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Hawkes Bay Regional Council

Te Tua Storage Scheme

HAWKES BAY REGIONAL COUNCIL

WWA0018 | Rev. 4

01 February 2018

TANK Catchment Model

Project no: WWA0018
Document title: Te Tua Storage Scheme modelling
Revision: 4
Date: 01 February 2018
Client name: Hawkes Bay Regional Council
Project manager: Jon Williamson
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File name: Report_Te Tua Storage Modelling Phase 1_01Feb2018.docx

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Document history and status

Rev	Date	Description	By	Review	Approved
1	15 Jan 2018	Memo – First edition	Emily Diack	15 Jan 2018	Jon Williamson
2	19 Jan 2018	Memo – edits to irrigation demand	Emily Diack	19 Jan 2018	Jon Williamson
3	24 Jan 2018	Memo – Changes to simulation runs and results	Emily Diack	24 Jan 2018	Jon Williamson
4	01 Feb 2018	Report – Final scenario simulations	Emily Diack	01 Feb 2018	Jon Williamson

Distribution of copies

Rev	Date issued	Issued to	Comments
1	15 Jan 2018	Jeff Smith (HBRC)	Issued as a memo
2	19 Jan 2018	Jeff Smith (HBRC)	Issued as a memo
3	24 Jan 2018	Jeff Smith (HBRC)	Issued as a memo
4	01 Feb 2018	Jeff Smith (HBRC)	

Contents

1. Introduction ... 1

2. Phase 1 ... 2

2.1 Model Configuration ... 3

2.1.1 Dam inlet ... 3

2.1.2 Te Tua Dam ... 3

2.1.3 Dam outlet: controlled augmentation release ... 4

2.2 Predictive Model Setup ... 5

3. Results ... 6

3.1 Model 1 ... 6

3.2 Model 2 ... 8

3.3 Model 3 ... 11

3.4 Model 4 ... 14

4. Assumptions and limitations ... 18

5. Recommendation ... 19

1. Introduction

In December 2017 HBRC requested the development of the TANK SOURCE catchment model to include the Te Tua Dam storage scheme. As part of the development, multiple scenarios were required to assess the capability and efficiency the Te Tua Dam to augment the Ngaruroro River under differing conditions.

There are three potential phases to the storage modelling. In preparation for the upcoming Water Augmentation Group (WAG) meeting, Phase 1 has been developed and completed.

This memo will outline the following for Phase 1:

- The objective;
- The model development;
- The simulation results; and
- The associated limitations and assumptions.

2. Phase 1

The objective of phase one is to simulate the performance of the Te Tua storage scheme over a 17-year period (Jul 2015 – Jul 2032), and assess its' ability to offset groundwater pumping impacts at the Fernhill monitoring location by augmentation water releases into the Ngaruroro River.

The basic configuration of the augmentation system in the SOURCE TANK catchment model is as follows, and shown in **Figure 1**:

- ***The dam inlet*** - The abstraction of water from the Ngaruroro River (upstream of Fernhill) to supply water to the Te Tua dam. The maximum inlet capacity is 0.8 m^3/s;
- ***The Te Tua dam*** – The dam has a maximum capacity of 5.0 Mm^3. In these scenarios, a maximum capacity of 4.5 Mm^3 has been simulated, as the consent holder requires the use of 0.5 Mm^3 for on-farm purposes; and
- ***The dam outlet*** - The augmentation release of water from the Te Tua dam back into the Ngaruroro River, with the purpose of offsetting the impacts of groundwater pumping.

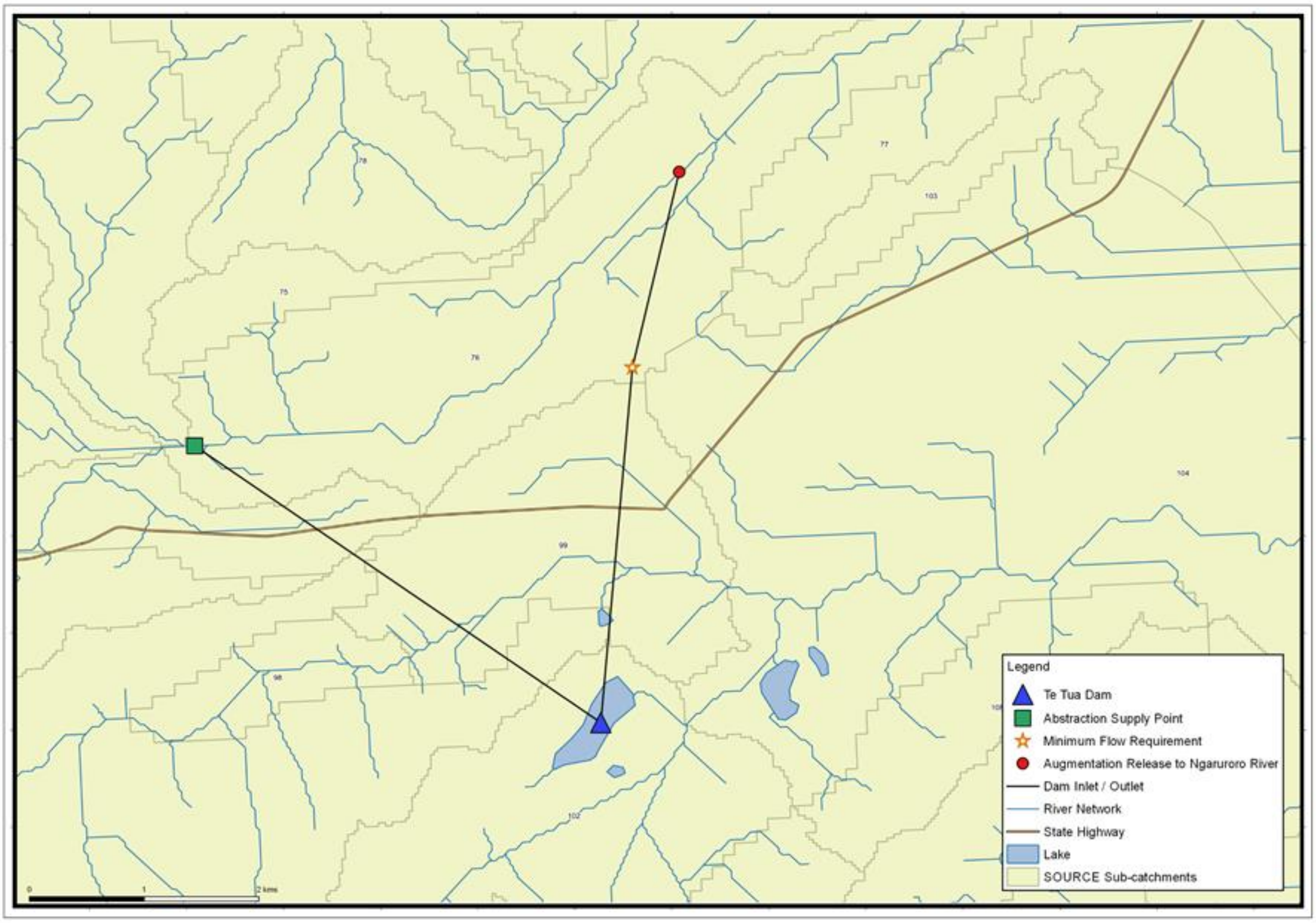


Figure 1. Schematic overview of the augmentation system configuration.

For the purpose of this modelling exercise multiple conditions have been configured at each of these features to allow a combination of scenarios to be tested under each minimum flow model. The development of each feature and the associated conditions are described in the following sections.

The Fernhill minimum flow models were provided by Rob Waldron, and are outlined in **Table 1**. The Te Tau Storage scheme has been added into each of these models, with four storage scenarios configured.

Table 1. Summary of the Fernhill minimum flows and provided models.

Model	SOURCE Model (from Rob)	Fernhill Minimum Flow (m^3/s)	Equivalent Minimum Flow[1] (m^3/s)
1	Base Case_Estimated Demand (8.3_SDZ1) 1980-2032	2.4	3.97
2	Base Case_Estimated Demand (8.3_SDZ1) 1980-2032 – Modified by WWA	3.0	4.35
3	N MF 70% T MF 75% Habitat_Estimated Demand (16.1_SDZ1) 1980-2032	3.6	4.84
4	N MF 80% T MF 90% Habitat_Estimated Demand (18.0_SDZ1) 1980-2032	4.0	5.12

2.1 Model Configuration

The following sections outline the Te Tua Storage scheme configured in each of the four Models (**Table 1**).

2.1.1 Dam inlet

The dam inlet is configured as a supply node in the SOURCE model. The supply point is configured at the upper most point of sub-catchment 76, downstream of the Maraekakako and Ngaruroro River confluence.

The abstraction condition configured at the supply point is as follows:

1. ***High flow allocation A*** – the maximum abstraction permitted (0.8 m^3/s) when the flow at Fernhill is greater than the median observed flow at Fernhill - 20 m^3/s. The calculated equivalent modelled flow is 22.12 m^3/s[1]

The allocation condition is configured using functions at the supply point, outlined in **Appendix A.**

2.1.2 Te Tua Dam

The Te Tua Dam is configured as a storage node, located in sub-catchment 102. The rainfall and potential evaporation data from sub-catchment 102 has been applied to the dam.

The dam storage dimensions were built into SOURCE using a relationship provided by Jeff Smith, **Figure 2**.

The dam is configured with a maximum volume of 4.5 Mm^3 and subsequently a maximum level of 11.524 m. The dam inlet controls the volume and rate of water delivered to the dam. There are two dam outlets. The ungated spillway and the controlled valve (for augmentation purposes). The controlled valve is described in the following section.

[1] The SOURCE model closes the water balance at each sub-catchment, which means that subsurface flows are reported in the river channel, whereas in practice these may be sub-surface flows associated with the riverbed. Consequently, SOURCE over predicts low flows by a consistent offset. To compensate for this, an equivalent minimum flow has been used. These values are based on the calculations carried out by Rob Waldron and provided in the following spreadsheet, “SOURCE minimum flows for scenarios.xlsx”

The ungated spill way is configured to flow into sub-catchment 102, and accounts for additional overflow from the dam due to rainfall (i.e. if the dam is at maximum capacity and precipitation occurs, the overflow caused by precipitation is released into sub-catchment 102).

Due to a SOURCE configuration issue, seepage has been excluded from these simulations. SOURCE allows the configuration of seepage into a dam, however produces an error and crashes when configured with a seepage relationship accounting for seepage from the dam to the groundwater table. This error was investigated within SOURCE, but given the tight time frame for the delivery of results the modelling process was continued without seepage configured.

However, it is considered that the results will not be sensitive to seepage, as our independent analysis of a likely seepage rates indicated that at maximum dam storage capacity, seepage to groundwater would be approximately 1.0 mm/d, assuming a 1 m thick dam liner of vertical hydraulic conductivity of $1x10^{-9}$ m/s. This is equivalent to approximately 0.006 m^3/s, which is a very small proportion of the flow volumes being modelled.

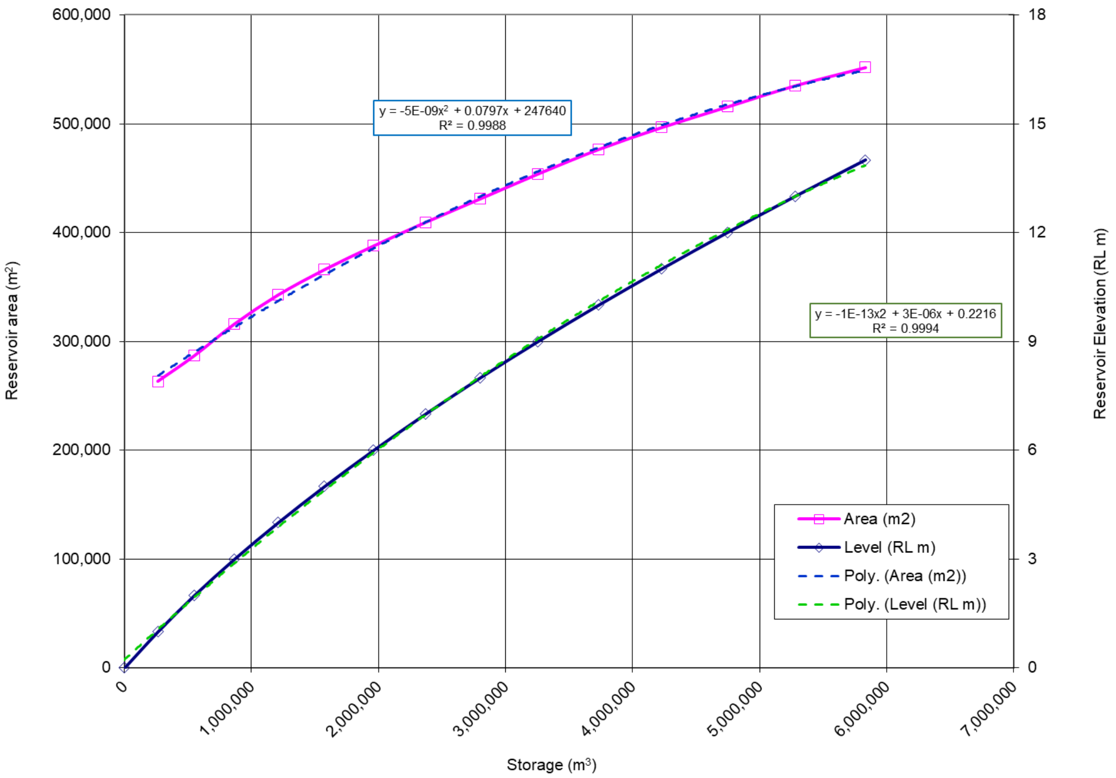


Figure 2. The Te Tua Dam static storage dimension relationship applied in SOURCE (provided by HBRC).

2.1.3 Dam outlet: controlled augmentation release

The Te Tua dam augmentation (controlled) release is configured with a minimum flow requirement node, which controls the release of water for augmentation purposes back into the Ngaruroro River, upstream of the Fernhill monitoring location in sub-catchment 76.

Two scenarios conditions are configured at the minimum flow requirement node:

1. ***Augmentation A*** – whenever flow at Fernhill is less than the modelled Fernhill minimum flow, then release the lesser of either:
   i. The augmentation required to achieve the scenario minimum flow (i.e. minimum flow – Fernhill Q); or
   ii. The groundwater abstraction impact (calculated by Pawel and provided by Jeff).
2. ***Augmentation B*** – release the maximum effect from groundwater pumping (approximately 0.98 m^3/s) from Te Tua Dam whenever flow at Fernhill is less than the scenario minimum flow.

Both allocation conditions are configured using functions, outlined in **Appendix A**.

2.2 Predictive Model Setup

As outlined in **Table 1**, four models were set up to run the required simulations for Phase 1. Each model is run with two alternative scenarios:

- ***Scenario A -*** Allocation A and augmentation A; and
- ***Scenario B -*** Allocation A and augmentation B;

The scenario descriptions refer to the conditions assigned to the dam inlet supply node and the minimum flow requirement. The following sections outline the key results for Phase 1 from each model.

The model is processed on a daily time step from 01 July 1980 to 30 June 2032.

3. Results

3.1 Model 1

Figure 3 outlines the key results from Model 1; the dam inlet abstractions from Ngaruroro River, the dam storage level, the augmentation demand required at Fernhill, the controlled augmentation release from the dam, and the flow of the Ngaruroro River at Fernhill.

Outlined in the first graph of **Figure 3** is the dam inlet abstraction rate. The maximum inlet capacity is 0.8 m^3/s. Slight differences are observed between Scenario A and Scenario B because of the observed difference in dam storage level in each Scenario. As seen in the second graph, the dam storage fluctuates around 4.5 Mm^3 until early 2030 for both Scenarios, when a high augmentation demand causes the dam storage level to drop to 2.31 Mm^3 in Scenario A and 1.29 Mm^3 in Scenario B.

The third and fourth graphs of **Figure 3** highlight the augmentation demand and release. Please note due to the nature of the model there is a one day offset between the augmentation demand and the augmentation release. Under both Scenarios the augmentation demand is met on the following day by the augmentation release, therefore no augmentation shortfalls are observed in Model 1. The frequency of augmentation demand and release increases over the model run, due to more frequent low flow conditions at Fernhill, with the highest frequency of augmentation observed in April 2030.

The fifth graph of **Figure 3** outlines the flow of the Ngaruroro River at the Fernhill gauge. Due to the different augmentation releases rates in both Scenarios the key differences are observed at periods of low flow, with little difference identified at high flow periods.

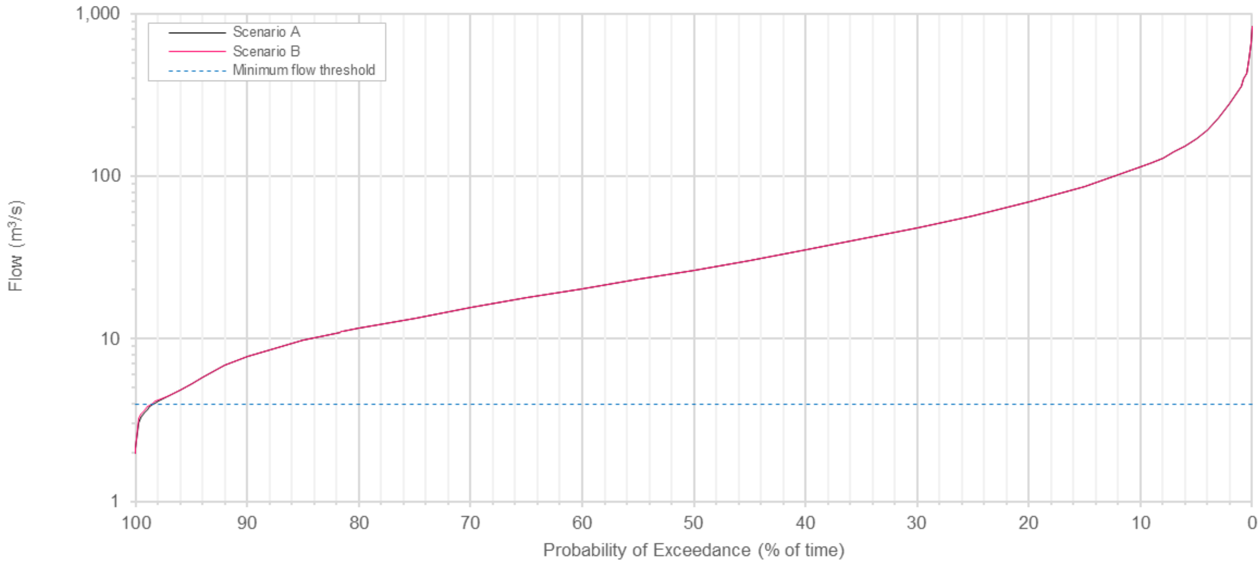
This is also highlighted in **Figure 4**, which details the flow duration curve (FDC) of the Ngaruroro River at Fernhill for Scenario A and B with the minimum flow threshold indicated. The second graph shows a closer look at the low flow periods, highlighting the difference between the Scenarios when flow drops below the minimum flow threshold of 3.97 m^3/s.

Table 2 summaries the mean daily water budget for Model 1. The purpose for providing this table is to i) demonstrate water balance closure, and ii) the relative difference between the various water balance components of each model (in a daily average sense). In both Scenarios the water budget is balanced. Scenario B has the largest inputs and outputs.

Table 2. Mean daily water budget for Model 1. All values are reported in m^3/d.

		Scenario A	Scenario B
INPUTS:	Rainfall	1,024.73	1,021.75
	River Abstraction	1,875.47	2,242.32
	Total IN	**2,900.20**	**3,264.07**
OUTPUTS:	Evaporation	1,386.91	1,385.10
	Seepage	-	-
	Augmentation Release	458.14	831.72
	Overflow	1,055.17	1,047.27
	NET change in storage	-0.02	(0.02)
	Total OUT	**2,900.20**	**3,264.07**
	IN – OUT	**0.00**	**0.00**

Figure 3. Key results from the four Scenarios configured in Model 1.



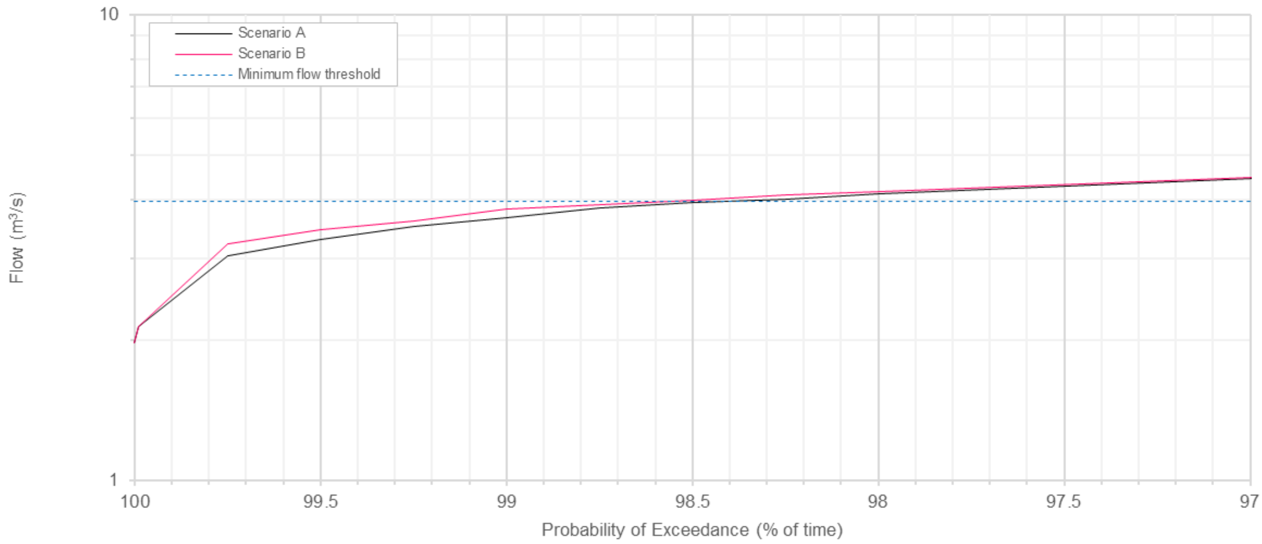


Figure 4. Flow duration curve of Ngaruroro River at Fernhill for Model 1.

3.2 Model 2

The first graph of **Figure 5** outlines the dam inlet abstraction rate. Similar to Model 1, Scenario A and B show slight differences between the abstraction rates and times as a result of the differences in dam storage level.

The storage level in both Scenarios fluctuates between 4.0 and 4.5 Mm^3 for the first 14 years. Again, in 2030, both Scenarios display a large drop in the dam storage due to high augmentation demands, with Scenario B displaying the largest drop in storage to a minimum storage value of 0.45 Mm^3, and Scenario A having a minimum storage volume of 1.42 Mm^3.

The third and fourth graphs of **Figure 5** highlight the augmentation demand and release. Again, the slight differences observed between the two graphs are a result of the one day offset between the demand and release. Neither Scenario in Model 2 fails to meet the augmentation demand at any time.

The last graph outlines the Ngaruroro River flow at Fernhill. The key differences between the Scenario runs are observed at low flow periods, highlighted in **Figure 6**. Where Scenario B has slightly higher flows during low flow periods in comparison for Scenario A.

Table 3 summaries the water budget calculations for Model 2, with both Scenario water budgets balancing.

Table 3. Mean daily water budget for Model 2. All values are reported in m^3/day.

		Scenario A	Scenario B
INPUTS:	Rainfall	1,021.91	1,016.55
	River Abstraction	2,305.86	2,978.50
	Total IN	**3,327.77**	**3,995.05**
OUTPUTS:	Evaporation	1,385.12	1,381.65
	Seepage	-	-
	Augmentation Release	888.68	1,595.27
	Overflow	1,053.99	1,018.15
	NET change in storage	-0.02	-0.02
	Total OUT	**3,327.77**	**3,995.05**
	IN – OUT	**0.00**	**0.00**

Figure 5. Key results from the four Scenarios configured in Model 2.

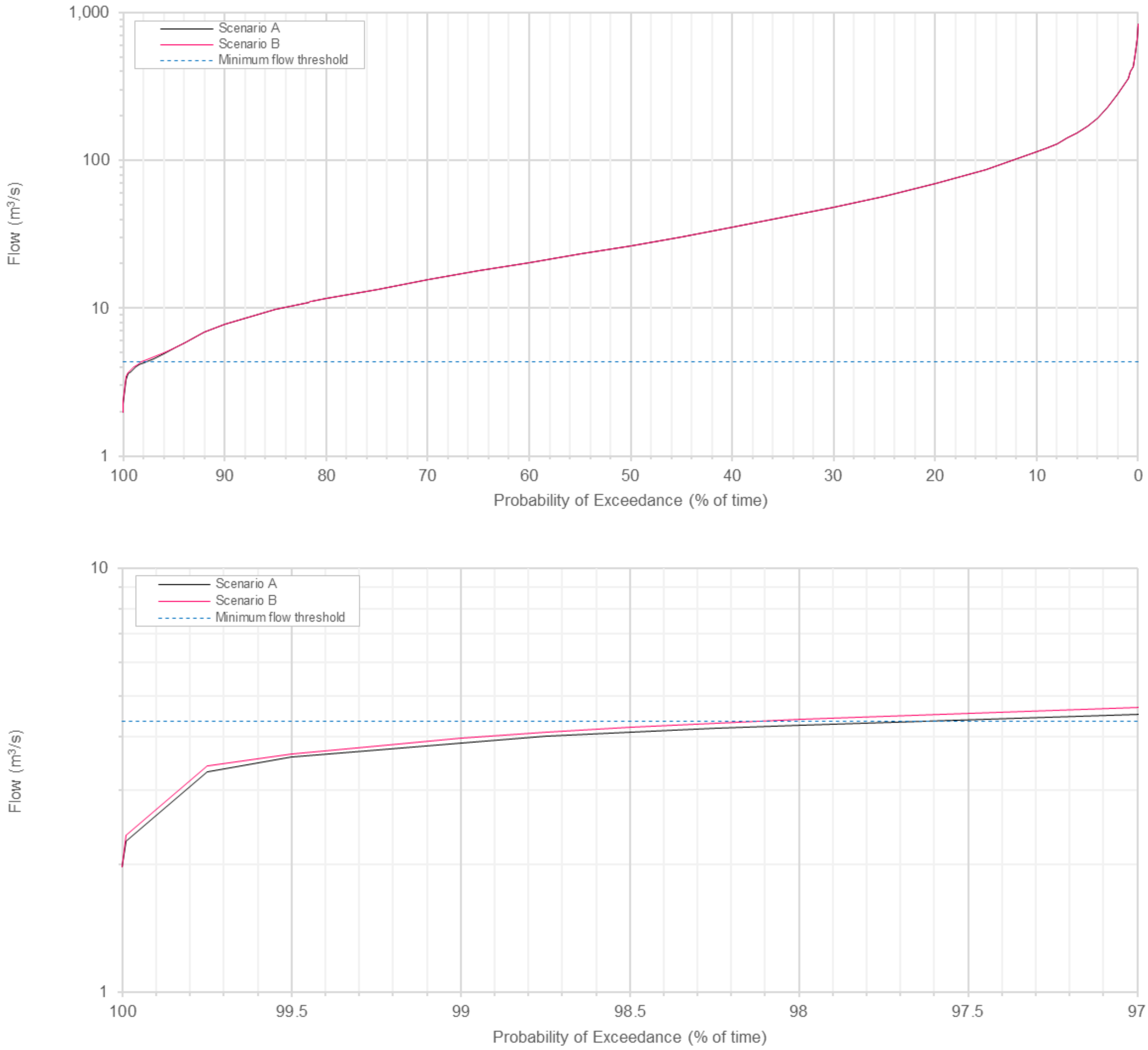


Figure 6. Flow duration curve of Ngaruroro River at Fernhill for Model 2.

3.3 Model 3

Figure 7 provides an overview of the key results for each Scenario run in Model 3. The dam inlet abstraction rates are similar to Model 1 and 2.

The dam storage level, is now fluctuating between 4.5 and 3.0 Mm^3 most of the run time, with the exception of the large storage level drop in April 2030. During this time Scenario B becomes empty. The dam is empty for a total of four day, 15 to 18 April, and becomes empty again the following month for another four days. It takes until the 5 September 2030 for the dam to reach full capacity again. Over the same time period the dam storage level in Scenario A reaches a minimum level of 0.70 Mm^3.

As a result of the dam becoming empty in Scenario B, augmentation demand is not always meet by the augmentation releases in Scenario B. Augmentation demand is not meet a total of 5 times, from the 15 - 17 April 2030 and the 17 - 18 of May 2030. During both periods the maximum short fall observed is 0.98 m^3/s, the minimum is 0.70 m^3/s. Augmentation demand is meet by the augmentation release in Scenario A.

While the above produces useful insights into the potential performance of the dam, it would be far more valuable to run a 1000-year stochastic rainfall record through the model to enable more robust statistical quantification of the supply reliability of the dam.

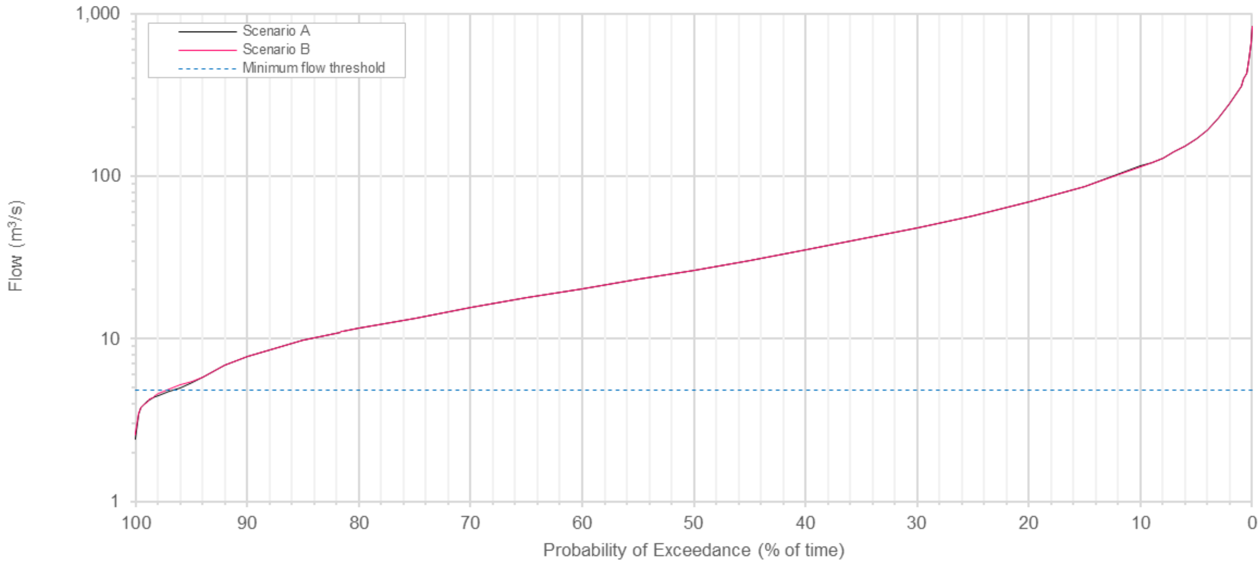
The flow at Fernhill is highlighted in the last graph of **Figure 7** and in **Figure 8**. Where the minimum flows observed in Scenario A is 2.41 m^3/s and to 2.57 m^3/s in Scenario B.

Table 4 summaries the water budget calculations for both Scenarios in Model 3. Each Scenario is maintaining a balanced water budget.

Table 4. Mean daily water budget for Model 3. All values are reported in m^3/day.

		Scenario A	Scenario B
INPUTS:	Rainfall	1,018.10	1,009.47
	River Abstraction	2,813.61	3,730.46
	Total IN	**3,831.71**	**4,739.93**
OUTPUTS:	Evaporation	1,382.56	1,376.14
	Seepage	-	-
	Augmentation Release	1,414.21	2,349.33
	Overflow	1,034.96	1,014.48
	NET change in storage	-0.02	-0.02
	Total OUT	**3,831.71**	**4,739.93**
	IN – OUT	**0.00**	**0.00**

Figure 7. Key results from the four Scenarios configured in Model 3.



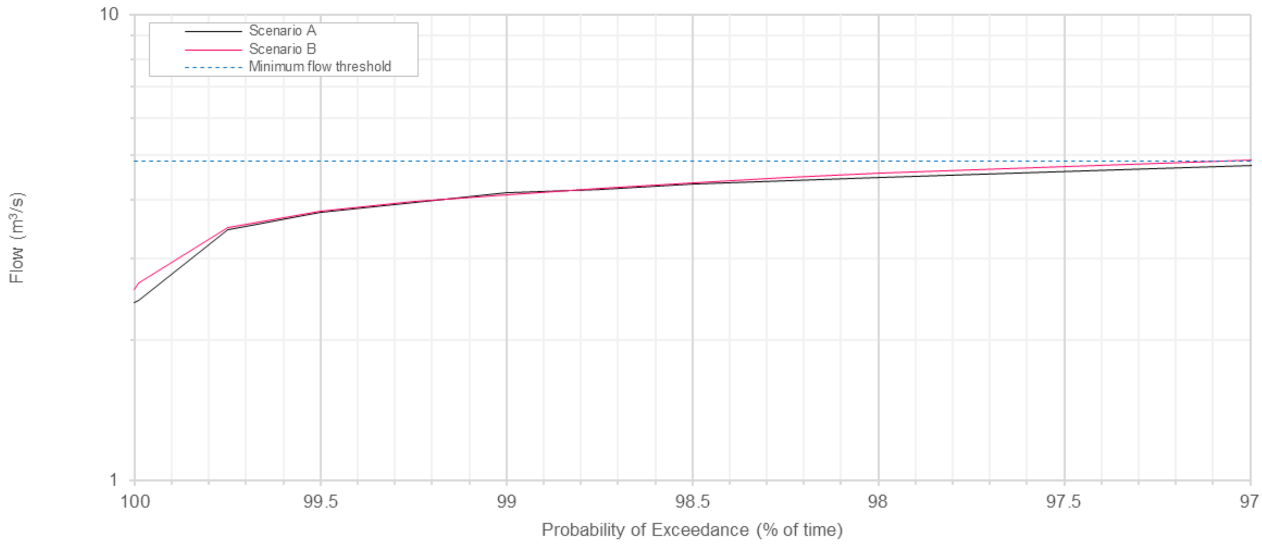


Figure 8. Flow duration curve of Ngaruroro River at Fernhill for Model 3.

3.4 Model 4

The results for Model 4 are outlined in **figure 9**. Similar to Model 3, the dam storage level in Scenario B becomes empty for 12 non-consecutive days in April and May of 2030. Consequently, the augmentation demand for this scenario is not met 9 times during this period.

This is a direct impact of the combination of abstraction condition A, and the augmentation condition B. During periods of extended low flow, where abstractions are restricted by condition A, the dam is not refilling. At the same time augmentation condition B is allowing the maximum volume possible to be released from the dam (0.98 m^3/s) whenever flow is below the minimum flow threshold, consequently preventing the dam from refilling or maintaining water.

Because the augmentation demand is not always meet in Scenario B, the minimum recorded flow of the Ngaruroro River at Fernhill, 1.59 m^3/s, **Figure 10**. The minimum simulated flow in Scenario A is 2.45 m^3/s.

Table 5 demonstrates that Model 4 is maintaining a closed water budget across both Scenario runs.

Table 5. Mean daily water budget for Model 4. All values are reported in m^3/day.

		Scenario A	Scenario B
INPUTS:	Rainfall	1,015.46	1,006.92
	River Abstraction	3,176.98	4,181.26
	Total IN	**4,192.44**	**5,188.18**
OUTPUTS:	Evaporation	1,380.53	1,373.35
	Seepage	-	-
	Augmentation Release	1,795.01	2,813.38
	Overflow	1,016.91	1,001.48
	NET change in storage	-0.02	-0.02
	Total OUT	**4,192.44**	**5,188.18**
	IN – OUT	**0.00**	**0.00**

Figure 9. Key results from the four Scenarios configured in Model 4.

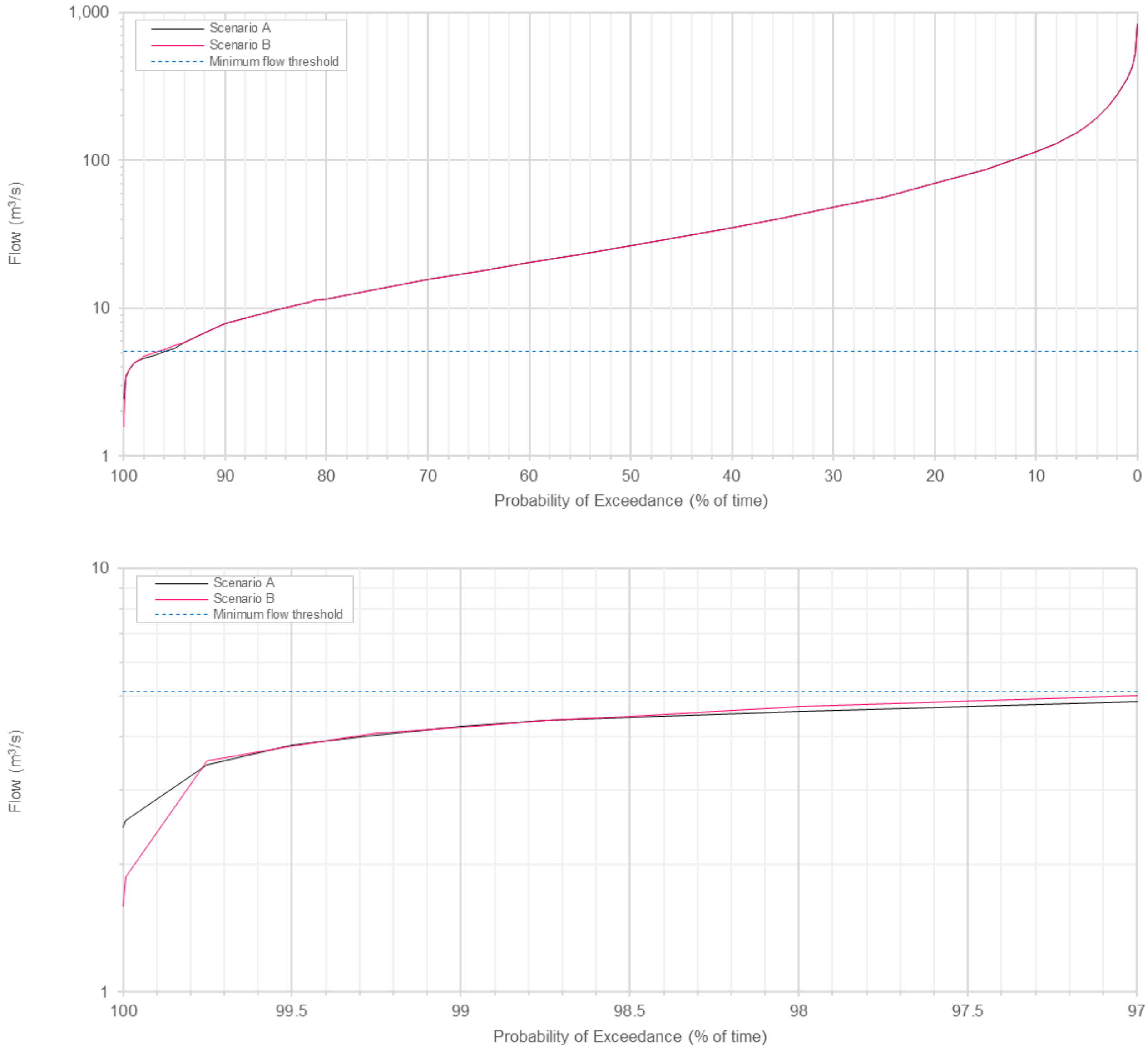


Figure 10. Flow duration curve of Ngaruroro River at Fernhill for Model 3.

4. Assumptions and limitations

Table 6 summarises the assumptions associated with the models utilised in Phase 1. There are two main assumptions that have been identified with the Phase 1 model runs. Both assumptions are considered to have minor influence on the simulation results and reliability.

Table 6. A summary of the assumptions associated with the Phase One Te Tua storage modelling.

Assumption	Description	Significance
There is no seepage from the dam	The SOURCE model would not allow a seepage relationship to be configured that reflects the movement of water from the dam to groundwater table.	Minor – an estimated calculation established that at full capacity the dam is only likely to lose 0.006m^3/s to seepage.
All dam overflows are delivered to SC 102	Any additional flows from the dam (i.e. not for augmentation purposes, such as rainfall overflow), is discharged into SC 102, where the Te Tua Dam is located.	Minor – this process does not impact the water budget of the system, and is a likely reflection of what is already occurring with the current dam development.

5. Recommendation

As indicated above, we would recommend preparing longer duration (say 1,000 years) stochastic rainfall for the SOURCE model and then re-running your preferred scenarios to enable accurate statistics to be calculated on storage supply reliability and impacts on flows.

We look forward to discussing the above results with you. If you have any question, comments, or require additional information please do not hesitate to get in touch with either of us.

Appendix A. Function Description

Table A-1 outlines the different functions set up and utilised in the various scenario simulations for the Te Tua storage scheme. The four function names in bold are the primary functions used to control the different scenarios, i.e. the abstraction conditions assigned to the supply node, and the augmentation release conditions assigned to the minimum flow requirement node.

Table A-1. Summary of the different functions used in the Te Tua Storage Scheme scenario simulations.

Name	Equation	Description	Unit
$Fernhill_Q	Modelled variable	The modelled flow generated at the Fernhill Gauge	m^3/s
$Fernhill_volume	Modelled variable	The modelled daily flow volume generated at the Fernhill Gauge	m^3
$Storage_volume	Modelled variable	The modelled storage volume of the Te Tua Dam	m^3
$GWPumping Impact	Timeseries variable	The impact of groundwater pumping on the Ngaruroro River in SC #076 (from Pawel – “FernhillFuture_GWpumpingEffect_20171212.xlsx”	m^3/s
$SC076_IrrigationDemand_volume	Timeseries variable	The daily irrigation demand utilised in SC #076. Used as a proxy for the irrigation needs under consent WP140480T. Taken from the originally supplied irrigation demand from Rob and the AquaLinc future irrigation estimates	m^3
$Fernhill_MF_Rate[2]	3.97	The Fernhill gauge minimum flow requirement	m^3/s
$Fernhill_MedianQ_Volume	1,910,908.8	The Fernhill gauge median flow (≡22.117 m^3/s)[3]	m^3
$MaxDiversion_Volume	69,120	The maximum daily volume that can be diverted from the Ngaruroro River to the dam. (≡ 0.8 m^3/s)	m^3
$Max_GWPumping_impact	0.98	The average maximum GW pumping impact – provided by HBRC	m^3/s
$MaxStorage_Volume	4,500,000	The maximum dam storage volume	m^3
$MaxStorage_Minus_MaxInflow	$Max_Storage_Volume - $MaxDiversion_Volume	When abstraction from the Ngaruroro River is required, this variable is used to restrict the abstraction so that the maximum storage capacity of the Te Tua dam is not exceeded.	m^3
$TeTuaDam_Abstract	IF($Storage_Volume <= $MaxStorage_Minus_MaxInflow ,$MaxDiversion_Volume,($Max_Storage_Volume-$Storage_Volume))	Calculation of actual abstraction from river capped at either available storage capacity in the dam or maximum diversion rate.	m3

[2] Value changes depending on the minimum flow modelling being used (refer to **Table 1**).
[3] From Rob Waldron. Measured median flow at Fernhill is 20m^3/s. To compensate for the difference between measure and modelled the equivalent median flow of the modelled data has been used – 22.117 m^3/s.

Name	Equation	Description	Unit
$HighFlowAllocation_A	IF($FernHill_Volume>=$Fernhill_MF_volume,$TeTuaDam_Abstract,0)	Condition controlling the volume of water that can be abstracted from the Ngaruroro River on the days controlled by the above function (A). If water can be abstracted the irrigation demand for that day is removed from the maximum diversion volume.	m^3
$Augmentation_to_meet_MF	IF($FernHill_Q<=$FernHill_MF_Rate,($FernHill_MF_Rate-$FernHill_Q),0)	The calculation used to determine the rate of water required to meet the minimum flow threshold of the Ngaruroro River, when Q is less than the minimum flow.	m^3/s
$Fernhill_MFR_AugmentationA	IF($FernHill_Q<=$FernHill_MF_Rate,IF($GWPumpingImpact<$Augmentation_to_meet_MF,$GWPumpingImpact,$Augmentation_to_meet_MF),0)	Augmentation condition A, where if $Q_{Fernhill}$ is less than the minimum flow the lesser of the following is released: the difference between $Q_{Fernhill}$ and the minimum flow requirement; or the volume needed to offset the impact of GW pumping (determined in the following spreadsheet – “FernhillFuture_GWpumpingEffect_20171212.xlsx”)	m^3/s
$Fernhill_MFR_AugmentationB	IF($FernHill_Q<=$FernHill_MF_Rate,$Max_GWPumping_impact,0)	Augmentation condition B, where if $Q_{Fernhill}$ is less than the minimum flow the maximum volume needed to offset the impact of GW pumping (980 L/s) is released (determined in the following spreadsheet – “FernhillFuture_GWpumpingEffect_20171212.xlsx”)	m^3/s