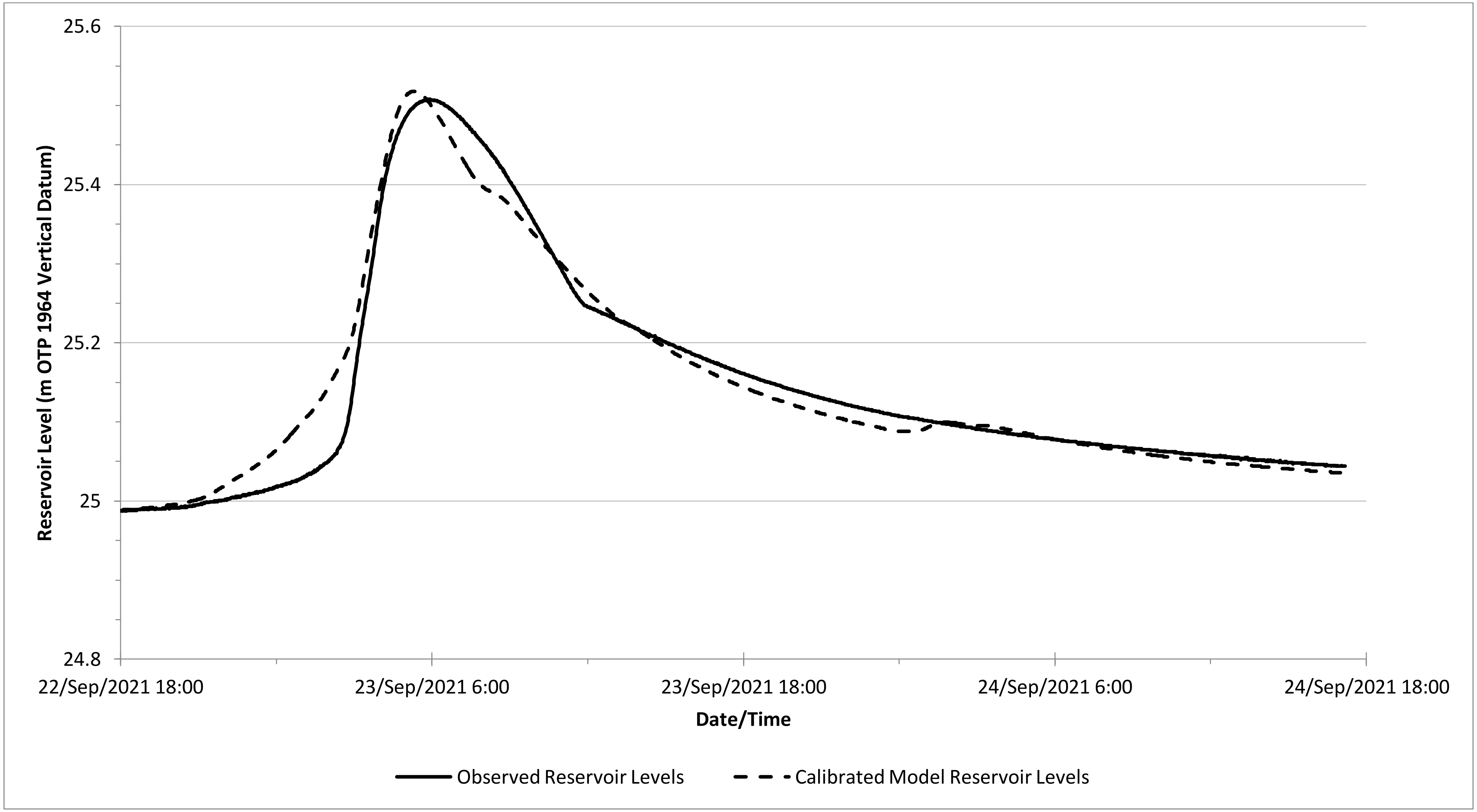


Figure 4. 17. Best-Fit Calibrated Model Reservoir Levels vs Observed Reservoir Levels for the 23rd September Storm Event

4.7 Final Parameter Determination

The final parameters that were adopted to be used in the simulations of the 1%AEP event for the different rainfall scenarios and cover conditions were taken based on Table 4.7 and observations of Figures 4.15, 4.16 and 4.17.

The final parameters were adopted using the criteria specified in Section 3.4.4. These criteria ensured the chosen parameters are the most conservative as they may need to be recommended for use in future remedial works on the dam and outlet structures.

Based on these criteria the following parameters were adopted as the final catchment parameters.

Table 4. 8: Final Catchment Parameters

Parameter	Value (Existing Cover Conditions)	Value (After Pine Tree Harvest Cover Conditions)
Time of Concentration	75 minutes	75 minutes
Lag Time (for HMS)	45 minutes	45 minutes
Initial Abstraction	3.0mm	3.0mm
Weighted Curve Number	41.2	55
Linear Reservoir 1 Initial Discharge (m^3/s)	0	0
Linear Reservoir 1 GW1 Fraction	0.06	0.06
Linear Reservoir 1 GW1 Coefficient (hours)	8	8
Linear Reservoir 2 Initial Discharge (m^3/s)	0.006	0.006
Linear Reservoir 2 GW2 Fraction	0.065	0.065
Linear Reservoir 2 GW2 Coefficient (hours)	80	80
Initial Elevation	24.912 m (OTP 1964)	24.912 m (OTP 1964)

The weighted curve number of 41.2 was used to identify the most appropriate Soil Type as Soil Group A. Table 4.9 displays a more likely representation of the different curve numbers associated with the catchment.

Table 4. 9: Weighted Curve Number (Calibrated)

Land Use	Group A Soil CN	Total Area (ha)	CN*Area(ha)
Bush, humid-climate, not grazed	30	24	720
Pasture, lightly grazed, fair condition	49	17.375	851.375
Sealed Roads/Impervious Areas	98	1.925	188.65
Woods-grass combination, fair condition	43	27	1161
Total		**70.3**	**2921**
CN*	**41.5**		

Table 4.9 was used to justify the final weighted Curve Number for the post pine tree harvesting conditions shown in Table 4.10. Note the weighted curve number in Table 4.8 has been rounded up to the nearest whole number when compared to the value in Table 4.10.

Table 4. 10: Weighted Curve Number (Post Pine Tree Harvest)

Land Use	Group A Soil CN	Total Area (ha)	CN*Area(ha)
Bush, humid-climate, not grazed	30	24	720
Pasture, lightly grazed, fair condition	49	17.375	851.375
Sealed Roads/Impervious Areas	98	1.925	188.65
Recently Regraded	77	27	2079
Total		**70.3**	**3839**
CN*	**54.6**		

The parameters in Table 4.8 were input into each storm event and the performance evaluation was completed to verify the suitability if the final catchment parameters.

Note that the Linear Reservoir 2 Initial Discharge parameters were taken from Table 4.7 for the model validation simulations in Section 4.7.1. The initial elevations were also kept at the observed elevation at the start of the simulation run for each different storm event.

4.7.1 Model Verification and Performance Analysis

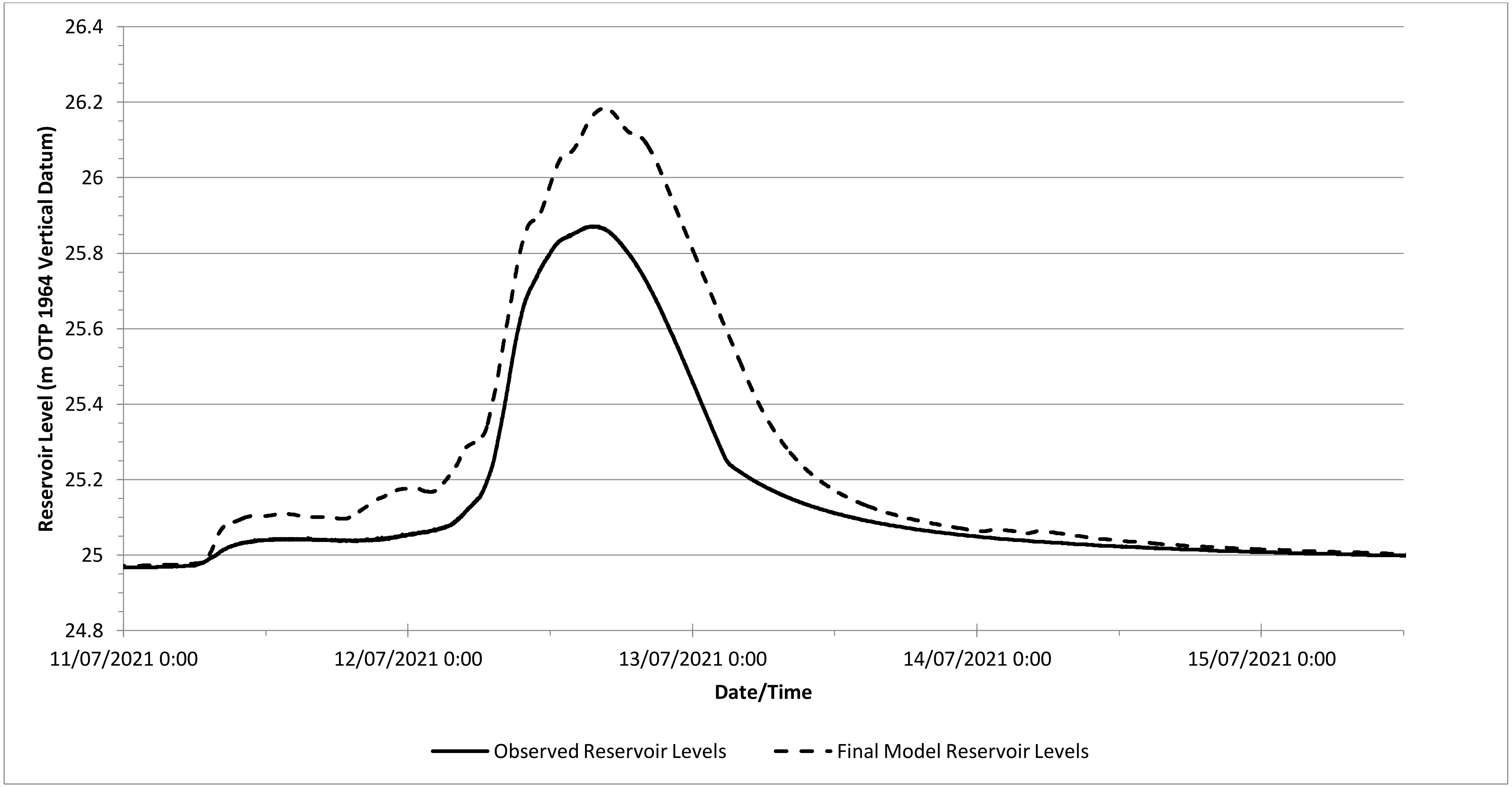


Figure 4. 18. Final Model Reservoir Levels vs Observed Reservoir Levels for the 12th July Storm Event

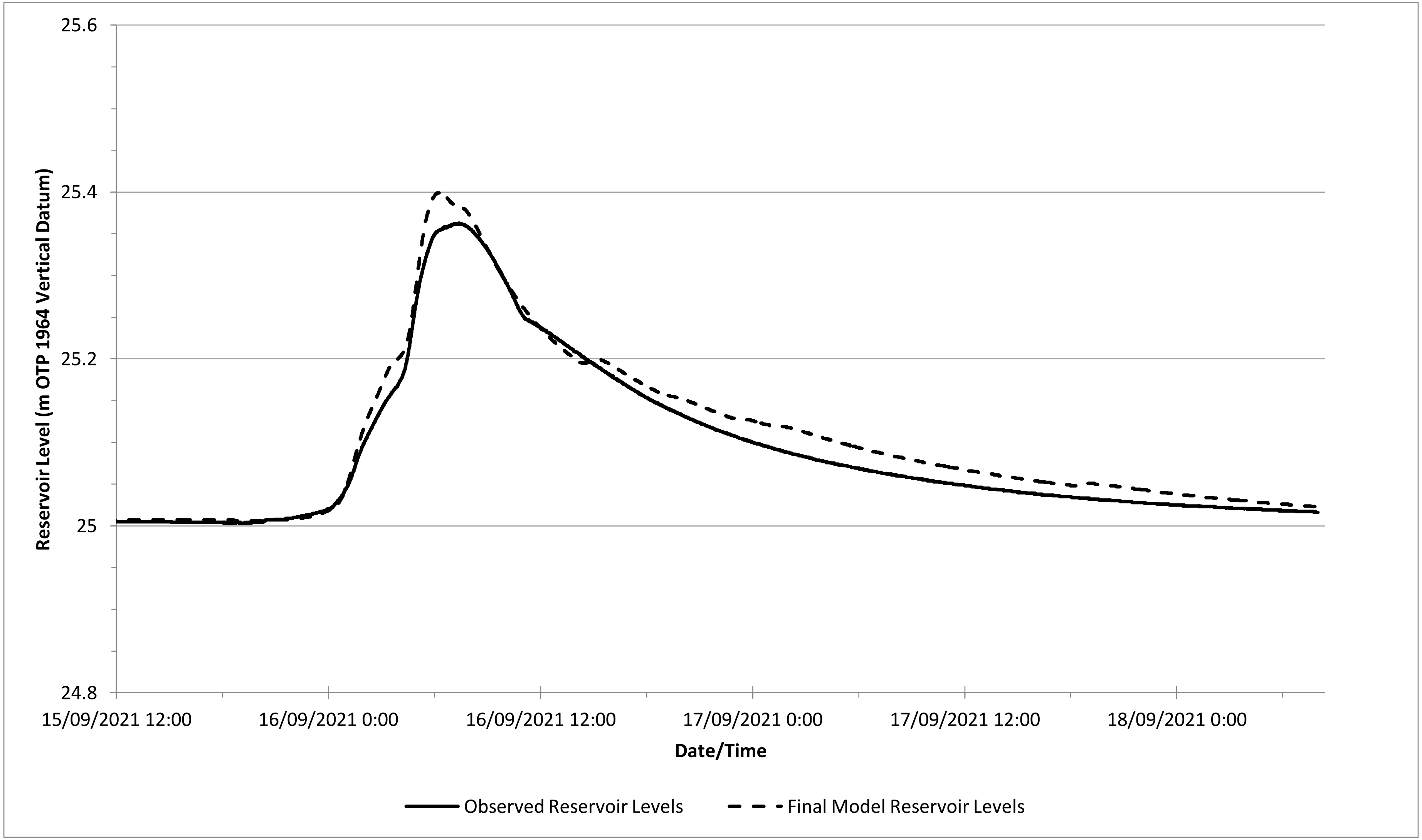


Figure 4. 19. Final Model Reservoir Levels vs Observed Reservoir Levels for the 16th September Storm Event

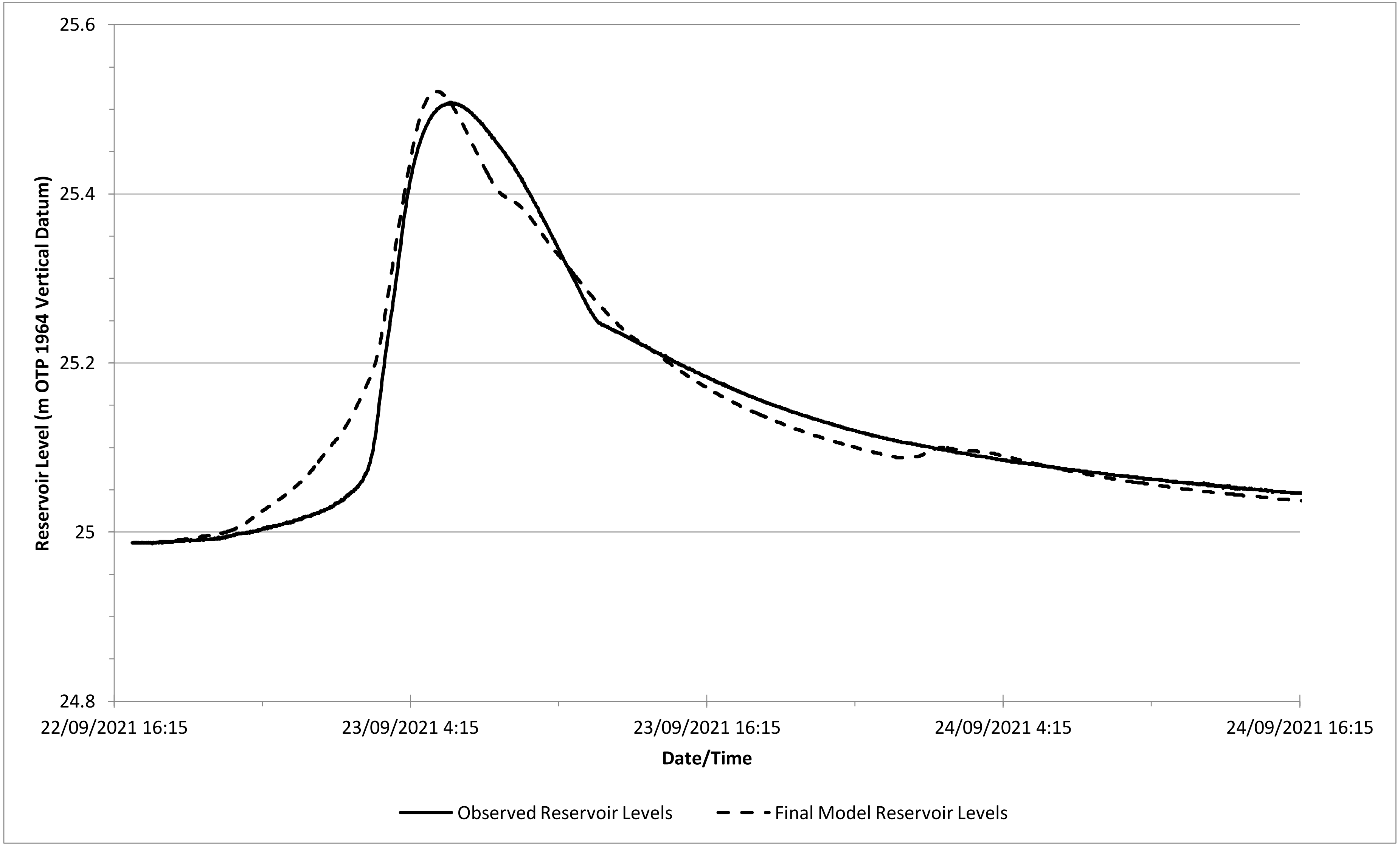


Figure 4. 20. Final Model Reservoir Levels vs Observed Reservoir Levels for the 23rd September Storm Event

Table 4. 11: Final Parameter Performance Evaluation

Parameter	Storm Event		
	12th July	**16th September**	**23rd September**
% Error in Peak Reservoir Level (%)	34.6	10.3	2.49
RMSE	0.131	0.0126	0.0163
n_t	0.833	5.48	4.27
NSE	0.703	0.976	0.964
Figure 2.19 Index	Acceptable	Very Good	Very Good
Predicted Reservoir Level Peak ≥ Observed Peak	Yes	Yes	Yes
Visual Inspection	Average Fit	Good Fit	Very Good Fit

4.8 1% AEP Simulations

4.8.1 Rainfall Data

The hypothetical storm events for the different scenarios are shown in Figure 4.21 and Figure 4.22. The simulations were run for 5 days to allow observation of the recession of the dam reservoir level after rainfall had stopped. The start date and time was set as the 1st January 2000 at 00:00 AM.

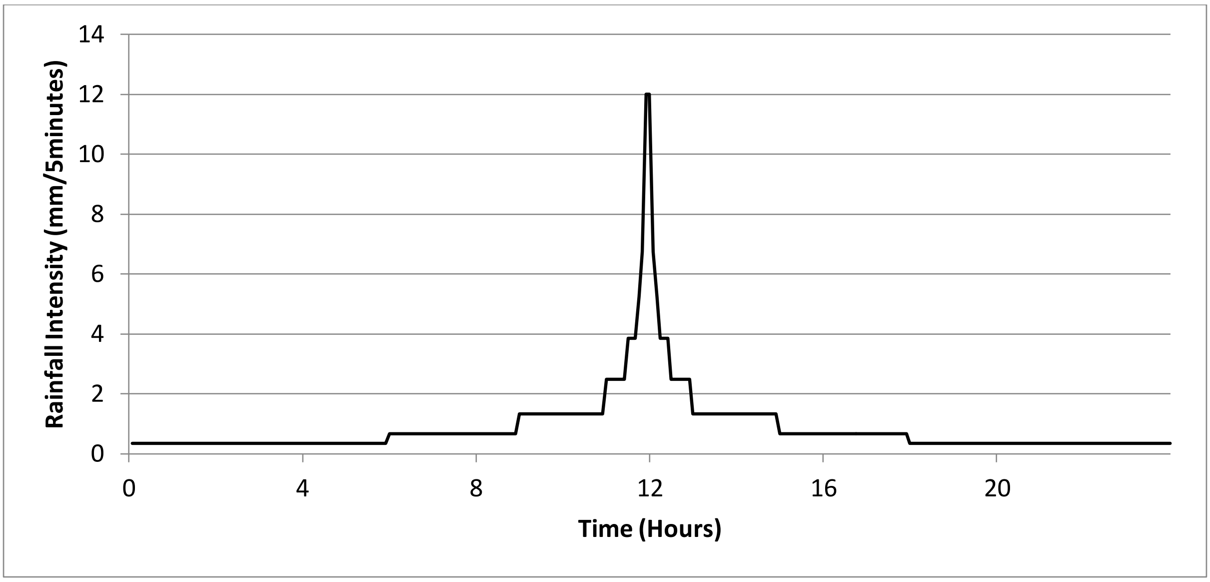


Figure 4. 21. Hypothetical Storm Event based on Historic Rainfall Data

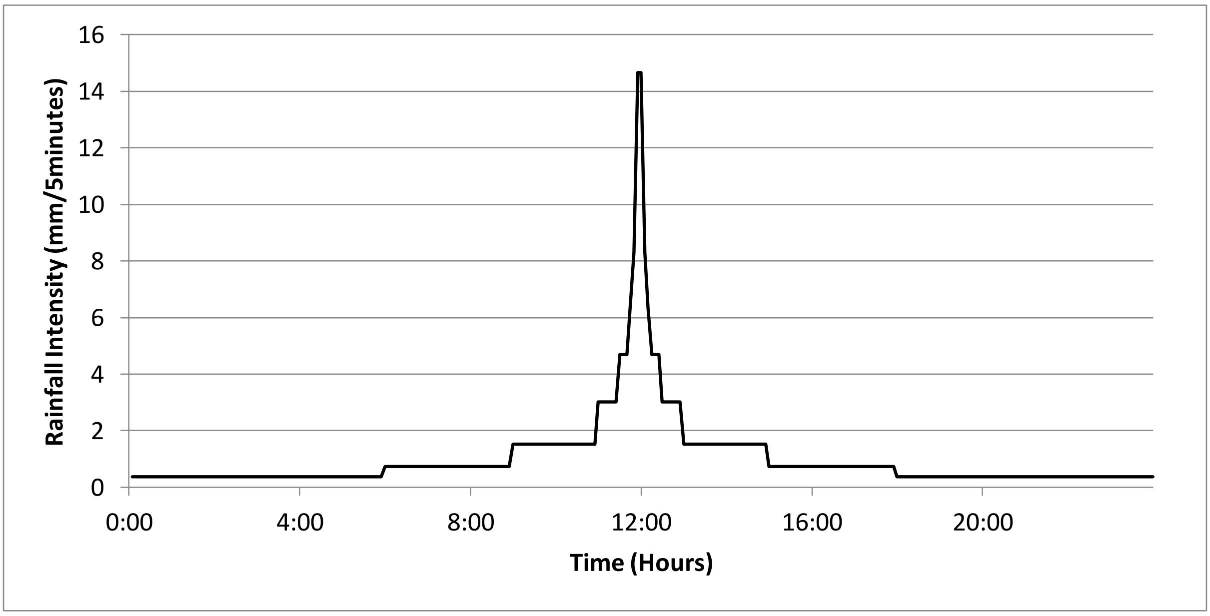


Figure 4. 22. Hypothetical Storm Event based on Climate Change Scenario RCP 6.0 for the Period 2081-2100

4.8.2 1% AEP Model Simulations

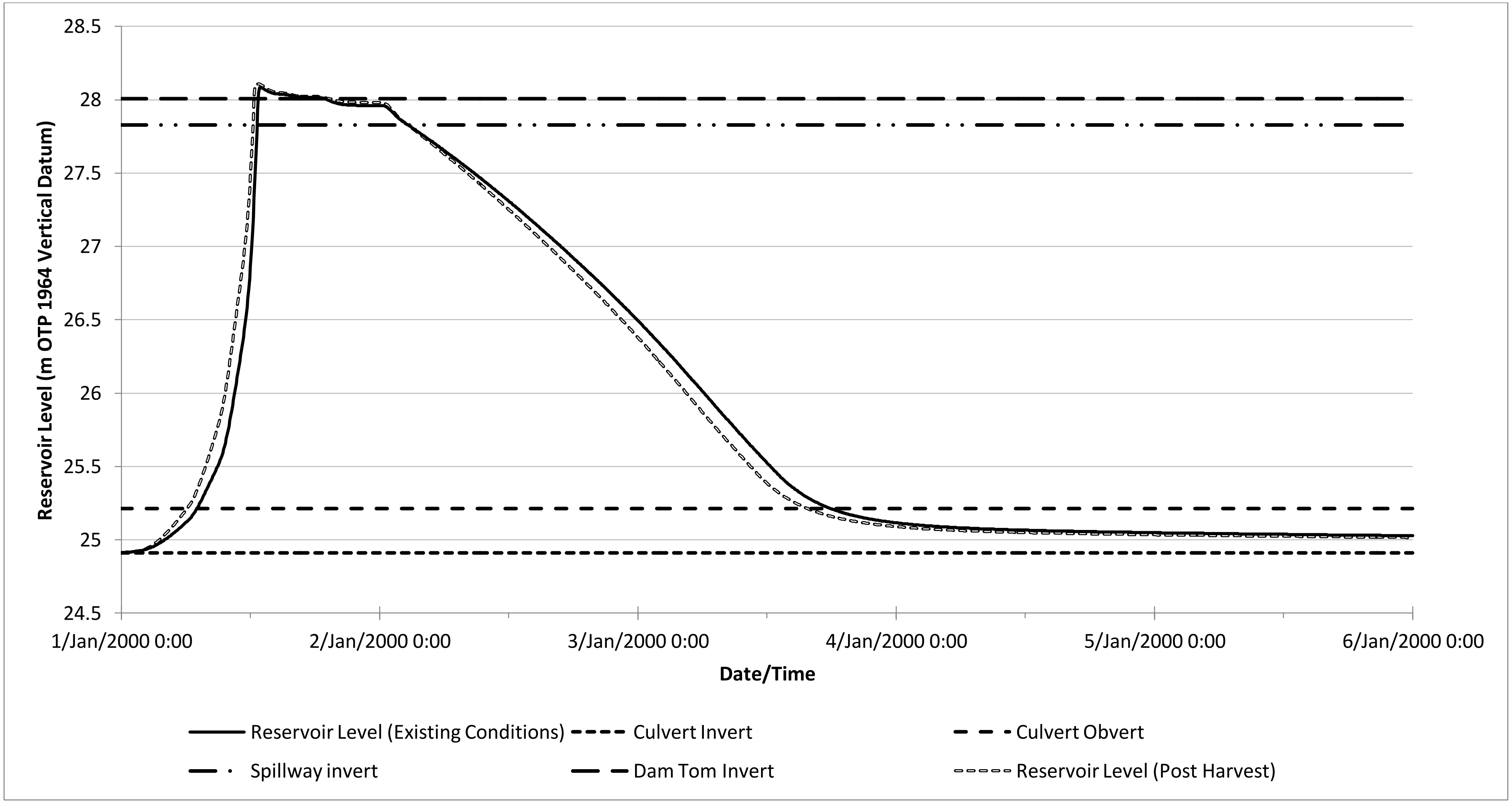


Figure 4. 23. 1% AEP Simulation for Both Cover Conditions using Historic Rainfall Data

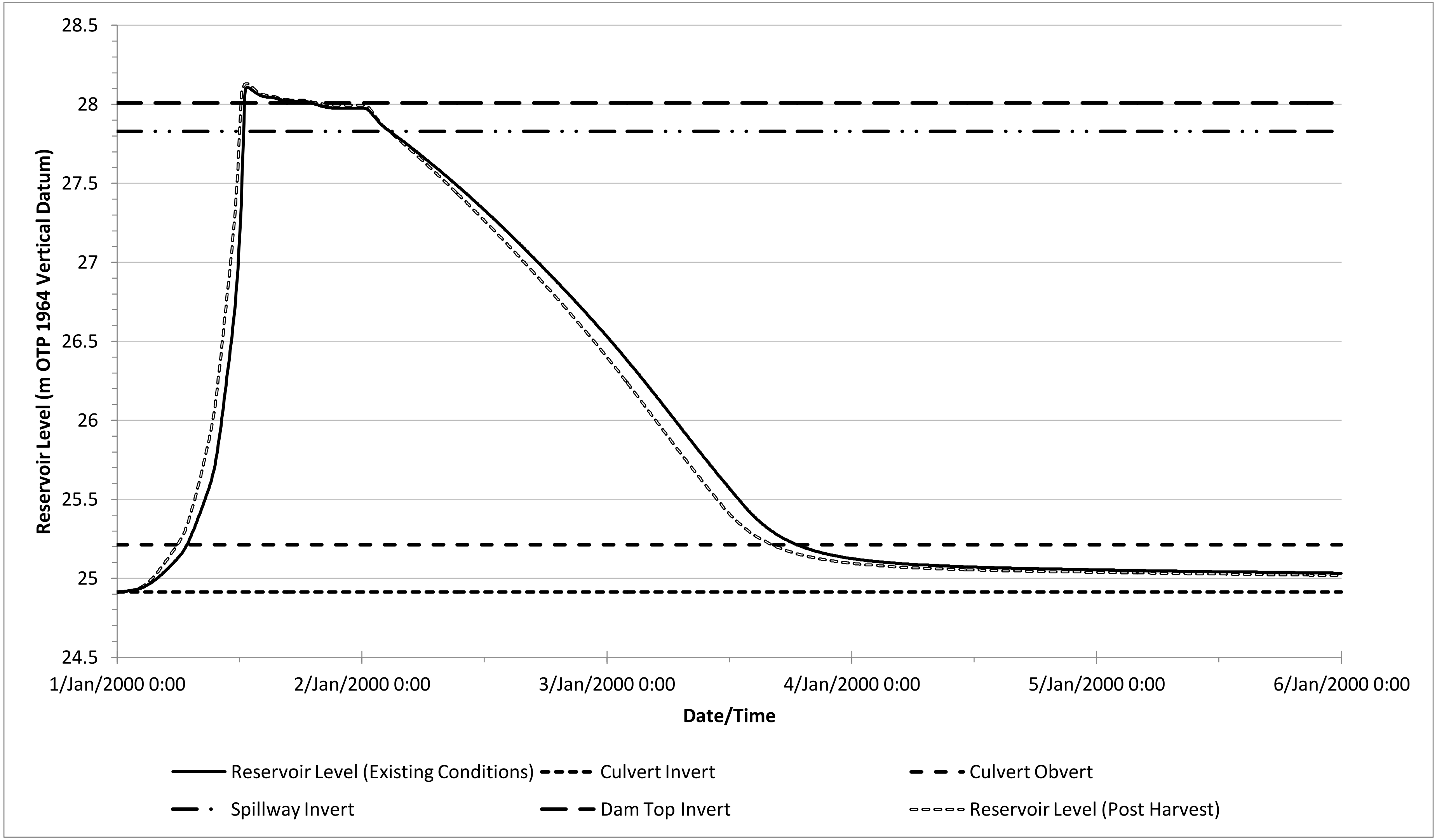


Figure 4. 24. 1% AEP Simulation for Both Cover Conditions and Rainfall with RCP6.0 for the period 2081-2100

Table 4. 12: 1% AEP Simulation Results

Observation	Simulation			
	Historic Rainfall-Existing Conditions	**Historic Rainfall-Post Pine Tree Harvest**	**Climate Change Rainfall-Existing Conditions**	**Climate Change-Post Pine Tree Harvest**
Peak Water Level (m OTP 1964)	28.085	28.109	28.107	28.131
Peak Inflow (m^3/s)	5.616	7.613	7.410	9.844
Peak Outflow (m^3s)	5.415	7.587	7.407	9.814
Breaching Spillway	Yes	Yes	Yes	Yes

5 Discussion

This chapter aims to get an understanding of the results displayed in Section 4. The chapter will discuss the performance of the existing dam and outlets structures for all Modelling scenarios, the appropriateness of using the TP-108 method in Northland along with the appropriateness of gauging catchments to calibrate model parameters and the potential sources of error involved in the project. This chapter also includes a review on the capability of HEC-HMS as free hydrological modelling software.

5.1 Existing Dam and Outlet Performance

The aim of the project was to assess the performance of the existing dam and outlet structures for a number of different scenarios. Based on the calibrated model parameters, the dam and outlet structures are not capable of conveying the 1% AEP hypothetical storm event for existing cover conditions and conditions after the harvesting of pine plantations, for both historic and climate change rainfall scenarios. This is shown in Table 4.12 and Figures 4.23 and 4.24. In all scenarios the spillway is breached, meaning water will flow over the top of the dam with the potential of causing failure. The predicted peak discharges range from 5.415 m^3/s (historic rainfall-existing conditions) to 9.814 m^3/s (climate change-post pine tree harvest).

The original design calculations predicted a peak discharge for a 1% AEP event of 3.12 m^3/s. The spillway was designed for this discharge based on a design flow depth of 0.5m over a length of 4.8544 m. After completing the topographic survey of the dam embankment and spillway, it was observed that the spillway length was only 3.082 m at the invert. It was also observed that there has been significant settlement of the dam top. The north-western end of the dam has a low point that is only 0.179 m above the spillway invert. This means the spillway only has 0.179 m of available flow at a reduced length before the dam over tops. This does not even take into account any impacts from wave run up. It is anticipated that the actual capacity of the spillway is significantly less than the 3.12 m^3/s that it was originally design for.

It is also interesting to compare the predicted peak discharges to the values calculated using the Rational Method in Section 2.9.2. Table 2.16 was used, as 31 minutes was the closest time of concentration to the calibrated final parameter. The Rational method determined the peak flow for existing cover conditions and historic rainfall data as7.9 m^3/s and existing cover and climate change rainfall as 9.6 m^3/s. The calibrated models had the same peak flows at 5.4 m^3/s and 7.4 m/s^3 respectively. It would be interesting to compare the Rational Method peak flow for the same time of concentration as the calibrated models, as they may be very similar.

Based on the Modelling, the dam requires remedial works immediately. The dam is insufficiently designed and constructed and is likely to overtop in a more frequent rainfall event than the 1% AEP it was originally design for.

5.2 Modelling Methods

The SCS curve number method was used in HEC-HMS to model the catchment response to real rainfall data based. The parameters used were determined by the TP-108 method and by calibrated parameters, determined from observed data. The appropriateness of each method and the limitations of the final model parameters are discussed below.

5.2.1 TP-108 Method

The TP-108 method, like the TR55 document it is based off, is aimed at providing a quick and reliable way to calculate the runoff from rainfall. It is empirically based, so the designer using it should be able to complete the analysis without the need for gauged data and specific site testing.

TP-108 Results

The way the TP-108 method was interpreted, based on best judgement from the suggestions and specifications in the document, has largely over predicted runoff and reservoir levels for all rainfall events. This is mainly due to a significantly higher weighted curve number being used, compared to the calibrated models. The TP-108 method was able to predict reasonable time of concentration and initial abstraction values. However, these were observed to fluctuate depending on the soil conditions at the start of the storm event.

TP-108 Soil Groups

The major issue with the TP-108 method is that the soil groups are based on Auckland geological groups. TP-108 clearly specifies that deeply weathered sandstones and mudstones with clay soils are soil group C (ARC 1999, p.8). The project site consisted of the Waipapa Group, which is observed and described as deeply weathered sandstones and mudstones with clay soils. This was contradictory to the calibrated curve numbers which indicate the catchment should be classed as soil group A. This makes it difficult to categorise a soil type into one of the four groups, without completing site specific infiltration testing.

TP-108 Summary

It is reassuring to know that the method is conservative. However, this can also lead to over design or inaccurate design. An example is with the current project. If the TP-108 method was the sole method used to determine the existing dam performance and predict the peak discharge, the cost of the remedial works would be much higher. Another example is if the method was used to size a detention reservoir. The reservoir would be majorly oversized and there would be unnecessary construction costs.

The TP-108 method was not considered appropriate to accurately predict the catchment response without extensive site testing, catchment gauging and regional verification of soil groups.

5.2.2 Calibrated Models

Calibrated models required a large amount of work to obtain the observed data, set up and run the models, then calibrate the parameters and assess the performance. Observations from the results of the calibrated modelling are summarised below.

Antecedent Soil Moisture Conditions

TP-108 specifies that the curve number and initial abstraction should be determined depending on the Antecedent Soil Moisture Condition of the catchment prior to the simulation (ARC 1999, p.7). The initial soil conditions were noticeably dryer prior to the July storm, when compared to the September storms. This could account for the variations in initial abstraction, time of concentration and weighted curve number between the calibrated July event and the calibrated September events. It was observed that the weighted curve number was trending higher as the winter months progressed and the soil conditions were becoming more saturated. This is to be expected, as the potential maximum retention value would be less as the soil is retaining more moisture before the storm begins. It is for this reason that the highest calibrated curve number was adopted in the final parameters. It allows a more conservative runoff prediction, while not majorly over predicting runoff like the TP-108 method.

Base-flow Modelling

The observed water level data was displaying very smooth attenuation behaviour in the catchment and reservoir. It was difficult to get the models to display this behaviour without altering the time of concentration to a very unrealistic value, which also considerably shifted the time of the peak reservoir elevation. It was decided to attempt to replicate the attenuation behaviour using a HEC-HMS base-flow method. The most appropriate method that was adopted for the project was the Linear Reservoir method. This method was difficult to establish consistent parameters for all storm events. This is likely due to the variations in rainfall patterns and intensities between the different storm events as well variations in the antecedent soil moisture conditions. The Linear Reservoir method did help create a better fit for the models and introduce some attenuation behaviour.

It was noted that HEC-HMS provides other modelling methods that can introduce attenuation. These include routing methods for the stream and introducing a number of sub-catchments with varying parameters and time of concentrations. It was decided against adopting these methods as the model was starting to become too complex and acceptable levels of fit were still able to be obtained using the linear reservoir method.

Soil Group

The results indicated that the soil group was more consistent with a group A soil. This was unexpected, based on the author's experience with soils in the Waipapa Group. After the model calibrations, previous work by Jacobson (2019) was reviewed. Jacobson (2019) completed infiltration tests and classified Whangarei soils into the various TR55 soil groups. Whangarei is closer to the project site than Auckland and contains areas consisting of the Waipapa Group. The Waipapa Group tests had infiltration rates greater than 8 mm/hour. This would place the group into soil category A; however, the moderately expansive nature of the silty clay residual soils had the Waipapa Group classed as a Group B soil. This study provides some level of confidence for adopting the final parameters that were chosen.

Unexpected Losses

The main reasons for the high levels of loss occurring in the catchment could be attributed to the following:

- The Waipapa Group is a Group A soil.

- There may be short circuit paths present in the catchment where runoff could be lost to directly recharge the aquifer.
- The catchment could contain large areas of alluvial and colluvial soils that could be retaining a high proportion of the loss.
- The curve number method does not accurately represent losses due to the large areas of canopy and thick forest floor mulch.
- The SCS loss and unit hydrograph method in HEC-HMS are not suitable for catchments of this type and in this region.

Of the reasons presented above, the first two are the most likely based on the rapid rate the reservoir returns to a steady base-flow. This is indicating the loss is actually being lost with only a small proportion contributing to interflow and base-flow. The SCS loss and unit hydrograph method in HEC-HMS was able to achieve acceptable levels of fit and was determined appropriate to model the catchment runoff.

Calibrated Model Summary

Calibrating model parameters based on gauged data is a very appropriate way to predict a catchment response for varying rainfall conditions. This can be seen by the differences between the TP-108 models and the final calibrated models. Although the method is more expensive and time consuming, the cost will be saved in the reduction in remedial works required. On the other hand, if the TP-108 method were to under predict runoff, a more suitable and safer design can be determined based on the more accurate calibrated parameters.

The calibration was able to achieve acceptable levels of fit when modelling all three different storm events with varying rainfall patterns and antecedent soil moisture conditions. The method was determined as a very appropriate method to model catchment hydrology to assess dam performance.

5.2.3 Model Limitations

The project involved modelling the dam catchment using a very simple empirical method with calibrated parameters obtained through gauged data. This means that the parameters that were obtained in the final calibration have been determined without a measured degree of confidence, based on only three rainfall events.

Spatial Data

The model was set up using elevation volume data obtained through LiDAR and a topographic survey. There is error in this data used; therefore, this error translates directly to the elevation volume data used in the models. Despite this potential error, models were still able to achieve similar rates of change in reservoir elevations compared to observed data.

Outlet Discharge

Another major potential source of error in the modelling was the use of HEC-HMS to model the discharge of the outlet structures. There were inconsistencies in the discharge between the observed data and the models. The observed data displayed a distinct point where the rate of change in the reservoir levels decreased, and the culvert was likely becoming unsubmerged. The empirical methods available in HEC-HMS provide a smooth transition at this point, which was not accurate to what is actually occurring.

Gauging Equipment and Data Processing

The equipment used and the processing of the data also introduce an element of potential error. The equipment was monitored for stationarity and accuracy regularly during the course of the project. The accuracies were always in accordance with NEMS standards for the highest quality level. Despite these attempts to minimise the error, the equipment is not monitored continuously and therefore, there could be periods where the equipment is not accurately measuring the data. Errors could also be introduced in the processing stage. The data was modified a number of times, and each time presents the opportunity for human error.

Personal Interpretation

It is likely that interpretations of final calibrated parameters will be different between different modellers and different hydrological modelling methods. This project aimed to keep the modelling methods similar to the methods specified in TP-108. This kept the models simple and allowed a valid comparison between the differences between calibrated and TP-108 models.

Rainfall Distribution

Using only one rain gauge does not accurately represent the spatial distribution of rainfall in the catchment. The model that was used assumes the rainfall recorded at the rain gauge was uniform over the entire catchment. Even though the catchment is relatively small, uniform rainfall distribution is very unlikely.

Despite all the potential errors, the final calibrated models still displayed acceptable levels of fit for all storm events. It is likely the potential errors could be contributing to reasons why the calibrated models are not representing a perfect fit. It should be noted that the potential errors should be considered when any recommendations and parameters are adopted for future work.

5.3 HEC-HMS

HEC-HMS was the main computer software used in the project. It provided a very efficient and user-friendly way to generate the simulations for the different models. It also allowed an easy way to observe the gauged data in conjunction with the modelled results.

The simplicity of the modelling method in HEC-HMS meant the calibration could be achieved manually, as the simulation times did not exceed 30 seconds.

HEC-HMS provides many different methods to transform rainfall into runoff hydrographs and model loss. The software was especially useful for the project as it allows reservoir routing and modelling of the discharge of various outlet structures.

The main issue encountered with HEC-HMS was the poor quality of the result figures. This meant that tabulated results had to be exported to EXCEL, in order to process legible figures to present in the Results Section.

6 Conclusion and Recommendations

6.1 Conclusion

The main focus of this project was to assess the performance on the existing earth embankment dam and outlets structures, based on various rainfall and land cover scenarios.

It was found that the original design used the wrong catchment area. The topographic survey revealed the spillway was smaller than the original design specifications and the dam top had settled, reducing the potential flow depth in the spillway. The combination of these factors indicates that the spillway is undersized.

The regional rainfall runoff method (TP-108) was found to over predict the runoff. Gauged data was obtained to construct calibrated models in HEC-HMS to provide a more accurate representation of the catchment response.

The gauged data indicated that there was considerably more loss occurring in the catchment than anticipated. The loss revealed the soil was behaving more like a group A soil. This was consistent with previous literature, but contradictory to the descriptions from TP-108 and initial judgement.

The final calibrated models had the spillway breach in all 1% AEP rainfall scenarios and cover conditions. This concludes that the dam and outlets structures have insufficient capacity for the required design specifications. Remedial works are required regardless of the proposed change in cover conditions or rainfall data used.

The project highlights the benefits of using gauged data to calibrate catchment parameters. The remedial works are likely to be cheaper whilst also maintaining the required safety of the outlet structures. This method is especially beneficial in smaller ungauged catchments where regional parameters have not been validated.

6.2 Recommendations

This project demonstrates a procedure to assess the performance of an existing dam and outlet structures using gauged data to calibrate HEC-HMS hydrological models.

The methodology used in this project allowed a successful calibration of the catchment parameters, despite the limitations presented in Section 5.2.3. In order to reduce the limitations that were identified, the following recommendations should be included in the methodology of similar projects. These recommendations are also suggested as future work to validate the results for the current project:

- Complete infiltration testing throughout the catchment to verify the soil type.
- Obtain high level topographic survey data over the entire reservoir flood area to obtain more accurate elevation volume data.
- Monitor the culvert outlet discharge for various reservoir levels and create an accurate discharge rating curve for culvert outlets.
- Set up rain gauges in more than one location to check the spatial distribution of rainfall.
- Obtain a total of at least six significant rainfall events to use for calibration.
- Verify results by adopting a second rainfall runoff modelling method.

6.2.1 Further Research

The outcomes of the project have identified the need for further research to improve hydrological modelling in the Far North District, New Zealand. The following items are suggested as future research in the area:

- There were contradictions between TP-108 soil group descriptions and actual soil infiltration rates. Further research could be conducted in the region, which categorises soils of different geological groups into one of the four soil types.

- Other TP-108 empirical formulas for time of concentration and specifications for the initial abstraction and curve numbers could be validated based on other gauged catchments in the region.

- It would be interesting to construct another modelling method like a rain on grid model in HEC-RAS to calibrate parameters and compare the 1% AEP simulations.

- The catchment gauging has provided a large amount of data. This data could be used for other areas of research. One in particular could include looking at the rainfall distribution and patterns in the area. This would likely require continual monitoring in the catchment, but it could potentially provide information on a more realistic 1% AEP event.

- Only three rainfall events were used in the current model to calibrate the parameters. It is likely this is not enough to be confident the model can predict runoff over a range of rainfall and catchment conditions. Further research could assess the number of events, or quality of the data that is required to obtain calibrated parameters that accurately represent the catchment behaviour, over a range of different rainfall durations/intensities.
- The SCS Curve Number Method based on TR55 provided a simple and easy to use method to model runoff. It may be possible that other simple rainfall runoff methods and unit hydrographs provide better predictions for the Far North District catchments. Further research could look into comparing rainfall runoff predictions from various methods to assess the most appropriate one for the region.

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Appendix A – Project Specification

ENG4111/4112 Research Project

Project Specification

For: Callum Smith

Title: Predictions for the Hydrological Performance of the Parua Stream Dam.

Major: Civil Engineering

Supervisors: Joseph Foley (USQ), Ben Perry (Technical Advisor)

Enrollment: ENG4111 – EXT S1, 2021

ENG4112 – EXT S2, 2021

Project Aim: The aim of the project is to assess the performance of the existing dam and outlet structures using calibrated HEC-HMS model parameters, determined from measured rainfall and water level data for existing land cover conditions and conditions after the harvesting of forestry blocks.

Programme: Version 3, 21st August 2021

1. Research NZ standards on gauging a stream in a catchment and recording rainfall.
2. Review currently available data logging equipment and choose the most accurate devices for the project.
3. Set up devices and design a monitoring program for collection of data and determine a elevation-storage relationship for the reservoir.
4. Research empirical methods for estimating catchment response to rainfall events.
5. Create a model for the catchment using the SCS method with TP108 Method in HEC-HMS.
6. Analyse raw data and identify catchment parameters in response to rainfall events.
7. Calibrate the HEC-HMS model to achieve the best fit to observed reservoir levels for a number of the larger rainfall events.
8. Run a calibrated model for the 1% AEP storm for existing cover conditions and post tree harvesting with the final calibrated parameters.
9. Evaluate the performance of the dam based on the 1% AEP models.

10. Evaluate the appropriateness of TP-108 and the SCS curve number method to model the dam catchment and the appropriateness of calibrating model parameters to get a better prediction of the change in reservoir elevation in response to rainfall.

If time and resources permit;

11. Make recommendations on the correct initial abstraction and other catchment parameters that should be used in similar NZ catchments.

Appendix B – Risk Management Plan

University of Southern Queensland

USQ Safety Risk Management System

Read Only View

Close

Develop as new RMP

Version 2.0

Safety Risk Management Plan

Risk Management Plan ID:	*Status:*	Current User:	Author:	Supervisor:	Approver:
RMP_2021_6073	*Approve*	[redacted]	[redacted]	[redacted]	[redacted]

Assessment Title:	Project Progress Report (Callum Smith)	Assessment Date:	27/09/2021
Workplace (Division/Faculty/Section):	204060 - School of Civil Engineering and Surveying	Review Date:	(5 years maximum)

Approver:	*Supervisor: (for notification of Risk Assessment only)*
Joseph Foley;	*Joseph Foley;*

Context

DESCRIPTION:

What is the task/event/purchase/project/procedure?	Catchment Analysis		
Why is it being conducted?	Engineering Research Project		
Where is it being conducted?	Matauri Bay, New Zealand		
Course code (if applicable)	ENG4111	Chemical Name (if applicable)	

WHAT ARE THE NOMINAL CONDITIONS?

Personnel involved	Callum Smith, VISION Consulting Engineering
Equipment	Rain Gauge and Water Level Sensors
Environment	Rural and coastal outdoors
Other	
Briefly explain the procedure/process	setting up and monitoring rain gauges and water level sensor, collecting data and analysing catchment response

Assessment Team - who is conducting the assessment?

Assessor(s):	Joseph Foley
Others consulted: (eg elected health and safety representative, other personnel exposed to risks)	*Ben Perry (Employer)*

Risk Matrix

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injury $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	**M**	**H**	**E**	**E**	**E**
Likely 1 in 100	**M**	**H**	**H**	**E**	**E**
Possible 1 in 1,000	**L**	**M**	**H**	**H**	**H**
Unlikely 1 in 10,000	**L**	**L**	**M**	**M**	**M**
Rare 1 in 1,000,000	**L**	**L**	**L**	**L**	**L**

Recommended Action Guide

Extreme:	**E**= Extreme Risk – Task ***MUST NOT*** proceed
High:	**H** = High Risk – Special Procedures Required (Contact USQSafe) Approval by VC only
Medium:	**M**= Medium Risk - A Risk Management Plan/Safe Work Method Statement is required
Low:	**L**= Low Risk - Manage by routine procedures.

Risk Register and Analysis

	Step 1	*Step 2*	*Step 2a*	*Step 2b*	*Step 3*			*Step 4*				
	Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional Controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:*** Has the consequence or probability changed?			
					Probability	*Risk Level*	*ALARP*		*Consequence*	*Probability*	*Risk Level*	*ALARP*
	Example											

	Working in temperatures over 35^0 C	*Heat stress/heat stroke/exhaustion leading to serious personal injury/death*	*catastrophic*	*Regular breaks, chilled water available, loose clothing, fatigue management policy.*	*possible*	*high*	*No*	*temporary shade shelters, essential tasks only, close supervision, buddy system*	*catastrophic*	*unlikely*	*mod*	*Yes*	
1	Working near water	Cold, wet, hypothermia	Major	Wear appropriate clothing, avoid entering water, take spare dry clothes	Unlike	Med...	☐	Communicate with office when alone and working near water	Major	Rare	Low	☑	
2	Property owner cancels project	Unforeseen conflict or issue with owner	Major	Ensure communication is regular and owner understands what is happening	Unlike	Med...	☑					☐	
3	Sheep on property	potential to eat cables, bump equipment rendering data unusable as stationarity is comprimised	Minor	Farm manager to keep sheep out of dam area	Likely	High	☐	communicate with farmer about sheep movement	Minor	Unlik	Low	☑	
4	Waves in reservoir	Cause fluctuation in sensor readings from localised wind	Minor	None currently in place	Almos	High	☐	Fix sensor to a PCv tube to prevent impact of waves due to wind	Minor	Unlik	Low	☑	
5	Floating debris in reservoir	Sensor becomes displaced rendering data useless	Minor	None currently in place	Likely	High	☐	Fix sensor to PVC pipe and then to warratahs to fix in place	Minor	Unlik	Low	☑	
6	Severe weather event	Reservoir overtops dam causing failure destroying equipment and reason for project	Major	Monitor weather and removed equipment if necessary	Rare	Low	☑					☐	
7	Loss of data	Accidental deletion, server crash or equipment malfunction loosing data	Minor	Server back up	Unlike	Low	☐	Take care to save data in multiple drives	Minor	Rare	Low	☑	
8	Equipment failure	Equipment breaks or stops working, missing rain events, loosing money and time	Moderate	Ensure equipment is good quality and set up correctly	Unlike	Med...	☐	Perform regular site visits to check equipment	Moder	Rare	Low	☑	

9	Loss of employment	Loose job and loose access to equipment and project	Moderate	Communicate with employer to ensure performance goals are met	Rare	Low	☑					☐	
10	Unable to establish communicatio n with supervisor	Not receiving communication and feedback from supervisor resulting in taking wrong direction and wasting time	Minor	Make sure I send reports and progress to supervisor.	Unlike	Low	☑					☐	
11	Insufficient weather events	Not enough rainfall events in the project time frame to generate conclusive results	Minor	Place equipment in the winter when rainfall events are more frequent and severe	Possib	Med...	☑					☐	
12	Vandalism to equipment	Intentional damage to the equipment resulting in a loss on money and project interruption	Moderate	Place equipment on private property	Rare	Low	☑		Moder			☑	
13	Cuts, scraps, strains, bruises	Setting up equipment, monitoring equipment and site visits in a rural setting resulting in scratches, trips etc	Minor	wear PPE and avoid visiting in bad weather conditions	Unlike	Low	☑					☐	
14	Unable to gain access to resources	Licensing or cost restraints to access resources required to complete project	Minor	Most resources already acquired	Unlike	Low	☑					☐	
15	Cannot process data	No results	Moderate	Ensure time is spent learning the software and equipment processes.	Rare	Low	☑					☐	

Step 5 - Action Plan (for controls not already in place)

	Additional Controls:	*Exclude from Action Plan: (repeated control)*	*Resources:*	*Persons Responsible:*	*Proposed Implementation Date:*
1	Communicate with office when alone and working near water	☐	Phone	Callum Smith	27/05/2021
3	communicate with farmer about sheep movement	☐	Timber posts, wire netting, phone	Callum Smith	11/06/2021
4	Fix sensor to a PCv tube to prevent impact of waves due to wind	☑			
5	Fix sensor to PVC pipe and then to warratahs to fix in place	☐	PVC pipe 500mm, 3 1200mm warratahs, treated timber pegs, 100mmx 50mm timber 6m long	Callum Smith	11/06/2021
7	Take care to save data in multiple drives	☐	USB, external harddrive	Callum Smith	27/05/2021
8	Perform regular site visits to check equipment	☐	Camera, GPS	Callum Smith	11/06/2021

Supporting Attachments

View Attachments

Click here to attach a file

Step 6 – Request Approval

Drafters Name:	*Callum Smith*	*Draft Date:*	*27/09/2021*
Drafters Comments:			

Assessment Approval: **All risks are marked as ALARP** 0

Maximum Residual Risk Level: **Medium - Cat 4 delegate or above Approval Required** 2

Document Status:	*Approve*

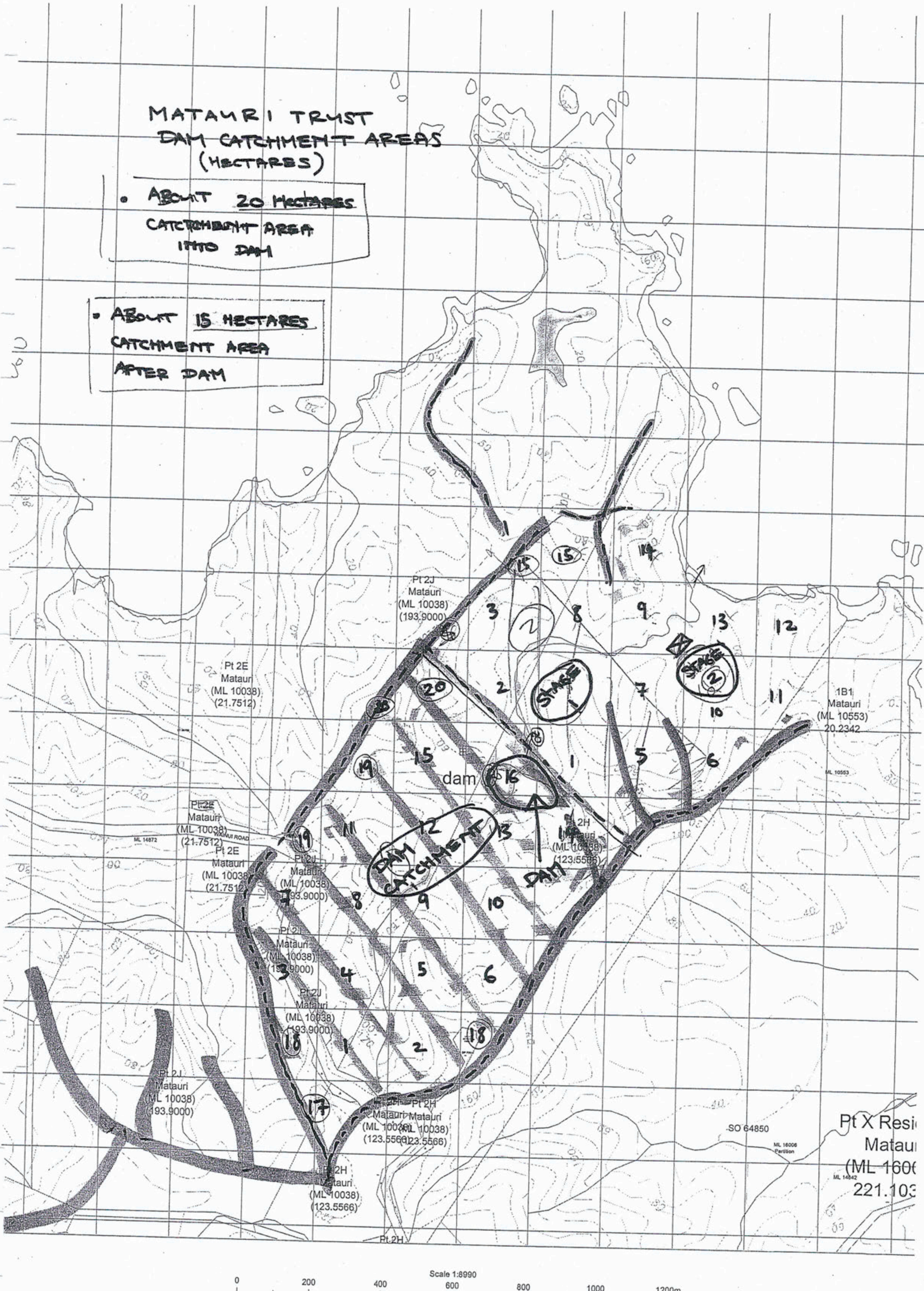
Step 6 – Approval

Approvers Name:	*Joseph Foley*	*Approvers Position Title:*	
Approvers Comments:			

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

Approval Decision:	*Approve*	*Approve / Reject Date:*	*27/09/2021*	*Document Status:*	*Approve*

Appendix C – Original Dam Design Documents



MATAURI TRUST
DAM CATCHMENT AREAS
(HECTARES)
• ABOUT 20 HECTARES
CATCHMENT AREA
INTO DAM
• ABOUT 15 HECTARES
CATCHMENT AREA
AFTER DAM
Pt 2J
Matauri
(ML 10038)
(193.9000)
Pt 2E
Matauri
(ML 10038)
(21.7512)
STAGE 1
STAGE 2
1B1
Matauri
(ML 10553)
20.2342
dam
DAM CATCHMENT
DAM
Pt 2H
Matauri
(ML 10038)
(123.5566)
SO 64850
Pt X Resi
Matau
(ML 160
221.103
Pt 2H
Scale 1:8990
0
200
400
600
800
1000
1200m

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Job No.	
Page No.	
Made by: J van Ameringen	Date:

Matauri Trust Dam Project

10 Year Storm Flow Rates

Dam area catchment area $= 20(\text{hectares}) \times 10{,}000(m^2) = 200{,}000(m^2)$

$$Q = \frac{C\,I\,A}{360}$$

$C = 0.40$ (Runoff co-efficient)

$I = 87\,(mm/hr)$ (Ten year storm rainfall intensity)

$A = 20,\ 6.5,\ 8.5$ (hectares)

$$Q = \frac{0.4 \times 87 \times 20}{360} = 1.9333$$
$$= 1.9\ m^3/s$$ (Dam catchment area flowrate)

$$Q = \frac{0.4 \times 87 \times 6.5}{360} = 0.6283$$
$$= 0.6\ m^3/s$$ (1st stage watercoarse flowrate)

$$Q = \frac{0.4 \times 87 \times 8.5}{360} = 0.8216$$
$$= 0.8\ m^3/s$$ (2nd stage watercoarse flowrate)

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Matauri Trust Dam Project

100 Year Storm Flow Rates

Dam area catchment area = 20 (hectares) x 10,000 (m^2) = 200,000 (m^2)

$$Q = \frac{CIA}{360}$$

C = 0.4

I = 140.4 (mm/hr) (100 year storm rainfall intensity)

A = 20, 6.5, 8.5 (hectares)

$$Q = \frac{0.4 \times 140.4 \times 20}{360} = 3.12\ m^3/s$$ (Dam catchment area flowrate)

$$Q = \frac{0.4 \times 140.4 \times 6.5}{360} = 1.014$$
$$= 1.0\ m^3/s$$ (1st stage watercourse flowrate)

$$Q = \frac{0.4 \times 140.4 \times 8.5}{360} = 1.326$$
$$= 1.3\ m^3/s$$ (2nd stage watercourse flowrate)

Matauri Trust Dam Project

Total dam water retention volume = 9000 m^3
Working dam water volume = 6000 m^3

10 Year Storm Catchment volume for 10 minutes

$1.9 \times 60 \times 10 = 1140\ m^3$ (Dam catchment area water volume)

$0.6 \times 60 \times 10 = 360\ m^3$ (1st stage watercoarse area water volume)

$0.8 \times 60 \times 10 = 480\ m^3$ (2nd stage watercoarse area water volume)

$6000\ m^3 + 1140\ m^3 = 7,140\ m^3$ (Approximate 10 year storm dam water volume)

100 Year Storm Catchment Volume (for 10 minutes)

$3.12 \times 60 \times 10 = 1872\ m^3$ (Dam catchment area water volume)

$1.0 \times 60 \times 10 = 600\ m^3$ (1st stage watercoarse area water volume)

$1.3 \times 60 \times 10 = 780\ m^3$ (2nd stage watercoarse area water volume)

$6000\ m^3 + 1872\ m = 7872\ m^3$ (Approximate 100 year storm dam water volume)

Existing Natural
Watercoarse channel

tmp#35.txt

Channel Calculator

Given Input Data:

```
     Shape ...........................  Trapezoidal
     Solving for .....................  Flowrate
     Slope ...........................  0.0200 m/m
     Manning's n .....................  0.0280
     Depth ...........................  0.5000 m
     Height ..........................  0.6000 m
     Bottom width ....................  0.3330 m
     Left slope ......................  1.0000 m/m (V/H)
     Right slope .....................  1.0000 m/m (V/H)
```

Computed Results:

```
     Flowrate ........................  0.8088 cms
     Velocity ........................  1.9419 mps
     Full Flowrate ...................  1.1979 cms
     Flow area .......................  0.4165 m2
     Flow perimeter ..................  1.7472 m
     Hydraulic radius ................  0.2384 m
     Top width .......................  1.3330 m
     Area ............................  0.5598 m2
     Perimeter .......................  2.0301 m
     Percent full ....................  83.3333 %
```

← Amount of water (approx) Existing natural watercoarse can cope with.

Critical Information

```
     Critical depth ..................  0.5262 m
     Critical slope ..................  0.0161 m/m
     Critical velocity ...............  1.7889 mps
     Critical area ...................  0.4521 m2
     Critical perimeter ..............  1.8213 m
     Critical hydraulic radius .......  0.2482 m
     Critical top width ..............  1.3854 m
     Specific energy .................  0.6923 m
     Minimum energy ..................  0.7893 m
     Froude number ...................  1.1094
     Flow condition ..................  Supercritical
```

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Matauri Trust Dam Project

Channel water Coarse Flow Capacity

Shape	Trapazoidal
Slope	0.200 m/m
Mannings no	0.0280
Depth	0.5000 m
Height	0.6000 m
Bottom width	0.3330 m
Left Slope	1.0000 m/m (V/H)
Right slope	1.0000 m/m (V/H)
Flow rate	0.8088 cms 0.81 m^3/s
Velocity	1.9419 mps

1st stage water coarse flowrates for 10 year storm (10 min) 0.6 m^3/s

Water Coarse can handle 0.81 m^3/s

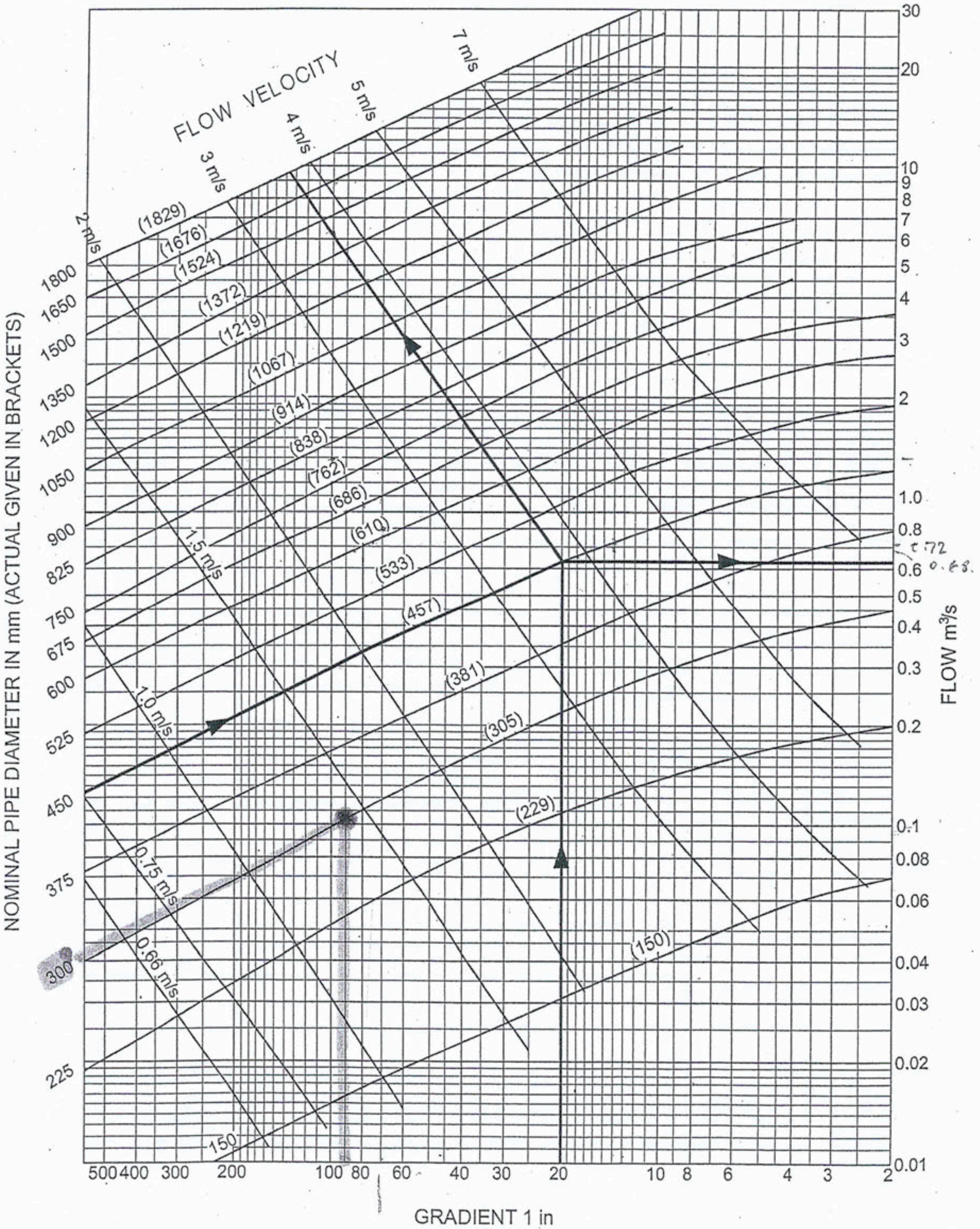
$0.81 - 0.6 = \boxed{0.21\ m^3/s}$ of potential flowrate

The damwater level pipe 300 ϕ at a 1.11% (1 in 90) gradient 0.10365 m^3/s, Velocity 1.47 m/s

$0.21 - 0.10 = 0.11\ m^3/s$ of excess flow rate

Figure **3: Pipe flow relationships for different combinations of internal diameter, velocity and gradient**

(Based on Manning's formula using n = 0.013 with an allowance for air entrainment)
Paragraphs 2.3.4 and 3.2.1



Example: A 450 internal diameter pipe with a gradient of 1 in 20 will have a flow of 0.63 m³/s at a velocity of 3.75 m/s

3m Dam Pipe Outlet Capacity ← Discharge Rate of 300 ∅ pipe when full

300 ∅ pipe @ 1 in 90 gradient = 103.19 l/s

$= 0.103 \text{ m}^3/\text{s}$

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3m Dam Water Pipe Outlet Volumes

300 ø pipe @ 1 in 90 gradient = 103.19 L/s
= 0.103 m^3/s

Water Discharge Volumes through 300 ø Pipe

0.103 × 60 × 60 × 1	= 371.0 m^3	(1 hour)	(9,371) m^3
0.103 × 60 × 60 × 6	= 2,225.0 m^3	(6 hours)	(11,225) m^3
0.103 × 60 × 60 × 12	= 4,450.0 m^3	(12 hours)	(13,450) m^3
0.103 × 60 × 60 × 24	= 8,899.0 m^3	(24 hours)	(17,899) m^3

(Pipe Flow Rate) (hours) Pipe dishcharge volume + 9000 m^3 Dam retention volume =

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Matamiri Trust Dam Project

Dam Spillway Design

$$Q = 0.57 (2g)^{1/2} \left(2/3 L h^{3/2} + 8/15 Z h^{5/2} \right)$$

where

Q = discharge through spillway

L = horizontal bottom width of spillway

h = depth of flow at design flow

Z = horizontal / vertical side slope

g = gravity (9.81)

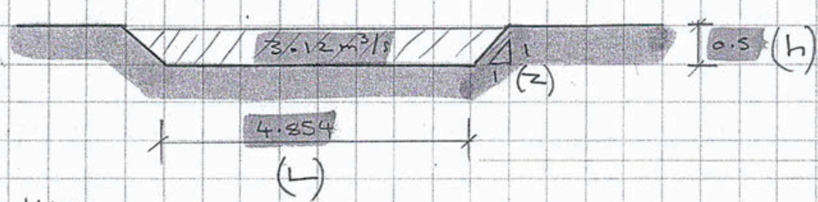
$$Q = 0.57 (19.62)^{1/2} \left(2/3 L \times 0.5^{2/3} + 8/15 \times 1 \times 0.5^{5/2} \right)$$

$$Q = 0.57 \times \sqrt{19.62} \times \left(2/3 \times L \times 0.5^{3/2} + 8/15 \times 1 \times 0.5^{5/2} \right)$$

$$\frac{\left(\left(\frac{Q}{0.57 \times \sqrt{2g}} \right) - \left(\frac{8}{15} \times Z h^{5/2} \right) \right)}{\left(\frac{2}{3} h^{3/2} \right)} = L$$

$$\frac{\left(\frac{3.12}{0.57 \times \sqrt{19.62}} \right) - \left(\frac{8}{15} \times 1 \times 0.5^{5/2} \right)}{\left(2/3 \; 0.5^{3/2} \right)} = L$$

$$\frac{(1.235 - 0.0942)}{0.235} = L = 4.8544 \text{ m}$$



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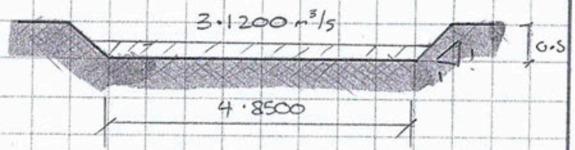
Matauri Trust Dam Project

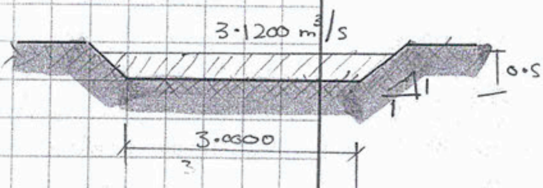
4·85m Wide Spillway Channel

		Concrete channel
Flowrate	cms	3·1200
Slope	m/m	0·1250 (1 in 8 gradient)
Mannings no.		0·0130
Flow Depth	m	0·1060
Height	m	0·5000
Bottom Width	m	4·8500
Left Slope	V/H	1·0000
Right Slope	V/H	1·0000
Velocity	mps	5·9383



3·00m Wide Spillway Channel

		Concrete Channel	Channel with Large Rocks
Flowrate	cms	3·1200	3·1200
Slope	m/m	0·1250	0·1250 (1 in 8 gradient)
Mannings no.		0·0130	0·0400
Flow Depth	m	0·1417	0·2782
Height	m	0·5000	0·5000
Bottom Width	m	3·0000	3·000
Left Slope	V/H	1·0000	1·0000
Right Slope	V/H	1·0000	1·0000
Velocity	mps	7·0106	3·4214



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Dam Retention Capabilities (in hours)

$$I = \frac{(371 + 9000) \times 1000)}{200{,}000 \times 0.5}$$

$= 93.7$ mm in 1 hour 150 year + event

$$I = \frac{(2225 + 9000) \times 1000}{200{,}000 \times 0.5}$$

$= 112.3$ mm in 6 hours 1 in 40 year event

$$I = \frac{(4{,}450 + 9000) \times 1000}{200{,}000 \times 0.5}$$

$= 134.5$ mm in 12 hours 1 in 20 year event

$$I = \frac{(8{,}990 + 1000) \times 1000}{200{,}000 \times 0.5}$$

$= 179.0$ mm in 24 hours 1 in 20 year event

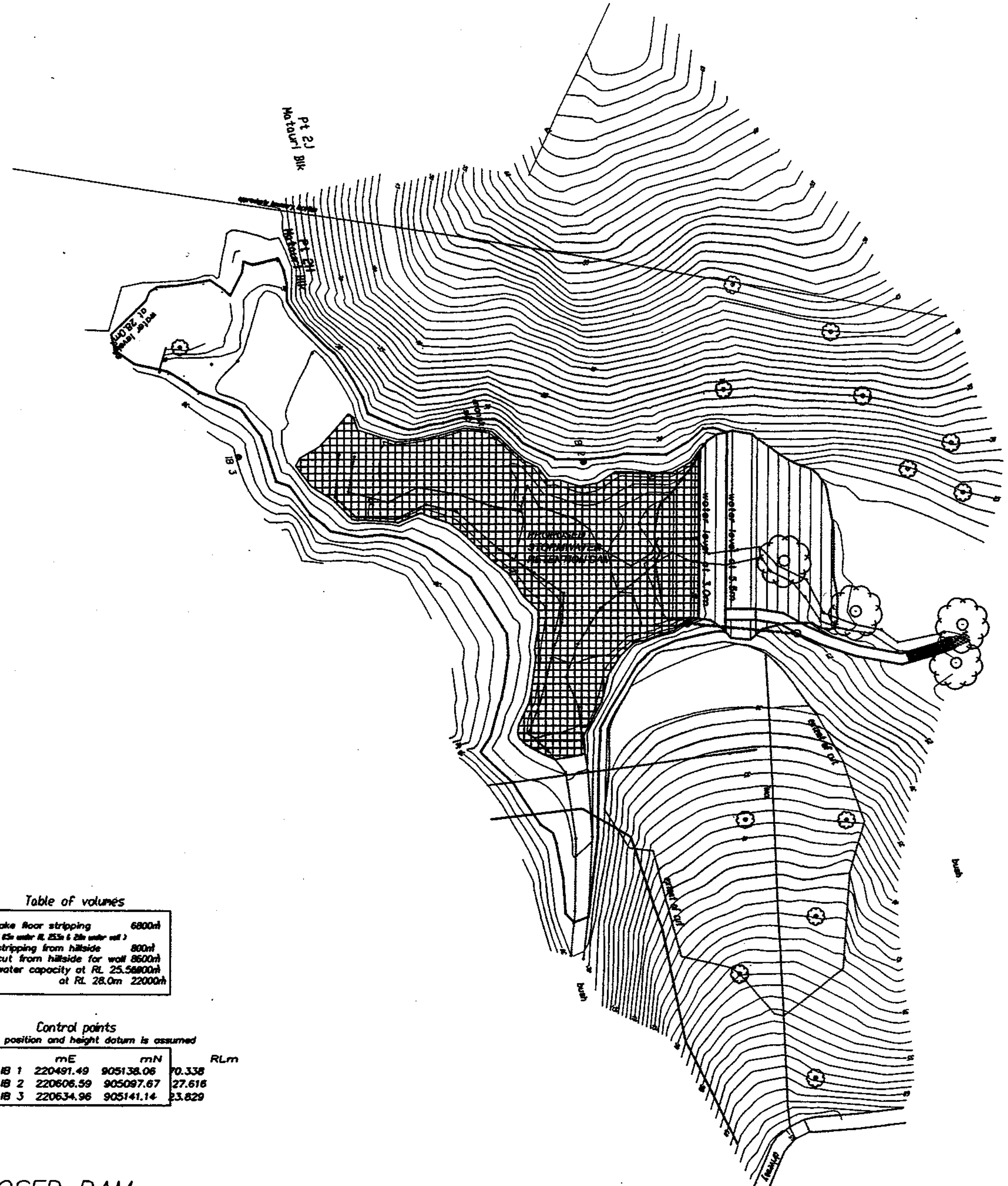

Table of volumes

lake floor stripping	6800m³
(85m under RL 25.5m & 28m under wall)	
stripping from hillside	800m³
cut from hillside for wall	8600m³
water capacity at RL 25.5	6800m³
at RL 28.0m	22000m³

Control points
position and height datum is assumed

	mE	mN	RLm
IB 1	220491.49	905138.06	70.338
IB 2	220606.59	905097.67	27.616
IB 3	220634.96	905141.14	23.829

PLAN OF PROPOSED DAM

Scale 1:1500 @ A3

No.	Revisions	Date	Appvd

Designed	–	Date	Print Date
Drawn	JVA	19/07	
Checked			
Approved			
Scale 1:1500 @ A3		Ref –	

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Matauri Trust

Project
Stormwater Retention Dam

Sheet Title
Proposed Dam Plan

Job No.	Sheet No.	Revision
	1/4 of shts	–

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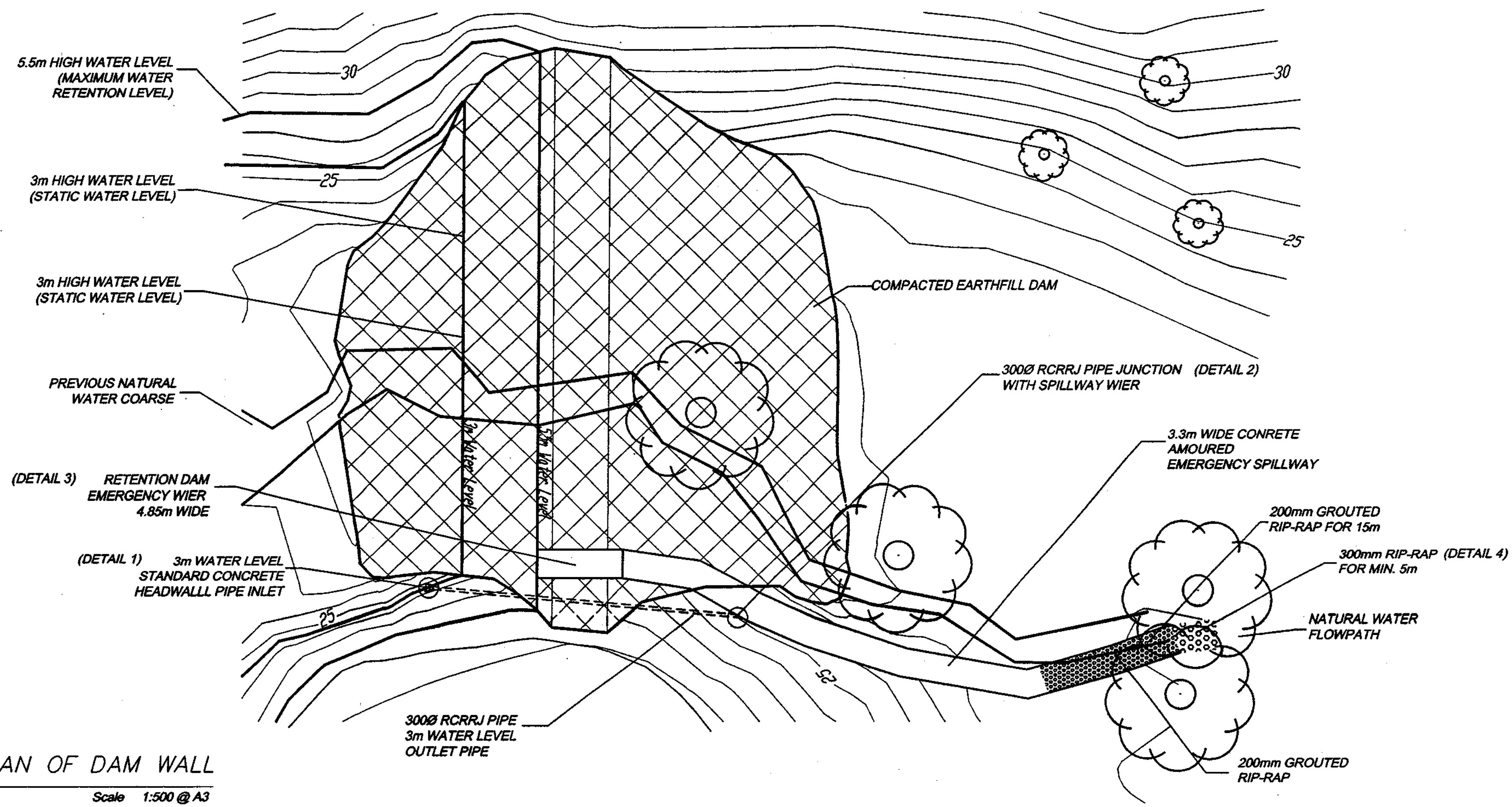
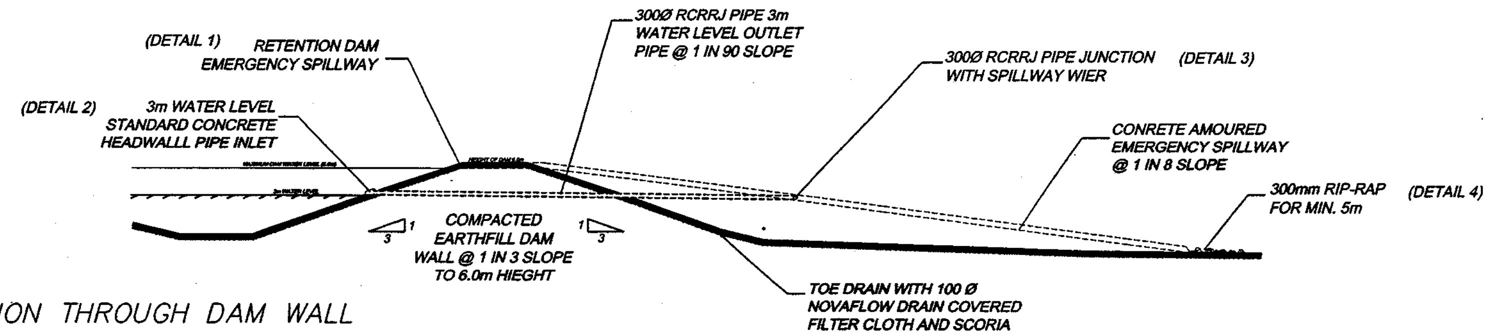


PLAN OF DAM WALL

Scale 1:500 @ A3



GENERAL SECTION THROUGH DAM WALL

Scale 1:500 @ A3

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Sheet Title: Plan of Dam Wall & Section through Dam Wall

Job No. | Sheet No. 2/4 of shts | Revision –

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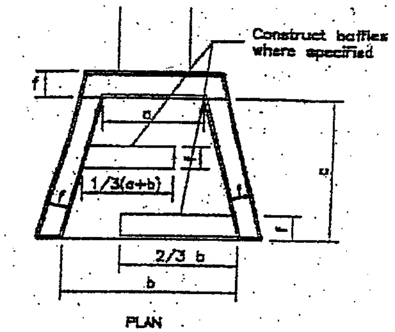
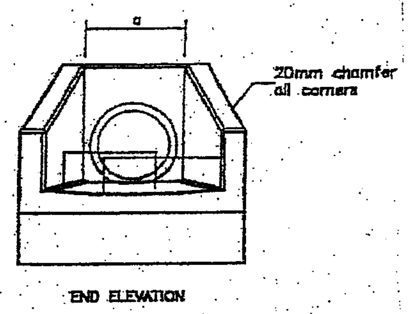
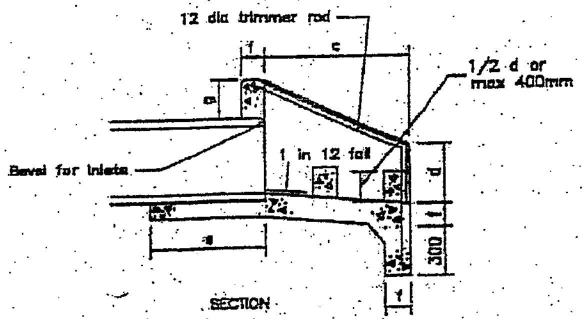


PLAN



END ELEVATION



SECTION

PRINCIPAL DIMENSIONS (mm)							
DIA OF PIPE	a	b	c C	d D	e E	f F	g G
150	300	450	600	200	325	100	150
230	380	600	700	250	425	100	150
300	450	750	750	300	525	100	150
375	550	900	850	350	625	100	150
450	630	1100	900	400	725	150	230
525	700	1200	1000	450	825	150	230
600	800	1400	1100	550	900	150	230
750	1000	1700	1200	600	1050	150	300
900	1170	2000	1450	650	1225	150	300
1050	1380	2300	1700	750	1375	150	300
1200	1520	2600	2100	750	1550	150	450
1350	1680	2800	2400	750	1725	150	450

A. Sec y x (a)
B. C Tan (y + 20°) + [A−C Tan(y − 20°)]
H. C x Sec (y + 20°)
J. C x Sec (y − 20°)

NOTES

1. Reinforce floors & walls with:

150 — 375	665 mesh
450 — 600	533 mesh or D10 rods at 250 crs.
675 — 900	D12 rods at 250 crs.
1050 — 1350	D12 rods at 150 crs.

All reinforcement shall be placed centrally in walls and floor,and shall be continuous between walls and floor.

2. These structures are subject to the approval of the Northland Regional Council.

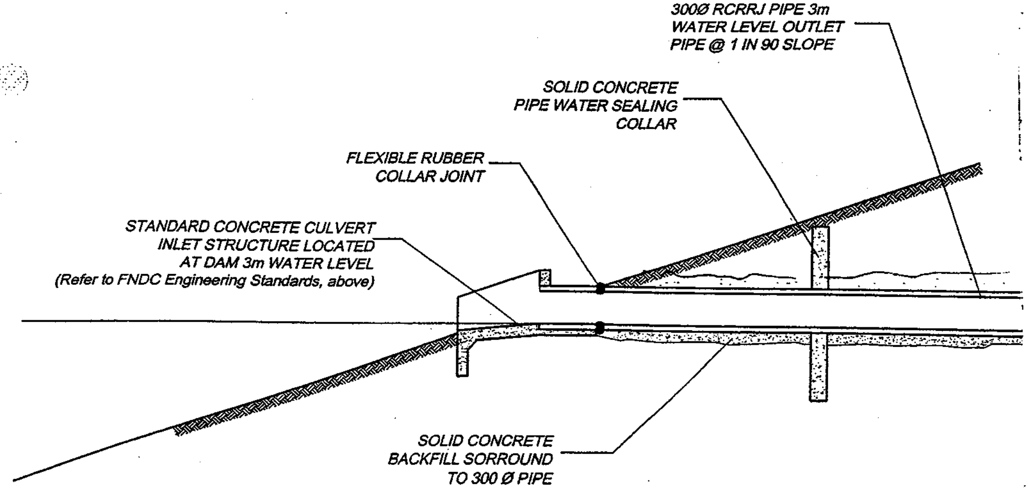
3. Laps in structural grade bars to be 300 min.

4. There shall be at least 2 bars in each direction over the top of the pipe.

5. Concrete shall be high or special in accordance with NZS 3104, constructed in accordance with NZS 3109.

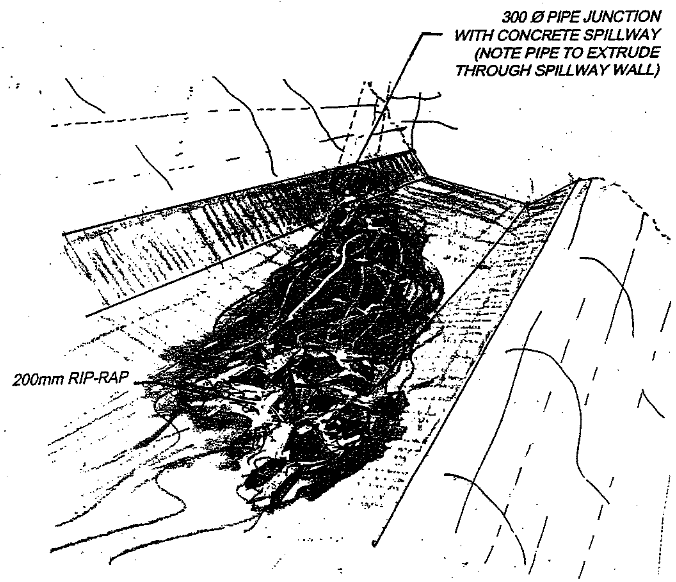
6. Baffles shall be constructed as shown when outlet velocities and soil conditions dictate, in extreme cases specific design may be required by the Council.

7. Inlet structures shall have reverse apron fall and no baffles.



STANDARD CONCRETE PIPE INLET

(DETAIL 1)



300 Ø PIPE SPILLWAY JUNCTION

(DETAIL 2)

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Project: Stormwater Retention Dam

Sheet Title: 300 Ø PIPE INLET & SPILLWAY JUNCTION

Job No.	Sheet No.	Revision
	3/4	—

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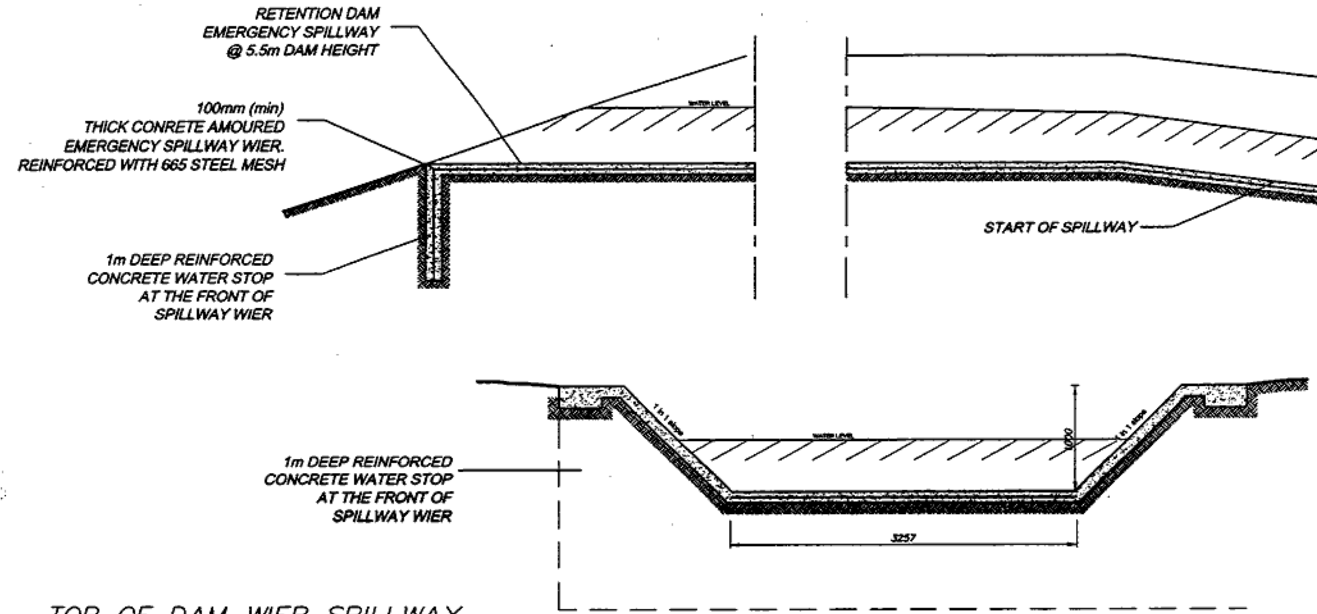
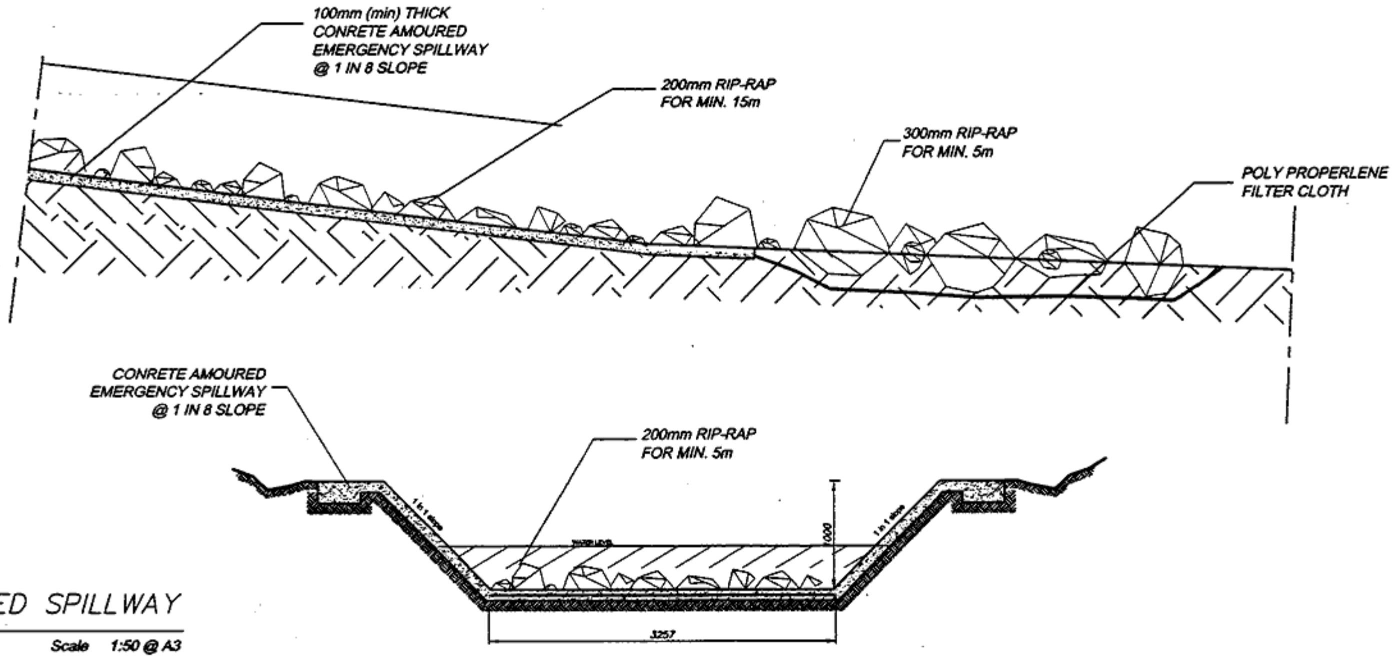


TOP OF DAM WIER SPILLWAY

(DETAIL 3) Scale 1:50 @ A3



CONCRETE RIP-RAPPED SPILLWAY

(DETAIL 4) Scale 1:50 @ A3

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Client
Matauri Trust

Project
Storrmwater Retention Dam

Sheet Title
Concrete Wier & Spillway Details

Job No. | Sheet No. 4/4 | Revision –

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Appendix D – Topographic Plan, Elevations and Spatial Data

Reservoir Elevation Volume Data

Table D. 1: Stage Storage Data for Reservoir Surface

Elevation (m OPT)	Contour Area (m^2)	Contour Interval (m)	Change in Volume (m^3)	Cumulative Volume (m^3)	Cumulative Volume ($1000m^3$ for HEC-HMS)
24.894	3296.99	N/A	N/A	0	0
24.9	3308	0.006	19.81	19.81	0.01981
24.91	3326.555	0.01	33.172775	52.982775	0.052982775
24.92	3345.11	0.01	33.358325	86.3411	0.0863411
24.93	3363.975	0.01	33.545425	119.886525	0.119886525
24.94	3382.84	0.01	33.734075	153.6206	0.1536206
24.95	3402.015	0.01	33.924275	187.544875	0.187544875
24.96	3421.19	0.01	34.116025	221.6609	0.2216609
24.97	3440.67	0.01	34.3093	255.9702	0.2559702
24.98	3460.15	0.01	34.5041	290.4743	0.2904743
24.99	3479.94	0.01	34.70045	325.17475	0.32517475
25	3499.73	0.01	34.89835	360.0731	0.3600731
25.01	3515.665	0.01	35.076975	395.150075	0.395150075
25.02	3531.6	0.01	35.236325	430.3864	0.4303864
25.03	3547.845	0.01	35.397225	465.783625	0.465783625
25.04	3564.09	0.01	35.559675	501.3433	0.5013433
25.05	3580.655	0.01	35.723725	537.067025	0.537067025
25.06	3597.22	0.01	35.889375	572.9564	0.5729564
25.07	3614.105	0.01	36.056625	609.013025	0.609013025
25.08	3630.99	0.01	36.225475	645.2385	0.6452385
25.09	3648.195	0.01	36.395925	681.634425	0.681634425
25.1	3665.4	0.01	36.567975	718.2024	0.7182024
25.11	3682.92	0.01	36.7416	754.944	0.754944
25.12	3700.44	0.01	36.9168	791.8608	0.7918608
25.13	3718.275	0.01	37.093575	828.954375	0.828954375
25.14	3736.11	0.01	37.271925	866.2263	0.8662263
25.15	3754.265	0.01	37.451875	903.678175	0.903678175
25.16	3772.42	0.01	37.633425	941.3116	0.9413116
25.17	3790.895	0.01	37.816575	979.128175	0.979128175
25.18	3809.37	0.01	38.001325	1017.1295	1.0171295
25.19	3828.16	0.01	38.18765	1055.31715	1.05531715
25.2	3846.95	0.01	38.37555	1093.6927	1.0936927

25.21	3866.06	0.01	38.56505	1132.25775	1.13225775
25.22	3885.17	0.01	38.75615	1171.0139	1.1710139
25.23	3904.595	0.01	38.948825	1209.962725	1.209962725
25.24	3924.02	0.01	39.143075	1249.1058	1.2491058
25.25	3949.06	0.01	39.3654	1288.4712	1.2884712
25.26	3974.1	0.01	39.6158	1328.087	1.328087
25.27	3988.445	0.01	39.812725	1367.899725	1.367899725
25.28	4002.79	0.01	39.956175	1407.8559	1.4078559
25.29	4017.39	0.01	40.1009	1447.9568	1.4479568
25.3	4031.99	0.01	40.2469	1488.2037	1.4882037
25.31	4046.845	0.01	40.394175	1528.597875	1.528597875
25.32	4061.7	0.01	40.542725	1569.1406	1.5691406
25.33	4076.815	0.01	40.692575	1609.833175	1.609833175
25.34	4091.93	0.01	40.843725	1650.6769	1.6506769
25.35	4107.3	0.01	40.99615	1691.67305	1.69167305
25.36	4122.67	0.01	41.14985	1732.8229	1.7328229
25.37	4138.295	0.01	41.304825	1774.127725	1.774127725
25.38	4153.92	0.01	41.461075	1815.5888	1.8155888
25.39	4169.805	0.01	41.618625	1857.207425	1.857207425
25.4	4185.69	0.01	41.777475	1898.9849	1.8989849
25.41	4201.83	0.01	41.9376	1940.9225	1.9409225
25.42	4217.97	0.01	42.099	1983.0215	1.9830215
25.43	4234.365	0.01	42.261675	2025.283175	2.025283175
25.44	4250.76	0.01	42.425625	2067.7088	2.0677088
25.45	4267.41	0.01	42.59085	2110.29965	2.11029965
25.46	4284.06	0.01	42.75735	2153.057	2.153057
25.47	4300.97	0.01	42.92515	2195.98215	2.19598215
25.48	4317.88	0.01	43.09425	2239.0764	2.2390764
25.49	4335.045	0.01	43.264625	2282.341025	2.282341025
25.5	4352.21	0.01	43.436275	2325.7773	2.3257773
25.51	4397.945	0.01	43.750775	2369.528075	2.369528075
25.52	4443.68	0.01	44.208125	2413.7362	2.4137362
25.53	4456.42	0.01	44.5005	2458.2367	2.4582367
25.54	4469.16	0.01	44.6279	2502.8646	2.5028646
25.55	4481.975	0.01	44.755675	2547.620275	2.547620275
25.56	4494.79	0.01	44.883825	2592.5041	2.5925041
25.57	4507.68	0.01	45.01235	2637.51645	2.63751645
25.58	4520.57	0.01	45.14125	2682.6577	2.6826577
25.59	4533.54	0.01	45.27055	2727.92825	2.72792825
25.6	4546.51	0.01	45.40025	2773.3285	2.7733285
25.61	4559.55	0.01	45.5303	2818.8588	2.8188588
25.62	4572.59	0.01	45.6607	2864.5195	2.8645195
25.63	4585.71	0.01	45.7915	2910.311	2.910311
25.64	4598.83	0.01	45.9227	2956.2337	2.9562337
25.65	4612.025	0.01	46.054275	3002.287975	3.002287975

25.66	4625.22	0.01	46.186225	3048.4742	3.0484742
25.67	4638.495	0.01	46.318575	3094.792775	3.094792775
25.68	4651.77	0.01	46.451325	3141.2441	3.1412441
25.69	4665.115	0.01	46.584425	3187.828525	3.187828525
25.7	4678.46	0.01	46.717875	3234.5464	3.2345464
25.71	4691.885	0.01	46.851725	3281.398125	3.281398125
25.72	4705.31	0.01	46.985975	3328.3841	3.3283841
25.73	4718.81	0.01	47.1206	3375.5047	3.3755047
25.74	4732.31	0.01	47.2556	3422.7603	3.4227603
25.75	4765.12	0.01	47.48715	3470.24745	3.47024745
25.76	4797.93	0.01	47.81525	3518.0627	3.5180627
25.77	4811.815	0.01	48.048725	3566.111425	3.566111425
25.78	4825.7	0.01	48.187575	3614.299	3.614299
25.79	4839.83	0.01	48.32765	3662.62665	3.66262665
25.8	4853.96	0.01	48.46895	3711.0956	3.7110956
25.81	4868.335	0.01	48.611475	3759.707075	3.759707075
25.82	4882.71	0.01	48.755225	3808.4623	3.8084623
25.83	4897.34	0.01	48.90025	3857.36255	3.85736255
25.84	4911.97	0.01	49.04655	3906.4091	3.9064091
25.85	4926.845	0.01	49.194075	3955.603175	3.955603175
25.86	4941.72	0.01	49.342825	4004.946	4.004946
25.87	4956.84	0.01	49.4928	4054.4388	4.0544388
25.88	4971.96	0.01	49.644	4104.0828	4.1040828
25.89	4987.335	0.01	49.796475	4153.879275	4.153879275
25.9	5002.71	0.01	49.950225	4203.8295	4.2038295
25.91	5018.33	0.01	50.1052	4253.9347	4.2539347
25.92	5033.95	0.01	50.2614	4304.1961	4.3041961
25.93	5049.82	0.01	50.41885	4354.61495	4.35461495
25.94	5065.69	0.01	50.57755	4405.1925	4.4051925
25.95	5081.805	0.01	50.737475	4455.929975	4.455929975
25.96	5097.92	0.01	50.898625	4506.8286	4.5068286
25.97	5114.285	0.01	51.061025	4557.889625	4.557889625
25.98	5130.65	0.01	51.224675	4609.1143	4.6091143
25.99	5147.265	0.01	51.389575	4660.503875	4.660503875
26	5163.88	0.01	51.555725	4712.0596	4.7120596
26.01	5244.11	0.01	52.03995	4764.09955	4.76409955
26.02	5324.34	0.01	52.84225	4816.9418	4.8169418
26.03	5343.615	0.01	53.339775	4870.281575	4.870281575
26.04	5362.89	0.01	53.532525	4923.8141	4.9238141
26.05	5382.42	0.01	53.72655	4977.54065	4.97754065
26.06	5401.95	0.01	53.92185	5031.4625	5.0314625
26.07	5421.72	0.01	54.11835	5085.58085	5.08558085
26.08	5441.49	0.01	54.31605	5139.8969	5.1398969
26.09	5461.515	0.01	54.515025	5194.411925	5.194411925
26.1	5481.54	0.01	54.715275	5249.1272	5.2491272

26.11	5501.805	0.01	54.916725	5304.043925	5.304043925
26.12	5522.07	0.01	55.119375	5359.1633	5.3591633
26.13	5542.585	0.01	55.323275	5414.486575	5.414486575
26.14	5563.1	0.01	55.528425	5470.015	5.470015
26.15	5583.865	0.01	55.734825	5525.749825	5.525749825
26.16	5604.63	0.01	55.942475	5581.6923	5.5816923
26.17	5625.64	0.01	56.15135	5637.84365	5.63784365
26.18	5646.65	0.01	56.36145	5694.2051	5.6942051
26.19	5667.905	0.01	56.572775	5750.777875	5.750777875
26.2	5689.16	0.01	56.785325	5807.5632	5.8075632
26.21	5710.665	0.01	56.999125	5864.562325	5.864562325
26.22	5732.17	0.01	57.214175	5921.7765	5.9217765
26.23	5753.92	0.01	57.43045	5979.20695	5.97920695
26.24	5775.67	0.01	57.64795	6036.8549	6.0368549
26.25	5899.445	0.01	58.375575	6095.230475	6.095230475
26.26	6023.22	0.01	59.613325	6154.8438	6.1548438
26.27	6051.13	0.01	60.37175	6215.21555	6.21521555
26.28	6079.04	0.01	60.65085	6275.8664	6.2758664
26.29	6107.03	0.01	60.93035	6336.79675	6.33679675
26.3	6135.02	0.01	61.21025	6398.007	6.398007
26.31	6163.08	0.01	61.4905	6459.4975	6.4594975
26.32	6191.14	0.01	61.7711	6521.2686	6.5212686
26.33	6219.28	0.01	62.0521	6583.3207	6.5833207
26.34	6247.42	0.01	62.3335	6645.6542	6.6456542
26.35	6275.635	0.01	62.615275	6708.269475	6.708269475
26.36	6303.85	0.01	62.897425	6771.1669	6.7711669
26.37	6332.135	0.01	63.179925	6834.346825	6.834346825
26.38	6360.42	0.01	63.462775	6897.8096	6.8978096
26.39	6388.785	0.01	63.746025	6961.555625	6.961555625
26.4	6417.15	0.01	64.029675	7025.5853	7.0255853
26.41	6445.59	0.01	64.3137	7089.899	7.089899
26.42	6474.03	0.01	64.5981	7154.4971	7.1544971
26.43	6502.545	0.01	64.882875	7219.379975	7.219379975
26.44	6531.06	0.01	65.168025	7284.548	7.284548
26.45	6559.65	0.01	65.45355	7350.00155	7.35000155
26.46	6588.24	0.01	65.73945	7415.741	7.415741
26.47	6616.91	0.01	66.02575	7481.76675	7.48176675
26.48	6645.58	0.01	66.31245	7548.0792	7.5480792
26.49	6674.32	0.01	66.5995	7614.6787	7.6146787
26.5	6703.06	0.01	66.8869	7681.5656	7.6815656
26.51	6817.705	0.01	67.603825	7749.169425	7.749169425
26.52	6932.35	0.01	68.750275	7817.9197	7.8179197
26.53	6960.78	0.01	69.46565	7887.38535	7.88738535
26.54	6989.21	0.01	69.74995	7957.1353	7.9571353
26.55	7017.775	0.01	70.034925	8027.170225	8.027170225

26.56	7046.34	0.01	70.320575	8097.4908	8.0974908
26.57	7075.035	0.01	70.606875	8168.097675	8.168097675
26.58	7103.73	0.01	70.893825	8238.9915	8.2389915
26.59	7132.555	0.01	71.181425	8310.172925	8.310172925
26.6	7161.38	0.01	71.469675	8381.6426	8.3816426
26.61	7190.335	0.01	71.758575	8453.401175	8.453401175
26.62	7219.29	0.01	72.048125	8525.4493	8.5254493
26.63	7248.38	0.01	72.33835	8597.78765	8.59778765
26.64	7277.47	0.01	72.62925	8670.4169	8.6704169
26.65	7306.69	0.01	72.9208	8743.3377	8.7433377
26.66	7335.91	0.01	73.213	8816.5507	8.8165507
26.67	7365.265	0.01	73.505875	8890.056575	8.890056575
26.68	7394.62	0.01	73.799425	8963.856	8.963856
26.69	7424.105	0.01	74.093625	9037.949625	9.037949625
26.7	7453.59	0.01	74.388475	9112.3381	9.1123381
26.71	7483.205	0.01	74.683975	9187.022075	9.187022075
26.72	7512.82	0.01	74.980125	9262.0022	9.2620022
26.73	7542.565	0.01	75.276925	9337.279125	9.337279125
26.74	7572.31	0.01	75.574375	9412.8535	9.4128535
26.75	7684.135	0.01	76.282225	9489.135725	9.489135725
26.76	7795.96	0.01	77.400475	9566.5362	9.5665362
26.77	7817.795	0.01	78.068775	9644.604975	9.644604975
26.78	7839.63	0.01	78.287125	9722.8921	9.7228921
26.79	7861.47	0.01	78.5055	9801.3976	9.8013976
26.8	7883.31	0.01	78.7239	9880.1215	9.8801215
26.81	7905.155	0.01	78.942325	9959.063825	9.959063825
26.82	7927	0.01	79.160775	10038.2246	10.0382246
26.83	7948.845	0.01	79.379225	10117.60383	10.11760383
26.84	7970.69	0.01	79.597675	10197.2015	10.1972015
26.85	7992.535	0.01	79.816125	10277.01763	10.27701763
26.86	8014.38	0.01	80.034575	10357.0522	10.3570522
26.87	8036.23	0.01	80.25305	10437.30525	10.43730525
26.88	8058.08	0.01	80.47155	10517.7768	10.5177768
26.89	8079.93	0.01	80.69005	10598.46685	10.59846685
26.9	8101.78	0.01	80.90855	10679.3754	10.6793754
26.91	8123.635	0.01	81.127075	10760.50248	10.76050248
26.92	8145.49	0.01	81.345625	10841.8481	10.8418481
26.93	8167.345	0.01	81.564175	10923.41228	10.92341228
26.94	8189.2	0.01	81.782725	11005.195	11.005195
26.95	8211.06	0.01	82.0013	11087.1963	11.0871963
26.96	8232.92	0.01	82.2199	11169.4162	11.1694162
26.97	8254.78	0.01	82.4385	11251.8547	11.2518547
26.98	8276.64	0.01	82.6571	11334.5118	11.3345118
26.99	8298.505	0.01	82.875725	11417.38753	11.41738753
27	8320.37	0.01	83.094375	11500.4819	11.5004819

27.01	8403.07	0.01	83.6172	11584.0991	11.5840991
27.02	8485.77	0.01	84.4442	11668.5433	11.6685433
27.03	8506.17	0.01	84.9597	11753.503	11.753503
27.04	8526.57	0.01	85.1637	11838.6667	11.8386667
27.05	8547.01	0.01	85.3679	11924.0346	11.9240346
27.06	8567.45	0.01	85.5723	12009.6069	12.0096069
27.07	8587.935	0.01	85.776925	12095.38383	12.09538383
27.08	8608.42	0.01	85.981775	12181.3656	12.1813656
27.09	8628.95	0.01	86.18685	12267.55245	12.26755245
27.1	8649.48	0.01	86.39215	12353.9446	12.3539446
27.11	8670.05	0.01	86.59765	12440.54225	12.44054225
27.12	8690.62	0.01	86.80335	12527.3456	12.5273456
27.13	8711.235	0.01	87.009275	12614.35488	12.61435488
27.14	8731.85	0.01	87.215425	12701.5703	12.7015703
27.15	8752.505	0.01	87.421775	12788.99208	12.78899208
27.16	8773.16	0.01	87.628325	12876.6204	12.8766204
27.17	8793.86	0.01	87.8351	12964.4555	12.9644555
27.18	8814.56	0.01	88.0421	13052.4976	13.0524976
27.19	8835.3	0.01	88.2493	13140.7469	13.1407469
27.2	8856.04	0.01	88.4567	13229.2036	13.2292036
27.21	8876.825	0.01	88.664325	13317.86793	13.31786793
27.22	8897.61	0.01	88.872175	13406.7401	13.4067401
27.23	8918.44	0.01	89.08025	13495.82035	13.49582035
27.24	8939.27	0.01	89.28855	13585.1089	13.5851089
27.25	9022.68	0.01	89.80975	13674.91865	13.67491865
27.26	9106.09	0.01	90.64385	13765.5625	13.7655625
27.27	9128.28	0.01	91.17185	13856.73435	13.85673435
27.28	9150.47	0.01	91.39375	13948.1281	13.9481281
27.29	9172.685	0.01	91.615775	14039.74388	14.03974388
27.3	9194.9	0.01	91.837925	14131.5818	14.1315818
27.31	9217.13	0.01	92.06015	14223.64195	14.22364195
27.32	9239.36	0.01	92.28245	14315.9244	14.3159244
27.33	9261.62	0.01	92.5049	14408.4293	14.4084293
27.34	9283.88	0.01	92.7275	14501.1568	14.5011568
27.35	9306.155	0.01	92.950175	14594.10698	14.59410698
27.36	9328.43	0.01	93.172925	14687.2799	14.6872799
27.37	9350.73	0.01	93.3958	14780.6757	14.7806757
27.38	9373.03	0.01	93.6188	14874.2945	14.8742945
27.39	9395.355	0.01	93.841925	14968.13643	14.96813643
27.4	9417.68	0.01	94.065175	15062.2016	15.0622016
27.41	9440.025	0.01	94.288525	15156.49013	15.15649013
27.42	9462.37	0.01	94.511975	15251.0021	15.2510021
27.43	9484.735	0.01	94.735525	15345.73763	15.34573763
27.44	9507.1	0.01	94.959175	15440.6968	15.4406968
27.45	9529.49	0.01	95.18295	15535.87975	15.53587975

27.46	9551.88	0.01	95.40685	15631.2866	15.6312866
27.47	9574.29	0.01	95.63085	15726.91745	15.72691745
27.48	9596.7	0.01	95.85495	15822.7724	15.8227724
27.49	9619.135	0.01	96.079175	15918.85158	15.91885158
27.5	9641.57	0.01	96.303525	16015.1551	16.0151551
27.51	9719.45	0.01	96.8051	16111.9602	16.1119602
27.52	9797.33	0.01	97.5839	16209.5441	16.2095441
27.53	9819.85	0.01	98.0859	16307.63	16.30763
27.54	9842.37	0.01	98.3111	16405.9411	16.4059411
27.55	9864.975	0.01	98.536725	16504.47783	16.50447783
27.56	9887.58	0.01	98.762775	16603.2406	16.6032406
27.57	9910.265	0.01	98.989225	16702.22983	16.70222983
27.58	9932.95	0.01	99.216075	16801.4459	16.8014459
27.59	9955.715	0.01	99.443325	16900.88923	16.90088923
27.6	9978.48	0.01	99.670975	17000.5602	17.0005602
27.61	10001.335	0.01	99.899075	17100.45928	17.10045928
27.62	10024.19	0.01	100.127625	17200.5869	17.2005869
27.63	10047.125	0.01	100.356575	17300.94348	17.30094348
27.64	10070.06	0.01	100.585925	17401.5294	17.4015294
27.65	10093.075	0.01	100.815675	17502.34508	17.50234508
27.66	10116.09	0.01	101.045825	17603.3909	17.6033909
27.67	10139.19	0.01	101.2764	17704.6673	17.7046673
27.68	10162.29	0.01	101.5074	17806.1747	17.8061747
27.69	10185.475	0.01	101.738825	17907.91353	17.90791353
27.7	10208.66	0.01	101.970675	18009.8842	18.0098842
27.71	10231.965	0.01	102.203125	18112.08733	18.11208733
27.72	10255.27	0.01	102.436175	18214.5235	18.2145235
27.73	10278.735	0.01	102.670025	18317.19353	18.31719353
27.74	10302.2	0.01	102.904675	18420.0982	18.4200982
27.75	10372.04	0.01	103.3712	18523.4694	18.5234694
27.76	10441.88	0.01	104.0696	18627.539	18.627539
27.77	10463.43	0.01	104.52655	18732.06555	18.73206555
27.78	10484.98	0.01	104.74205	18836.8076	18.8368076
27.79	10507.015	0.01	104.959975	18941.76758	18.94176758
27.8	10529.05	0.01	105.180325	19046.9479	19.0469479
27.81	10551.565	0.01	105.403075	19152.35098	19.15235098
27.82	10574.08	0.01	105.628225	19257.9792	19.2579792
27.83	10597.075	0.01	105.855775	19363.83498	19.36383498
27.84	10620.07	0.01	106.085725	19469.9207	19.4699207
27.85	10643.555	0.01	106.318125	19576.23883	19.57623883
27.86	10667.04	0.01	106.552975	19682.7918	19.6827918
27.87	10691.035	0.01	106.790375	19789.58218	19.78958218
27.88	10715.03	0.01	107.030325	19896.6125	19.8966125
27.89	10739.575	0.01	107.273025	20003.88553	20.00388553
27.9	10764.12	0.01	107.518475	20111.404	20.111404

27.91	10789.34	0.01	107.7673	20219.1713	20.2191713
27.92	10814.56	0.01	108.0195	20327.1908	20.3271908
27.93	10840.475	0.01	108.275175	20435.46598	20.43546598
27.94	10866.39	0.01	108.534325	20544.0003	20.5440003
27.95	10892.985	0.01	108.796875	20652.79718	20.65279718
27.96	10919.58	0.01	109.062825	20761.86	20.76186
27.97	10946.87	0.01	109.33225	20871.19225	20.87119225
27.98	10974.16	0.01	109.60515	20980.7974	20.9807974
27.99	11002.135	0.01	109.881475	21090.67888	21.09067888
28	11030.11	0.01	110.161225	21200.8401	21.2008401
28.01	11092.765	0.01	110.614375	21311.45448	21.31145448
28.02	11155.42	0.01	111.240925	21422.6954	21.4226954
28.03	11177.885	0.01	111.666525	21534.36193	21.53436193
28.04	11200.35	0.01	111.891175	21646.2531	21.6462531
28.05	11222.97	0.01	112.1166	21758.3697	21.7583697
28.06	11245.59	0.01	112.3428	21870.7125	21.8707125
28.07	11268.37	0.01	112.5698	21983.2823	21.9832823
28.08	11291.15	0.01	112.7976	22096.0799	22.0960799
28.09	11314.09	0.01	113.0262	22209.1061	22.2091061
28.1	11337.03	0.01	113.2556	22322.3617	22.3223617
28.11	11360.14	0.01	113.48585	22435.84755	22.43584755
28.12	11383.25	0.01	113.71695	22549.5645	22.5495645
28.13	11406.53	0.01	113.9489	22663.5134	22.6635134
28.14	11429.81	0.01	114.1817	22777.6951	22.7776951
28.15	11453.265	0.01	114.415375	22892.11048	22.89211048
28.16	11476.72	0.01	114.649925	23006.7604	23.0067604
28.17	11500.35	0.01	114.88535	23121.64575	23.12164575
28.18	11523.98	0.01	115.12165	23236.7674	23.2367674
28.19	11547.78	0.01	115.3588	23352.1262	23.3521262
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28.25	11692.165	0.01	116.800025	24049.30803	24.04930803
28.26	11716.49	0.01	117.043275	24166.3513	24.1663513
28.27	11740.99	0.01	117.2874	24283.6387	24.2836387
28.28	11765.49	0.01	117.5324	24401.1711	24.4011711
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28.3	11814.84	0.01	118.025025	24636.9744	24.6369744
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28.32	11864.53	0.01	118.521075	24873.7681	24.8737681
28.33	11889.555	0.01	118.770425	24992.53853	24.99253853
28.34	11914.58	0.01	119.020675	25111.5592	25.1115592
28.35	12021.77	0.01	119.68175	25231.24095	25.23124095

28.36	12128.96	0.01	120.75365	25351.9946	25.3519946
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28.38	12173.53	0.01	121.623875	25595.0195	25.5950195
28.39	12195.825	0.01	121.846775	25716.86628	25.71686628
28.4	12218.12	0.01	122.069725	25838.936	25.838936
28.41	12240.425	0.01	122.292725	25961.22873	25.96122873
28.42	12262.73	0.01	122.515775	26083.7445	26.0837445
28.43	12285.04	0.01	122.73885	26206.48335	26.20648335
28.44	12307.35	0.01	122.96195	26329.4453	26.3294453
28.45	12329.67	0.01	123.1851	26452.6304	26.4526304
28.46	12351.99	0.01	123.4083	26576.0387	26.5760387
28.47	12374.315	0.01	123.631525	26699.67023	26.69967023
28.48	12396.64	0.01	123.854775	26823.525	26.823525
28.49	12418.97	0.01	124.07805	26947.60305	26.94760305
28.5	12441.3	0.01	124.30135	27071.9044	27.0719044
28.51	12463.64	0.01	124.5247	27196.4291	27.1964291
28.52	12485.98	0.01	124.7481	27321.1772	27.3211772
28.53	12508.33	0.01	124.97155	27446.14875	27.44614875
28.54	12530.68	0.01	125.19505	27571.3438	27.5713438
28.55	12553.035	0.01	125.418575	27696.76238	27.69676238
28.56	12575.39	0.01	125.642125	27822.4045	27.8224045
28.57	12597.755	0.01	125.865725	27948.27023	27.94827023
28.58	12620.12	0.01	126.089375	28074.3596	28.0743596
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28.6	12664.86	0.01	126.53675	28327.2094	28.3272094
28.61	12687.24	0.01	126.7605	28453.9699	28.4539699
28.62	12709.62	0.01	126.9843	28580.9542	28.5809542
28.63	12732.005	0.01	127.208125	28708.16233	28.70816233
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28.72	12933.63	0.01	129.2242	29863.1135	29.8631135
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28.75	13000.905	0.01	129.896875	30252.13138	30.25213138
28.76	13023.34	0.01	130.121225	30382.2526	30.3822526
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28.81	13135.56	0.01	131.24335	31036.22465	31.03622465
28.82	13158.01	0.01	131.46785	31167.6925	31.1676925
28.83	13180.475	0.01	131.692425	31299.38493	31.29938493
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28.91	13360.285	0.01	133.490375	32361.01368	32.36101368
28.92	13382.78	0.01	133.715325	32494.729	32.494729
28.93	13562.42	0.01	134.726	32629.455	32.629455
28.94	13742.06	0.01	136.5224	32765.9774	32.7659774
28.95	13766.66	0.01	137.5436	32903.521	32.903521
28.96	13791.26	0.01	137.7896	33041.3106	33.0413106
28.97	13815.965	0.01	138.036125	33179.34673	33.17934673
28.98	13840.67	0.01	138.283175	33317.6299	33.3176299
28.99	13865.475	0.01	138.530725	33456.16063	33.45616063
29	13890.28	0.01	138.778775	33594.9394	33.5949394
29.01	13915.19	0.01	139.02735	33733.96675	33.73396675
29.02	13940.1	0.01	139.27645	33873.2432	33.8732432
29.03	13965.115	0.01	139.526075	34012.76928	34.01276928
29.04	13990.13	0.01	139.776225	34152.5455	34.1525455
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29.06	14040.37	0.01	140.2781	34432.8505	34.4328505
29.07	14065.595	0.01	140.529825	34573.38033	34.57338033
29.08	14090.82	0.01	140.782075	34714.1624	34.7141624
29.09	14116.15	0.01	141.03485	34855.19725	34.85519725
29.1	14141.48	0.01	141.28815	34996.4854	34.9964854
29.11	14166.915	0.01	141.541975	35138.02738	35.13802738
29.12	14192.35	0.01	141.796325	35279.8237	35.2798237
29.13	14217.885	0.01	142.051175	35421.87488	35.42187488
29.14	14243.42	0.01	142.306525	35564.1814	35.5641814
29.15	14269.06	0.01	142.5624	35706.7438	35.7067438
29.16	14294.7	0.01	142.8188	35849.5626	35.8495626
29.17	14320.45	0.01	143.07575	35992.63835	35.99263835
29.18	14346.2	0.01	143.33325	36135.9716	36.1359716
29.19	14372.05	0.01	143.59125	36279.56285	36.27956285
29.2	14397.9	0.01	143.84975	36423.4126	36.4234126
29.21	14423.855	0.01	144.108775	36567.52138	36.56752138
29.22	14449.81	0.01	144.368325	36711.8897	36.7118897
29.23	14475.87	0.01	144.6284	36856.5181	36.8565181
29.24	14501.93	0.01	144.889	37001.4071	37.0014071
29.25	14528.09	0.01	145.1501	37146.5572	37.1465572

29.26	14554.25	0.01	145.4117	37291.9689	37.2919689
29.27	14580.52	0.01	145.67385	37437.64275	37.43764275
29.28	14606.79	0.01	145.93655	37583.5793	37.5835793
29.29	14633.16	0.01	146.19975	37729.77905	37.72977905
29.3	14659.53	0.01	146.46345	37876.2425	37.8762425
29.31	14686.01	0.01	146.7277	38022.9702	38.0229702
29.32	14712.49	0.01	146.9925	38169.9627	38.1699627
29.33	14739.07	0.01	147.2578	38317.2205	38.3172205
29.34	14765.65	0.01	147.5236	38464.7441	38.4647441

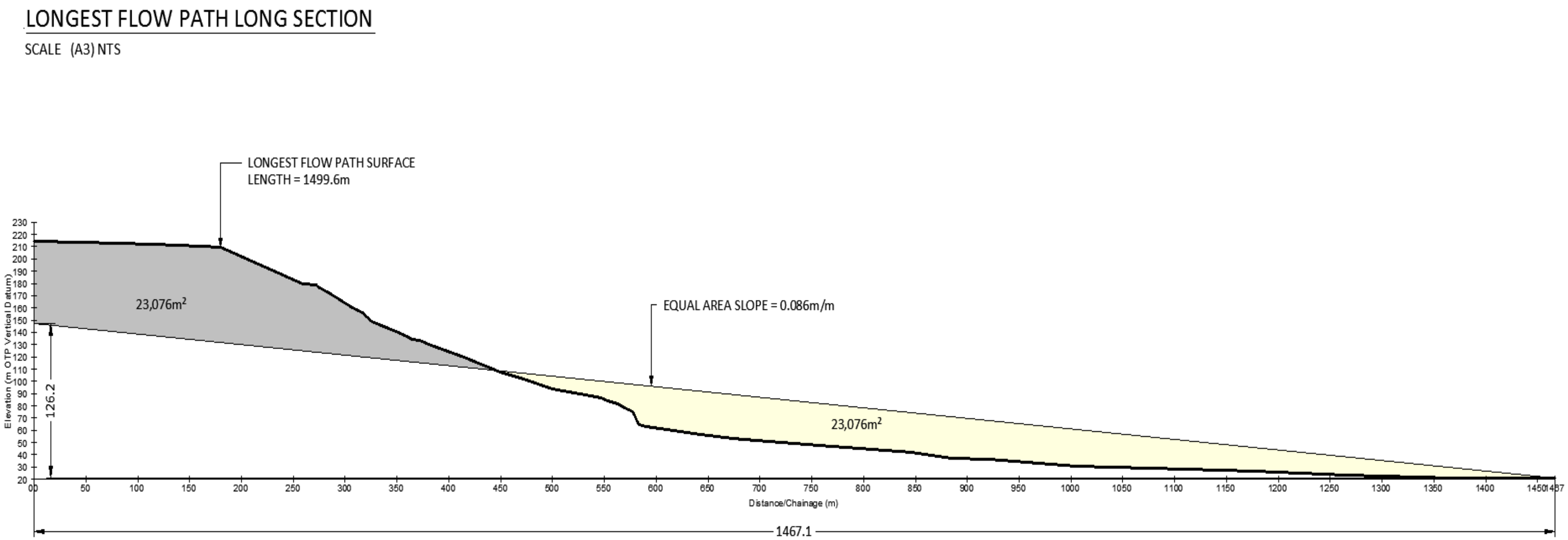
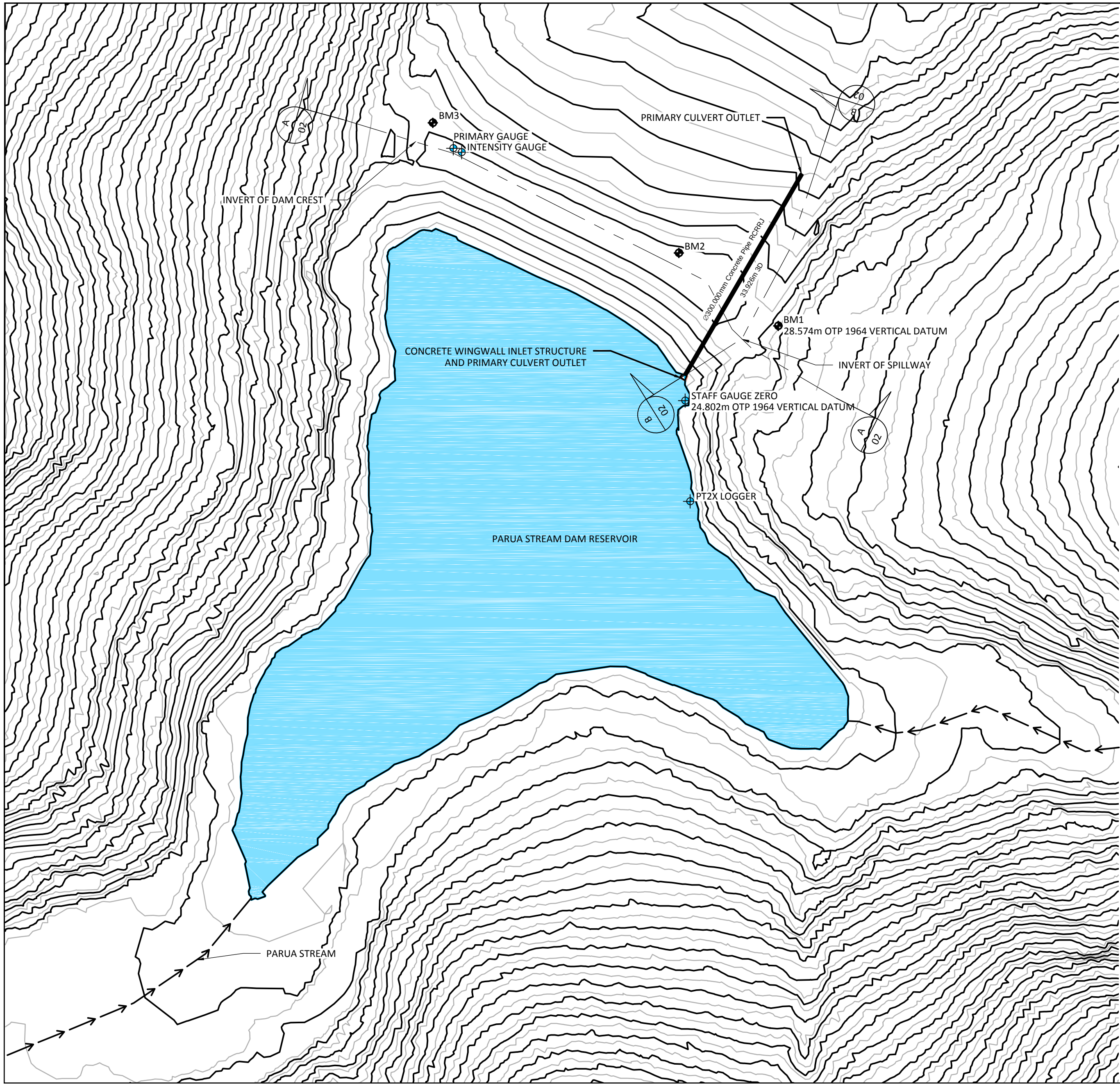
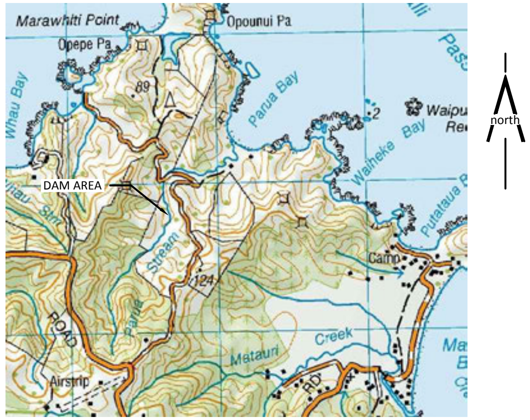


Figure D. 1. Longest flow path, long section for Time of Concentration calculation





LOCALITY PLAN

SCALE (A3) NTS

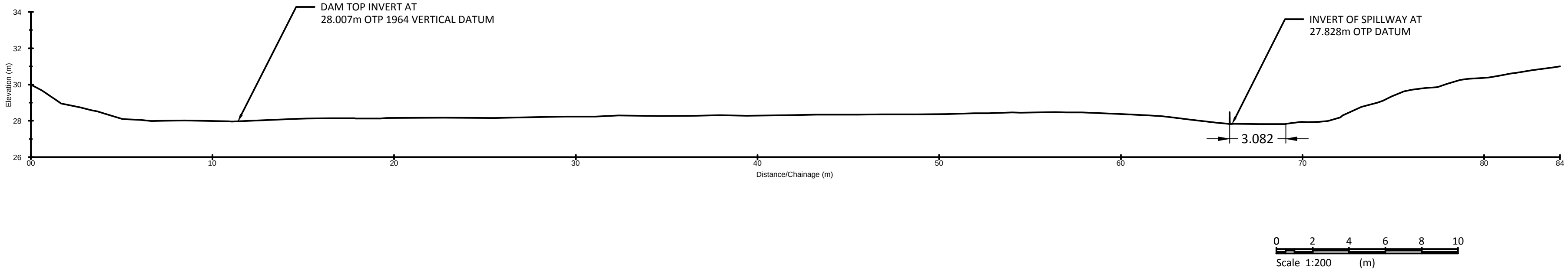
LEGEND	
1m CONTOUR	
0.5m CONTOUR	
INFERRED RESERVOIR WATER LEVEL	
PRIMARY CULVERT OUTLET	
MONITORING EQUIPMENT	
BENCHMARK	
STREAM OR CHANNEL	

0 5 10 15 20 25

Scale 1:500 (m)

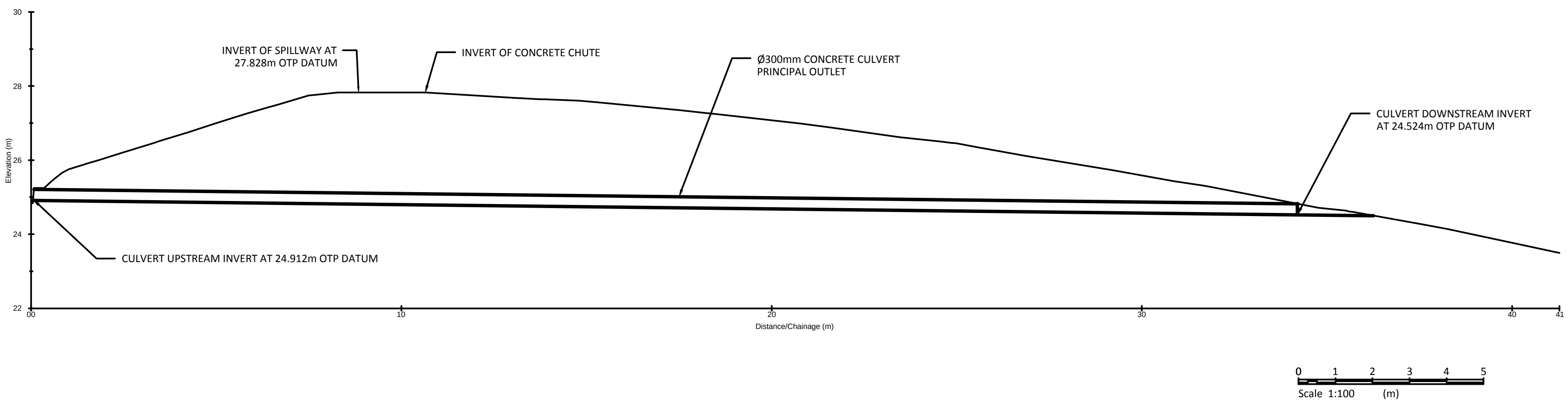
A / 01 DAM AND SPILWAY CREST - LONG SECTION

SCALE (A4) 1:200

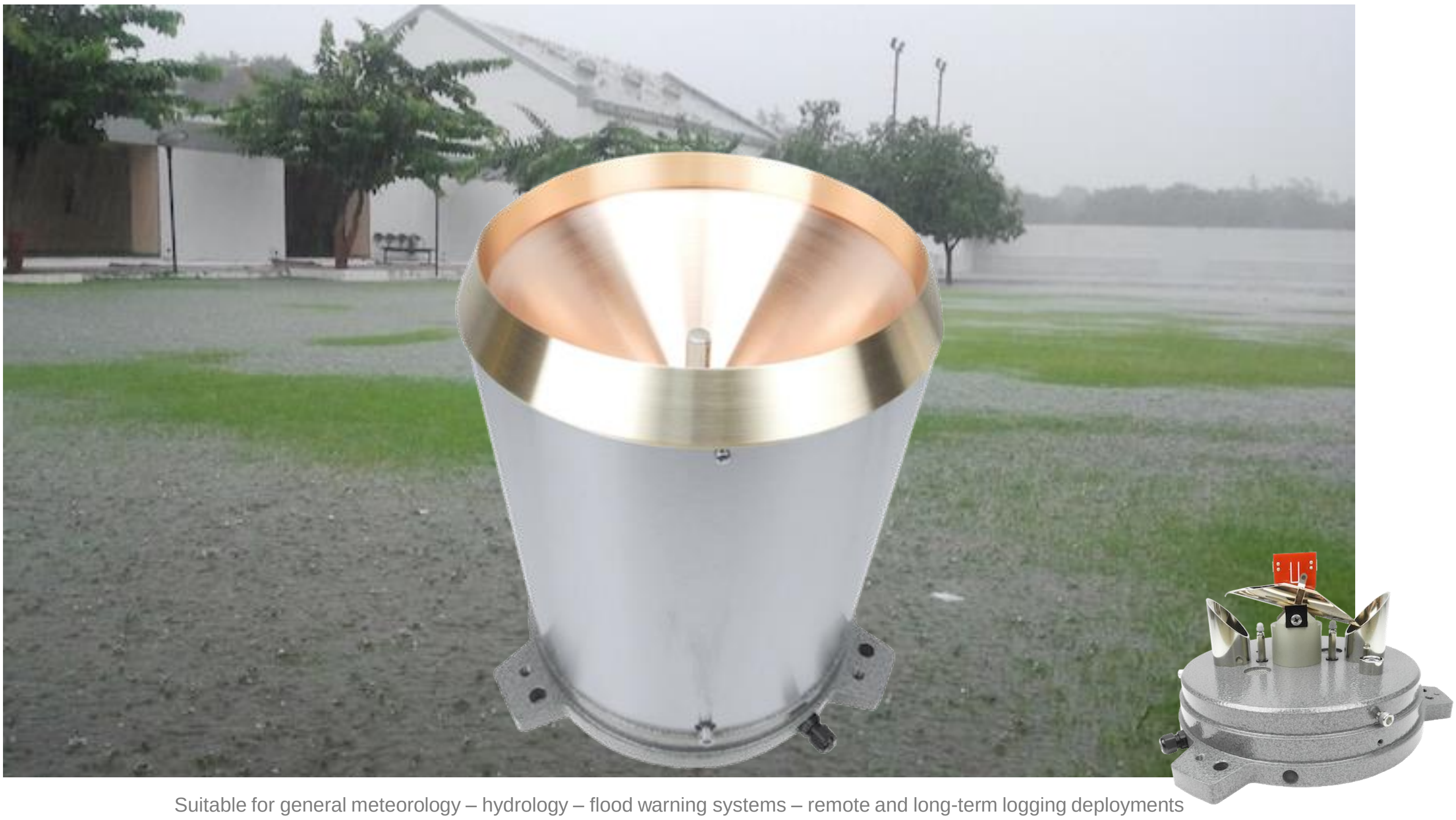


B / 01 SPILLWAY - LONG SECTION

SCALE (A4) 1:100



Appendix E – Equipment Specifications



Suitable for general meteorology – hydrology – flood warning systems – remote and long-term logging deployments

Datasheet

RIM-7499-STD Rain Gauge

The RIMCO RIM-7499 range of siphon controlled tipping bucket rain gauges are professional instruments designed and constructed for long-term operation with minimal maintenance under all climatic conditions. All materials are corrosion resistant. These proven instruments are accurate to within 3% up to rainfall rates of 190mm/hr.

The RIM-7499-STD (standard) comes with a lower specification funnel and calibration than the RIM-7499-BOM (Bureau Of Meteorology) version. The STD version is ultimately the ideal low-cost alternative to the BOM version. The lower cost RIM-7499-STD can however, be ordered with the higher specification 1% BOM calibration.

Rain falling on the 203mm collecting funnel is directed through a siphon control unit and discharges as a steady stream into a two-compartment bucket mounted in an unstable equilibrium. As each compartment fills, the bucket tilts alternately about its axis. Each tip forces a contact closure by magnetic means corresponding to 0.2, 0.25 or 0.5mm of rainfall according to bucket capacity. A calibration certificate is supplied with every RIM-7499 rain gauge.

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Applications

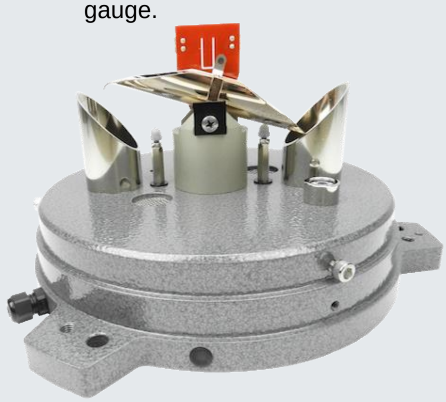
- General meteorology
- Water resources studies
- Hydrology
- Flood warning systems
- Automatic logging systems
- Remote and long-term logging deployments

Features

- Rugged and corrosion resistant construction
- Minimal maintenance, 25 years+ deployment life
- Low friction, non-seizing bucket bearings
- Gold plated buckets for minimal retention
- Dual reed-switch output
- Stable calibration
- Built-in bubble level
- Optional heater for operations below –30°C
- Optional self-powered internal counter
- Mounting pedestal available

Specifications

Collector diameter	203mm (8'') ± 0.2mm
Resolutions	0.2mm 0.25mm 0.5mm (0.01" & 0.02" to special order)
Accuracy	±3% to 190mm/hr Can measure up to 347mm/hr (4%)
Contacts	Two normally open magnetically actuated reed switches Individual protection built-in
Reed-switch rating	50V AC/DC @0.5A non-inductive
Closure timing	50ms min 150ms max Max bounce time 0.75ms up to 500mm/hr
Termination	Screw termination (2.5mm²)
Heating option	12 or 24V AC/DC (48W max) operation with electronic thermostatic control (P/N 7499-TCH) Specify operating voltage at time of order
Data logger	Several models available depending on application requirements. Some data loggers may be installed within the body of the rain gauge.



OBSERVATOR instruments

RIMCO an Observator brand

Dimensions

Height	300mm
Body diameter	230mm
Base diameter	280mm

Physical

Net weight	5.5kg
Shipping weight	7.0kg
Packing carton	330x330x430mm

Materials

Collector	Copper
Jacket	Stainless steel
Base	Cast marine grade Aluminium
Bucket	Gold plated brass
Bridge	Anodized marine Grade Aluminium
Switch holder	Delrin®
Fasteners	Stainless steel

Ordering Information

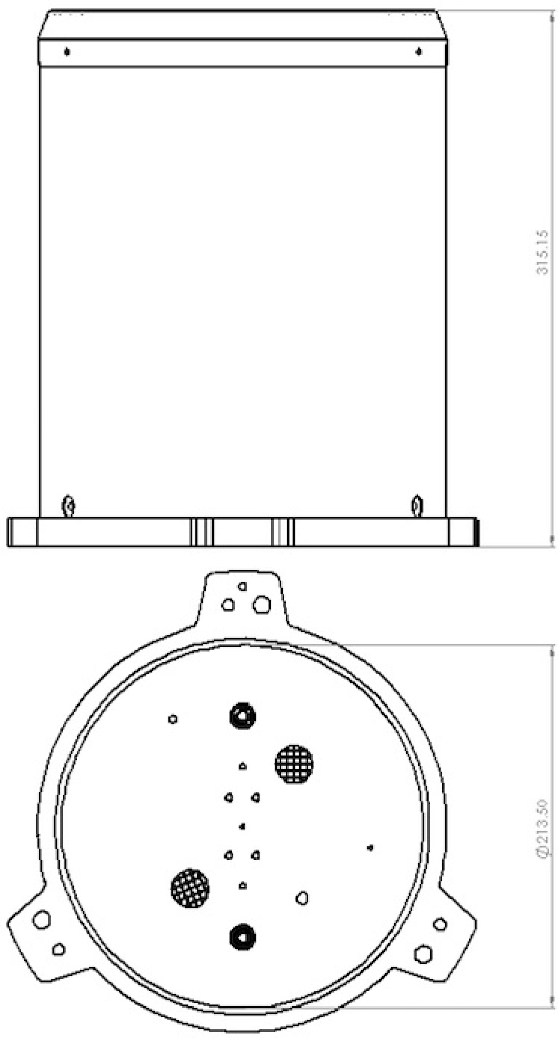
RIM-7499-020-STD	Rain gauge 0.2mm bucket
RIM-7499-025-STD	Rain gauge 0.25mm bucket
RIM-7499-050-STD	Rain gauge 0.5mm bucket
	Order options as required

Note:

- RIM-7499-BOM version is available for more accurate funnel collector specification.
- Non-siphon and imperial resolution versions are also available with differing accuracy specification.
- Other RIMCO rain gauge models are also available with 200cm2 (RIM-8500) and 300mm (RIM-8300).

Mounting

A rugged mounting pedestal that elevates the collection rim 1m above ground level (P/N 8000PED1).



Welcome to the world of Observator

Solutions beyond expectations. That's what sets Observator apart. We believe in taking the extra step. Retaining our competitive edge, through innovation and uncompromised support, are key to success. As an ISO 9001:2015 certified company, we apply the highest quality standards to our products and systems.

Solutions beyond expectations

Since 1924 Observator has evolved to be a trend-setting developer and supplier in a wide variety of industries. From instruments for meteorological and hydrological solutions, air and climate technology, to high precision mechanical production, window wipers and sunscreens for shipping and inland applications.

Originating from the Netherlands, Observator has grown into an internationally oriented company with a worldwide distribution network and offices in Australia, Germany, the Netherlands, Singapore and the United Kingdom.

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PT2X Smart Sensor

PRESSURE/TEMPERATURE WITH DATA LOGGING

APPLICATIONS

Pump and slug tests

Stormwater runoff monitoring

Well, tank, tidal levels

River, stream, reservoir gauging

Wetland monitoring

Resource administration

Features

- Measures & records pressure/level and temperature
- Low power
- Modbus® RTU (RS485) and SDI-12
- ±0.05% FSO typical accuracy
- Thermally compensated
- Small diameter — 0.75” (1.9 cm)
- 520,000 records in non-volatile memory
- Barometric compensation utility for use with absolute sensors
- Free, easy-to-use Aqua4Plus 2.0 software

Contact Your Supplier

The **Seametrics PT2X** Smart Sensor is an integrated data logger and pressure/temperature sensor and is ideal for monitoring groundwater, well, tank, and tidal levels, as well as for pump and slug testing. This sensor networks with all of the Seametrics Smart Sensor family.

This industry standard digital RS485 interface device records up to 520,000 records of pressure/level, temperature, and time data, operates with low power, and features easy-to-use software with powerful features. Constructed with 316 stainless steel or titanium, PTFE, and fluoropolymer, this sensor provides high-accuracy readings in rugged and corrosive field conditions.

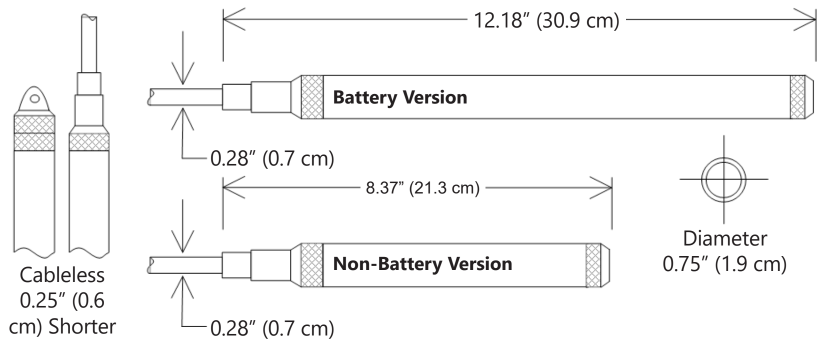
Two replaceable internal AA batteries power the PT2X. (Auxiliary power supplies are available for data intensive applications.) The unit is programmed using Seametrics’ easy-to-use Aqua4Plus 2.0 control software. Once programmed the unit will measure and collect data on a variety of time intervals.

Several PT2Xs, or a combination of PT2Xs and other Seametrics Smart Sensors, can be networked together and controlled directly from a single computer.

While most will use the PT2X with our free, easy-to-use Aqua4Plus 2.0 software, it is by no means limited to that software. You can use your own Modbus® RTU or SDI-12 software or logging equipment to read measurements, thus tying into your existing telemetry and control systems.

PT2X Smart Sensor
PRESSURE/TEMPERATURE
WITH DATA LOGGING

Dimensions



Specifications*

Housing & Cable	**Weight**	0.8 lb. (0.4 kg)	
	Body Material	Acetal & 316 stainless or titanium	
	Wire Seal Material	Fluoropolymer and PTFE	
	Cable	Submersible: polyurethane, polyethylene, or ETFE (4 lb./100 ft., 1.8 kg/30 m)	
	Desiccant	1-3 mm indicating silica gel	
	Field Connector	Standard	
Temperature	**Operating Range**	Recommended: -15˚ to 55˚C (5˚ to 131˚F) Requires freeze protection kit if using pressure option in water below freezing.	
	Storage Range	Without batteries: -40˚ to 80˚C (-40˚ to 176˚F)	
Power	**Internal Battery**	Two replaceable lithium 'AA' batteries - Battery life: 18 months at 15 min. polling interval (may vary do to environmental factors)	
	Auxiliary	12 Vdc - Nominal, 9-15 Vdc - range	
Communication	**Modbus®**	RS485 Modbus® RTU, output=32bit IEEE floating point	
	SDI-12	SDI-12 (ver. 1.3) - ASCII	
Logging	**Memory**	4MB - 520,000 records	
	Logging Types	Variable, user-defined, profiled	
	Logging Rates	8x/sec maximum, no minimum	
	Baud Rates	9600, 19200, 38400	
	Software	Complimentary Aqua4Plus 2.0	
	Networking	32 available addresses per junction (Address range: 1 to 255)	
	File Formats	.a4d and .csv	
Output Channels		**Temperature**	**Depth/Level**
	Element	Digital IC on board	Silicon strain gauge transducer, 316 stainless or Hastelloy
	Accuracy	±0.5°C — 0° to 55°C (32˚ to 131˚F) ±2.0°C — below 0°C (32˚F)	±0.05% FSO (typical, static) ±0.1% FSO (maximum, static) (B.F.S.L. 20˚C)
	Resolution	0.1˚C	0.0034% FS (typical)
	Units	Celsius, Fahrenheit, Kelvin	PSI, FtH$_2$O, inH$_2$O, mmH$_2$O, mH$_2$O, inH$_2$O, cmHg, mmHg, Bars, Bars, kPa
	Range	-15˚ to 55˚C (5˚ to 131˚F)	Gauge: PSI: 1[1], 5, 7, 15, 30, 50, 100, 300 FtH$_2$O: 2.3[1], 12, 35, 69, 115, 231, 692 mH$_2$O: 0.7[1], 3.5, 5, 10.5, 21, 35, 70, 210 Absolute[2]: PSI: 30, 50, 100, 300 FtH$_2$O: 35, 81, 196, 658 mH$_2$O: 10, 24, 59, 200
	Compensated	---	0˚ to 40˚C (32˚ to 104˚F)
Max operating pressure		1.1 x full scale	
Over pressure protection		3x full scale up to 300psi	
Burst pressure		1000 psi (approx. 2000 ft or 600 m)	
Environmental		IP68, NEMA 6P	

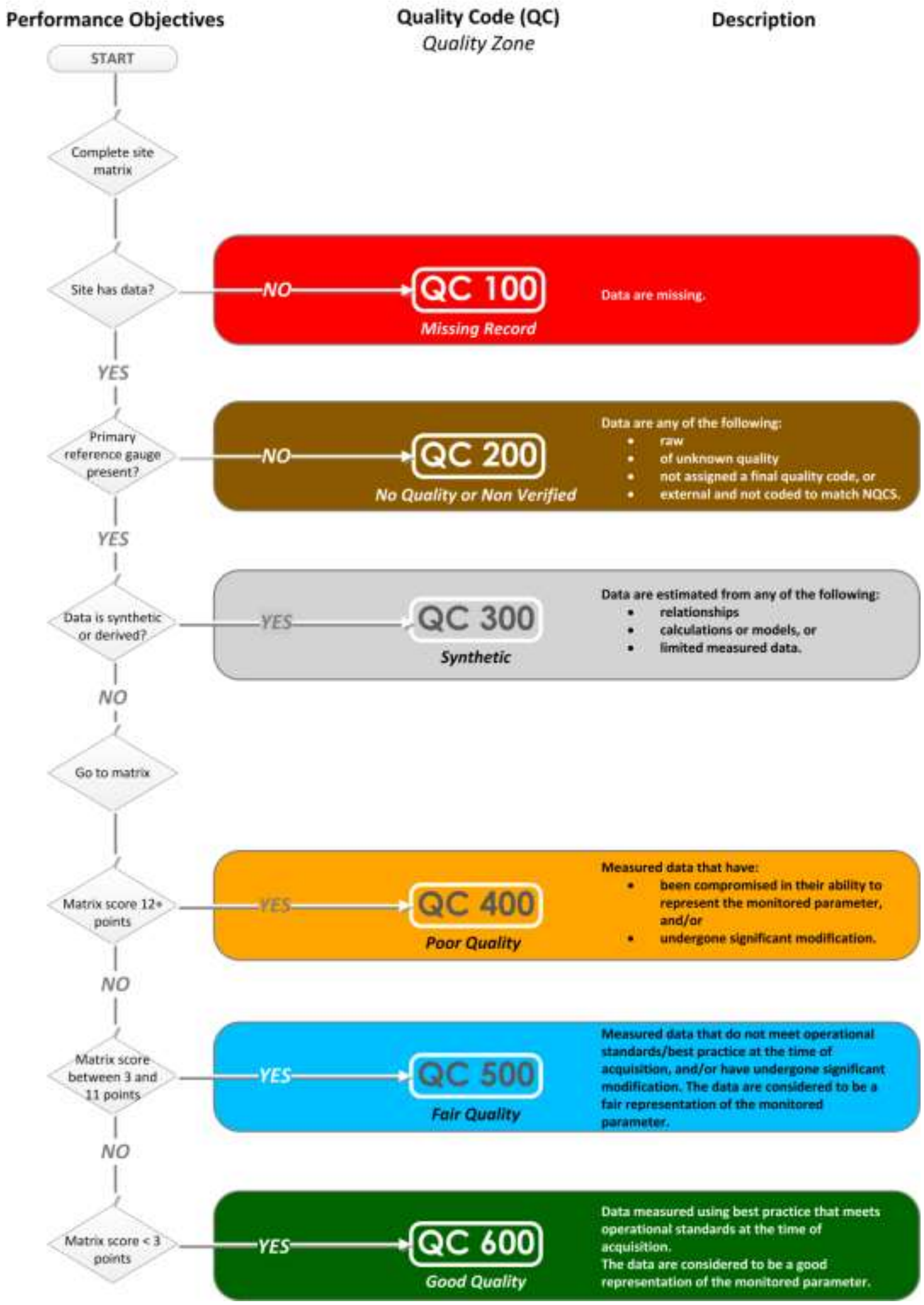
**Specifications subject to change. Please consult out web site for the most current data (seametrics.com). Modbus is a registered trademark of Schneider Electric.*
1 ±0.25% accuracy FSO (max) at this range
2 Depth range for absolute sensors has 14.7 PSI subtracted to give actual depth allowed.

Seametrics • 19026 72nd Avenue South • Kent, Washington 98032 • USA
(P) 253.872.0284 • (F) 253.872.0285 • 1.800.975.8153 • seametrics.com

Appendix F – Rainfall Gauge Site Evaluation

Quality Codes – Rainfall

All data shall be quality coded in accordance with the NEMS *Quality Code Schema.* The schema permits valid comparisons within and across multiple data series. Use the following flowchart to assign quality codes to all rainfall intensity data. Where necessary, refer to the Rainfall Site Matrix and Rainfall Data Quality Matrix.



Rainfall Site Matrix

When quality coding rainfall data, assess your site against the following matrix.

Criteria	3 Points	1 Point	0 Points
Site Topography 200m radius from site *Section* 2.1	Site on steeply sloping land > 34° *or* on a roof ☐	Site on moderate sloping land (19°–34°) ☐	Site on flat land – slope <19^{0} ☑
Exposure Average annual wind speed *Section* 2.2	Site subject to high wind (>6 m/s) ☐	Site subject to moderate wind (3–6 m/s) ☑	Subject to low winds (<3 m/s) *or* ground level with anti-splash grid ☐
Obstructed Horizon Within a 100 m radius of the gauge *Section* 2.3	> 10° obstruction within 2:1 in any 45° segment ☐	< 10° obstruction within 2:1 in any 45° segment ☐	No obstruction within 2:1 distance to height ☑
Distance Between Gauges *Section* 3.2	Distance between gauges < 600 mm or > 2000 mm ☐		Distance between gauges 600–2000 mm ☑
Resolution of Primary Reference Gauge *Section* 3.3.1	Cannot be read to ≤ 1mm ☐		Can be read to ≤ 1mm ☑
Orifice Height - Primary Reference Gauge *Section* 3.3.2	0–285 mm *or* > 325mm *or* no primary reference gauge ☐		305mm ±20mm *or* ground level (with anti-splash grid) ☑
Orifice Diameter - Primary Reference Gauge *Section* 3.3.3	< 127 mm *or* > 203 mm ☐		127–203 mm ☑

Continued on next page...

Criteria	3 Points	1 Point	0 Points
Orifice Height - Intensity Gauge *Section* 3.4.2	600–1000 mm and does not match PRG *or* > 1000 mm ☐	600–1000 mm and matches PRG ☐	285–600 mm *or* ground level (with anti-splash grid) ☑
Orifice Diameter - Intensity Gauge *Section* 3.4.3	<127 mm or >203 mm ☐	☐	≥ 127 mm and ≤ 203 mm ☑
Resolution of Intensity Gauge *Section* 3.4.4	> 1 mm ☐	0.5–1.0 mm ☐	≤ 0.5 mm ☑
Measurement Timing Section *3.6*	Totalising period > 60 s and not event recording ☐		Totalising period ≤ 60 s *or* event recording ☑
SITE SCORE = 1			

Annex B – Topography

Site topography is defined by the slope at which the site including its surrounding 200m is situated.

Calculating the Slope of a Site

The slope of the site can be calculated using the following trigonometric formula:

$$\text{Tan}\ \theta = O/A \text{ (opposite/adjacent)}$$

where: θ = slope (in degrees)

O = elevation change within the extent measured
(maximum elevation – minimum elevation)

A = diameter of the area measured (400 m)

$O = (560–545) = 15$

$A = 400$

$\text{Tan}\ \theta = 15/400$

or

$\theta = \text{Tan}^{-1}\ (15/400)$

$\theta = 2.15^0$

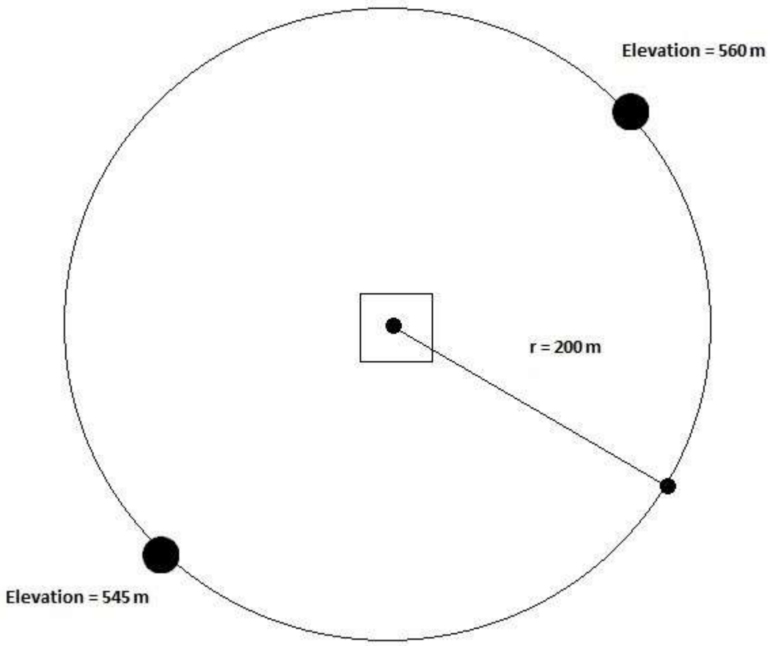


Figure 1 – Example of slope calculation

Appendix G – Rainfall Data from NRC Towai at Weta Station

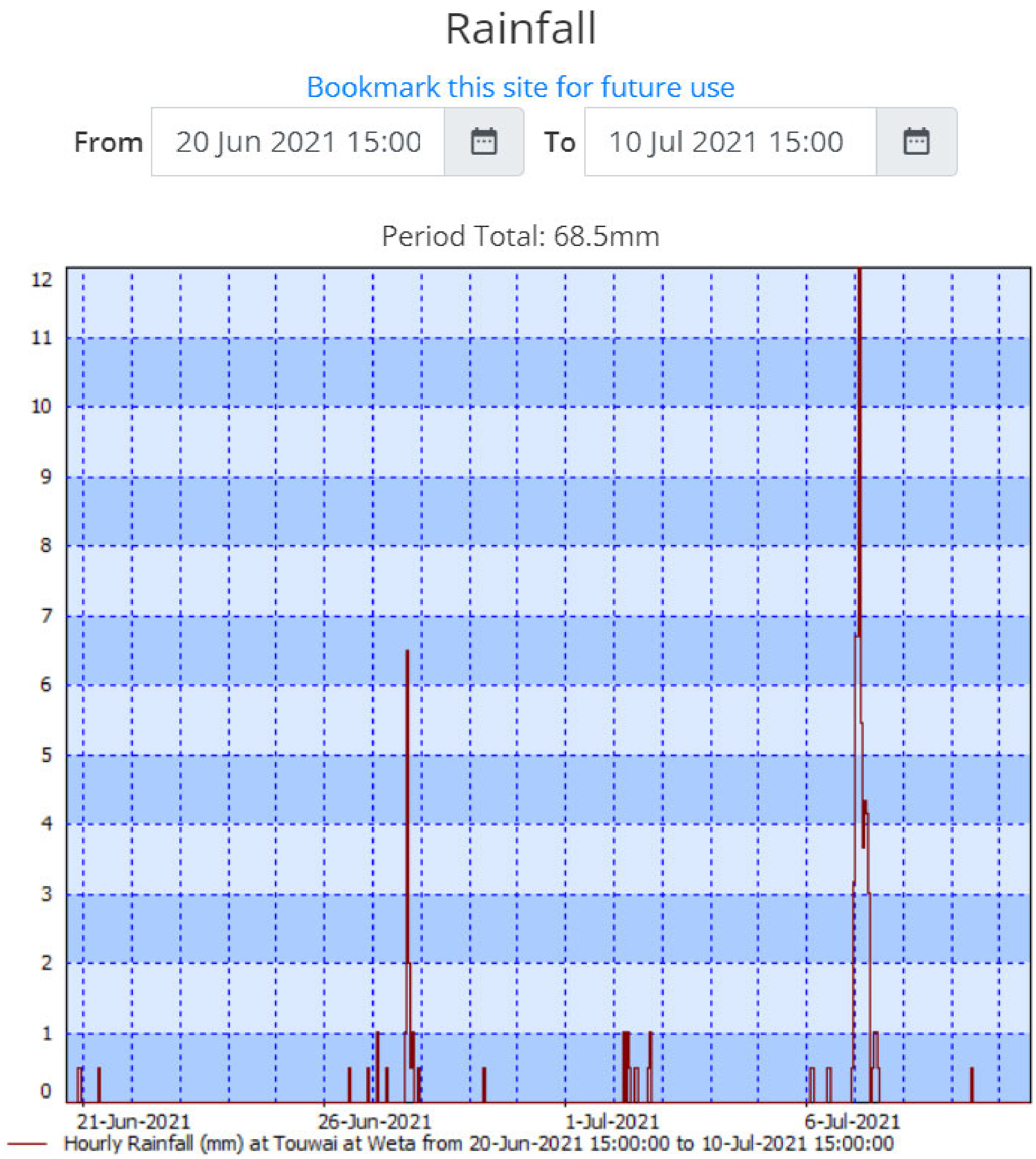


Figure G. 1. Rainfall conditions before 13th July Storm Event

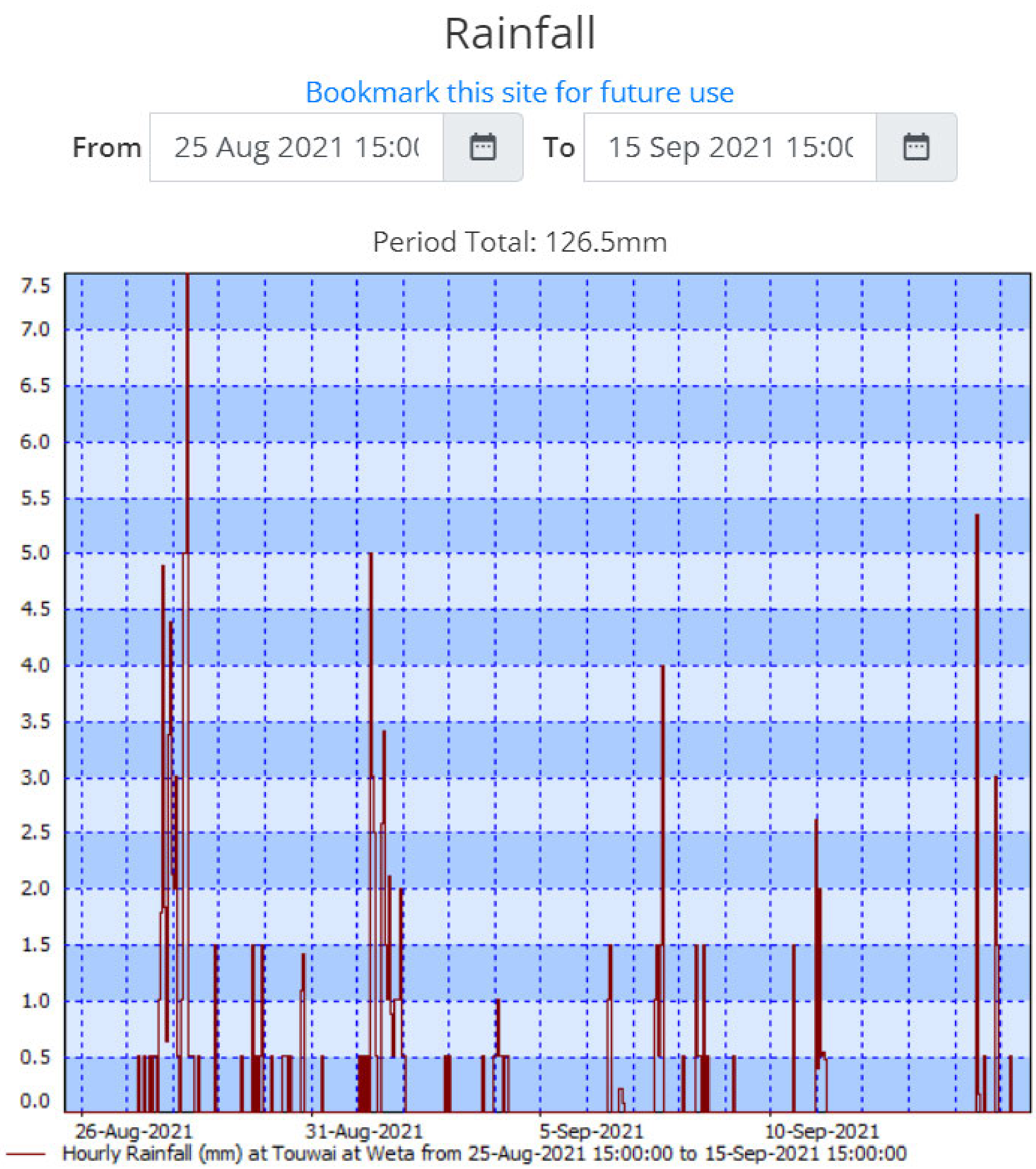


Figure G. 2. Rainfall Conditions before 16th September Storm Event

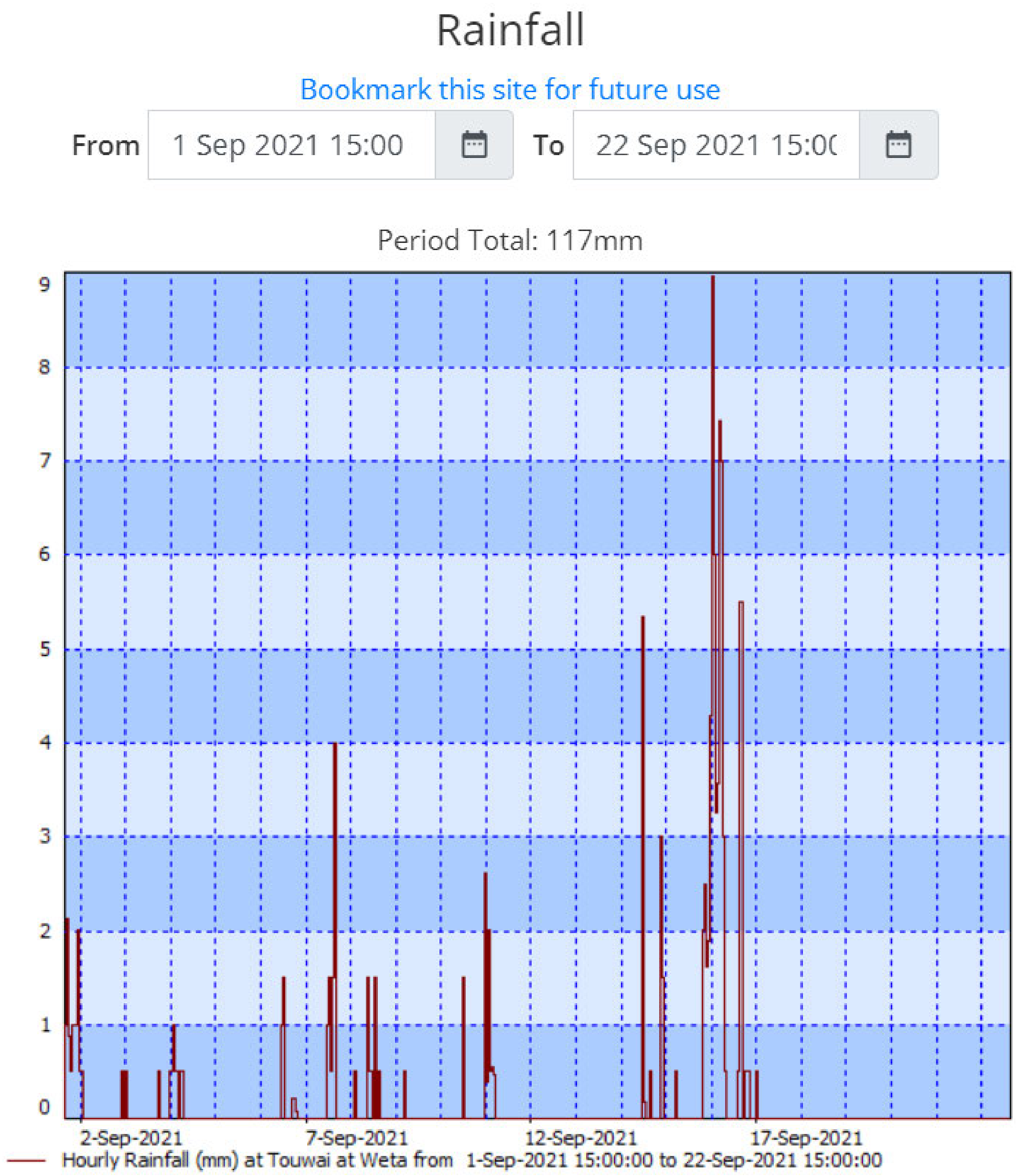


Figure G. 3. Rainfall Conditions before 23rd September Storm Event

Appendix H – Site Monitoring Verifications

Table H. 1: Results from Rain Gauge Verification

Date	Days of record	Primary Gauge Depth (mm)	Intensity Gauge Cumulative Depth (mm)	Error (%)	Acceptable
27/07/2021	24	203	195.4	3.74	Yes
2/09/2021	37	110	109.4	0.545	Yes
24/09/2021	22	117	113.8	2.74	Yes

Table H. 2. Results from Water Level Sensor Verification

Date/Time	Days of record	Single Measurement on Logger	Measured Staff Gauge Level	Error (mm)	Acceptable
27/07/2021 13:30	24	227	225	2	Yes
2/09/2021 10:00	37	236.4	235	0.592	Yes
24/09/2021 17:00	22	256	255	0.391	Yes