Bay of Plenty Regional Council
18-May-2015

Rangitāiki Spillway Optimisation




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Client: Bay of Plenty Regional Council

Co No.: N/A

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18-May-2015

Job No.: 42075348

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Quality Information

Document Rangitāiki Spillway Optimisation

Ref 42075348

Date 18-May-2015

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Reviewed by Justine Bennett

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
Rev 1	24 April 2015	Draft for Client Review	Justine Bennett	
Final	18 May 2015	Final for Issue	Justine Bennett	

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Executive Summary

Bay of Plenty Regional Council (BOPRC) has commissioned AECOM Consulting Services Ltd (formerly URS NZ Ltd) to assess alternative flood mitigation options in the Rangitāiki Catchment upstream of Reid's Spillway as part of the larger Rangitāiki Floodway Project. The aim of this project is to reduce the flows during large flood events (1% AEP) at the spillway. The objective of the work is to show whether other alternative, upper catchment options could create additional benefits for the Rangitāiki Floodway Project. A further objective is to possibly reduce the need for further structural works currently planned downstream of the spillway as part of the Rangitāiki Floodway Project.

The work has built on options that have been identified in an earlier phase of the River Scheme Sustainability Project. The peak flow over the spillway in a 1% AEP is planned to be 190m³/s under the proposed design. The aim of this assessment is to reduce the river flows upstream of the spillway which will result in reduction of flows down the floodway which has a current capacity of 95m³/s. To put this in perspective then the target objective is to reduce the proposed spillway design flood peak by up to 95m³/s, which is approximately 10Mm³ of flood water that needs to be managed. To achieve such an outcome is likely to require significant major projects or actions because of the large amount of water involved.

The approach to the assessment has been to consider the operation of Matahina dam during flood conditions and the consent rules that govern its operation. Based on consideration of these rules and alternatives the potential flood impact/benefit of diversions or dams upstream have been assessed and the benefit of flood storage areas on the lower flood plain has been quantified.

The crux of our findings is that the Rangitāiki River channel and Reid's floodway capacity is approximately 700m³/s however the controlled spill from Matahina is capped at 500m³/s. However, if inflows exceed the outflow the storage behind the dam becomes full and the higher inflows simply flow through the storage and downstream of Matahina. When these flows exceed 700m³/s this leads to flooding on the plains because the flow is greater than the 700m³/s capacity of the river and the floodway. Our primary suggestion is that the controlled releases from Matahina be modified to match downstream capacity and be activated earlier in a storm event to provide more storage in the Matahina Reservoir. Other measures to store/use flood water upstream and downstream of Matahina would provide additional security.

The results show that improved flood forecasting and the triggering of a management response earlier than occurs at present will provide an outcome in the 1%AEP event that has the flood peak contained within existing river banks and the floodway. This is achieved through lowering the water level in the Matahina reservoir to 70mRL and an increase of the rate of discharge to 650m³/s.

Applying such management techniques has a risk of failure if equipment does not record rainfall in the large event, the telemetry fails, the radar malfunctions, or the event is an exception to the conditions used in the catchment flow forecasting model. Still the same can be said for hard engineered solutions such as stopbanks. Even so it is recommended that some security is provided for failure or over design events by way of flood storage areas with bunding on the flood plain adjacent to the existing floodway and alongside the river.

Other options that have been considered fall short of meeting the overall objective but they do provide some reduction in flood peak. Our view is these are a compromise when compared to the less expensive and complete solution of controlling flood flows from Matahina Dam. However, diversion of flow from the Horomanga or Whirinaki catchments to artificially recharge groundwater in the Galatea basin could provide some reduction in the flood peak and a water source for irrigation. This is the only potential for multiple use of water so that costs can be shared. For this managed aquifer recharge the only way it could be afforded would be if there was an end user for the water.

Based on our assessment we recommend that the following be considered as a preferred approach to flood management and the recommended actions be undertaken to facilitate the establishment of the preferred options.

1) Undertake a review of the rules for flood management at Matahina Dam and confirm an operation that maximises flow in the river and spillway at approximately 700m³/s.

2) Improve the accuracy of flood forecasting with an optimised raingauge network.

3) Provide defined bunded areas to capture over design events or "failures" on the lower flood plain.

4) Consider managed aquifer recharge in the Galatea basin as part of a multiple water use project in conjunction with irrigation interests.

5) Consider consenting and mitigation requirements for land use change where it impacts the hydrologic regime and increases flood peaks such as conversion of forest to pasture to ensure that the level of service provisions for the flood control structures is maintained and not compromised by a modified runoff regime brought about with changes from forestry to pasture.

Estimated costs for the recommended options are:

- Revision of the Matahina dam operating rules and upgrading of the flood forecasting capabilities - $1M;
- Provision of flood plain bunded storage ranges from $0.86M to $4.76m depending on location and finalised bund height;
- Development of a managed aquifer recharge diversion in the Galatea basin $45.36M. While expensive for flood control it would equate to only $4,500/ha for an irrigation scheme of 10,000ha, although groundwater extraction bore costs would need to be added for irrigation.

1.0 Introduction

1.1 Purpose

Bay of Plenty Regional Council (BOPRC) has commissioned AECOM Consulting Services Ltd (formerly URS NZ Ltd) to assess alternative flood mitigation options in the Rangitāiki Catchment upstream of Reid's Spillway as part of the larger Rangitāiki Floodway Project. The aim of this project is to reduce the flows during large flood events (1% AEP) at the spillway. The objective of the work is to show whether other alternative, upper catchment options could create additional benefits for the Rangitāiki Floodway Project. A further objective is to possibly reduce the need for further structural works currently planned downstream of the spillway as part of the Rangitāiki Floodway Project.

1.2 Background

1.2.1 Rangitāiki Floodway Widening Project

The Rangitāiki Floodway Widening Project forms part of the wider Edgecumbe-Rangitāiki River Flood Mitigation Project. It includes geotechnical strengthening of the stopbank foundations on the Rangitāiki River and construction of a spillway control structure to assist with controlling flows down the Floodway.

The Floodway widening part of the project has encountered significant challenges. These include geotechnical engineering difficulties, discovery of structural weakness in the existing floodway stopbanks and the need to raise low-level Floodway stopbanks that were not in the original scope of work. Together this has significantly increased the scope and estimated cost of this part of the project.

The major works involved in widening the lower reach of the Rangitāiki Floodway commenced during 2011-2012 and progressed well with approximately 1,300 lineal metres of the Floodway widening completed that year. Then during 2013-2014, 2 kms of stopbank work and 1500 linear metres of channel widening was completed. The length of completed work was shorter than planned as geotechnical challenges were still being resolved for part of the 2013-2014 works section. This financial year physical works are continuing upstream of completed works with an additional 1600 linear metres of stopbank and 700 linear metres of channel widening works currently underway.

1.2.2 River Scheme Sustainability Project

BOPRC is responsible for the sustainable management of water resources from groundwater and surface water systems. The BOPRC has initiated the River Scheme Sustainability Project (RSS) which is looking at alternative flood management methodologies for the five major river and drainage schemes operated by BOPRC. One of the high priority catchments is the Rangitāiki Catchment due to the planned capital expenditure.

The RSS incorporates four phases; vision, investigation, analysis and framework. The project is currently in Phase 2. This is the investigation phase in which information knowledge; concepts and key foundations are being established and investigated at a high level.

Phase 3 will interrogate any of the investigatory work streams to provide more detail and a higher level of confidence as required, including the optioneering ideas gathered in Phase 2. An ecosystem services workstream will also be added to facilitate whole of catchment decision making for flood mitigation.

Phase 4 will provide a 100 year framework and guide the management of river schemes, feeding into the Rivers and Drainage Schemes Asset Management Plan, Ten Year Plan, annual works programs and management programs.

1.3 Scope of this Project

The optioneering investigation for the RSS has identified 37 possible soft and hard engineering options. The goal of this assessment was to consider these 37 options and develop feasible alternative catchment wide solutions to reduce peak flood flows at the Rangitāiki Floodway. At present the floodway can carry 95m^3/s which is 95m^3/s less than the proposed design. The flow over the spillway in a 1% AEP is planned to be 190m^3/s under the proposed design. The aim of this assessment is to reduce the river flows upstream of the spillway reducing flows down the floodway which has a current capacity of 95m^3/s.

BOPRC is looking for catchment wide options to reduce the peak flood flows at the spillway. The reduction may occur through a single option or a combination of multiple options. A range of options and alternatives were considered (but not limited to the 37 options identified previously). A combination of options can be used to achieve desired results and the generic options which have been identified by the RSS Project to date need to be further assessed. Options to enhance already existing structures and other alternative engineering options are to be included. The location of the hard and soft engineering options were to be identified and an assessment of the effects to be carried out in terms of advantages and disadvantages of each option.

To put this in perspective the target objective is to match the current flood way capacity of $95m^3/s$ and this means reducing the flood peak by up to $95m^3/s$, which is approximately $10Mm^3$ of flood water that needs to be managed. The volume has been derived from the flood hydrograph. To achieve such an outcome is likely to require significant major projects or actions because of the large amount of water involved.

2.0 Approach

2.1 The Objectives

The objectives of this project are to investigate options that could reduce overflows to Reid's Floodway. This essentially means that a flow reduction of 95m^3/s would be required to eliminate the need for any upgrading of the Floodway.

2.2 1% AEP Flood Event

The objectives require that the 1% AEP event is used as the basis for any assessment. For this work the July 2004 major flood event has been used as the test case for the options analysis. This event is considered to reasonably represent the 1% AEP event and is available as a calibrated catchment model. The peak flow is 804m^3/s.

2.3 Matahina Dam

Matahina Dam is currently part of the flood management within the catchment and is a critical node where the flow regime is modified by the storage at the dam. It is the most downstream of three dams in the catchment and as such it is the critical node for flood control. It is the subject of consent conditions for its operation and so any consideration of options for flood management need to be undertaken along with the operation of Matahina dam and any proposed changes to the operating rules.

For this assessment of flood management options Matahina dam has been selected as a dividing point in the catchment. Upstream of Matahina the focus is on options addressing peak flow. Downstream of Matahina dam the focus is on peak flow reduction and the management of flood water levels.

2.4 The Analysis

To manage floods there are a limited number of broad actions that can be taken. These are:

- Diversion to remove water from the catchment to reduce flood impact;
- Detention to hold back some of the runoff so that the flood peak is reduced;
- Retention which is similar to diversion in its effect and holds water within the catchment to reduce the flood peak;
- Containment which involves establishing barriers to constrain the extent of any flooding, such as with stopbanks;
- Land purchase and leasing of floodable areas;
- Planning controls that focus on runoff generation or the application of the controls listed above; and
- Financial instruments such as insurance and compensation.

For this analysis these broad areas of flood management have been applied in terms of the RSS identified options and then further refined in terms of actions as outlined in Table 2.

2.4.1 The RSS Options

The relationship to previous work on the RSS and the extent of analysis done as part of this assessment are provided in Table 1.

Table 1 Options Review

No.	Option	Potential Opportunities	Detailed Analysis
1	New Dams	The potential for impounding structures for multiple uses resulted in no strong candidates being identified because of storage volume limitations.	No
2	New dams (temporary flood flow storage structures)	A number of sites considered.	Yes

No.	Option	Potential Opportunities	Detailed Analysis
3	Flood gates at headwaters	Option irrelevant for 100yr flood as volumes too large.	No
4	Detention Zones Temporary Flood Flow Storage	Areas of floodplain considered.	Yes
5	Flood Zones	Similar to 4.	Yes
6	Bunding (including floodplain storage bunds, slow release)	Similar to 4.	Yes
7	Alternative river alignment	Downstream of spillway so out of scope.	No
8	Interceptor channels with diversions	Considered along with flood plain assessments under 4.	Yes
9	Inter -catchment transfers	Considered for upper catchment plateau region and on lower flood plain.	Yes
10	Turning pasture to ecotourism, wetland, forestry or aquaculture etc.	Not likely to significantly impact large flood flows. Similar to 4 or 11 from an analysis perspective.	No
11	Land-use Controls (including land and soil management practices along river)	Forest v pasture runoff considered in relation to land use change. Impact of vegetation on river volumes addressed.	Yes
12	Managed retreat	Considered in relation to 4 from an analysis perspective.	Yes
13	Bio-mimicry Solutions	Unlikely to impact larger floods significantly but applied to concept design in relation to river regime modification at diversions.	No
14	Repositioning of stopbanks	A lower river option so out of scope other than considerations of spilled flows upstream of Reid's.	No
15	Ecological corridors	Unlikely to impact larger floods significantly.	No
16	Flood storage wetland / Wetland Restoration	Similar to 4, 5 or 6 from an analysis perspective.	Yes
17	Pump station improvements	Unlikely to impact larger floods significantly as focus is smaller more frequent flood events.	No
18	Woody debris	Similar to 13 and 15.	No
19	Natural Flood Management	Similar to 4, 5 & 6 from an analysis perspective.	Yes
20	Channel Improvements with multipurpose use	Diversion options and floodplain storage alternatives considered.	Yes
21	Slowing the Flow (through land management practices)	Much of the catchment is in forest so more forest will have negligible impact on slowing flow. Increasing vegetation on flood plains will only provide minimal additional storage.	No
22	Agricultural and upland drainage modification	None as irrelevant for 100yr flood volumes.	No
23	Removal of obsolete structures	None as irrelevant for 100yr flood volumes.	No
24	Modify or enhance structure (dam raising)	Only in relation to dam raising at Matahina. Aniwhenua was considered impractical and likely to provide minimal benefit. It would be similar to the new dam considered between Matahina and Aniwhenua. Wheao dam is in the Upper catchment and analysis indicates that any flow attenuation in that subcatchment has minimal impact of flood flow downstream of Matahina dam.	Yes
25	Sediment Management	Not significant because any sediment option would only work if Matahina Dam is removed. Alternative would be artificial	No

No.	Option	Potential Opportunities	Detailed Analysis
		replenishment with sediment mined from upstream sources.	
26	Wave energy dissipation	Out of scope.	No
27	Dredging of lower river/estuaries	Out of scope.	No
28	Policy (Insurance policy to cover flood damage)	Possible but needs to be considered as part of 4, 5 & 6 from an analysis perspective.	Yes
29	Flood Risk Management	Similar to 4, 5 & 6 from an analysis perspective.	Yes
30	Gravel Management	No as unlikely to be significant in the 100yr event but is part of ongoing operations as will have impact of water levels.	No
31	Managed Groundwater / Aquifer Recharge(MAR)	Potential in Galatea basin.	Yes
32	Land use change	Forest v pasture runoff considered in relation to land use change. Impact of vegetation on river volumes addressed. Similar to 11.	Yes
33	Higher Stopbanks	Lower river option so out of scope except for consideration of 4, 5 & 6.	Yes partial
34	Landownership /Lease back	Similar to 4, 5, 6, 28 & 29.	Yes
35	Flood Compensation	Similar to 4, 5, 6, 28 & 29.	Yes
36	Room for the River	Out of scope as requires lower river consideration.	No
37	Reduction in Level of Services	Not considered as other alternatives exist.	No
38	Matahina Operation Rules	Significant benefit possible.	Yes
39	Integrated early warning system	Considered as part of 38.	Yes

The refinement of these options into analysis scenarios, then further into options and specific analysis actions are tabulated in Table 2.

Table 2 Analysis Scenarios

Scenario	Option	Action
A - Planning Controls & Financial and purchasing instruments	Land use	Hydrologic modelling with land use change - pasture and exotic forestry only. Test case in the upper catchment.
	Defined flood compensation areas	Designated (bunded) flood zones – only with respect to upstream of Reid's spillway. Suitable lease back areas or compensation for flooding.
	Building exclusion zones	Defined flood extent areas - only with respect to upstream of Reid's spillway. Suitable lease back areas.
B - Containment	Defined spillway(s)	Identify one of more spillways upstream of Reid's including consideration of combination with spill and bunded areas.
C - Detention	Existing Dam raising	Model storage increase options and also link with operational control for relevance.
	New Upper catchment dam	Model storage upstream of Murupara.
	New dam between Aniwhenua and Matahina	Not much different to increasing Matahina storage.

Scenario	Option	Action
	New dam below Matahina	No hydro or irrigation interest so would be very expensive just for flood control.
	Single sub catchment dam	Model major sub catchment potential dams.
	Multiple sub catchment dams	Model potential smaller dams in combination.
D - Retention / Diversion	Managed Aquifer Recharge	Model diversion flows that could be used for groundwater recharge in the Galatea basin.
	Diversion	Model water diversion in upper catchment.
E - Operational control	Flood forecasting	Consider physical drawdown limitations and then model existing and alternative operational rules.

3.0 Matahina Dam

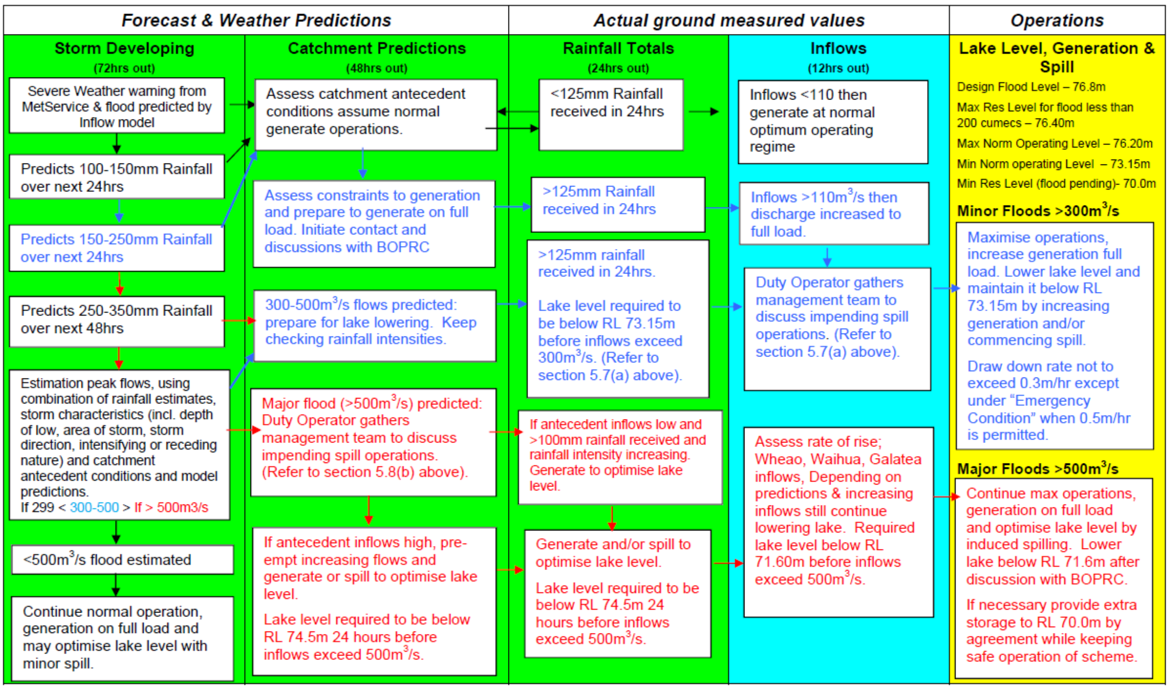
3.1 Introduction

The first stage of our assessment considers Matahina Dam consent rules, develops an insight into the critical operating variables, reviews the performance of the dam operation during the July 2004 event and determines if rule modifications would be appropriate. Treating Matahina Dam as a starting point is essential as it is a critical node within the catchment and is controlled so can provide proactive control measures.

3.2 Matahina Operating Rules

Figure 1 summarizes the Matahina Dam operation rules during a flood event. It is dependent on the forecast of rainfall in relation to 100mm, 150mm and 250mm storm rainfall thresholds. If between 100mm and 150mm of rainfall is forecast then the boxes with black lettering are followed. If rainfall is forecast between 150mm and 200mm then the boxes with blue lettering are followed. For a rainfall prediction of more than 250mm then the boxes with red lettering are followed. Once the rainfall criteria have been assessed then flow criteria of 300m^3/s and 500m^3/s come into play as thresholds for decision making.

Figure 1 Derivation of Minor or Major Floods



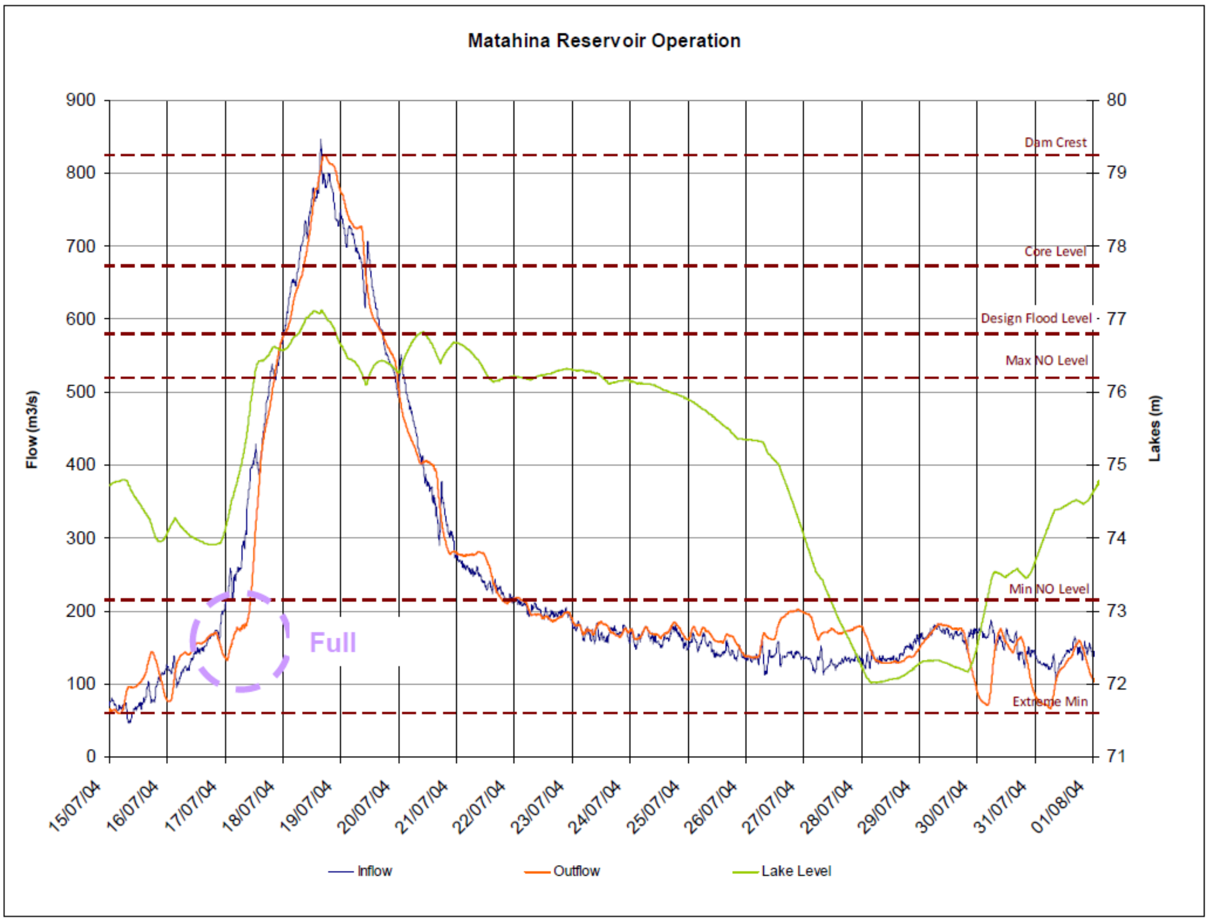
Source: Lake Matahina Flood Management Plan, TrustPower Ltd, January 2014.

3.2.1 Rule Analysis and the July 2004 Storm

To assess the rules we have taken the actual storm event records for the July 2004 event and assumed that they could be forecast as they occurred. The analysis determined the first time a rain depth of 100mm, 150mm and 250mm occurred in the following 24hrs and 48hrs as this is part of the decision process to determine if a blue or red lettered box track needs to be followed.

The analysis showed that the 100mm rain depth could have been predicted over 48hours before the flood peak time. This would trigger the blue path for flood management. For the red pathway to be triggered 250mm had to be predicted. In terms of the storm records from 13 raingauges only one had rainfall exceeding 250mm although 2 others had rainfall exceeding 247mm. Most rain gauges indicated that the blue pathway should have been followed in the July 2004 event. This was in fact the case but these actions did not have the required outcome of controlling the flood peak as shown in Figure 2. It shows that water level increases to over 77mRL and flow peaked at over 800m^3/s. The rule does not appear to be effective in a 100 year event.

Figure 2 Matahina Reservoir Operation



To have achieved the desired flood control during the July 2004 event a lower rainfall threshold trigger for blue and red pathway action is required and flow thresholds need to be revised. This would release water earlier and at a higher rate and so limit the flood peak.

3.2.2 Rule Review

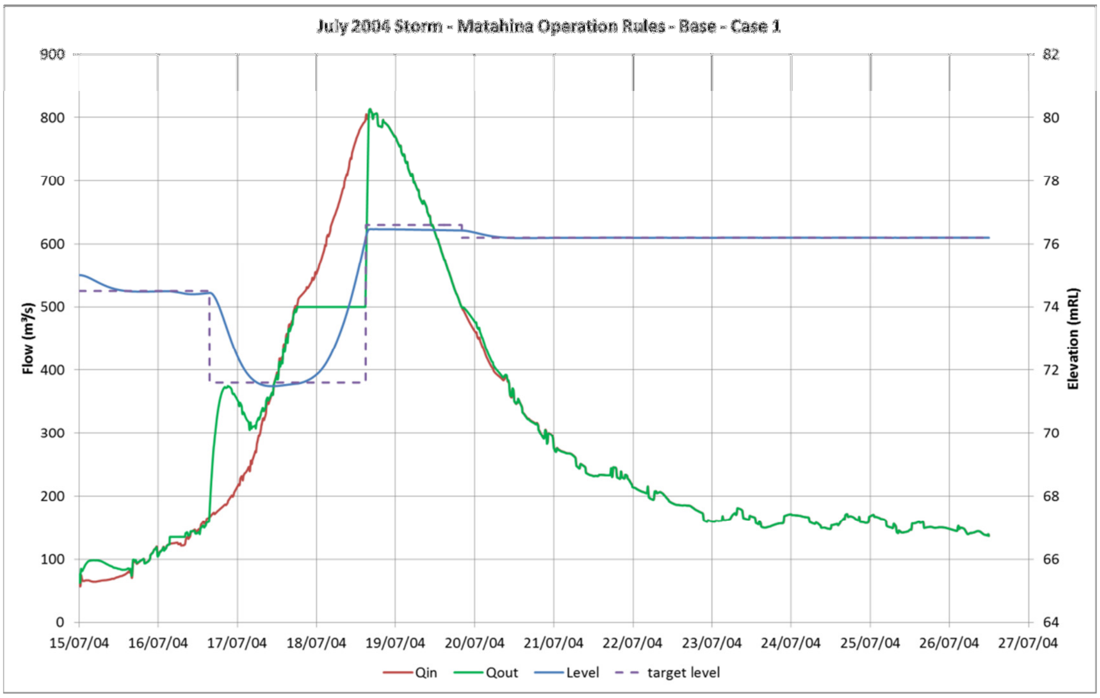
Based on the observations relating to the July 2004 event our analysis has considered the application of a red pathway scenario assuming that rainfall thresholds are lowered and rainfall is predicted with a degree of accuracy. The changes considered are the water level thresholds in the reservoir which trigger action to be taken and the discharge to be permitted. We have applied the rule that triggers the outflow of 500m^3/s but also added one that allows over 600m^3/s to maximise the river capacity to carry floods. The 600m^3/s has been selected because that is the threshold for Reid's spillway to start operating, and reflects the flow capacity on the lower Rangitāiki River. These are summarised in Table 3 showing the 5 cases that are used in subsequent analysis with the combination of maximum outflow and lowered water level limits. The lower water level has been limited by engineering constraints but we understand that it could be possible to lower the water level threshold to less than 70.0mRL.

Table 3 Rules for Each Option

	Max Outflow	Lower
	m³/s	mRL
Case 0	No rule; Q in = Q out	
Case 1	500	71.6
Case 2	500	70.0
Case 3	Variable (Optimum)	71.6
Case 4	Variable (Optimum)	70.0

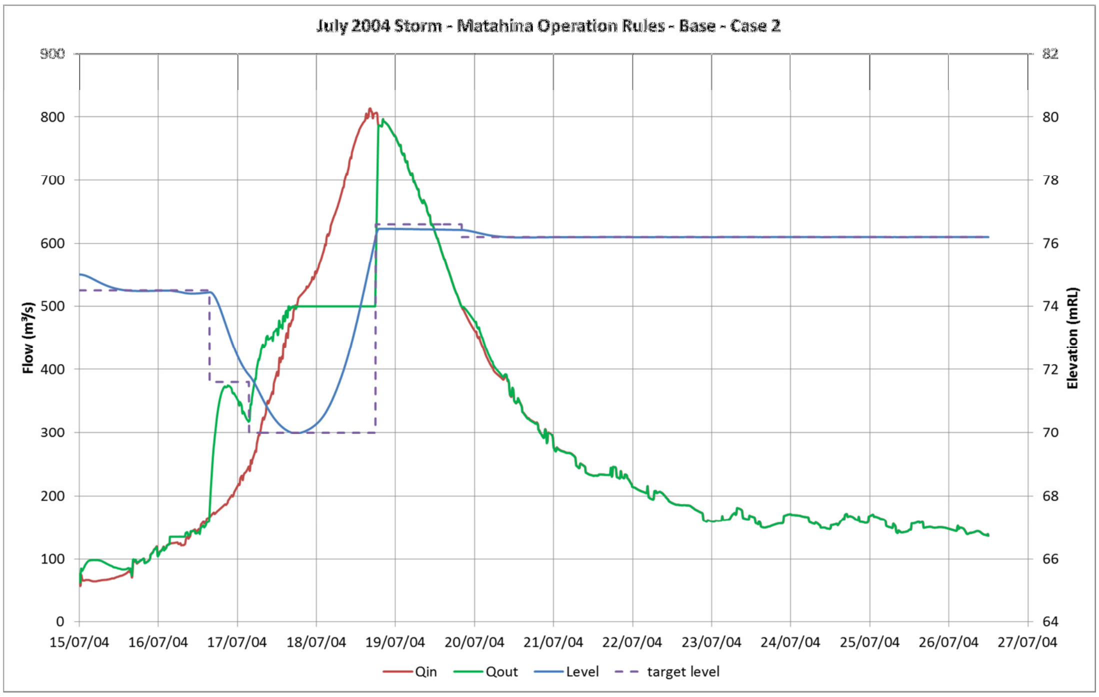
The results of the different cases are shown in Figure 3 to Figure 6 and Table 4. The red pathway is followed for all cases. In Figure 3 the inflow and outflow are virtually the same, with little impact on the flood peak, so the flood management rules have had no significant impact at a threshold of 500m³/s. The changes are triggered at times based on the assumptions used in the modelling and based on the management plan. In this case they are instantaneous changes in the model but would be more gradual in reality during a flood event.

Figure 3 Case 1 (Q_{max}=500m^3/s, Lower lake level=71.6m)



Allowing the water level to be lowered to 70mRL in Case 2 has a minor impact on the flood peak with some lowering and offsetting of the time of occurrence but the impact on the flood peak does not meet objectives and is very little different to having no rules at all.

Figure 4 Case 2 (Q_{max}=500m^3/s, Lower lake level=70.0m)



By increasing the flow that can be discharged to 645m^3/s, sooner during the storm event in case 3, the peak outflow is significantly less than the inflow as shown in Figure 5 where the peak outflow (green line) is well below the peak inflow (red line).There are further improvements in case 4 by also allowing a lowering of the water level to 70mRL as shown in Figure 6 where the peak discharge is only 615m^3/s.

Figure 5 Case 3 (Q_{max}=variable, Lower lake level=71.6m)

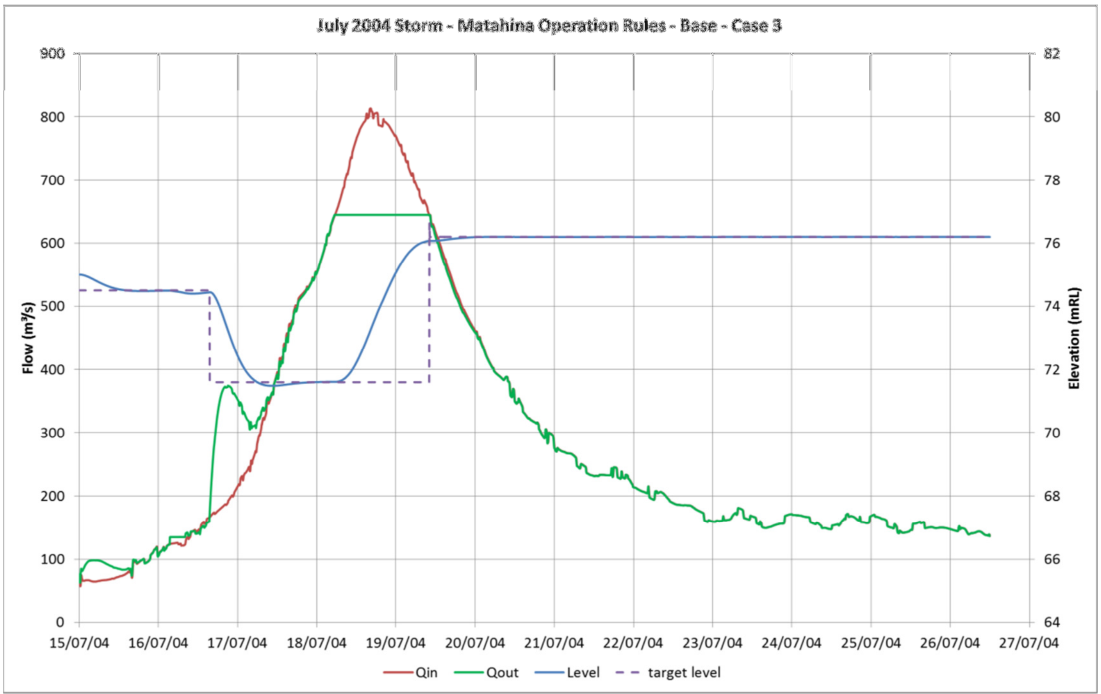
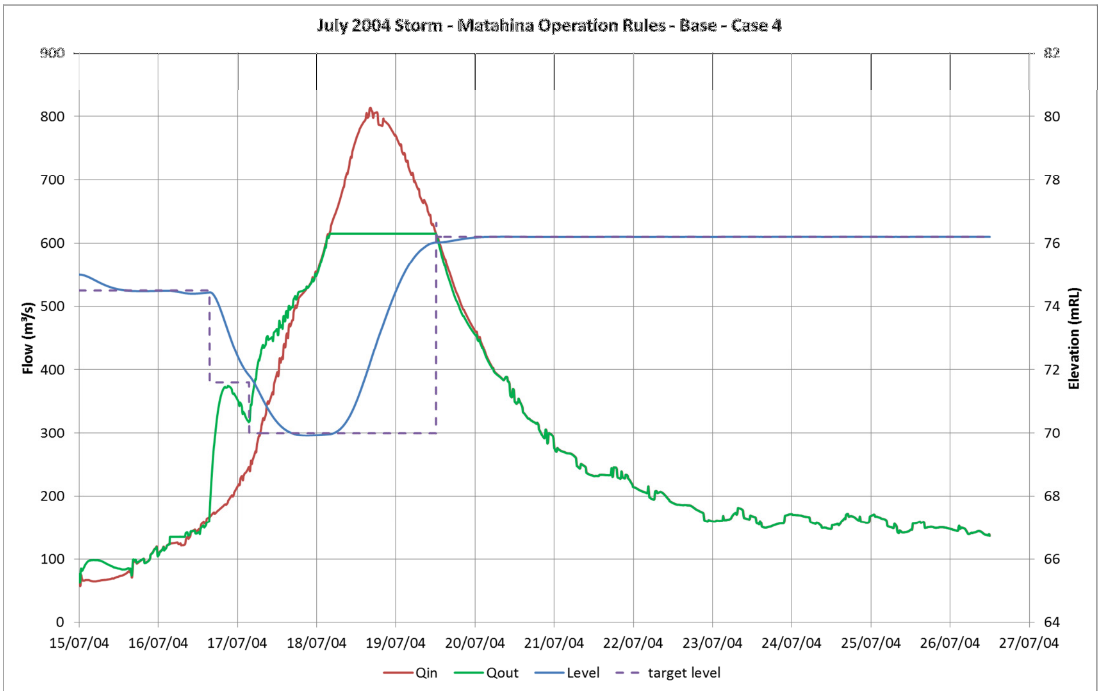


Figure 6 Case 4 (Q_{max}=variable, Lower lake level=70.0m)



The results of the 4 cases are summarised in Table 4 and show the peak outflow and the reduction in peak outflow. The results indicate that in the July 2004 flood event, had it been managed with the rules for cases 3 and 4, then there would not have been flow over Reid's spillway. Flood management with either earlier intervention and / or lower water levels could increase storage availability and therefore allow more attenuation of the flood peak.

Table 4 Results of Cases 1 to 4

	Qmax	Lower	Peak Inflow	Peak Outflow	Reduction
Case 1	500	71.6	8130	8130	0
Case 2	500	70.0	8130	796.0	-17
Case 3	645	71.6	8130	645.0	-168
Case 4	615	70.0	8130	615.0	-198

Each of the 5 cases have been assessed against the proposed options for flood control that are considered in the following assessment to compare benefits between the options and against the rules for operating Matahina during a flood event.

It should be noted though that while there was flow over Reid's spillway in the 2004 event, the major cause of the flooding was due to a breach of the stopbank. Although optimal operation of Matahina dam in a 2004 like event can reduce peak flows downstream, there is no guarantee that failure will not occur. Strengthening of main river stopbanks and a control mechanism to allow spill to Reid's floodway at lower flow peaks is prudent to provide a margin of safety and other operational options to reduce flood risk.

4.0 Rangitāiki Option Analysis and Modelling

4.1 Base Scenario

To assess the differences between and the benefits of the proposed options a base scenario is used to provide the benchmark. The base scenario is the calibrated Rangitāiki event of July 2004. To facilitate comparison between each of the options the operational rules for the Matahina and Aniwhenua dams are held constant and set as:

- Matahina Dam: Outflow = Inflow; water level = 75.7Mrl;
- Aniwhenua Dam: Outflow = Inflow; water level = 146.3mRL.

The impact of each option is assessed by comparing the hydrographs downstream of the Matahina Dam.

4.2 Options

The options that have been considered are listed in Table 5 with the option numbering included. They reflect the scenarios listed in Table 2.

Table 5 Options

Upstream of Murupara	Whirinaki Catchment	Horomanga Catchment	Mid catchment Storage	Lower Rangitāiki Flood Plain
1a – Diversion out of the catchment (D)	2a – New dam (C)	3 – New dam (C)	4a – Matahina raising (B)	Zone 1 – Additional spill zone (A, D)
1b Land use changes – pasture/forest (A)	2b Managed aquifer recharge weir (D)		4b – New dam d/s Aniwhenua (C) (similar effect would occur if Aniwhenua dam was raised)	Zone 2 – Multiple spill points (A, D)
1c New Dam (C)	2c Managed aquifer recharge gate (D)		4c – New dam d/s Matahina (C)	Zone 3 – Multiple compartments (A, D)
	2d Managed aquifer recharge flow control (D)		4d – Multiple sub catchment dams (C)	Zone 4 – Left bank storage (A, D)
			4e – Matahina Flood rules (E)	Tarawera Diversion (D)

Details of each of the options are described in detail in Appendix A for the Upper Rangitāiki and Appendix B for the lower Rangitāiki. Dam and reservoir details are provided along with a map of location including the extent of the impoundment, and the comparative hydrographs of inflows and outflows. For most of the new proposed dams the storage volume required is only sufficient for flood attenuation. In the lower flood plain bunding location and extent is provided on a map along with the diversion channel.

4.3 Optioneering Analysis Upper Rangitāiki Catchment

The analysis has been undertaken comparing each of the options in Table 5 against the base scenario case with the 5 different operating rules at Matahina. An extensive explanation of each option by case is described along with summary tables and graphs of inflows and outflows at Matahina are given in Appendix A.

The results are summarised in terms of the impact on peak flows in Table 6.

Table 6 Upper Rangitāiki Options – Peak flow reduction downstream of Matahina Dam.

Option #	Option Description	Case					Comment
		0	1	2	3	4	
		Base	500m^3/s & 71.6 WL	500m^3/s & 70.0 WL	600+m^3/s & 71.6 WL	600+m^3/s & 70.0 WL	
		m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	
1a	Out of catchment diversion u/s of Murupara	-20	-20	-41	-188	-218	
1b	Land use change u/s of Murupara						Range +65m^3/s for grass to -15m^3/s for forest
1c	New dam u/s of Murupara on Rangitāiki						Negligible benefit because of slow catchment response
2a	New dam on Whirinaki	-87	-102	-142	-213	-218	
2b	Galatea MAR – weir control	-82	-87	-116	-232	-263	
2c	Galatea MAR – gated optimised flow	-59	-67	-112	-228	-258	
2d	Galatea MAR – hydrograph control	-106	-114	-142	-248	-258	
3	Horomanga Dam	-38	-67	-112	-228	-258	
4a	Matahina Dam raising		-100 (5m raising)	-100 (4m raising)	-200 (2m raising)	-230 (2m raising)	Significant raising required for marginal benefit plus other alternatives provide more benefit
4b	New Dam downstream of Aniwhenua	-58.0					Better dam options so not considered further
4c	New Dam below Matahina Dam	-83.0					Better dam options so not considered further
4d	Multiple Sub-catchment	Varies up to 200m^3/s depending on storage (assumed off line volumes)					Range from 1 to 50 dams tested. Does

Option #	Option Description	Case					Comment
		0 Base	1 500m^3/s & 71.6 WL	2 500m^3/s & 70.0 WL	3 600+m^3/s & 71.6 WL	4 600+m^3/s & 70.0 WL	
		m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	
	Dams						not include on line routing storage requirements – only hydrograph volumes
4e	**Matahina Operation Rules Analysis**	**0**	**0**	**-17**	**-168**	**-198**	Base case with no other options

4.3.1 Matahina Operation

As outlined in section 3.2.2 and highlighted as Option 4e in Table 6 there is a reduction in peak outflow of 198m^3/s if the outflow limit from Matahina is increased, the time of the release occurs closer to the start of a storm event, and the amount of flood storage in the dam increased by early lowering of water levels to 70mRL (even lower might be possible to improve things even further). This outcome means that virtually no water will over top the spillway into Reid's floodway because the flow would be reduced to approximately 600m^3/s which is the approximate capacity of the Lower Rangitāiki river channel.

Given this benefit that can be accrued by modifying dam operating rules and improving flood forecasting all other options need to provide a similar benefit under the base case with no intervention (Case 0) to warrant further consideration as a standalone flood control measure. However, multiple use options for best use of the water resource in the catchment need consideration especially as they provide an element of risk management should flood forecasting for Matahina Dam rule management prove inadequate in a particular event.

4.3.2 Upper Murupara Subcatchment

Three options have been considered as potential options for flood management in the catchment. None of these options are significant in providing flood management.

Diversion (1A)

A diversion of 20m^3/s from the catchment would require an expensive tunnel to the Middle Waikato catchment and the benefits are similar to option 4e so there is little to be gained in terms of flood management by diverting headwater runoff. The impact is negligible because runoff in the sub catchment is delayed flow from high infiltration of rainfall into the soil and retention as the runoff travels through shallow groundwater to the river. It acts like its own natural detention area and because it delays flow to the lower catchment the main flood peak in the rest of the catchment has long passed when upper catchment flow arrives at Matahina.

Dam (1C)

A potential dam site has been considered upstream of Murupara but it has even less impact than the diversion flow that had been considered so this option has not been taken forward as a viable alternative.

Landuse (1B)

Land use management can impact flood runoff as pasture and exotic forest land use have different runoff characteristics. Conversion to pasture increases runoff and to forest runoff decreases as the trees mature. Very large areas are required to change to effect a significant change in catchment runoff. However, consideration of an extreme land use change to a mono culture did not result in a change in runoff sufficient to provide adequate flood management improvements. Consideration of a conversion to a mono culture indicates that an all pasture environment would increase runoff by up to 65m^3/s while complete mature forest cover would decrease flood peak runoff by 15m^3/s. Clearly land use control is not an option as a flood control solution for the Floodway proposal but it is an issue for ongoing flood management and the performance of flood control measures. The assessment indicated that a gradual change in land use will change the flood regime to the extent that design

levels of service could be compromised, particularly with conversion of forest to pasture. Mitigation measures, similar to that required for urban subdivision runoff effects, may need to be considered to maintain the flood protection levels of service in the catchment. A land use change to pasture would mean that Reid's spillway would operate more often and the level of service would decrease slightly. Consequently an economic benefit from land use change would be a financial cost elsewhere in the catchment. Planning control measures to maintain hydrologic neutrality are recommended or alternatively a mitigation / fee structure developed for the creation of flood management impacts.

4.3.3 Flood Control Dams (2a, 3, 4b)

A number of storage improvement options have been considered; raising Matahina, creation of new dams upstream and downstream of Matahina, and construction of new dams on the Whirinaki or Horomanga Rivers. Each of these options provides some improvement for flood management. If there is no change in the operation of Matahina the level of flow reduction is between $38m^3/s$ and $87m^3/s$ which is less than 50% of the flow reduction required to eliminate the need for an upgrade to the Floodway. With changes in the rules for Matahina dam operation each option does provide some improvement over just the rule change outcome but this then means that the lower river channel carrying capacity, of $600m^3/s$, would not be maximised and there is little point providing something that is not needed, unless benefits are accrued for over design events; greater than the 100 year event. Further the assessment has maximised the available storage for flood control so there is little further opportunity to consider a high degree of retention.

In addition to the single large flood control dams consideration of multiple smaller dams has been considered. Assuming that the stored volume equates to a similar reduction in runoff then it is possible if the dam sites could be located then up to $200m^3/s$ could be reduced from the flood peak. The number of dams required with an average volume has been determined for a range of flow reduction targets. The reality of these dams performing to the extent required is low because any of the dams that are located in an on line situation would require coordination and a larger storage volume to be effective.

4.3.4 Galatea Basin Managed Aquifer Recharge (2a, 2b, 2c)

Three alternative approaches to diverting flood runoff to groundwater through a managed structure have been considered. Depending on the configuration and infiltration rates approximately 100ha of land would be required. The area has been derived from a sensitivity analysis of different infiltration rates and flow routing. The selective capture of flow across a centralised part of the flow range that leaves peak flow and frequent small flood flows in the river to maintain river regime characteristics appears to be the most significant in terms of improving flood management.

However, before such an option could be considered detailed understanding of the groundwater environment is required and an alternative water use such as irrigation would be required to assist with the funding of such a scheme. Assessment of irrigation demand in the Galatea basin in previous studies has indicated some $17Mm^3$ of storage per season is required on average. An assessment of the groundwater regime would be required to ascertain the feasibility of meeting this requirement through an MAR scheme. Further the economics for irrigation would need reconsideration as a MAR scheme involves pumping. Previous scheme concepts have been based on dams with stored water that is gravity supplied through a canal system.

An alternative to the MAR approach would be to establish a water harvesting network of smaller storages. These are considered elsewhere in this report. A larger area would be required compared to an MAR infiltration zone and much storage would be required to ensure effective flood control. Further it would be a distributed management system that may be more difficult to manage.

4.4 Optioning Analysis - Lower Catchment

4.4.1 Analysis of Upper Catchment Hydrographs in the Lower Rangitāiki

The hydrographs from the cases assessed through the Matahina Dam have been applied to the Lower Rangitāiki flood plain to identify the flow split between the river and the flood way flow. The flow upstream of the spillway, the flow in the river downstream of the spillway and the floodway flows are provided in Table 7. The table indicates that by changing the management rules at Matahina Dam will by itself provided the desired outcome with no flow in the floodway. Diversion of flows in the Galatea Basin to groundwater through managed aquifer recharge would also go very close to achieving the same outcome with relatively small contained flow in the floodway.

Table 7 River and Floodway Flows

Event	Peak flow Rangitāiki River U/S Spillway	Peak flow in Floodway	Peak flow in Rangitāiki River D/S Spillway
	m^3/s	m^3/s	m^3/s
Base Case 0	827	157	670
Base Case 1	803	141	662
Base Case 2	781	126	665
Base Case 3	691	67	624
Base Case 4	662	42	622
Murupara diversion Option 1, Case 0	810	147	664
Whirinaki Dam Option 2a, Case 0	751	110	642
Galatea Basin MAR Option 2b, Case 0	761	116	645
Galatea Basin MAR Option 2c, Case 0	781	128	653
Galatea Basin MAR Option2d, Case 0	737	102	635
Horomanga Dam Option 3, Case 0	795	137	658
Q Max (no intervention)	827	157	670

The Rangitāiki Base Case 0 has highest flows at all 3 locations compared to the other cases and scenarios. The spillway starts spilling at approximately 615m^3/s. The 215m^3/s (the flow above 615m^3/s when the peak flow is 827m^3/s) remaining is then distributed between the Rangitāiki River and the Floodway. The spillway is wider than the river, so the majority of the additional flow above 615m^3/s enters the spillway; however, an extra 55m^3/s stays in the Rangitāiki River.

The flow in the floodway has been further assessed and determined under a range of options. The results showed that the flow is dominated by flood peak rather than flood volume. Consideration and comparison of options with the flood peak is therefore appropriate.

4.4.2 Flood Zones

Five flood management options have been identified for the lower Rangitāiki floodplain in Table 5. These are four separate flood containment zone options and one option of diverting flow from one of the zones to the Tarawera River. Details of each of the zones and maps of their locations are provided in Appendix B.

The approach has been to consider flood zone requirements for containment based the overflow volume if the river and the floodway are flowing at capacity i.e approximately 700m^3/s for existing river and floodway capacity.

Table 8 shows the required storage volume that is required for zones 1 and 2 and the peak water level for each of the 4 zones.

Table 8 Spillway Overflow Storage Requirements

Scenario	Level in Zone 1		Level in Zone 2		Level in Zone 3	Level in Zone 4
	Mm³	mRL	Mm³	mRL	mRL	mRL
Base Case 0	7.4	1.9	7.4	2.9	5.7	3.68
Base Case 1	3.9	1.1	3.9	1.9	4.3	3.02
Base Case 2	2.4	0.7	2.4	1.3	3.6	2.68
Base Case 3	0.0	-1.8	0.0	-1.3	0.2	0.55
Base Case 4	0.0	-1.8	0.0	-1.3	0.2	0.55
Murupara Diversion Option 1, Case 0	5.8	1.6	5.8	2.4	5.1	3.40
New Whirinaki Dam Option 2a, Case 0	1.8	0.5	1.8	1.0	3.3	2.50
Galatea MAR Weir Option 2b, Case 0	2.4	0.7	2.4	1.3	3.6	2.69
Galatea Gate Option 2c, Case 0	3.2	0.9	3.2	1.6	4.0	2.88
Galatea Flow Control Option 2d, Case 0	1.3	0.3	1.3	0.8	3.0	2.35
Horomanga Dam Option 3, Case 0	4.74	1.3	4.7	2.2	4.6	3.21

4.4.3 Additional Spillway in the Lower Rangitāiki River

If the Rangitāiki River and/or the Reid's Canal are to spill, then the most likely area of spill is between the river and canal. Zone 1 has been identified with one spillway and Zone 2 is an optimised version with 2 spillways. Zone 3 is separate cells each with its own spillway. Zone 4 is on the left bank of the Rangitāiki River and has one spillway and requires bunding to protect Edgecumbe and SH2.

The results show that no spill would occur if the rules were altered at Matahina Dam. In all other cases there is some spill and containment of the additional flood water is required. When there is no control on the inflow and outflow at Matahina then the next "best" option is one version of the diversion to groundwater in the Galatea Basin (Option 2d).

If, for instance, the Zone 2 option was selected then for the worst case option the storage would be 2.9m deep and require a bund of over 3m high. Other options would require between 0 and 2m of bunding.

While these bunded areas for capturing over flow flood water are not necessary in some cases and, store little water under other scenarios they would provide additional security in the event of a "failure" of the flood forecasting system or other structural measures in some situations and depending on the location. Individual building bunding would provide flood protection for the buildings but there would be limited control on the lateral extent of flooding on the flood plain. Providing a bunded capture zone controls lateral spread and defines an area where financial or purchase instruments could also be introduced.

4.4.4 Spillway and Diversion to Tarawera River and Whakatane River

A spillway and channel to the Whakatane River seems impracticable due of the topography of the plains, but a diversion to Tarawera River appears to be possible. A spillway can be built upstream of the existing spillway and discharge towards the Tarawera through the local draining channel. The channel would require an upgrade to ensure sufficient capacity. Also, as the channel discharges into the mouth of the Tarawera River, discharging will not be possible unless the tide is low and the Tarawera River water level allows discharge. For this reason storage might be required to detain the waters before being discharge.

5.0 Costs, Benefits & Issues

5.1 Options and Costs

The options with estimated costs and comments are tabulated in Table 9 and detailed in Appendix C.

Table 9 Options, Costs and Benefits

Option		Estimated Cost	Benefits & Issues
1a	Out of catchment diversion u/s of Murupara	N/A	The cost of tunnel, canal and storage in the receiving catchment would be many times what other dams within the Rangitāiki catchment would cost. Cultural issues with inter catchment transfers.
1b	Land use change u/s of Murupara	N/A	Not a fully effective measure in terms of managing floods but significant land use change will change runoff patterns and potentially impact level of service standards for flood control structures so planning control and mitigation measures need to be considered.
1c	New dam u/s of Murupara on Rangitāiki	$82.16M	Has little effect on the flood peak in the lower catchment because the flow is delayed and the flood peak from the rest of the catchment has past.
2a	New dam on Whirinaki	$41.75M	Provides a potential reduction of around 50% of the ultimate target. Insufficient storage for multiple use options. Would modify the river regime and impact sediment transport.
2b	Galatea MAR – weir control	$44.57M	Would only divert peak flow and while MAR is an option there are other better flood control diversion scenarios. Like all the MAR options would require additional investigations of the suitability of the groundwater receiving environment and an alternative use for the replenished groundwater. The delaying of the flow may lead to less annual spill at the hydro dams and an increase in generation. The groundwater would be available for irrigation and be an alternative to a storage dam. The cost equates to approximately $4,500/ha (based on a 10,000ha irrigated area) which is a relatively cheap cost for an irrigation scheme although the extract bore costs need to be added.
2c	Galatea MAR – gated optimised flow	$45.36M	Use of control gates would improve the flood control aspects of an MAR scheme but does have slightly higher flood levels than 2b.
2d	Galatea MAR – hydrograph control	$45.36M	Optimising the diversion to MAR during stages of a storm event provides the best flood management outcomes. It delivers the greatest flood improvements and will provide the best management of exist river regimes and sediment transport.
3	Horomanga Dam	$40.73M	Provides a potential reduction of around 50% of the ultimate target. Insufficient storage for multiple use options. Would modify the river regime and impact sediment transport.

Option		Estimated Cost	Benefits & Issues
4a	Matahina Dam raising		This would require changing the operation of the dam and the 2m to 5m height increase required needs further investigation. Not costed because other alternatives provide better and more complete outcomes.
4b	New Dam downstream of Aniwhenua		Provides a potential reduction of around 50% of the ultimate target. Insufficient storage for multiple use options. Raising Aniwhenua would have a similar outcome. Not costed because other alternatives provide better and more complete outcomes.
4c	New Dam below Matahina Dam		Provides a potential reduction of around 50% of the ultimate target. Insufficient storage for multiple use options. Not costed because other alternatives provide better and more complete outcomes.
4d	Multiple Sub-catchment Dams		This would require numerous dams with optimised control to be effective. Further any on line storage locations would increase storage volume required. Theoretically possible but difficult to control and likely to be very expensive.
4e	Matahina Operation Rules Analysis	$1M	The most promising and least expensive method for improving flood management. It has risks in that it relies on flood forecasting for decision making. Maximising lower river flow needs consideration in terms of any additional potential effects on bank stability and integrity. Detailed consideration is required to ascertain the need for revision of existing consent conditions for any change in operational rules.
5a	Zone 1 – Additional spill zone	$4.76M	Provides security for over design events and “failure” of any flood forecasting options.
5b	Zone 2 – Multiple spill points	$4.76M	Provides security for over design events and “failure” of any flood forecasting options.
5c	Zone 3 – Multiple compartments	$0.86M	Provides security for most of the flood volume and “failure” of any flood forecasting options.
5d	Zone 4 – Left bank storage	$7.16M	Provides security for over design events and “failure” of any flood forecasting options. A number of buildings and Edgecumbe in the zone so these would require additional bunding.
5e	Tarawera Diversion		An addition to 5d option as an alternative outlet. Not required for above Reid’s spillway flood control options but may be of merit for lower river channel management.

5.2 Power Generation Losses Analysis

We understand that on an annual basis there is some normal loss of generation because of spills at Matahina. However, during a large storm event with flood forecasting there is a planned spill and the loss may be more than would happen if the sole objective was to maximise returns from generation. Consequently there is a loss of income potential because of the provision of flood management through Matahina Dam. Our analysis has

indicated this could have been a loss of 430Mwhr during the July 2004 event based on the flow management assumptions that have been made, and would amount to approximately $100,000. This is a small cost for a relatively infrequent event such as the 100 year storm. This cost may be covered by existing self-insurances costs that are already collected. Details are provided in Appendix C.

6.0 Recommendations

Based on our assessment we recommend that the following be considered as a preferred approach to flood management and the recommended actions be undertaken to facilitate the establishment of the preferred options.

1) Undertake a review of the rules for flood management at Matahina Dam and confirm an operation that maximises flow in the river and spillway at approximately $700m^3/s$. This would involve assessing numerous historic events to optimise the rules, and consideration of lower water level thresholds than have been considered in this report.

2) Improve the accuracy of flood forecasting with an optimised raingauge network that has resilience of operation included even if there is redundant data should there be no operational failures during an event. This would include the rainfall and flow network, the use of radar based forecasts and measurements and an optimised catchment flow forecasting model. Much of this exists or is being worked on at present and is simply a matter of giving a higher priority to the effort and providing the investment to have the best forecasting system possible.

3) Provide defined bunded areas to capture over design events or "failures" on the lower flood plain. These would only operate in rare circumstances. The defined areas need to be optimised around existing structures and farm operations.

4) Consider managed aquifer recharge in the Galatea basin as part of a multiple water use project in conjunction with irrigation interests, including a detailed assessment of the groundwater regime.

5) Consider consenting and mitigation requirements for land use change, especially conversion to pasture whee flows are increased, on combined land areas exceeding 100ha of converted land.

Appendix A

Upper Rangitāiki Options & Outcomes

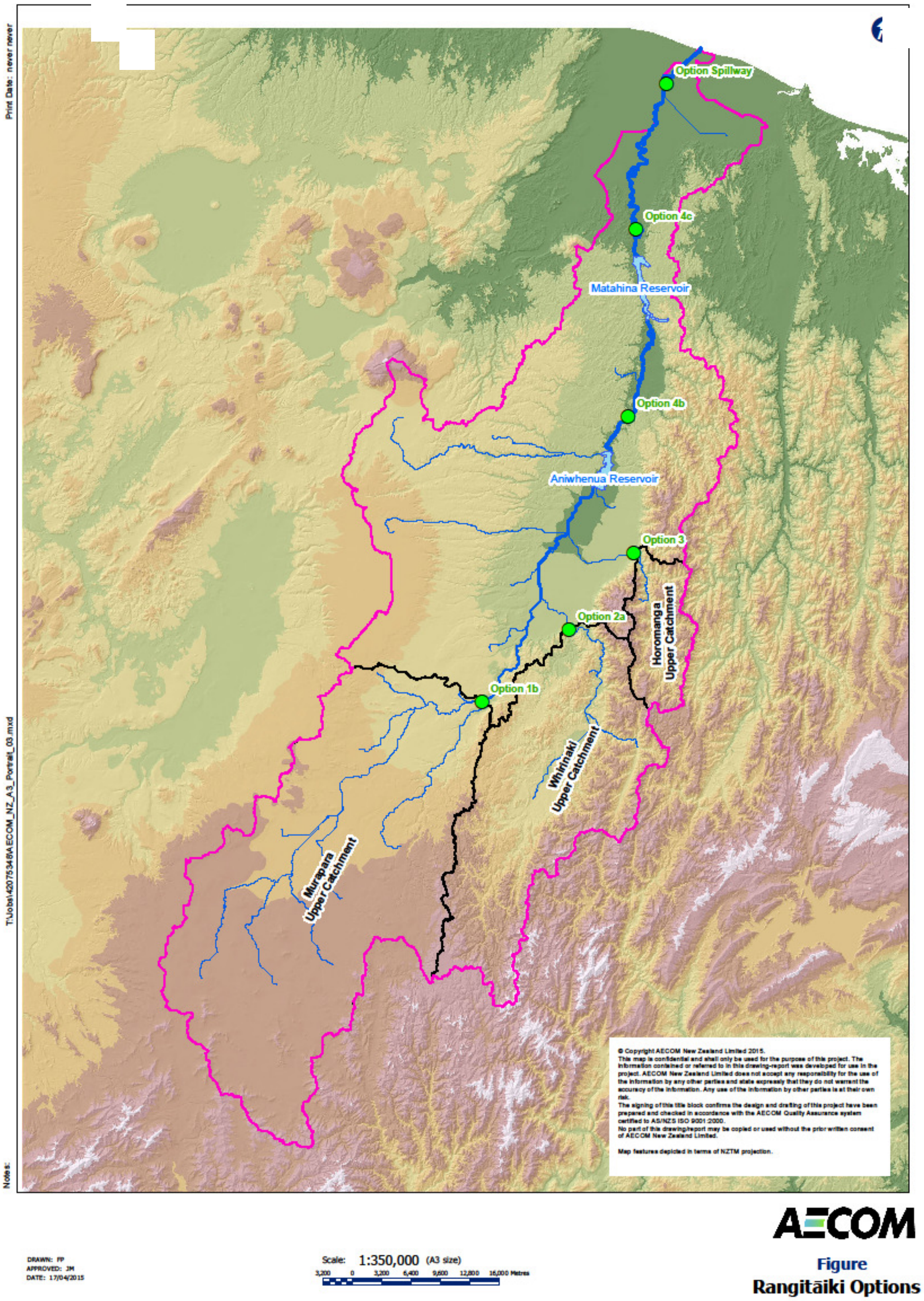
Appendix A Upper Rangitāiki Options

A 1.0 Upper Rangitāiki Options

A 1.1 Scenario Details and Assumptions

Figure 7 shows the main catchments and reservoirs of the Rangitāiki along with some of the option locations.

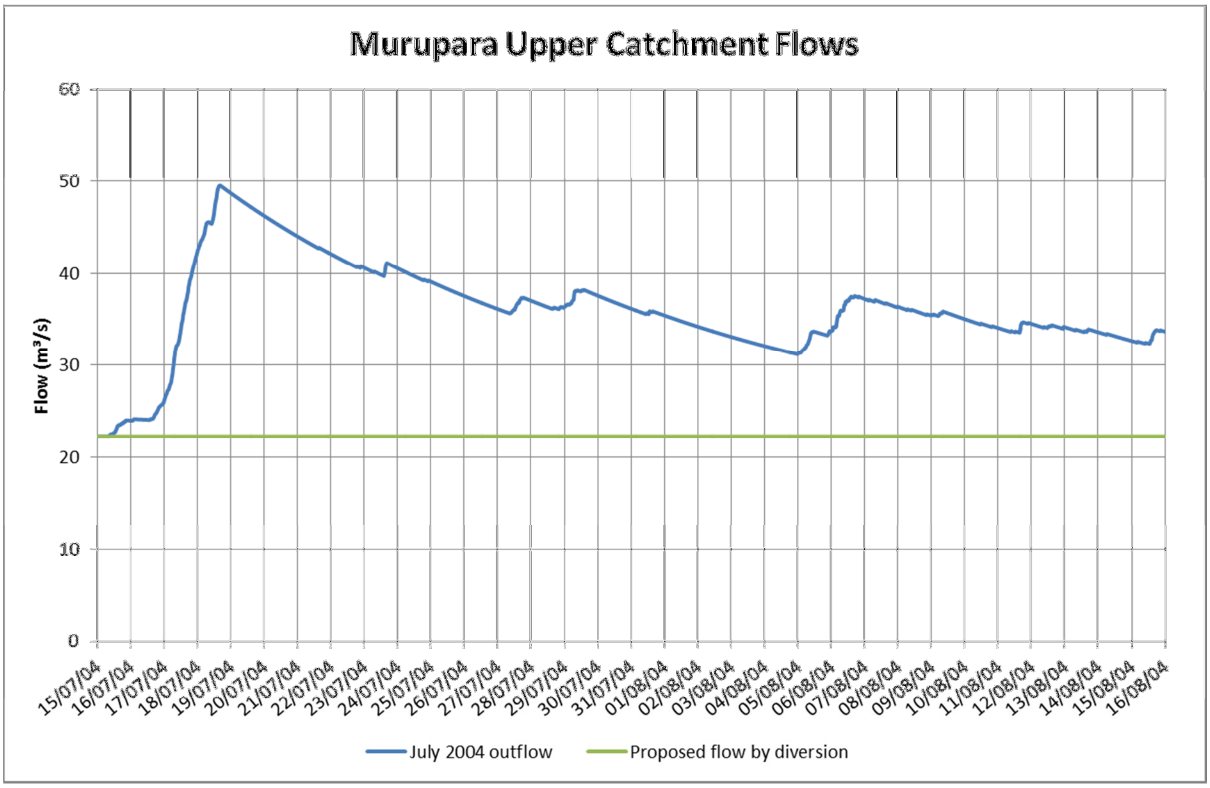
Figure 7 Main Catchments and Reservoirs



A 1.2 Murupara Catchment Flow Diversion (Option 1a)

Flow reduction from the upper Murupara catchment is considered based on a hypothetical diversion of $20m^3/s$. Figure 8 shows the flows for the event of 2004 and the possible flow diversion into a neighbouring catchment.

Figure 8 Murupara Upper Catchment Flows and Diverted Flow



A 1.3 Murupara Dry Dam (Option 1b)

A conceptual dam has been assessed at a location upstream from Murupara on the Rangitāiki River. The location and extent of storage is shown in Figure 9, the concept design details and summary results in Table 10, and the inflow and outflow hydrographs in Figure 10.

From the records and previous studies done in the upper catchment of the Rangitāiki River, the flows passing through the Murupara flow gauge have a relatively small peak flow with a large volume distributed over several weeks. The detention provided in the area by the large wet lands, highly permeable soil and flat plains are more effective than any potential dam in the catchment.

Figure 9 Murupara Dry Dam

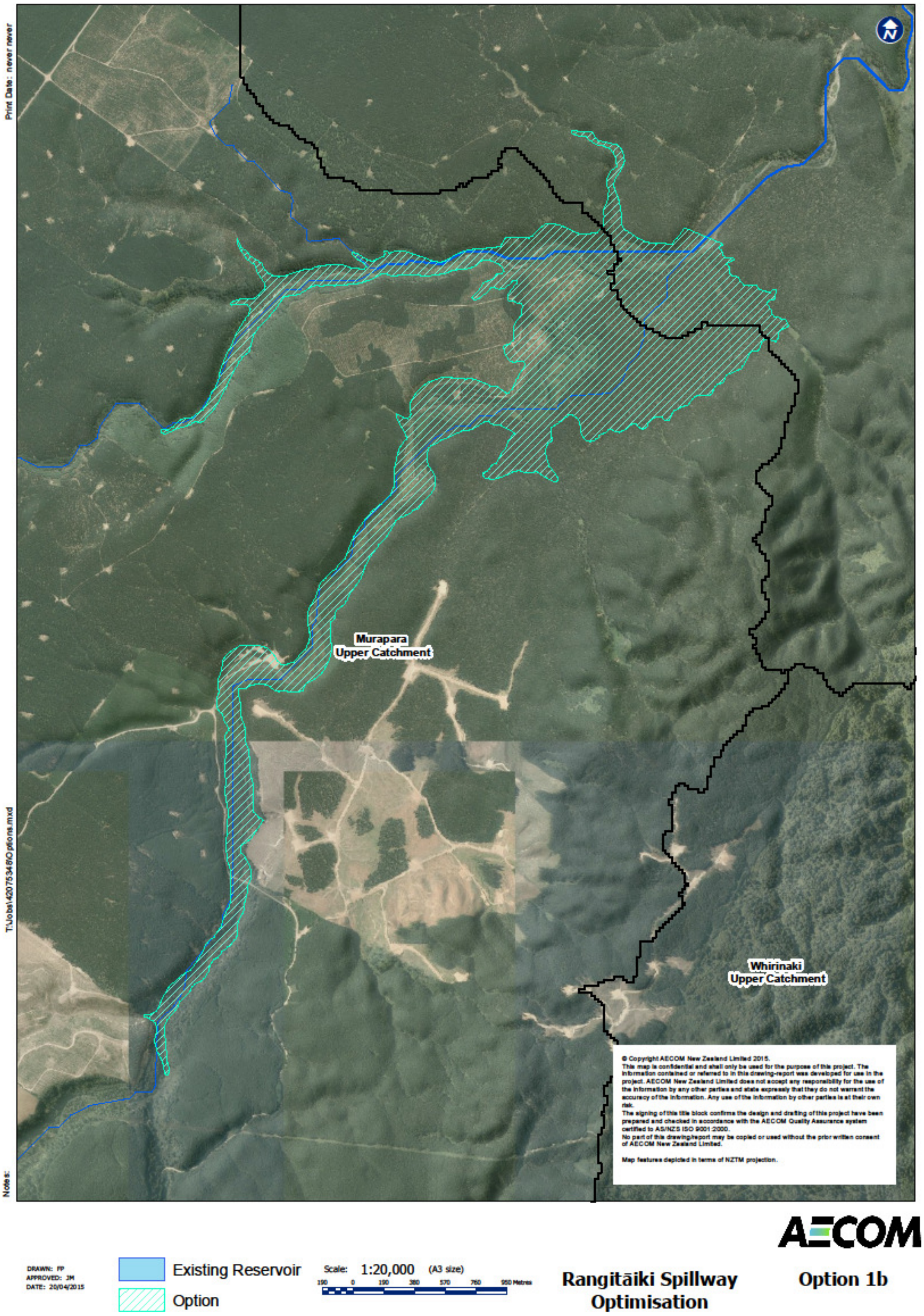
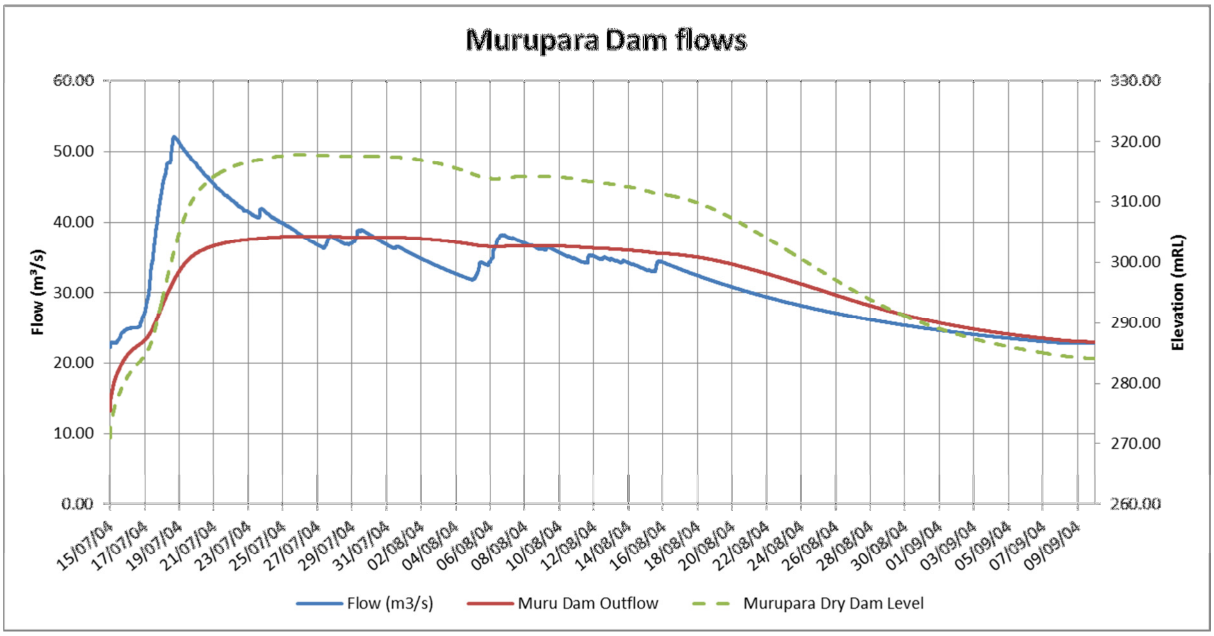


Table 10 Murupara Dry Dam Details

Item	Value	Unit
Dam Invert	264.0	mRL
Dam Orifice Area	1.5	m²
Dam Orifice Height	1.2	m
Approx. maximum free flow	5.7	m³/s
Inflow Peak	52.1	m³/s
Outflow Peak	38.0	m³/s
Peak Reduction	14.1	m³/s
Maximum Flow Reduction	20.4	m³/s
Maximum Water Level	317.8	mRL
Maximum Water Depth	53.8	m
Maximum Volume at peak	7.18	Mm³
Maximum Flooded Area at peak	55.9	Ha
Time of Detention	~ 2 months	

Figure 10 Murupara Dry Dam Flow and Water Level



A 1.4 Whirinaki Catchment Dry Dam (Option 2a)

A dam has been conceptually designed and located as shown in Figure 11. It consists of a head wall up to about 300mRLm with an approximate invert at 236mRL. The outlet has been defined with an orifice at the invert with an approximate area of 8.7m² as tabulated in Table 11. The inflow and outflow hydrographs are given in Figure 12 where the flow reduction is over 100m^3/s.

Figure 11 Whirinaki Dam

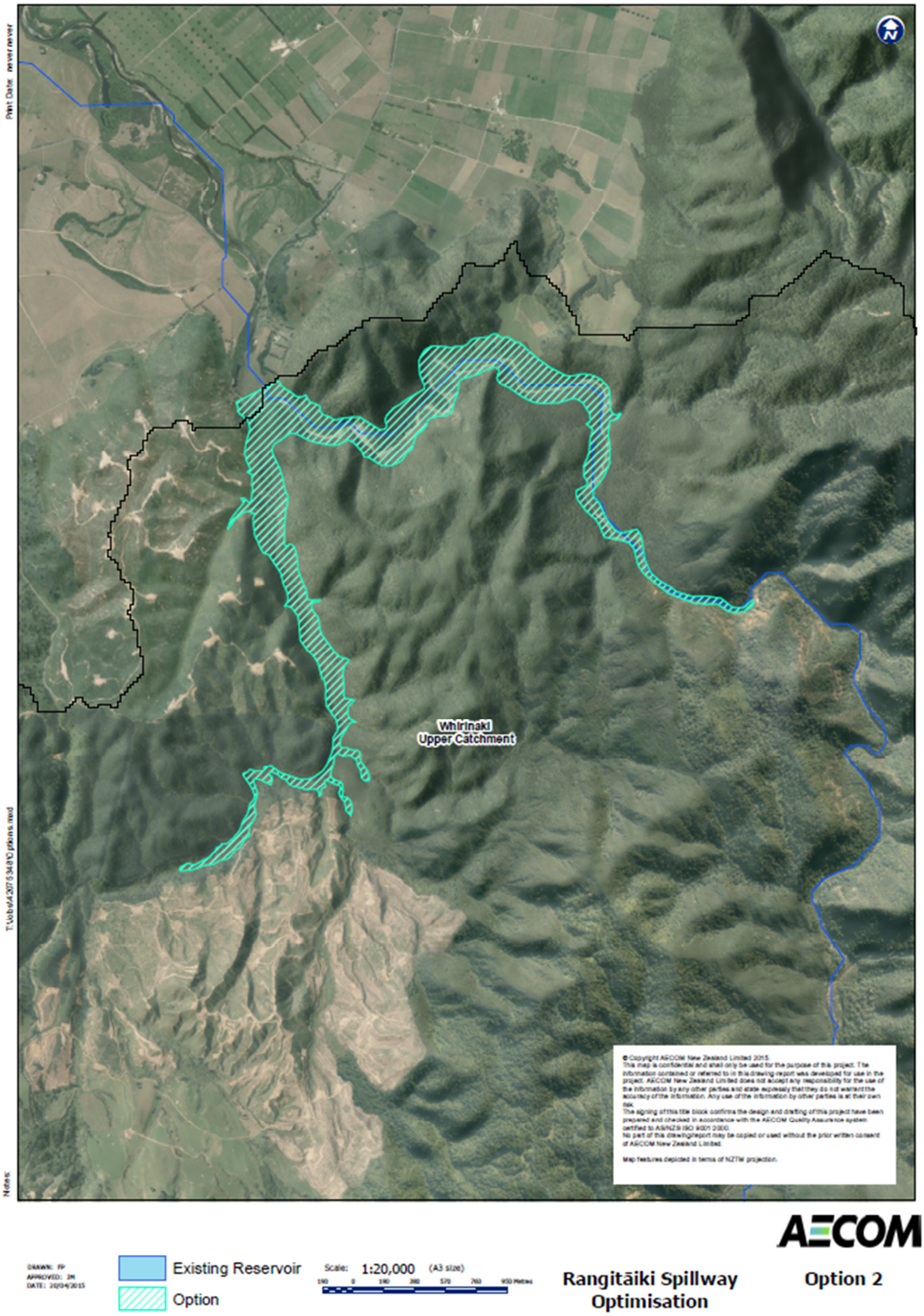
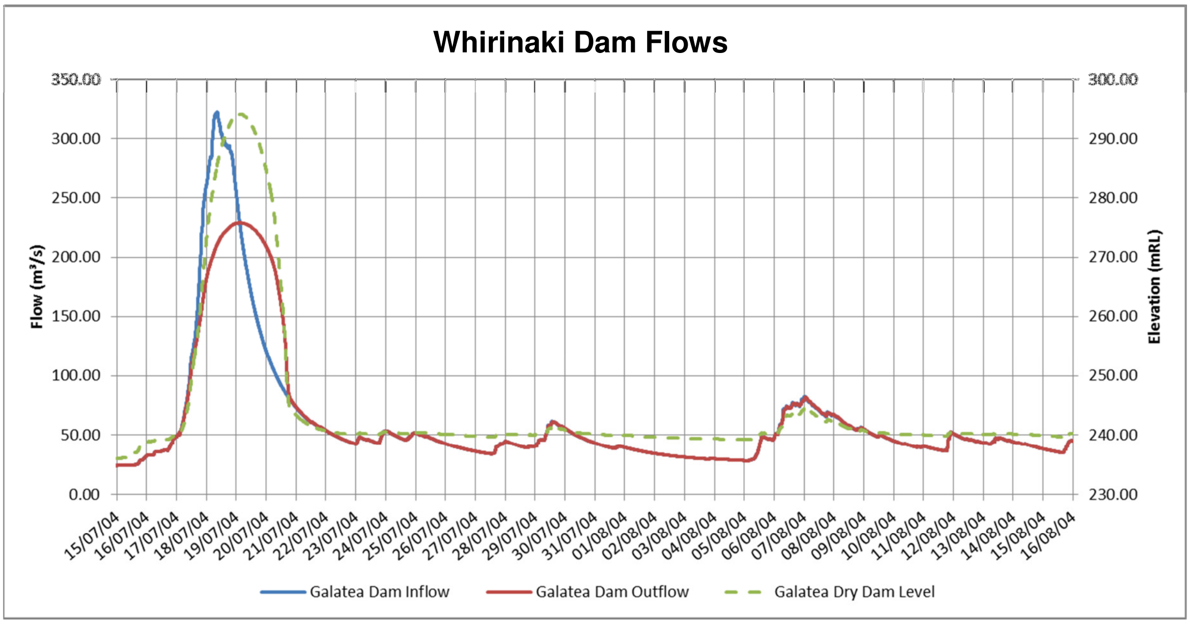


Table 11 Whirinaki Dry Dam Details

Item	Value	Unit
Dam Invert	236.0	mRL
Dam Orifice Area	8.7	m²
Dam Orifice Height	3.0	m
Approx. maximum free flow	52.7	m³/s
Inflow Peak	321.9	m³/s
Outflow Peak	228.9	m³/s
Peak Reduction	93.0	m³/s
Maximum Flow Reduction	113.4	m³/s
Maximum Water Level	294.1	mRL
Maximum Water Depth	58.1	m
Maximum Volume at peak	8.95	Mm³
Maximum Flooded Area at peak	66.9	Ha

Figure 12 Whirinaki Dam Inflow, Outflow and Water Level



An important feature of the dam is that the peak is delayed, so the reduction is amplified. The impact of this reduction and the shifting of peak of the hydrograph at the downstream control point is the purpose of designing a dam to attenuate the runoff.

A 1.5 Galatea Basin Aquifer Recharge; Weir Diversion Type (Option 2b)

The Galatea Basin is a highly productive farming area where there has been interest in irrigation for a number of years. Various sources of water for irrigation have been considered. In this case a diversion from the Whirinaki

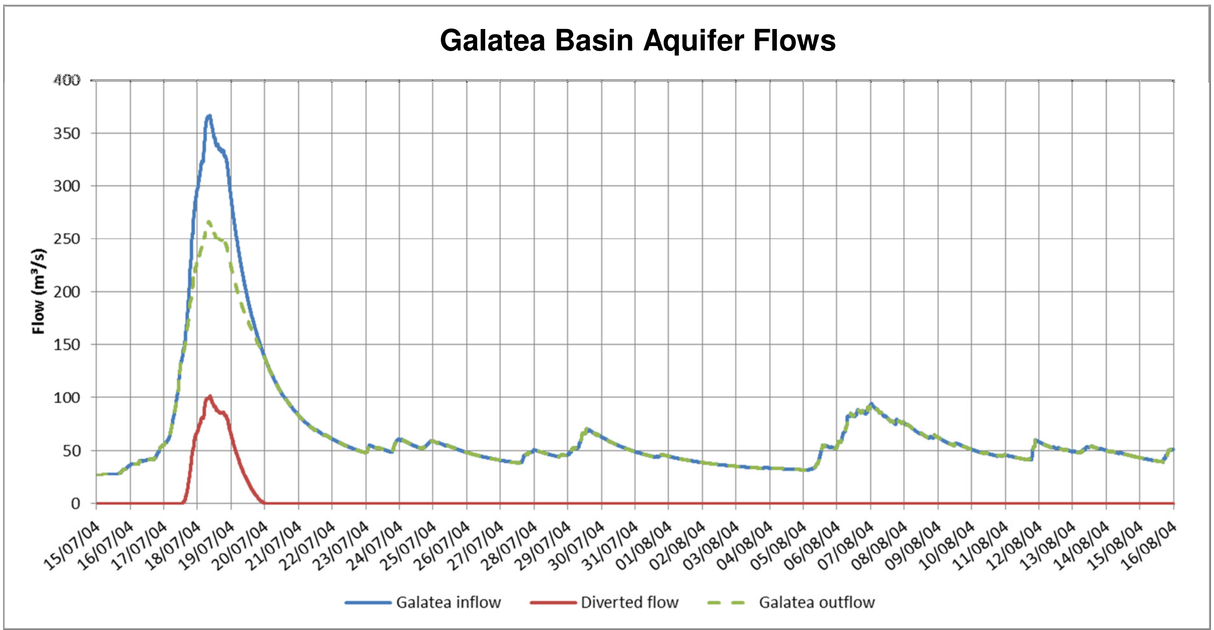
has been considered. It could equally be a split diversion with diverted flow from both the Horomanga and the Whirinaki from a flood management perspective. The diversion point is similar to the dam location in Option 2a.

Three types of flow management/capture have been considered for managed aquifer recharge (MAR) in the basin. The first is a lateral weir to divert peak flow and details are provided in Table 12 along with the impact on flood flows as shown in Figure 13.

Table 12 Galatea Basin Aquifer Recharge, Weir Diversion Details

Item	Value	Unit
Weir Invert	195.9	mRL
Weir width	30.0	m
Approx. maximum free flow	133.2	m³/s
Inflow Peak	366.7	m³/s
Outflow Peak	266.7	m³/s
Peak Reduction (diverted)	102.0	m³/s
Volume diverted	10.8	Mm³

Figure 13 Galatea Basin Aquifer Recharge, Weir Diversion Flow and Water Level



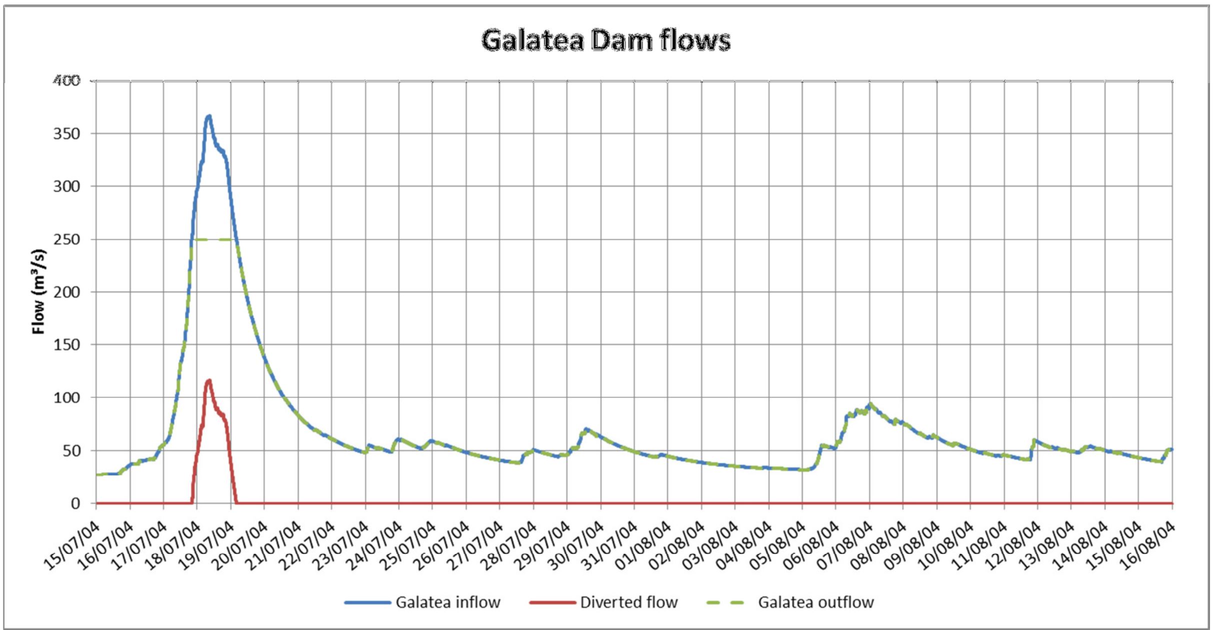
A 1.5.1 Galatea Aquifer recharge, Optimised Gated Diversion Flow Type (cut flow; Option 2c)

The second option is a control gated diversion flow as shown in Table 13 and Figure 14.

Table 13 Galatea Aquifer Recharge, Optimised Gated Diversion Details

Item	Value	Unit
Inflow Peak	366.7	m³/s
Outflow Peak	250.0	m³/s
Peak Reduction (diverted)	116.7	m³/s
Volume diverted	7.9	Mm³

Figure 14 Galatea MAR; Optimised Gated Diversion Flow and Water Level



A 1.6 Galatea Aquifer Recharge; Middle Flows Diversion (2 weirs type; Option 2d)

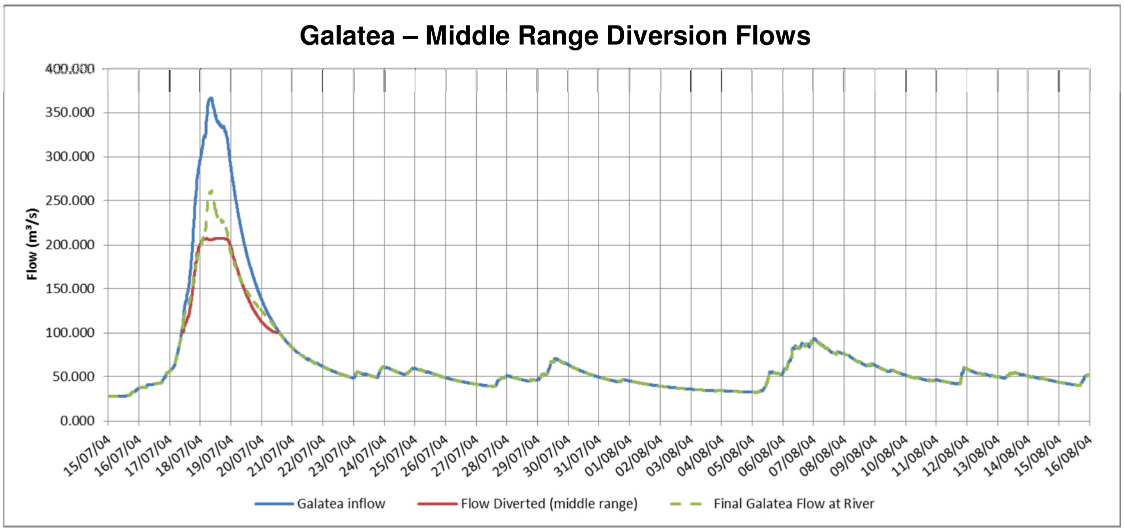
The third option considers that the middle range of flows will be diverted, per example between the 100-200m³/s flows. This will be implemented with a set of 2 weirs that would cut the hydrograph in two sections to isolate the middle portion as defined in Table 14 and Figure 15.

Table 14 Galatea Aquifer Recharge; Middle Range Diversion Details

Item	Value	Unit
Weir at River to divert over Q threshold		
Q threshold at river	100.0	m³/s
Weir Invert (at model XS)	195.7	mRL
Weir width	30.0	m
Weir at Well to return Peak overt Q diverted limit		
Q limit	100.0	m³/s
Diversion channel Width	20	m
Diversion channel slope	0.02	m/m

Item	Value	Unit
Diversion channel manning	0.025	$s/m^{1/3}$
Return Weir width	10	m
Return Weir invert (depth)	1.87	m
Flow Diversion and Reduction		
Inflow Peak	366.7	m^3/s
Outflow Peak	261.0	m^3/s
Peak Reduction	105.7	m^3/s
Max Flow reduction	107.7	m^3/s
Volume diverted	15.8	Mm^3

Figure 15 Galatea MAR; Middle Range Diversion Flow and Water Level



The Volume diverted would be used to recharge the aquifer. For the 100yr event it would be almost 16Mm³ recharged over a period of about 3 days, with an average rate of about 60m³/s and a peak about 100m³/s.

For this option to be viable for flood control it is necessary that 15Mm³ is available in the aquifer to store the diverted flow. To be viable for irrigation, it is necessary that the volume infiltrated every year is enough to provide the required demand of water.

Horomanga Flow Reduction – Dry Dam (Option 3)

A dam concept is suggested for the Horomanga catchment to mitigate the impact of large floods. The location features and performance are summarized in and Figure 16 and Figure 17 and Table 15.

Figure 16 Horomanga Dry Dam

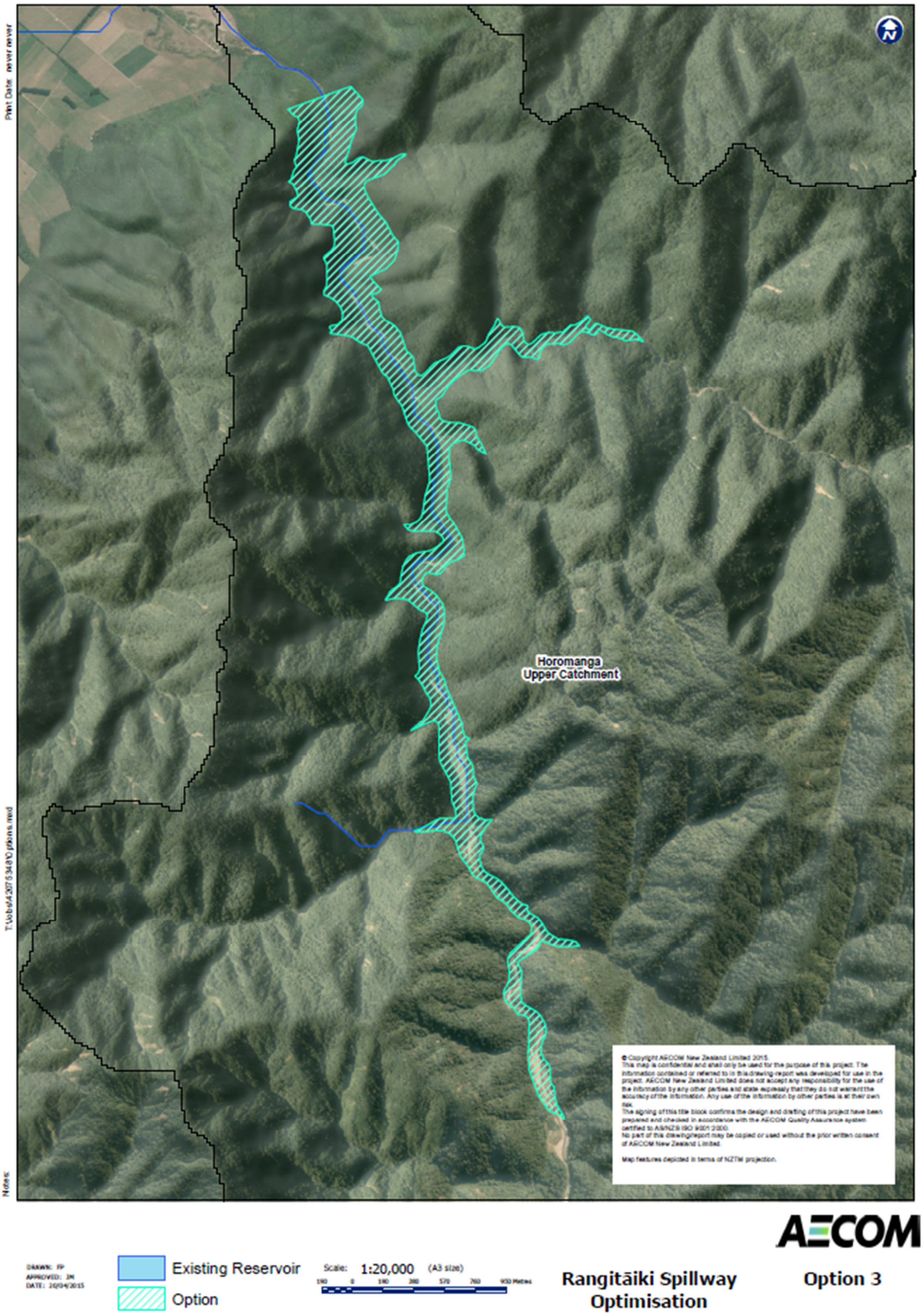
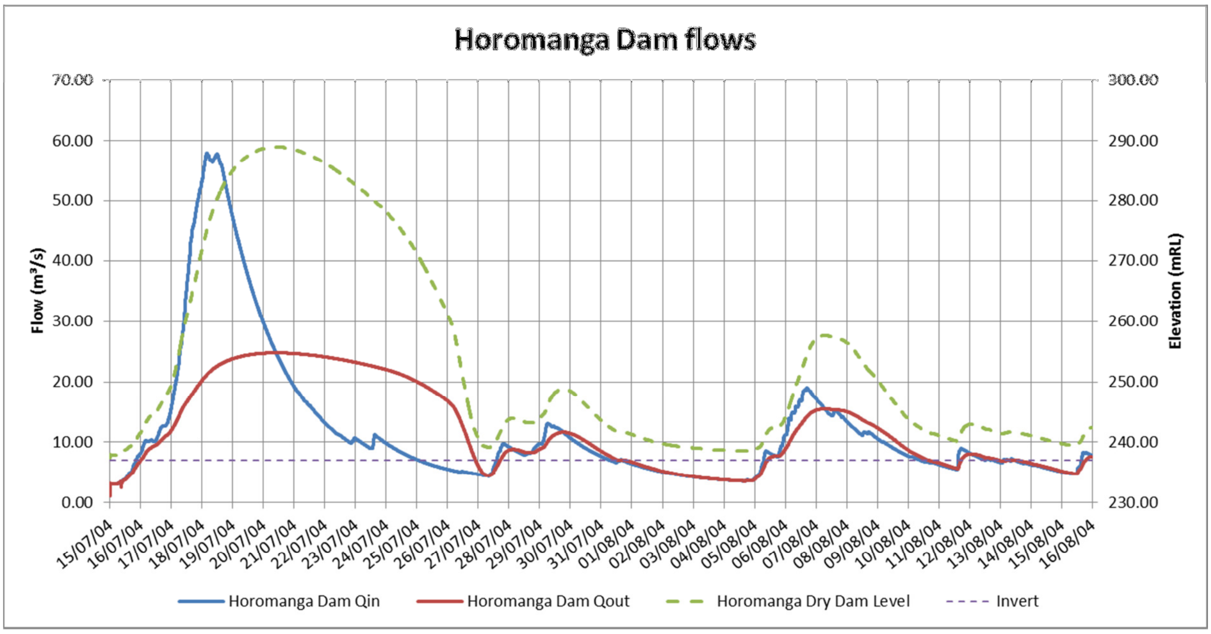


Table 15 Horomanga Dry Dam Details

Item	Value	Unit
Dam Invert	237.0	mRL
Dam Orifice Area	1.0	m²
Dam Orifice Height	1.0	m
Approx. maximum free flow	3.5	m³/s
Inflow Peak	57.9	m³/s
Outflow Peak	24.8	m³/s
Peak Reduction	33.1	m³/s
Maximum Flow Reduction	36.7	m³/s
Maximum Water Level	289.0	mRL
Maximum Water Depth	52.0	m
Maximum Volume at peak	5.83	Mm³
Maximum Flooded Area at peak	33.4	Ha

Figure 17 Horomanga Dry Dam Flow and Water Level



A 1.7 New Dam between Matahina and Aniwhenua (Option 4b)

A new dam location is shown in Figure 18, the dam characteristics in Table 16 and the resultant flows in Figure 19.

Figure 18 New Dam between Matahina and Aniwhenua

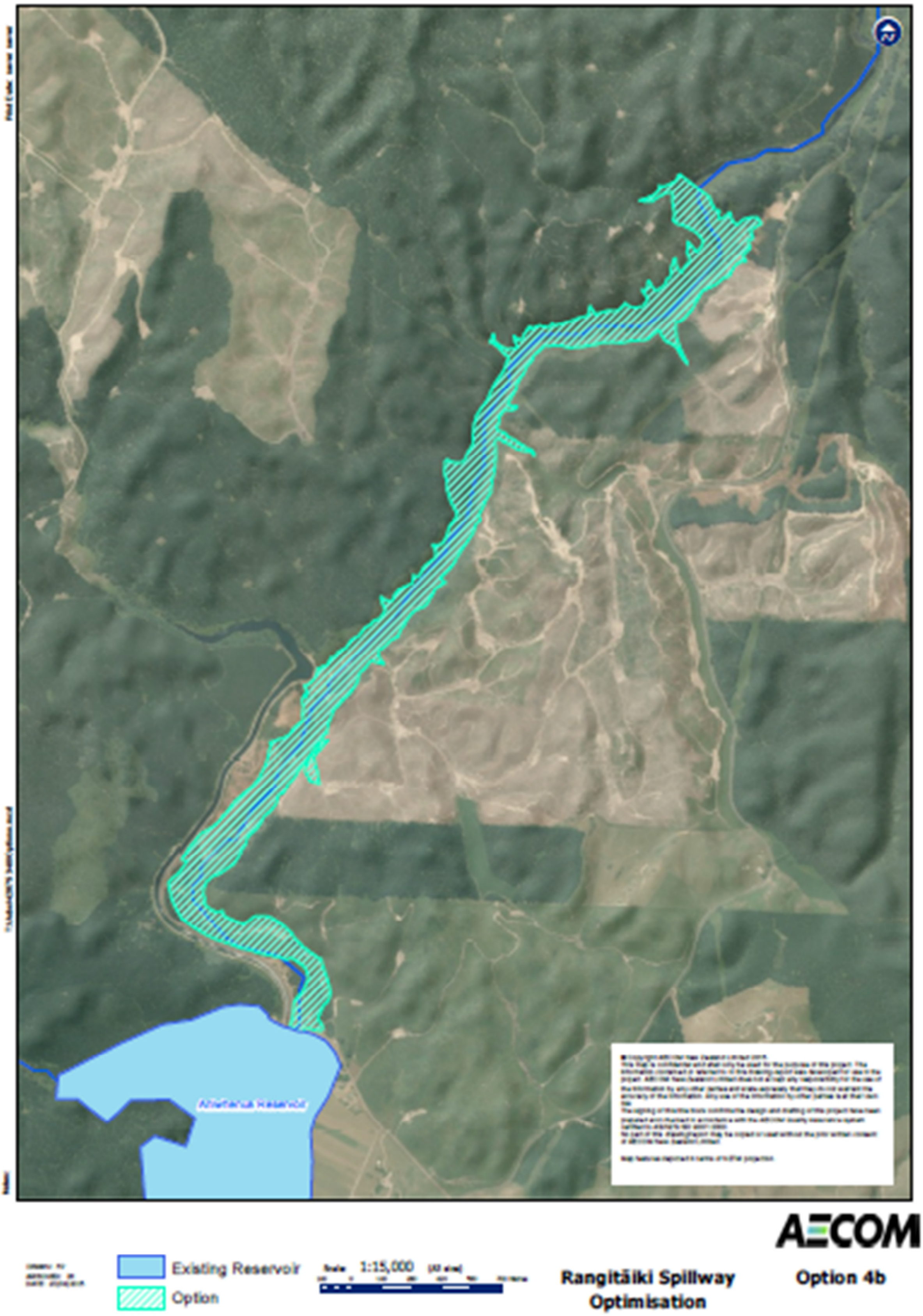
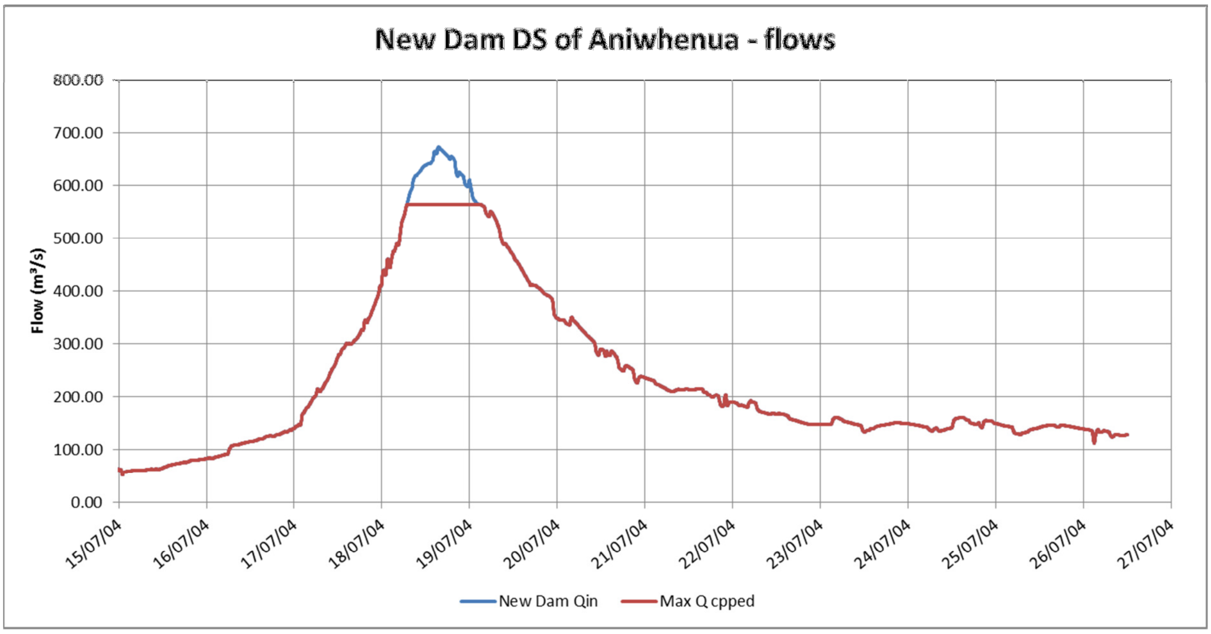


Table 16 New Dam Characteristics

Item	Value	Unit
Dam Invert	96.0	mRL
Gated Dam, operation required		
Inflow Peak	674.4	m³/s
Outflow Peak	564.4	m³/s
Peak Reduction	110.0	m³/s
Maximum Water Level	124.9	mRL
Maximum Water Depth	28.9	mRL
Maximum Volume at peak	4.4	Mm³
Maximum Flooded Area at peak	33.4	ha

Figure 19 Option 4b - New Dam Down Stream of Aniwhenua - Flows



A 1.8 Dry Dam below Matahina (Option 4c)

There is some room available to place a dam in downstream of Matahina Dam. The volume is not very large, but it would allow some peak control. Figure 20 shows the location and Figure 21 the volume and conceptual long profile. Dam details are provided in Table 17 and inflow and outflow hydrographs in Figure 22.

Figure 20 Dry Dam below Matahina

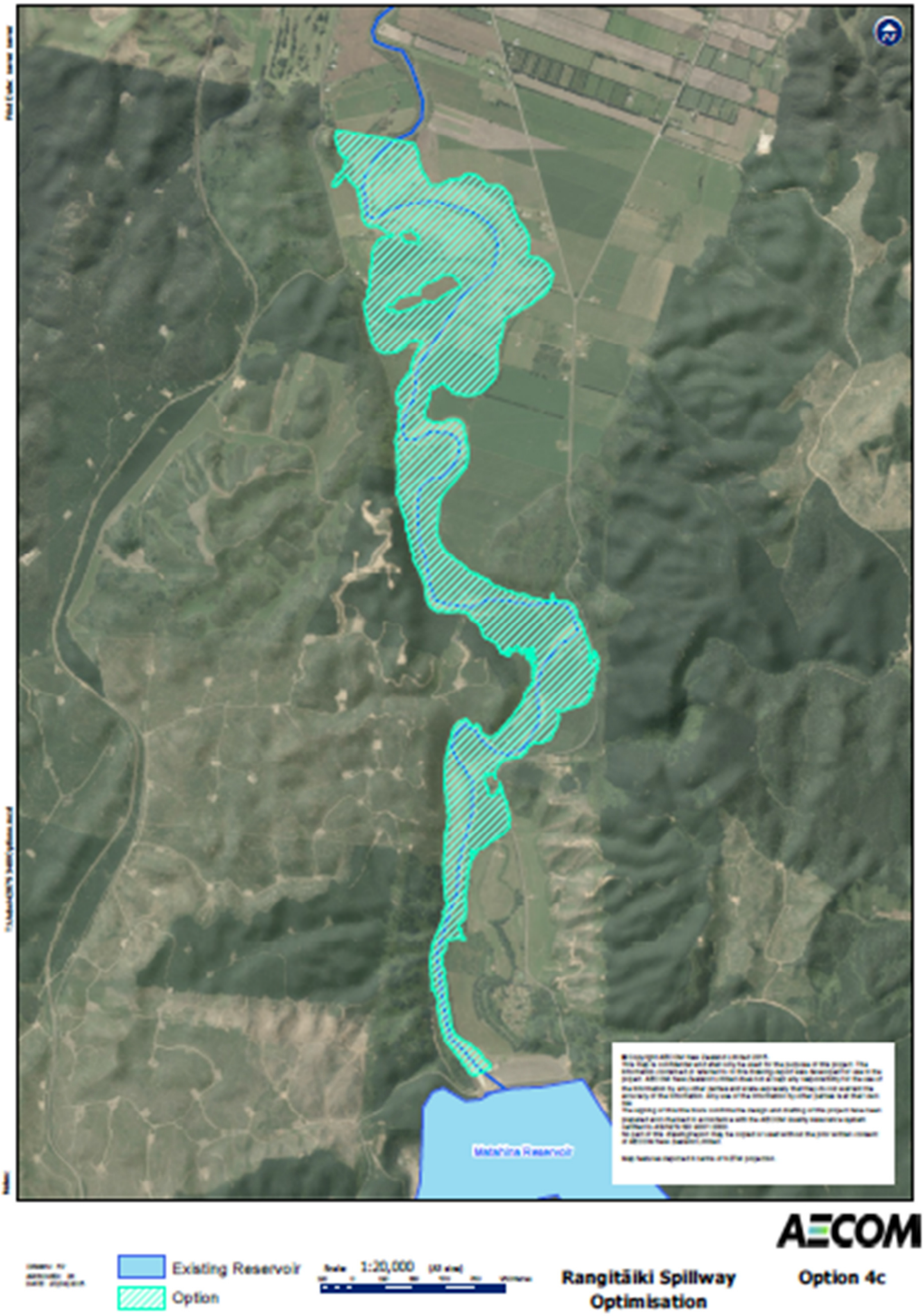


Figure 21 Volumes

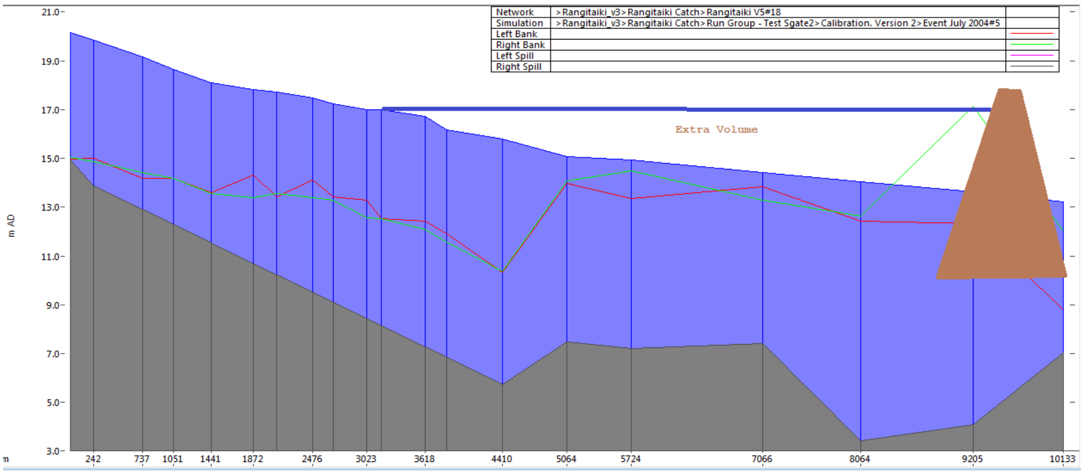
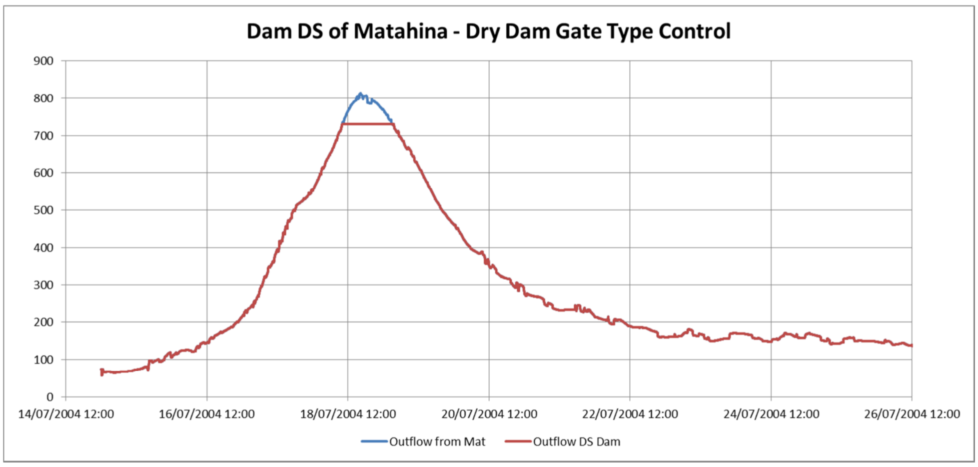


Table 17 Dam Orifice Area

Item	Value	Unit
Dam Invert	9.0	mRL
Dam Orifice Area	85.0	m²
Dam Orifice Height	1.7	m
Approx maximum free flow	387.6	m³/s
Inflow Peak	813.4	m³/s
Outflow Peak	784.3	m³/s
Peak Reduction	29.1	m³/s
Maximum Water Level	16.8	mRL
Maximum Water Depth	7.8	m
Maximum Volume at peak	3.37	Mm³
Maximum Flooded Area at peak	103.3	Ha

Figure 22 Dam Downstream of Matahina – Gate Type Control



A 2.0 Optioneering Analysis - Upper Rangitāiki Catchment

The optioneering analysis that has been undertaken largely follows the same format for each option where the inflows, outflows and water levels at Matahina dam are plotted and then the results of peak information provided in a summary table.

A 2.1 Murupara Upper Catchment Flow Diversion (Option 1a)

The results of the analysis are shown in Figure 23 to Figure 27 and Table 18. The results show that there is a flow reduction which is improved significantly with changed operational rules at Matahina Dam

Figure 23 Case 0: Base flow vs Option, no operation rules at Matahina

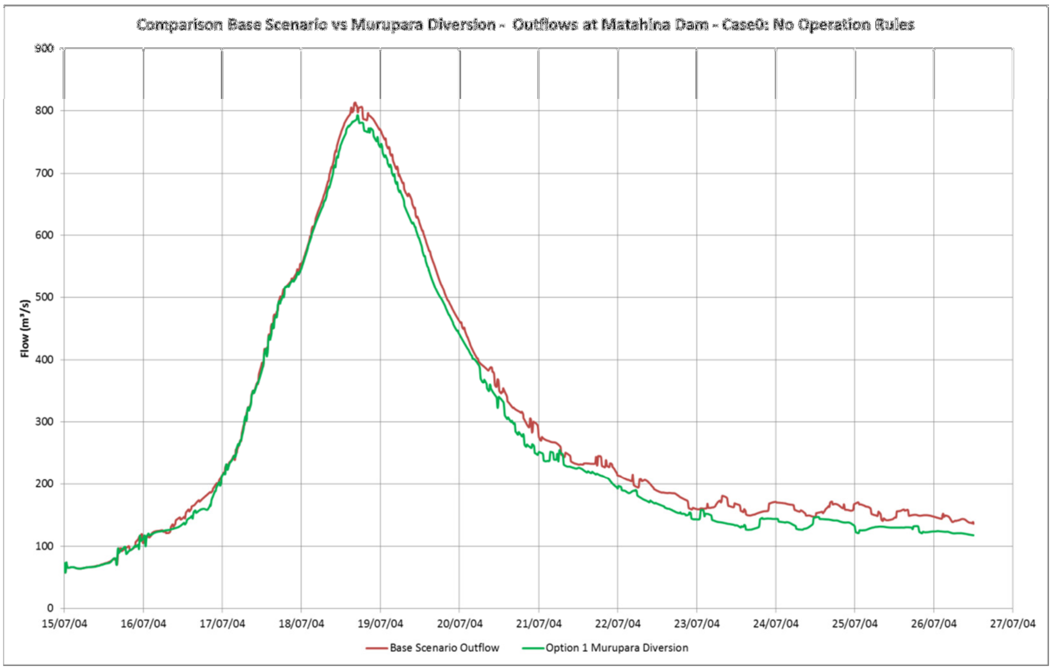


Figure 24 Option 1a - Case 1

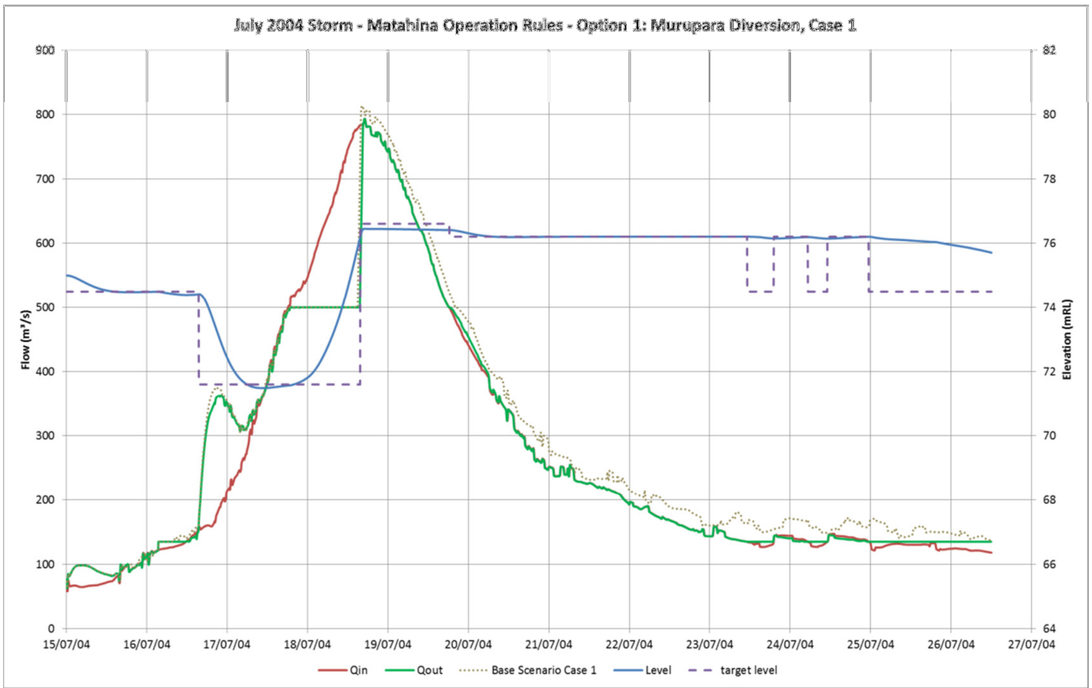


Figure 25 Option 1a - Case 2

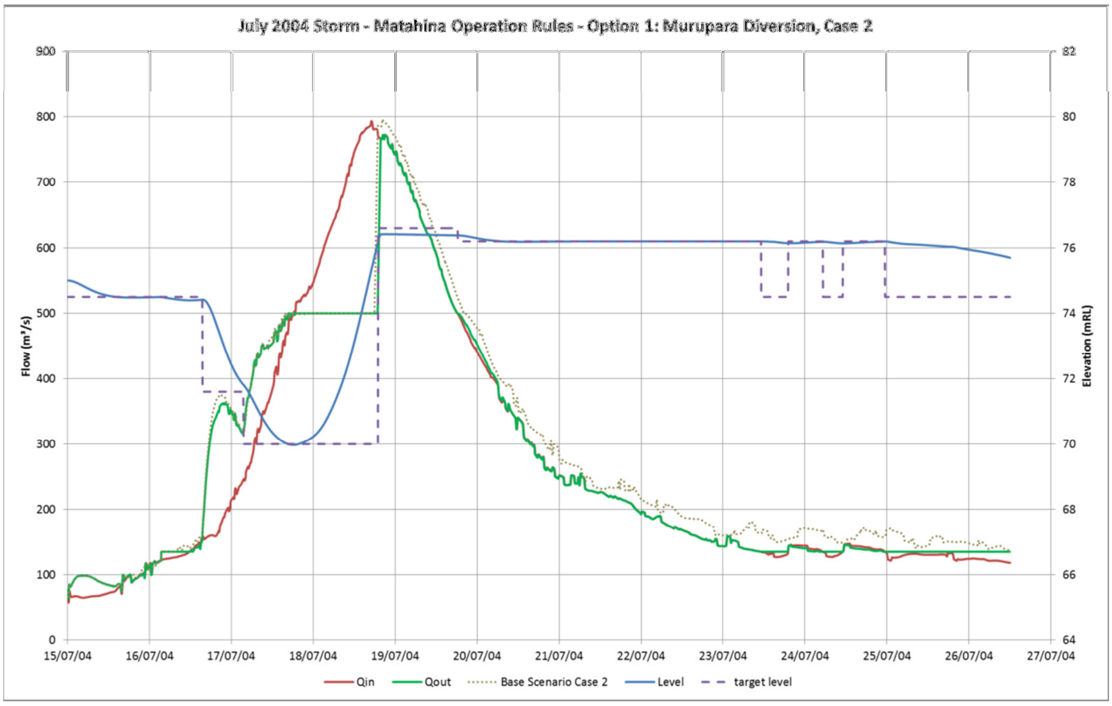


Figure 26 **Option 1a - Case 3**

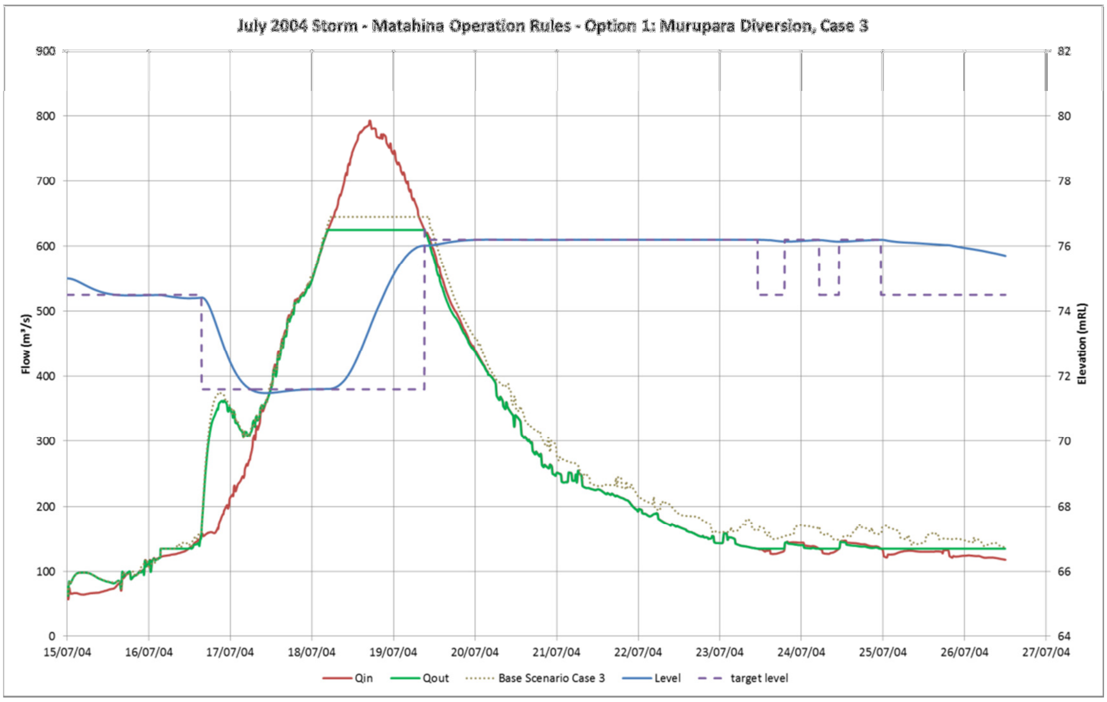


Figure 27 **Option 1a - Case 4**

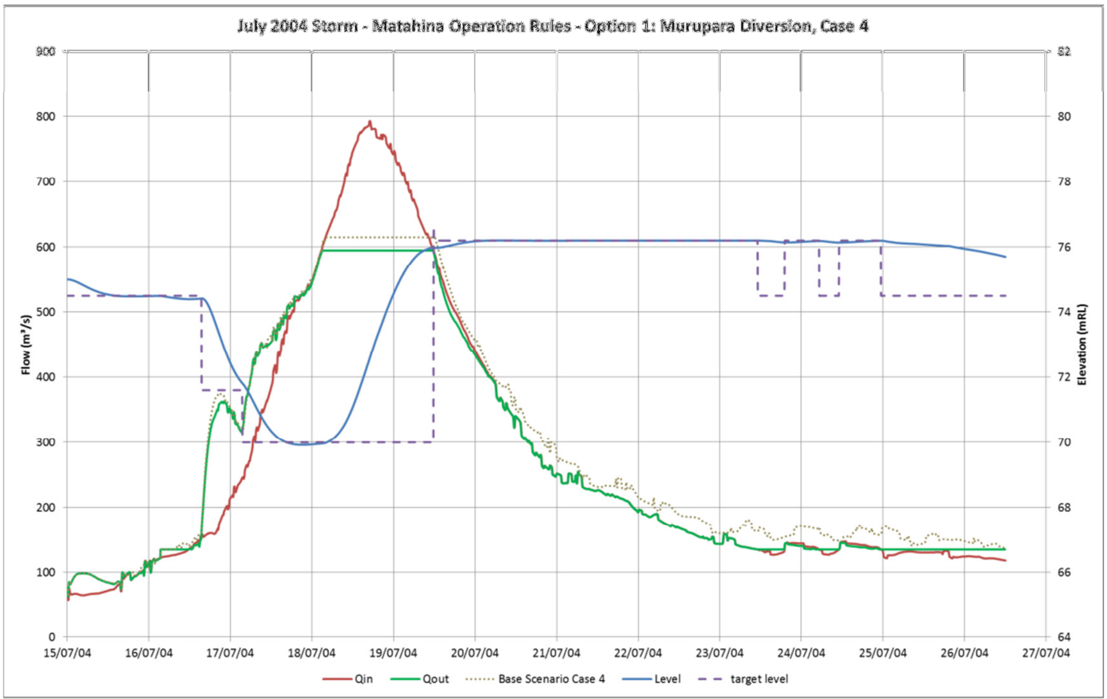


Table 18 Case Results

	Qmax	Lower	Peak Inflow	Peak Outflow	Rise	Rule Reduction	Total Reduction
	m³/s	mRL	m³/s	m³/s	m	m³/s	m³/s
Case 0	No rule		813.4	793.2		0	-20
Case 1	500	71.6	793.2	793.2	0	0	-20
Case 2	500	70.0	793.2	772.3	0	-21	-41
Case 3	625	71.6	793.2	625.0	0	-168	-188
Case 4	595	70.0	793.2	595.0	0	-198	-218

A 2.2 Murupara Dry Dam (Option 1b)

The Murupara Dry dam has not been included for additional analysis as it offers negligible benefits in terms of peak flow reduction at Matahina dam from a flood control perspective because of the significant delay in the flows reaching Matahina dam.

A 2.3 Murupara Landuse Change (Option 1c)

From the preliminary review of options we know that if 5% of the grass in the whole catchment upper catchment (upstream of Te Teko) is turned into forest, then there is an average reduction of volume of 9Mm^3 for an event such as the July 2004 event. The same increase would occur if the change goes from forest into grass. Using the flow records, the calibrated model results and the land use coverage runoff coefficients have been determined for areas covered by grass and forest, based on the Curve Numbers described by the US SCS.

To assess the potential impact of land use change four scenarios as shown in Table 19 were assessed and the new runoff volumes were estimated:

Table 19 Effect of Change in Land Use on catchment area

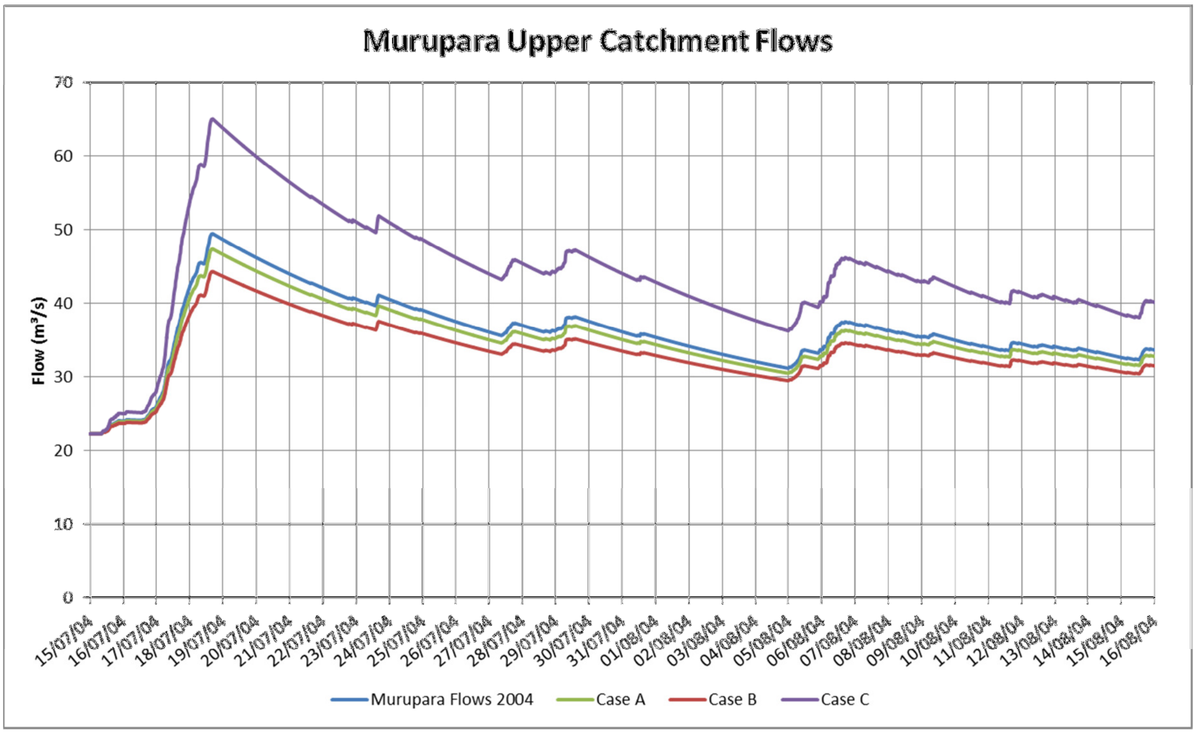
	Base	Case A	Case B	Case C
Grass	20%	10.0%	0.0%	100.0%
Forest	77%	87.1%	100.0%	0.0%
Other	3%	3%	0.0%	0.0%
Total Runoff Mm^3	47.2	43.6	38.3	74.2
Reduction, Mm^3		3.6	8.9	-30.6

Based on proportionality this leads to flow reduction at the outlet to Matahina dam as shown in Table 20 and Figure 28. The outcome is that land use change will only have a minor impact on changing flood flows from the upper catchment at Matahina but if enough area of land is converted to pasture then the level of service for flood management could be compromised.

Table 20 Flow Reduction with Change in Land Use

	Peak flow	Reduction (m^3/s)
Murupara July 2004 baseflow	22.29	
Base Case	49.491	
Case A	47.411	2.080
Case B	44.341	5.150
Case C	65.038	-15.547

Figure 28 Murupara Upper Catchment Flows



A 2.4 Galatea Dry Dam (Option 2a)

The results of the analysis are shown in Figure 29 to Figure 33 and Table 21. The results show that there is a flow reduction of only 87m³/s which is improved significantly with changed operational rules at Matahina Dam.

Figure 29 Option 2a - Case 0

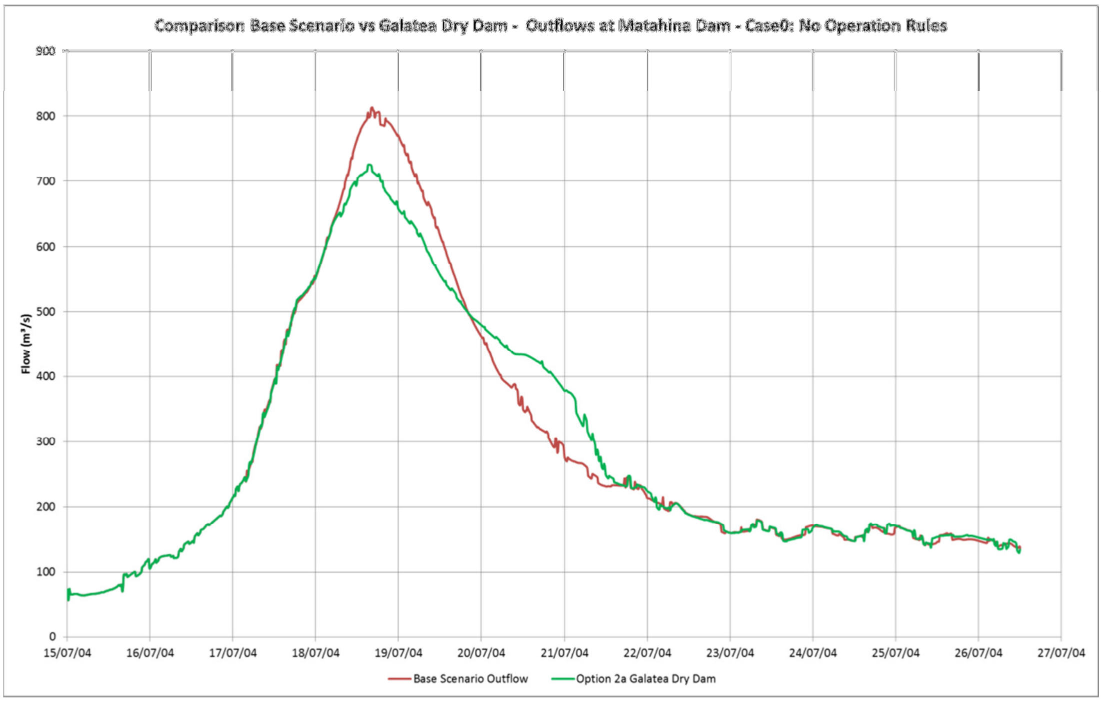


Figure 30 Option 2a - Case 1

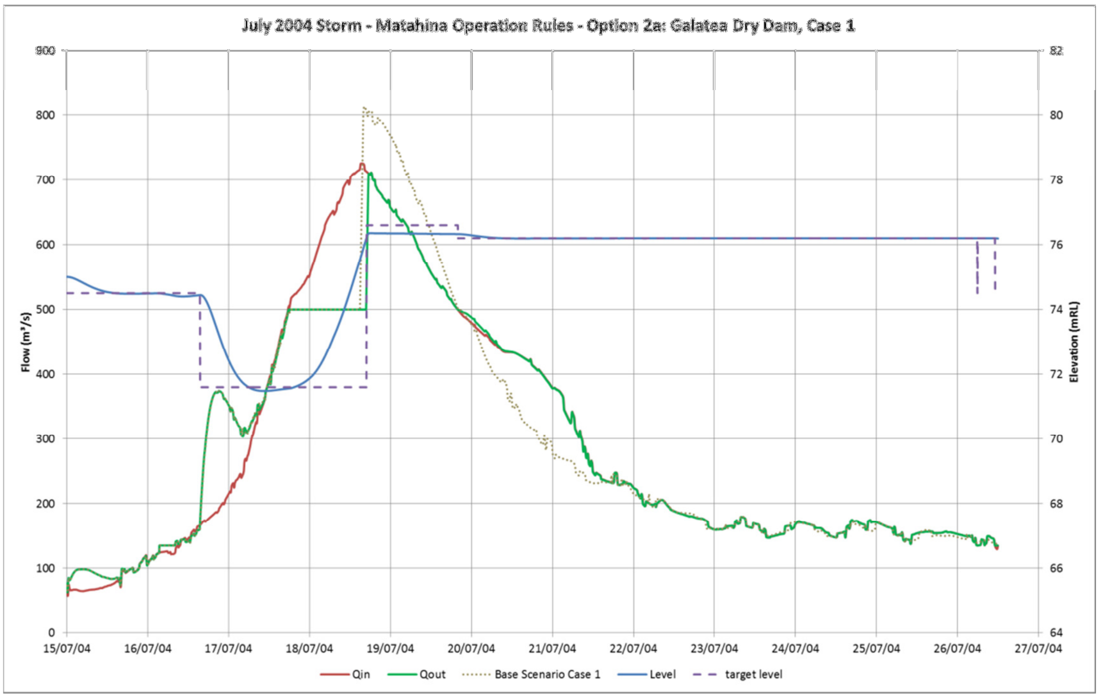


Figure 31 Option 2a - Case 2

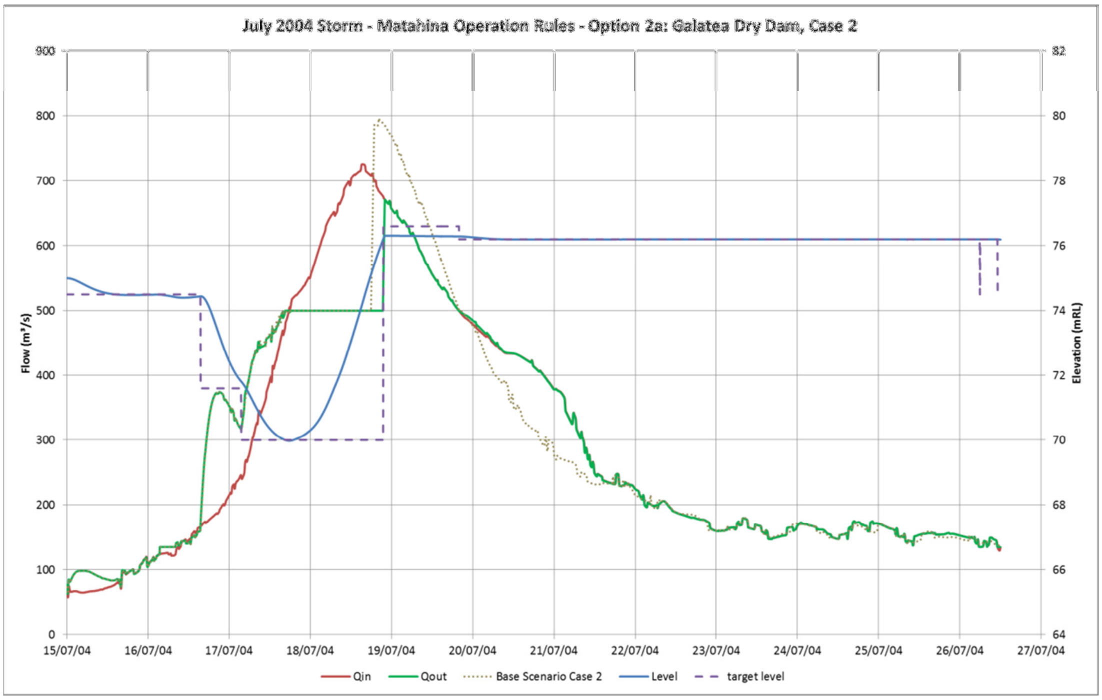


Figure 32 Option 2a - Case 3

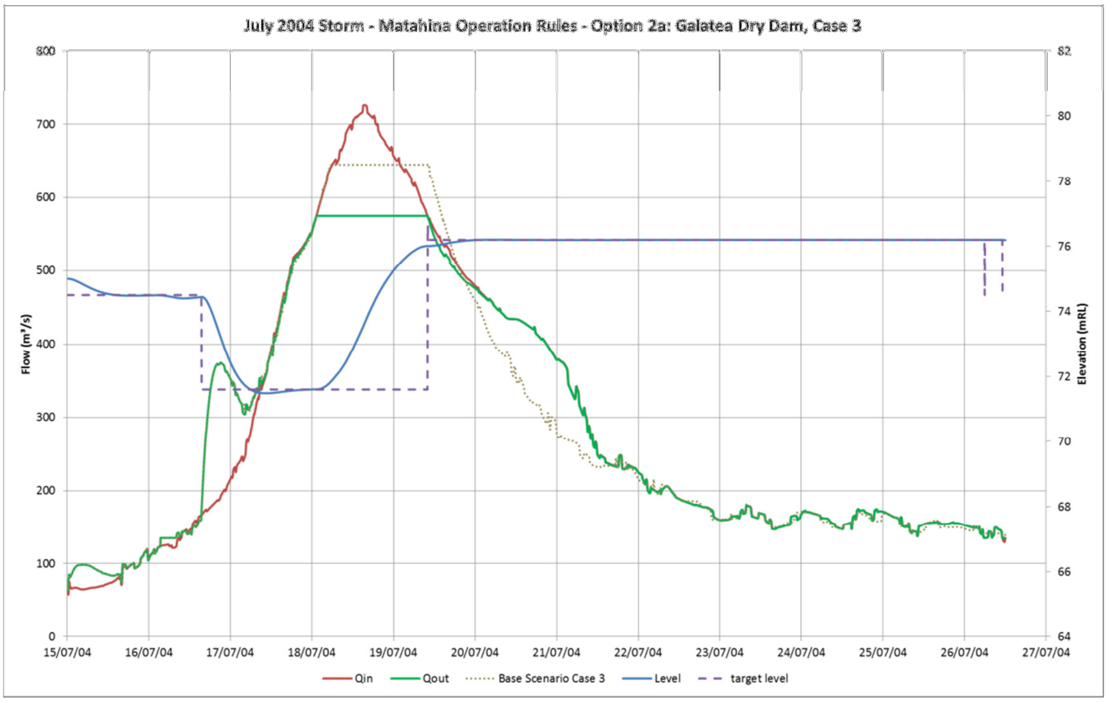


Figure 33 Option 2a - Case 4

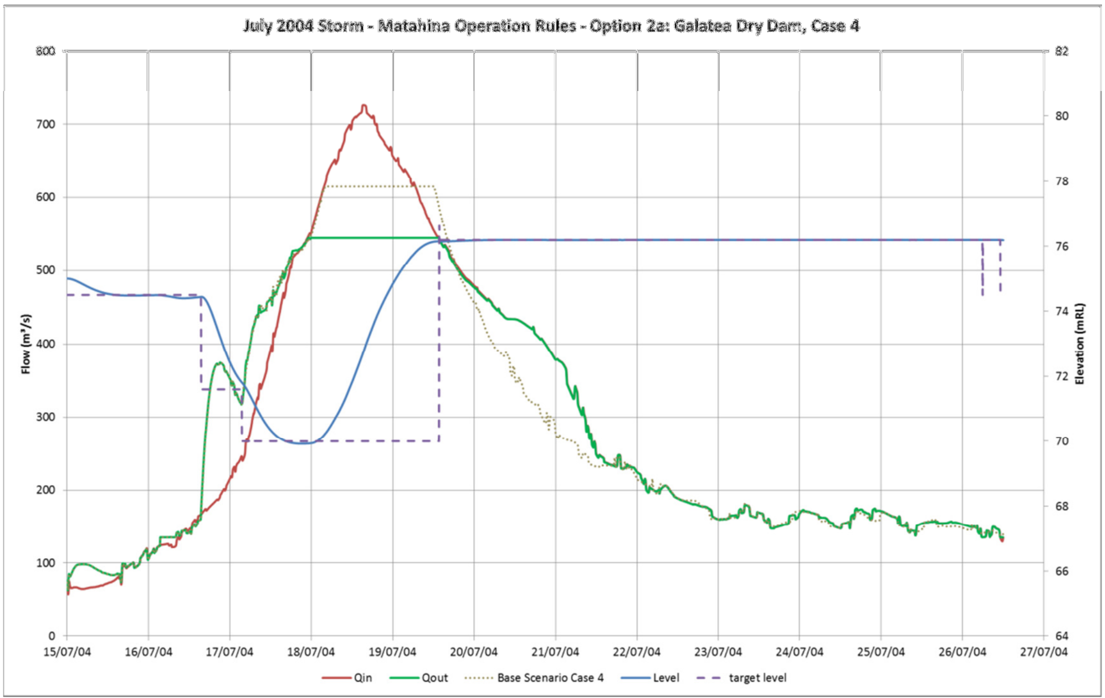


Table 21 Option 2a - Results of Cases 1 to 4

	Qmax	Lower	Peak Inflow	Peak Outflow	Rule Reduction	Total Reduction
	m³/s	mRL	m³/s	m³/s	m³/s	m³/s
Case 0	No rule		813.4	725.9	0	-87
Case 1	500	71.6	725.9	711.5	-14	-102
Case 2	500	70.0	725.9	671.0	-55	-142
Case 3	575	71.6	725.9	600.0	-126	-213
Case 4	545	70.0	725.9	595.0	-131	-218

A 2.5 Galatea MAR (diversion based on lateral weir; Option 2b)

The results of the analysis are shown in Figure 34 to Figure 38 and Table 22. The assessment shows that there would be a reduction of 82m^3/s in peak flow and that would increase to 263m^3/s with changes to operations at Matahina dam. This outcome would generate reductions in peak flow such that the river and floodway were not flowing full.

Figure 34 Option 2b - Case 0

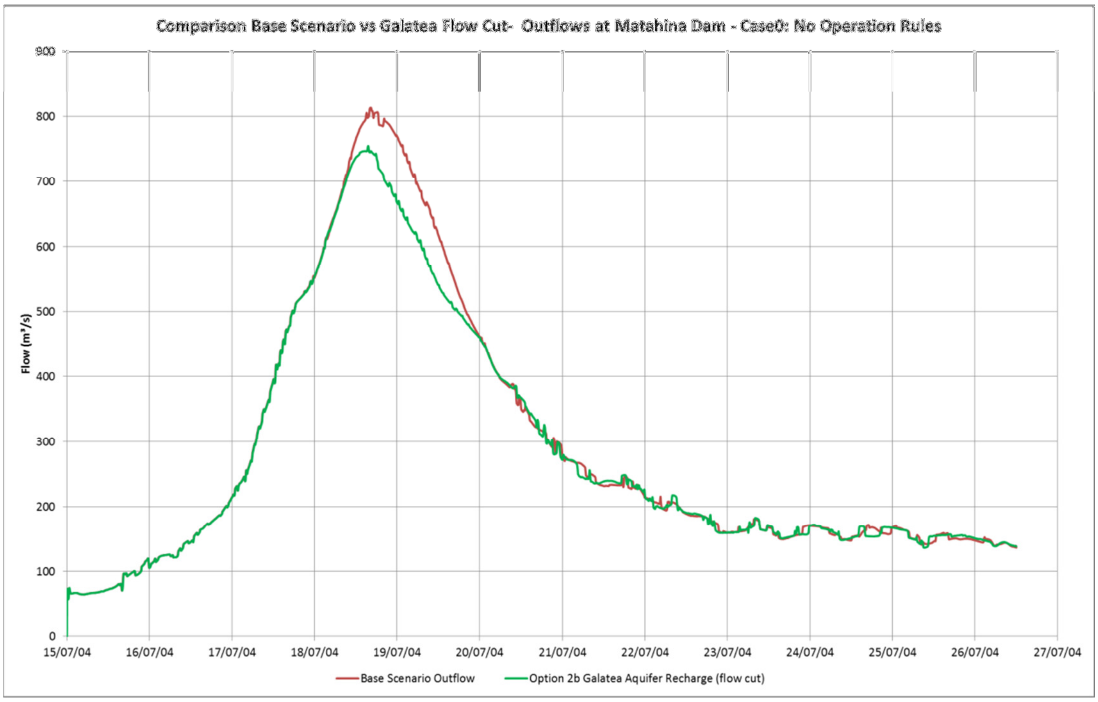


Figure 35 Option 2b - Case 1

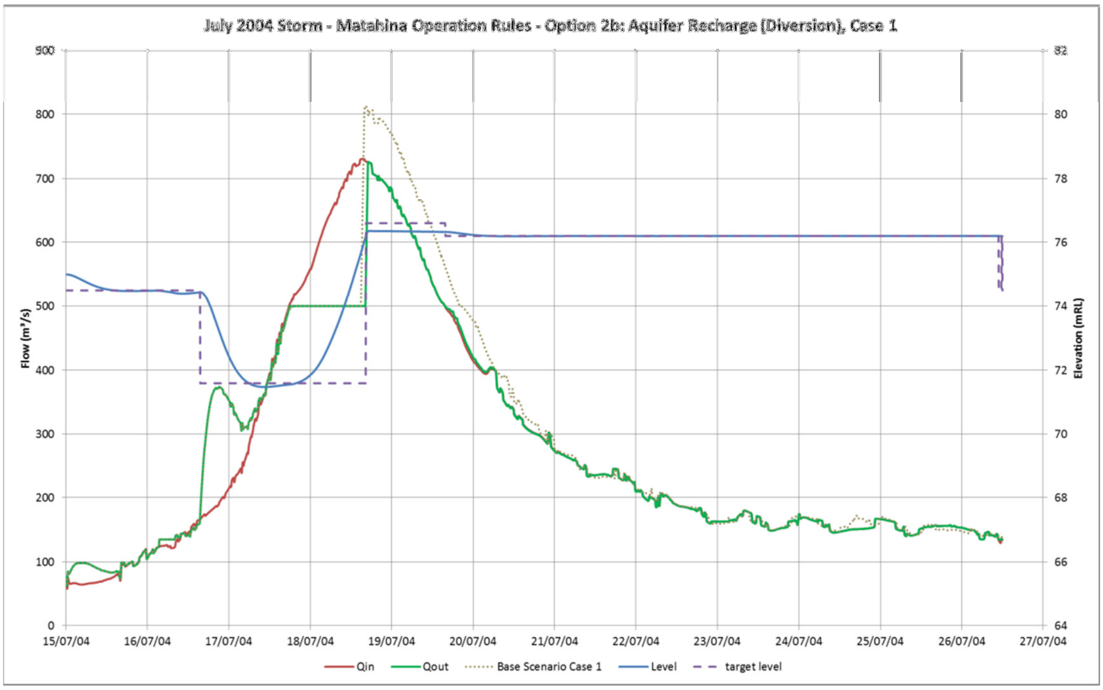


Figure 36 Option 2b - Case 2

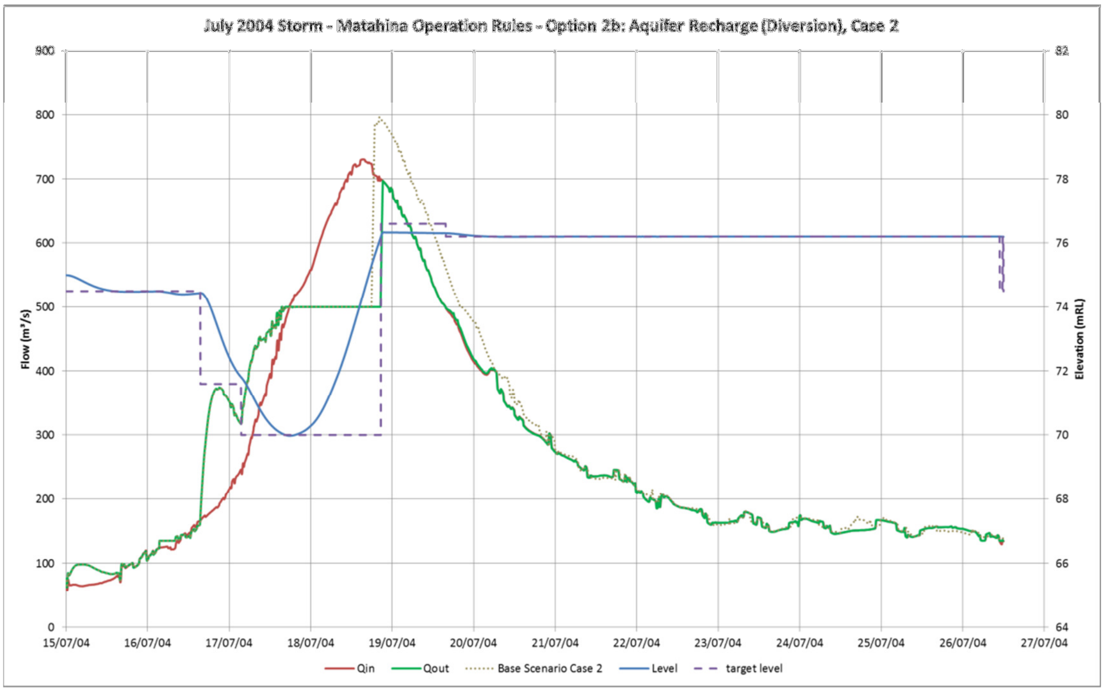


Figure 37 Option 2b - Case 3

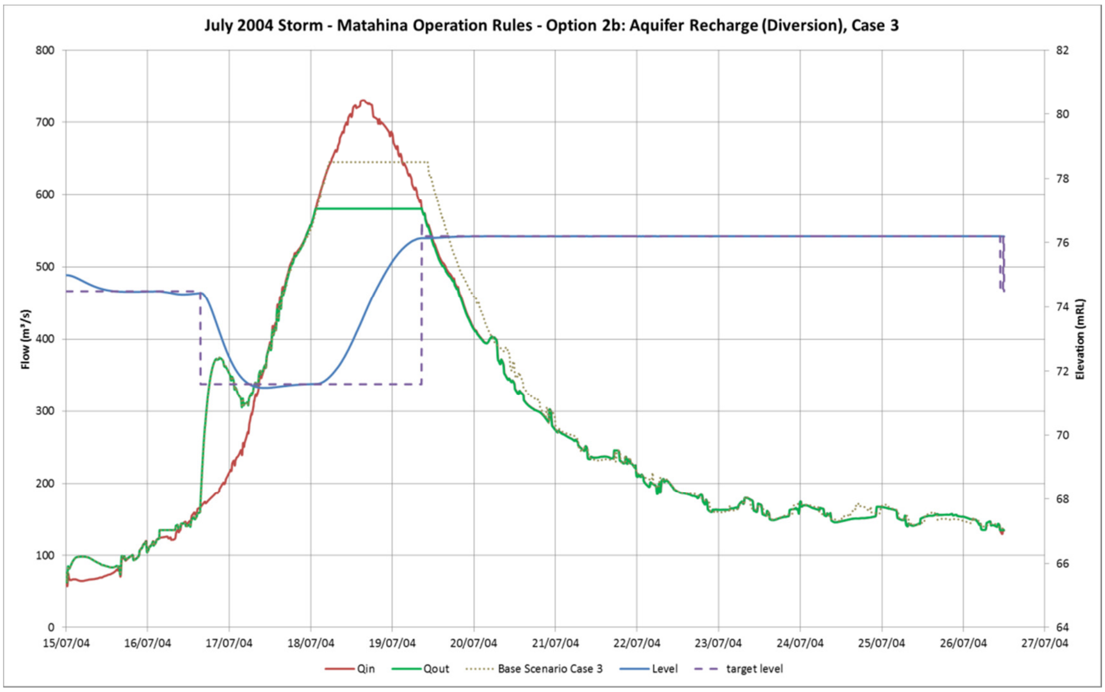


Figure 38 Option 2b - Case 4

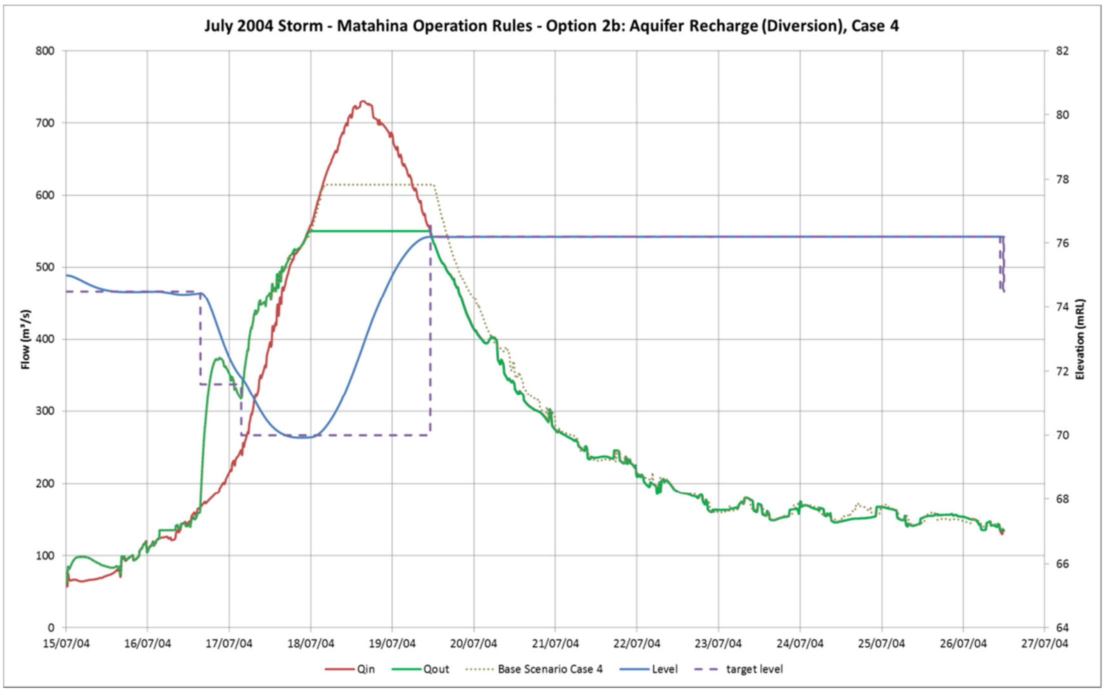


Table 22 **Option 2b - Results of Cases 1 to 4**

	Qmax	Lower	Peak Inflow	Peak Outflow	Rule Reduction	Total Reduction
	m³/s	mRL	m³/s	m³/s	m³/s	m³/s
Case 0	No rule		813.4	731.0	0	-82
Case 1	500	71.6	731.0	726.2	-5	-87
Case 2	500	70.0	731.0	697.5	-33	-116
Case 3	580	71.6	731.0	580.9	-150	-232
Case 4	550	70.0	731.0	550.0	-181	-263

A 2.6 Galatea MAR (Option 2c)

The results of the analysis are shown in

Figure 39 to Figure 42 and Table 23. The results provide a slightly reduced flood management benefit compared to option 2b.

Figure 39 Option 2c - Case 0

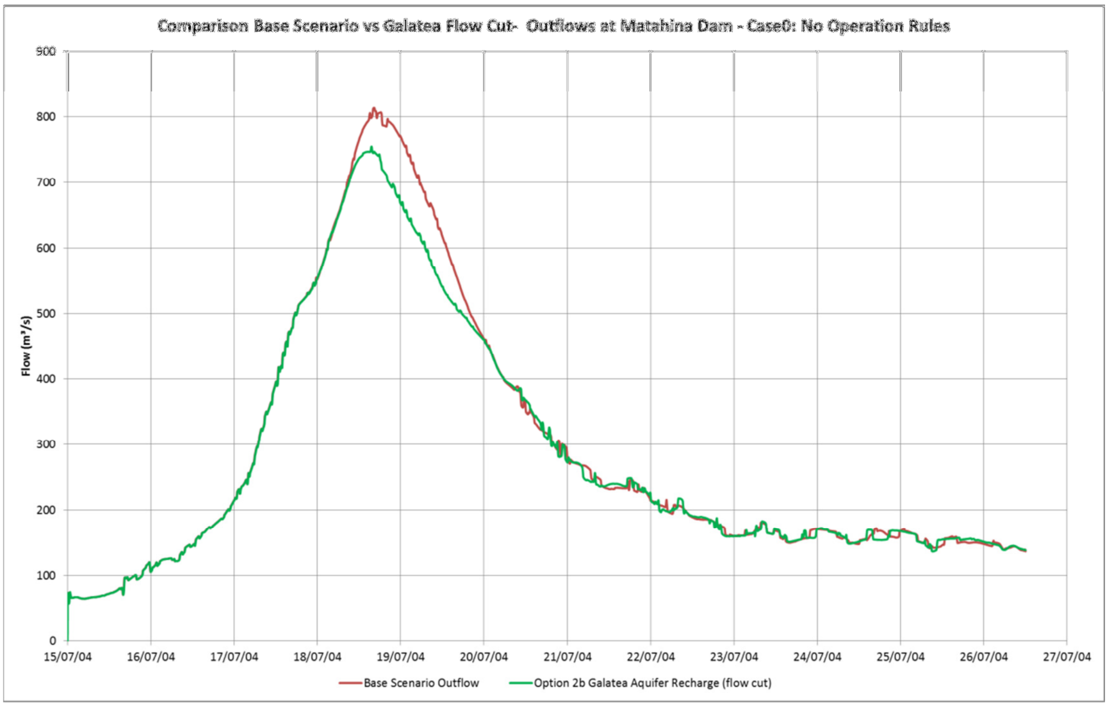


Figure 40 Option 2c - Case 1

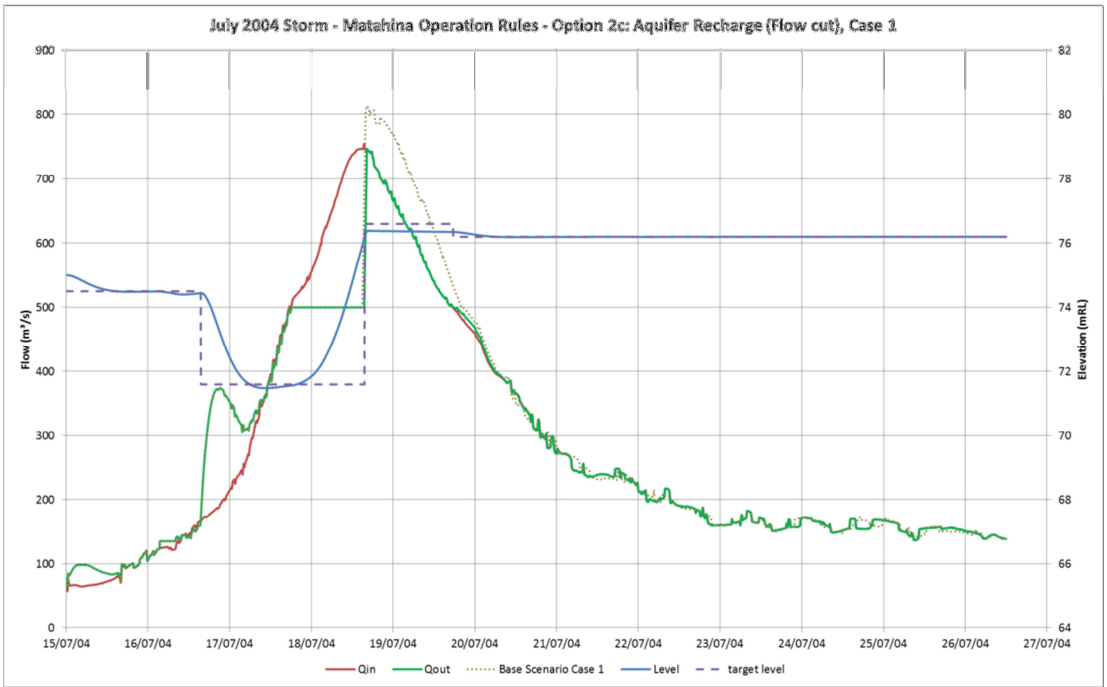


Figure 41 Option 2c - Case 2

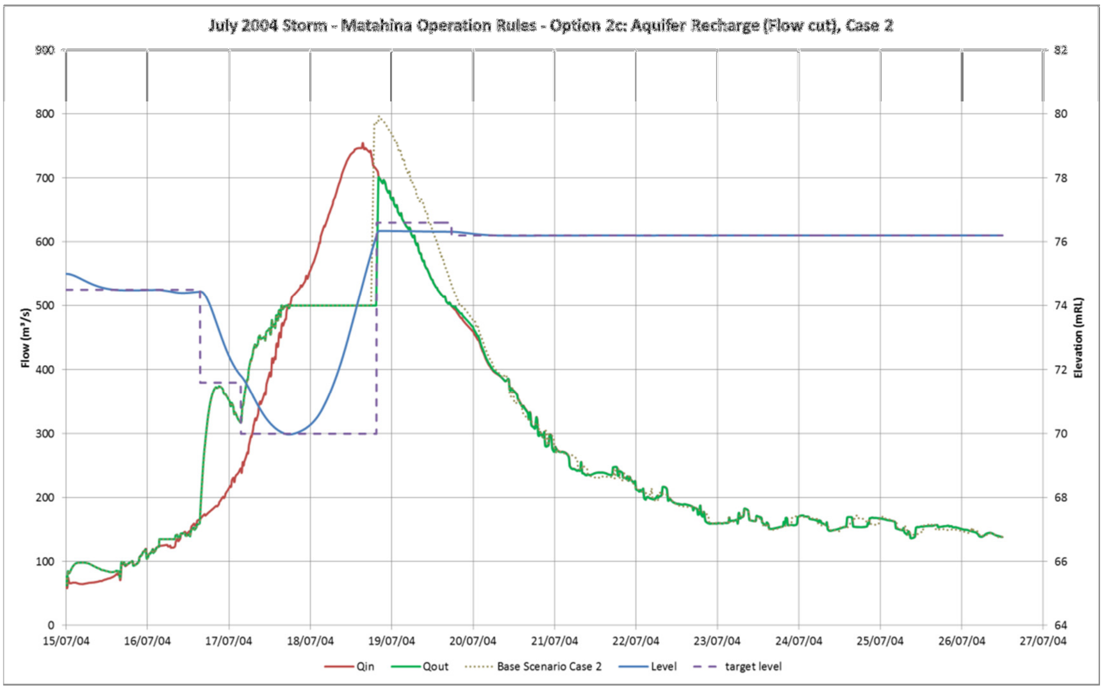


Figure 42 Option 2c - Case 3

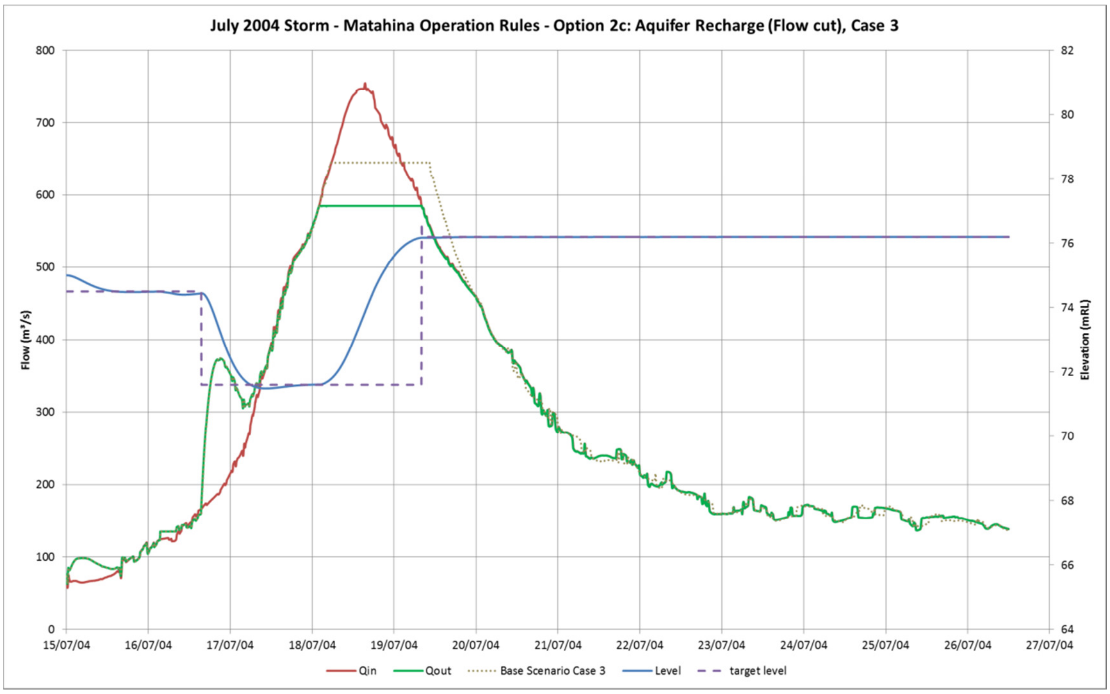


Figure 43 Option 2c - Case 4

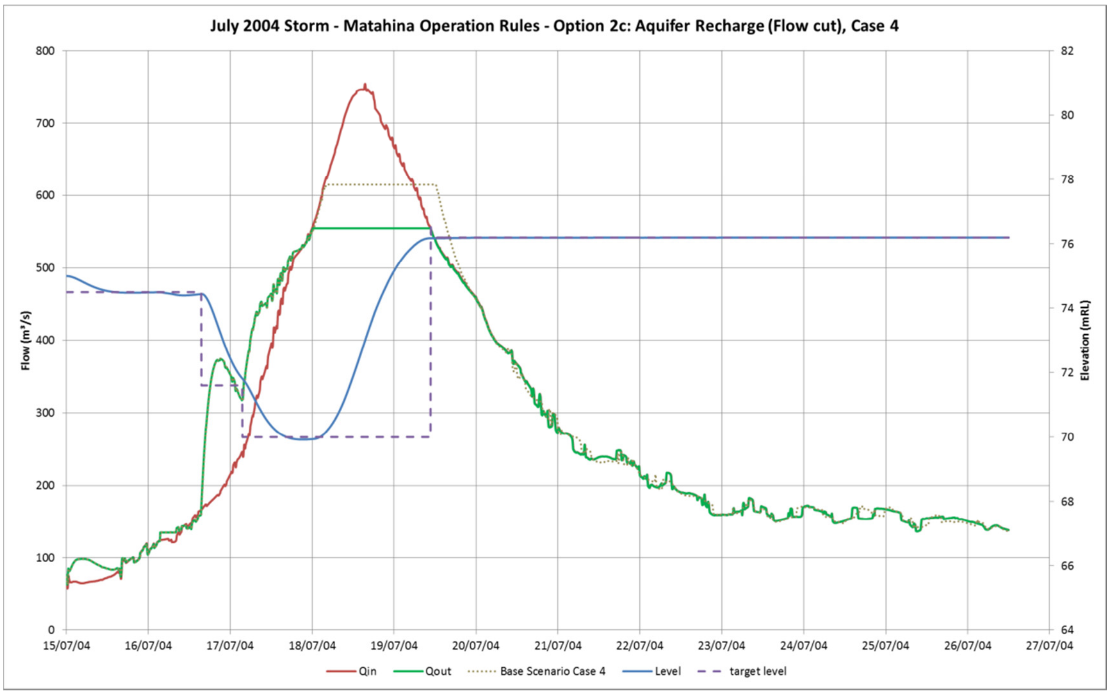


Table 23 Option 2c - Results for Cases 1 to 4

	Qmax	Lower	Peak Inflow	Peak Outflow	Rule Reduction	Total Reduction
	m³/s	mRL	m³/s	m³/s	m³/s	m³/s
Case 0	No rule		813.4	754.7	0	-59
Case 1	500	71.6	754.7	746.5	-8	-67
Case 2	500	70.0	754.7	701.8	-53	-112
Case 3	585	71.6	754.7	585.5	-169	-228
Case 4	555	70.0	754.7	555.0	-200	-258

A 2.7 Galatea MAR (Option 2d)

The results of the analysis are shown in Figure 44 to Figure 48 and Table 24 where the outcome is similar to the other MAR diversion options.

Figure 44 Option 2d - Case 0

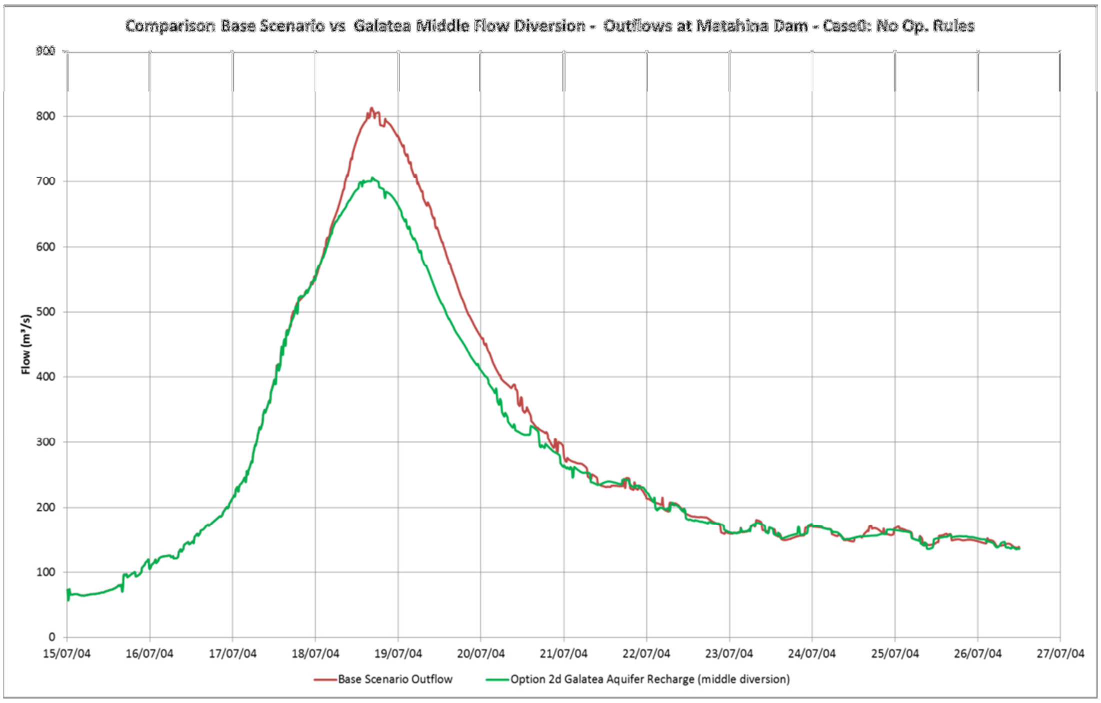


Figure 45 Option 2d - Case 1

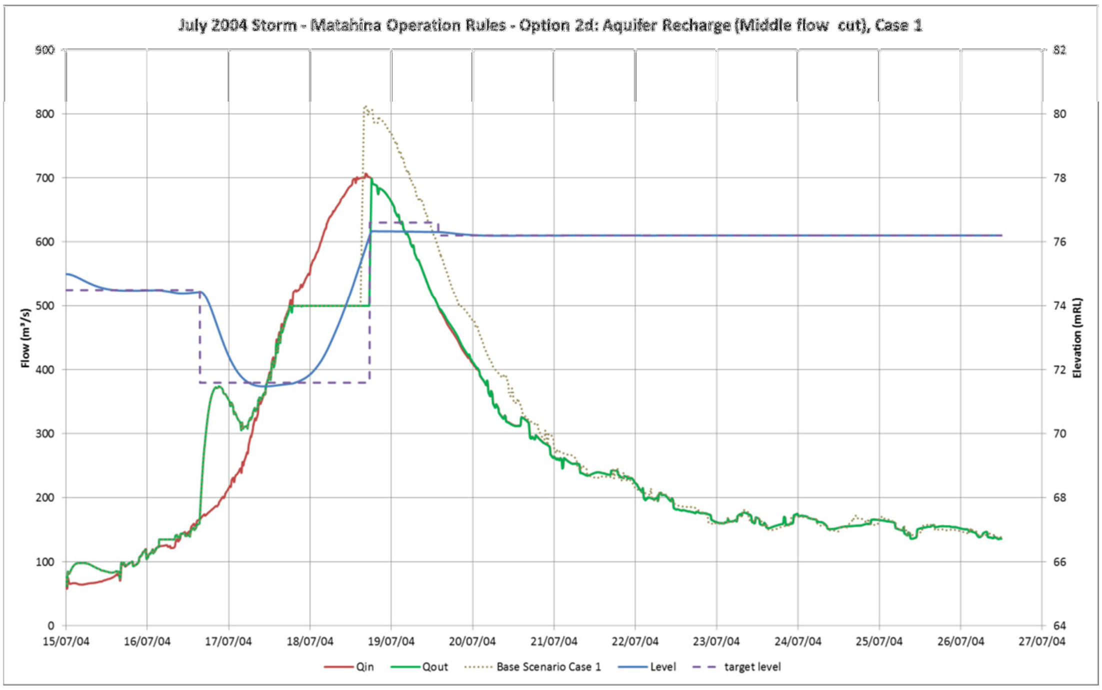


Figure 46 Option 2d - Case 2

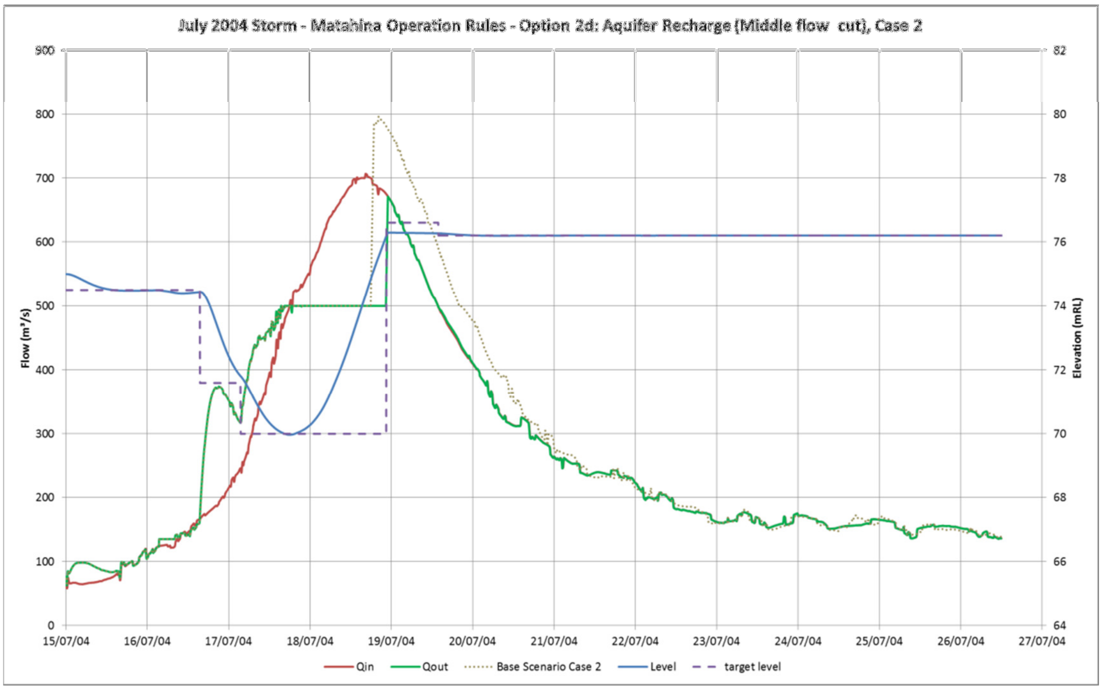


Figure 47 Option 2d - Case 3

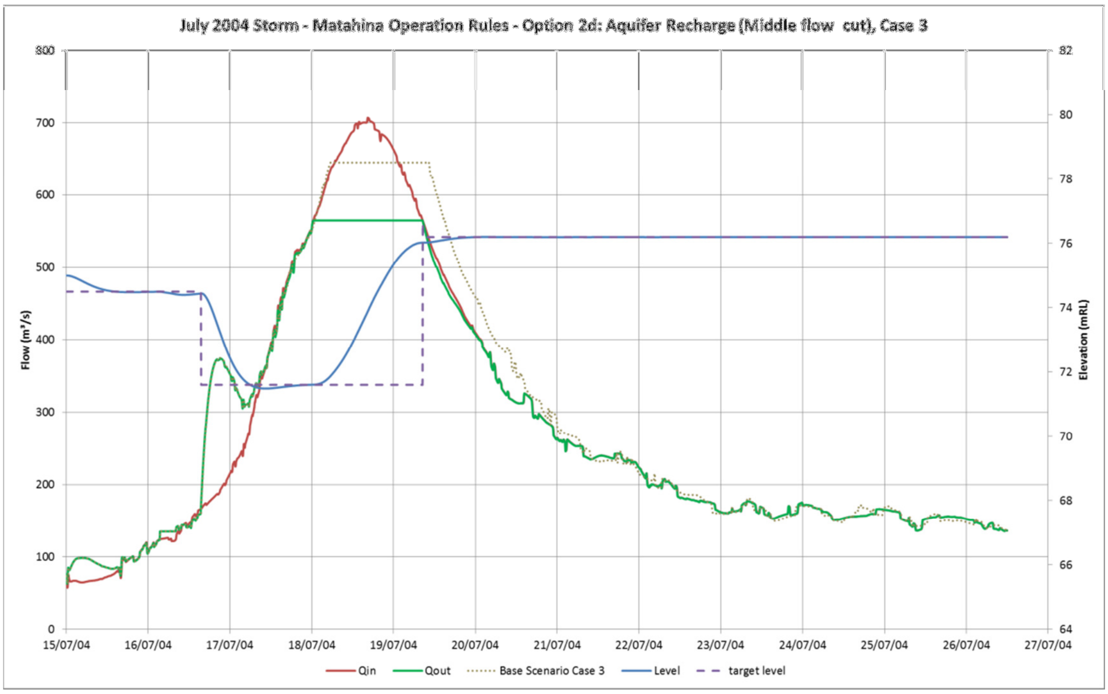


Figure 48 Option 2d - Case 4

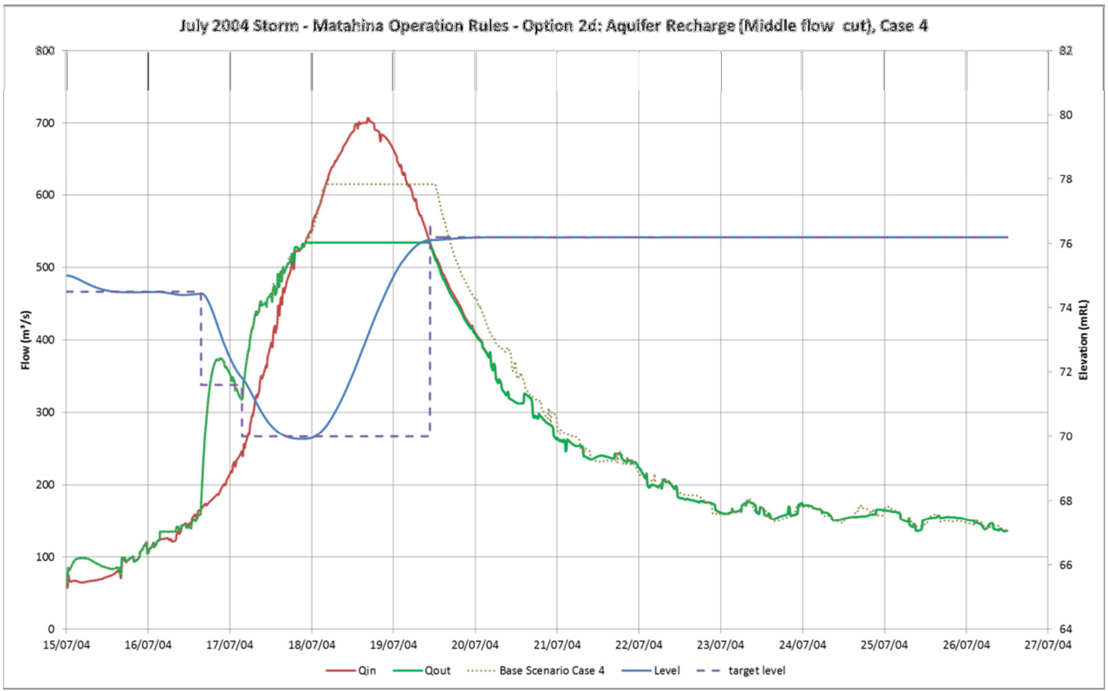


Table 24 Option 2d - Results for Cases 1 to 4

	Qmax	Lower	Peak Inflow	Peak Outflow	Rule Reduction	Total Reduction
	m³/s	mRL	m³/s	m³/s	m³/s	m³/s
Case 0	No rule		813.4	707.1	0	-106
Case 1	500	71.6	707.1	746.5	-8	-114
Case 2	500	70.0	707.1	701.8	-36	-142
Case 3	565	71.6	707.1	565.1	-142	-248
Case 4	535	70.0	707.1	535.0	-152	-258

A 2.8 Horomanga Dry Dam (Option 3)

The results of the analysis are shown in Figure 49 to Figure 53 and Table 25. Again the significant improvements in flow reduction are not achieved until the management regime at Matahina dam is modified.

Figure 49 Option 3 - Case 0

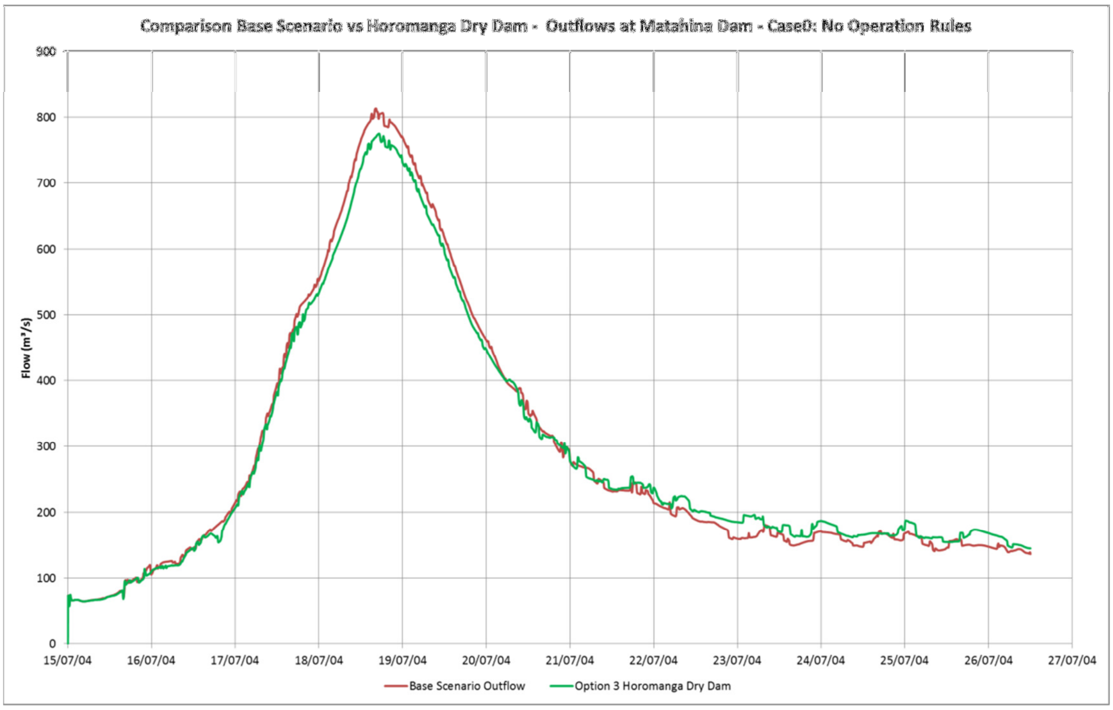


Figure 50 Option 3 - Case 1

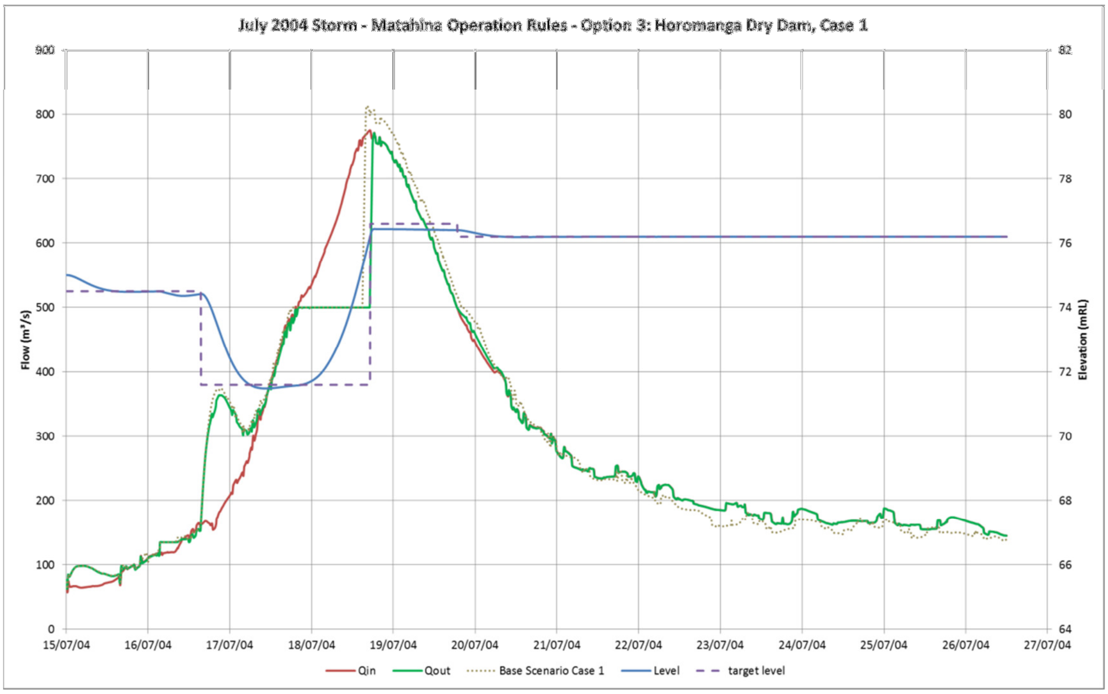


Figure 51 Option 3 - Case 2

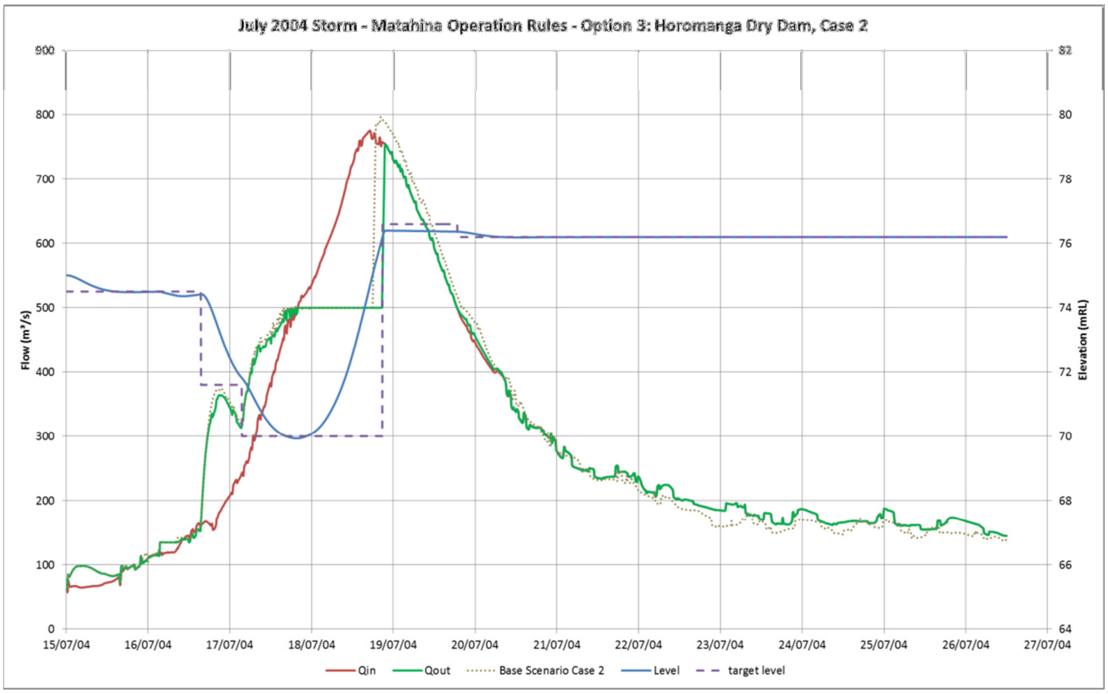


Figure 52 Option 3 - Case 3

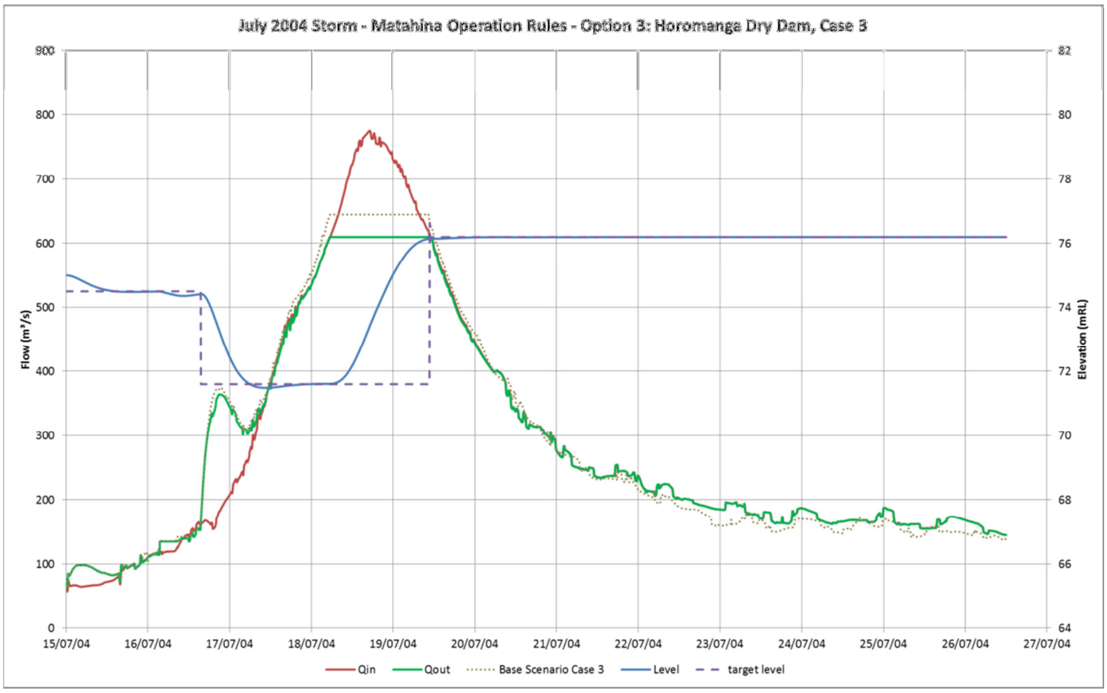


Figure 53 Option 3 - Case 4

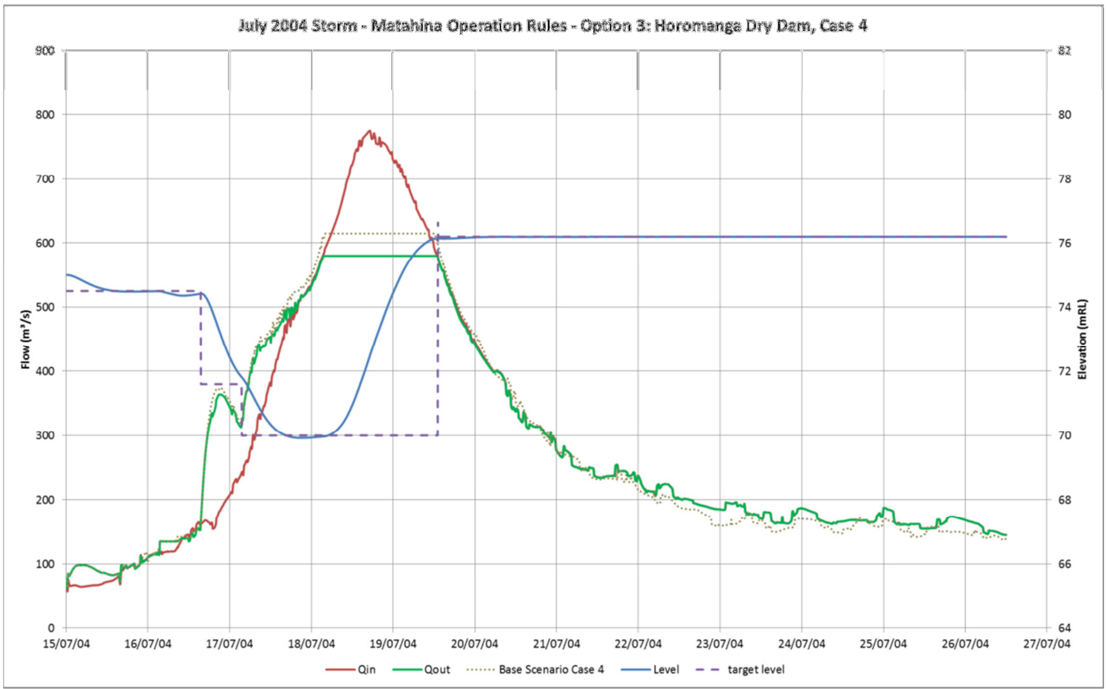


Table 25 Option 3 - Results for Cases 1 to 4

	Qmax	Lower	Peak Inflow	Peak Outflow	Rule Reduction	Total Reduction
	m³/s	mRL	m³/s	m³/s	m³/s	m³/s
Case 0	No rule		813.4	775.4	0	-38
Case 1	500	71.6	775.4	746.5	-29	-67
Case 2	500	70.0	775.4	701.8	-74	-112
Case 3	610	71.6	775.4	585.5	-190	-228
Case 4	580	70.0	775.4	555.0	-220	-258

A 2.9 Matahina Dam Raising (Option 4a)

The results of the analysis are shown in Figure 54 to Figure 57. Various height increases from 2m to 5m have been considered. The benefits are similar to those with other options but the practicality of achieving the raising at the dam is doubtful.

Figure 54 Option 4 - Case 1

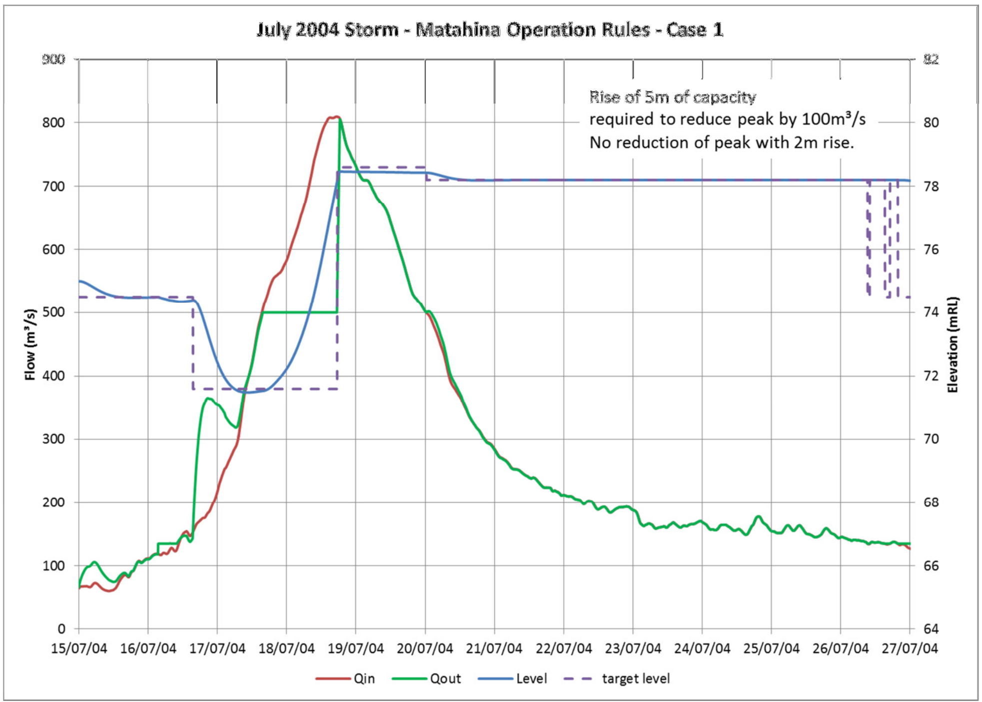


Figure 55 Option 4 - Case 2

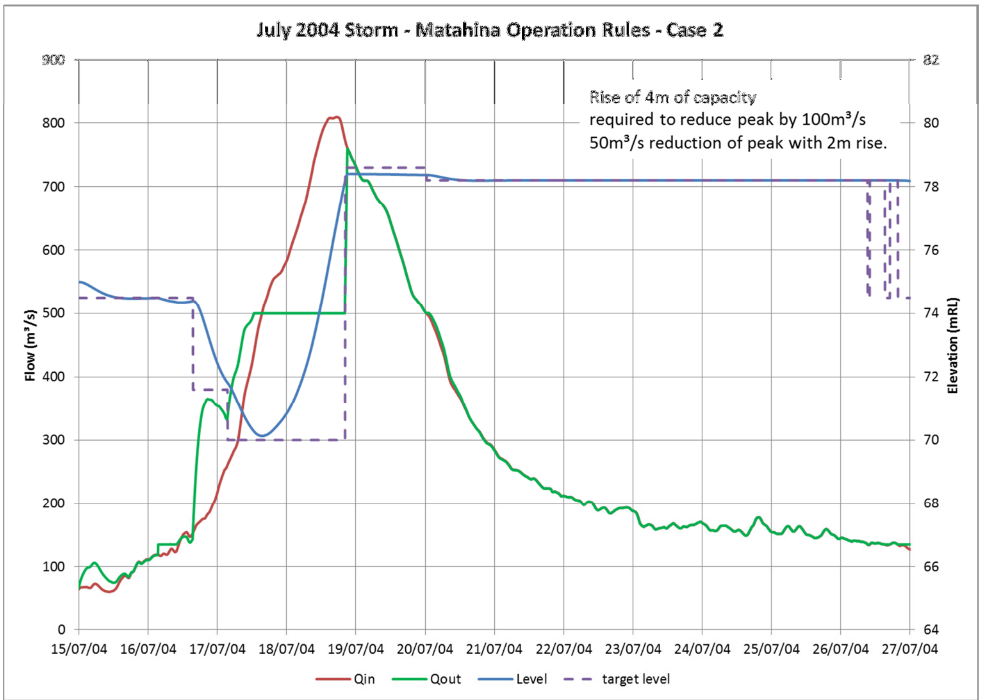


Figure 56 Option 4 - Case 3

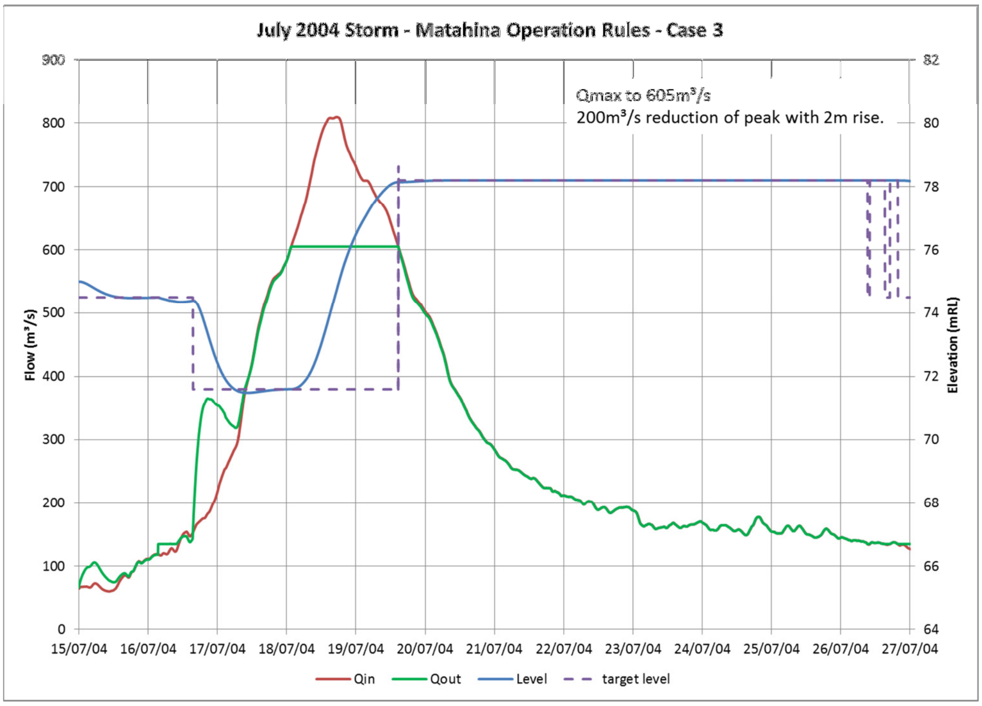
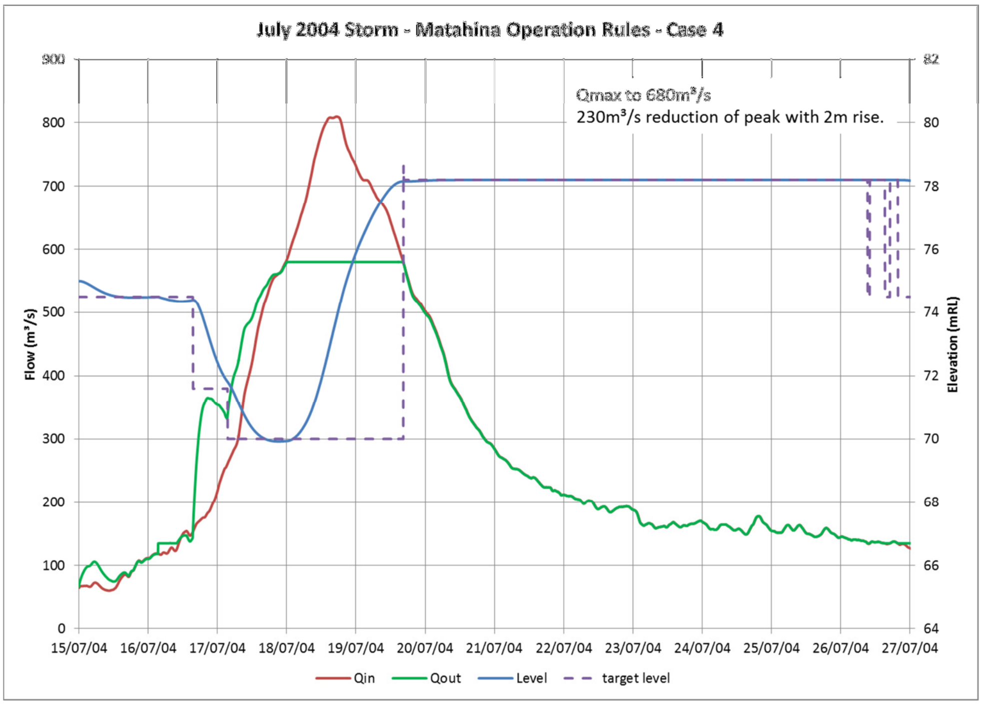


Figure 57 Option 4 - Case 4



The results show that dam raising, along with revised operation of flood controls at Matahina Dam does lead to reduced flow downstream of the dam.

A 2.10 New Dam between Matahina and Aniwhenua (Option 4b)

The results of the assessment are shown in Figure 58 and Table 26. A reduction larger than 100m³/s in the new reservoir is possible, however, the lateral catchments, the shape of the new outflow hydrograph and the routing up to the Matahina Dam outlet smooths the benefits that at the Matahina outlet (with no rules, Case 0) there is a benefit less than 60m³/s. Specific hydrograph component management and precise flood forecasting could improve outcomes but most of the benefit is gained at Matahina.

Figure 58 New Dam Performance

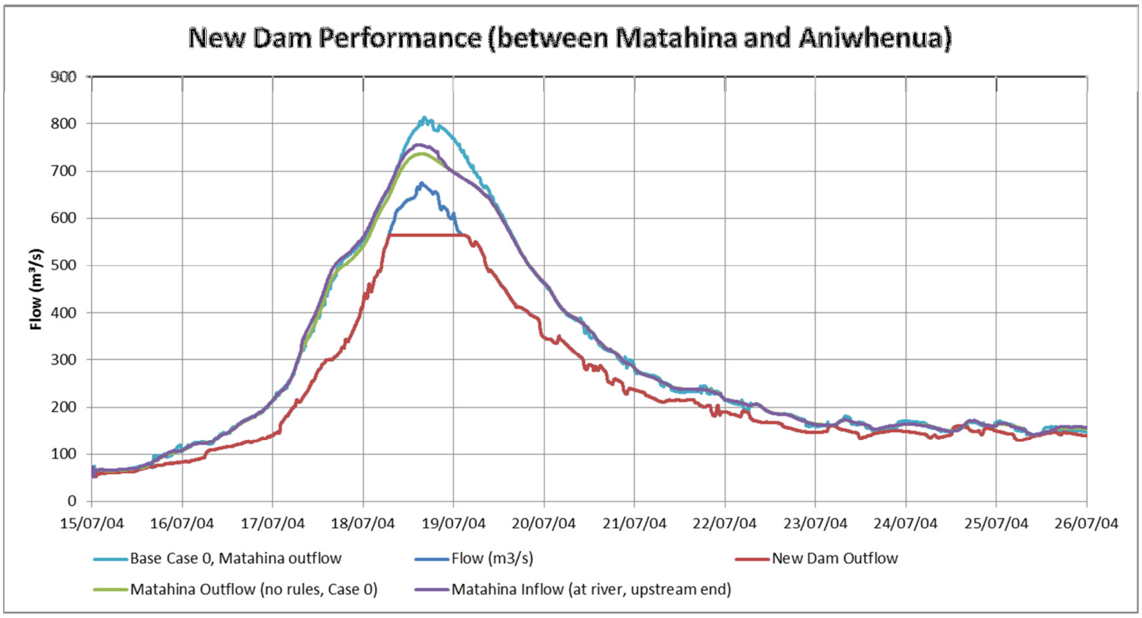


Table 26 New Dam

Location	Peak Flow m^3/s
New Dam Inflow (US of Aniwhenua)	674.4
New Dam Outflow	564.4
Matahina Inflow (at river, upstream end)	736.4
Matahina Outflow (no rules, Case 0)	754.9
Base Case 0, Matahina outflow	813.4
Reduction at New Dam	110.0
Reduction at Matahina outlet (no rules)	58.5

A 2.11 Dry Dam Below Matahina (Option 4c)

Two types of dam outlet control have been considered and the results are provided in Figure 59 and Figure 60 and Table 27 and Table 28.

Figure 59 Dam Downstream of Matahina

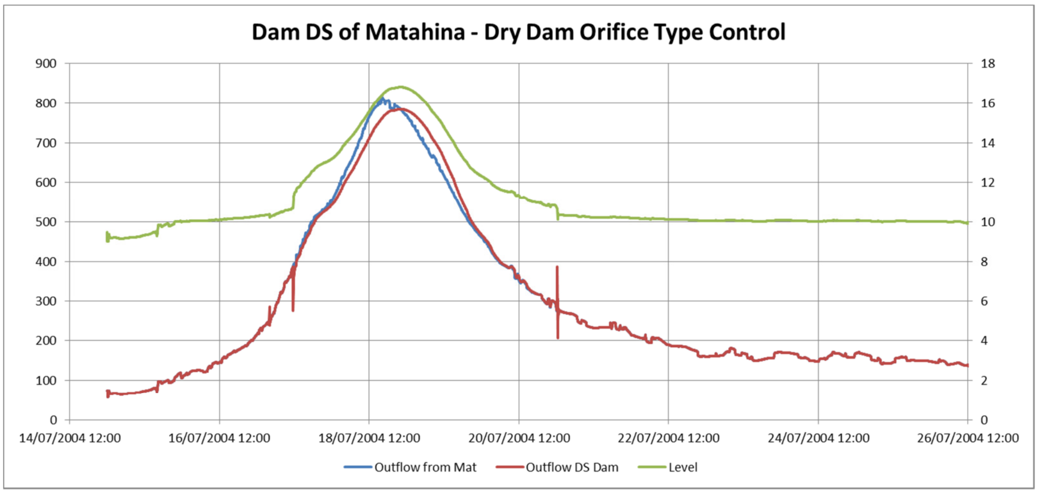


Table 27 Dam Orifice Area

Item	Value	Unit
Dam Invert	9.0	mRL
Dam Orifice Area	85.0	m²
Dam Orifice Height	1.7	m
Approx maximum free flow	387.6	m³/s
Inflow Peak	813.4	m³/s
Outflow Peak	784.3	m³/s
Peak Reduction	29.1	m³/s
Maximum Water Level	16.8	mRL
Maximum Water Depth	7.8	m
Maximum Volume at peak	3.37	Mm³
Maximum Flooded Area at peak	103.3	Ha

Figure 60 Dam Downstream of Matahina – Gate Type Control

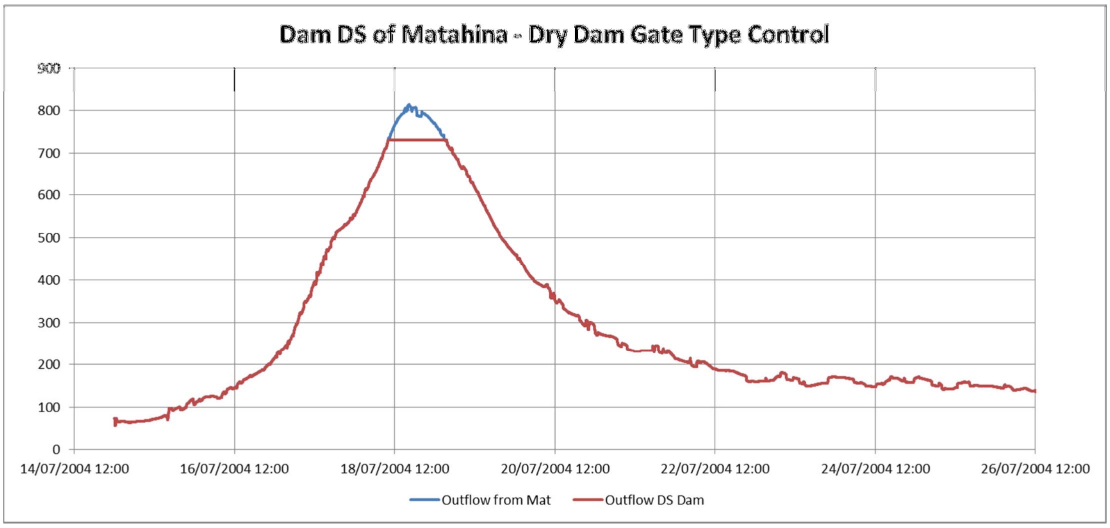


Table 28 Item Value

Item	Value	Unit
Dam Invert	9.0	mRL
Gated Dam control		
Inflow Peak	813.4	m³/s
Outflow Peak	730.0	m³/s
Peak Reduction	83.4	m³/s
Maximum Water Level	16.6	mRL
Maximum Water Depth	7.6	m
Maximum Volume at peak	2.97	Mm³
Maximum Flooded Area at peak	100.8	Ha

The maximum level of about 16.6mRL is higher than the invert of the cross section downstream of the Matahina Dam, which makes it an unsafe solution as there would be interaction with the Matahina Dam, and this needs to be avoided for operation and to allow a proper flood control. Even then with an optimum operation, the maximum possible reduction is about 83m³/s which is not enough to meet flood management objectives.

A 2.12 Multiple Sub-catchment Dams (Option 4d)

Theoretically a multiple dam system over the upper catchment should be able to control floods in the lower Rangitāiki plains. It is estimated that to reduce the 1% AEP event peak by 100m³/s it is required to store about 4Mm³ (Table 29).

Table 29 Volumes from 2004 Event

Volume of 2004 Matahina inflow hydrograph	Value	Unit
Volume of peak 50m³/s	1.3	Mm³
Volume of peak 100m³/s	3.9	Mm³
Volume of peak 150 m³/s	8.3	Mm³
Volume of peak 200 m³/s	14.2	Mm³
Volume TOTAL of hydrograph at Matahina Inflow	332.8	Mm³

Theoretically this volume could be split into a number of smaller reservoirs along the catchment to spread the cost and impact of a major reservoir. Very precise catchment modelling and forecasting would be required for small dams to be effective. Since this is realistically impracticable, the volume stored in smaller dams would need to be larger, and will depend on the distance from the lower Rangitāiki.

Considering the event of July 2004, Figure 61 shows the required volumes for different ranges of reduction from the peak.

Figure 61 Flow Downstream of Matahina Dam

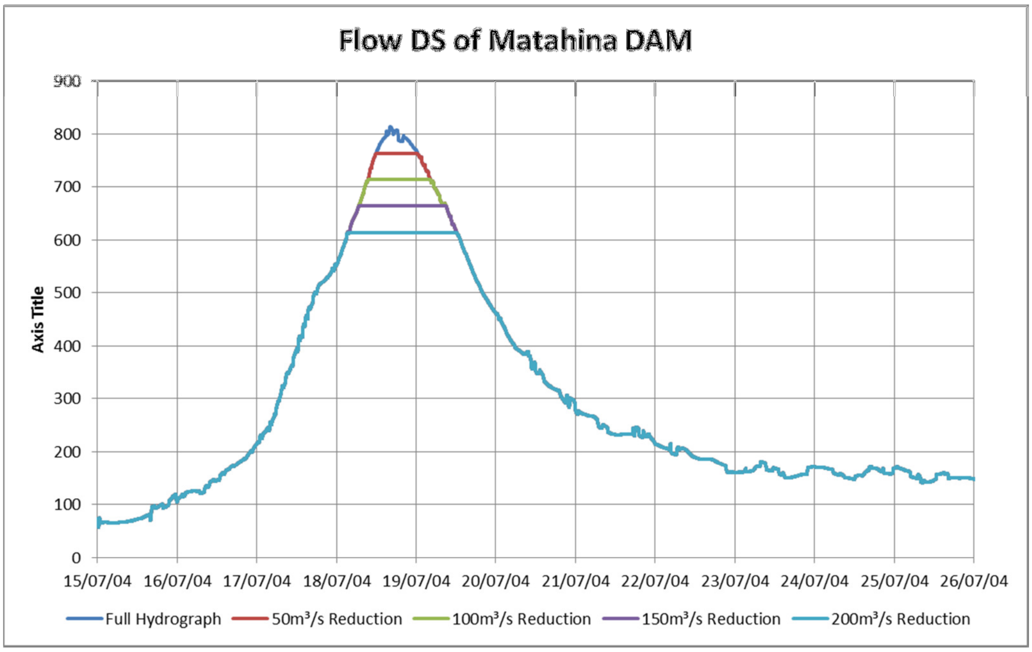


Table 30 and Table 31 show the flow reduction and the storage volume required for a number of reservoirs.

Table 30 Peak flow storage requirements

Peak Flow	Flow Reduction	Threshold flow	Duration of Peak	Minimum Volume to store peak	Ave Flow Reduction
m³/s	m³/s	m³/s	hrs	Mm³	m³/s
Qp	Qr	Qmax	Tp	Vp	Qa
813	0	804	2.3	0.00	0.0
763	50	754	14.3	1.17	22.8
713	100	704	20.6	4.05	54.6
663	150	654	27.4	8.07	81.7
613	200	604	34.1	13.37	109.0

Table 31 Dam Numbers, Storage Volumes and Discharge Reduction

	Volume Required (total), Mm^3				Volume Required (each reservoir), Mm^3			
# Dams	$50m^3/s$	$100m^3/s$	$150m^3/s$	$200m^3/s$	$50m^3/s$	$100m^3/s$	$150m^3/s$	$200m^3/s$
1	1.4	4.0	8.1	13.4	1.40	4.05	8.09	13.41
2	1.8	4.9	9.4	15.2	0.91	2.46	4.71	7.62
3	2.4	6.1	11.3	17.8	0.79	2.02	3.75	5.94
4	3.0	7.3	13.3	20.7	0.74	1.83	3.33	5.18
5	3.6	8.8	15.6	24.0	0.73	1.76	3.13	4.81
6	4.4	10.4	18.3	27.8	0.73	1.74	3.05	4.64
7	5.3	12.3	21.4	32.2	0.76	1.76	3.05	4.60
8	6.3	14.6	24.9	37.3	0.79	1.82	3.12	4.66
9	7.6	17.2	29.2	43.3	0.84	1.91	3.24	4.81
10	9.0	20.4	34.2	50.5	0.90	2.04	3.42	5.05
12	10.5	23.3	38.6	56.2	0.87	1.94	3.21	4.69
15	12.6	27.6	45.0	64.9	0.84	1.84	3.00	4.32
20	16.2	34.8	55.8	79.3	0.81	1.74	2.79	3.96
30	23.4	49.2	77.4	108.1	0.78	1.64	2.58	3.60
50	37.8	78.0	120.6	165.7	0.76	1.56	2.41	3.31

Even though very optimistic assumptions have been used, the total volume required grows quickly with the number of reservoirs and with it the cost of building and managing them. As the number grows, a better forecast and prediction is required to store the most effective portion of the local hydrograph, as the timing of arrival and portion that lowers river peak flow changes with each location and the combination of storages.

A 2.13 Matahina Dam Rules (Option 4e)

A complete analysis of the Matahina Dam and options are explained in Section 3.0.

It mainly addresses the need to have an effective flow forecast to estimate the optimum outflow from Matahina for a particular flood event. It is estimated that with the optimised rule and tools the flow can be reduced almost $200m^3/s$ in the Matahina Dam.

Appendix B

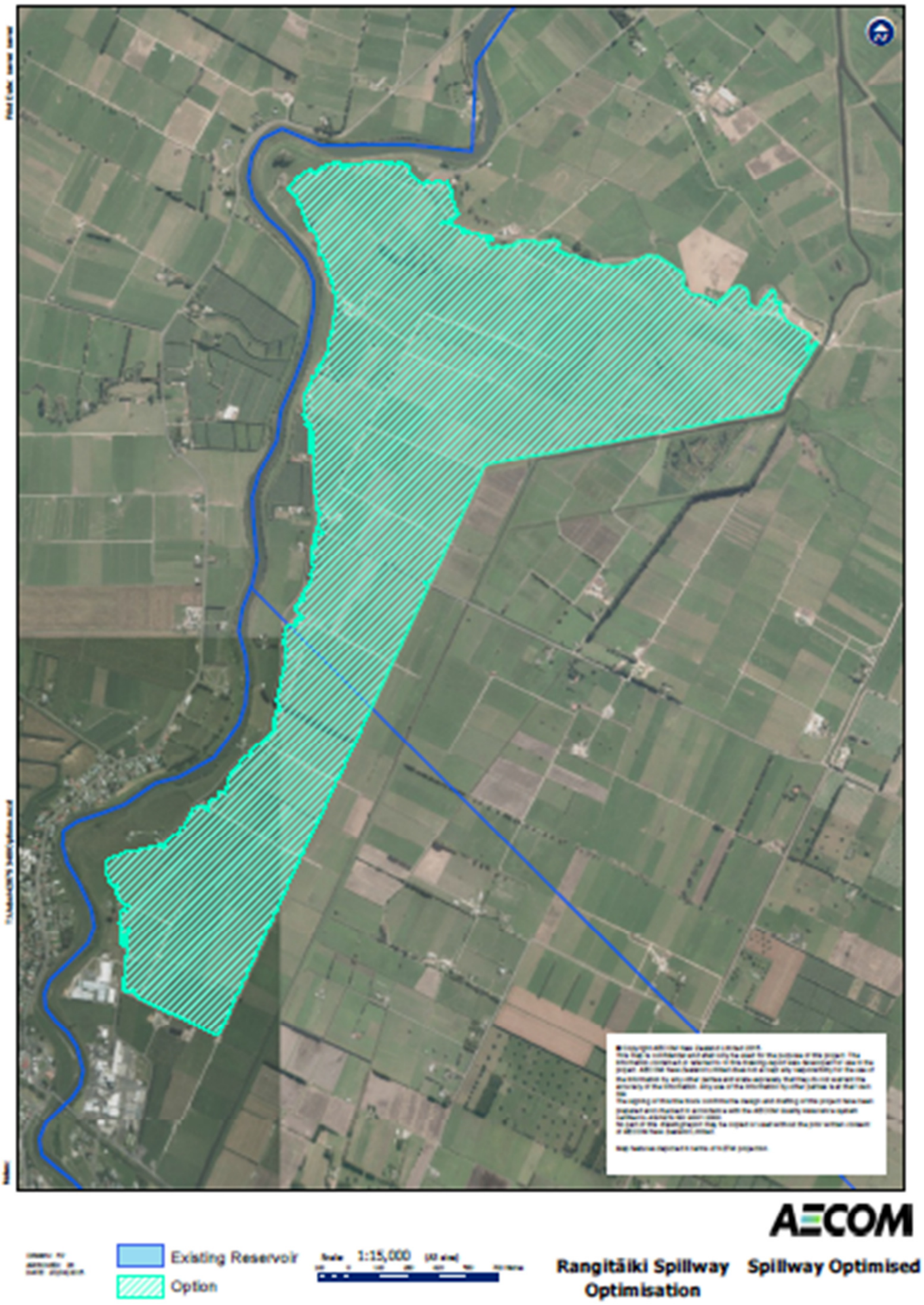
Lower Rangitāiki Options & Outcomes

Appendix B Lower Rangitāiki Options

B 1.0 Zone 1

If the Rangitāiki River and/or the Reid's Canal are to spill, then the most likely area of spill is between the river and canal. Zone 1 has been identified as the area between the floodway and the river as shown in Figure 62.

Figure 62 Zone 1 Spill Area



The water level and volume of water than would spill into Zone 1 are shown in Table 32.

Table 32 Zone 1 – Water Volume and Level

Scenario	Id	Cap	Top of Hydrograph	Level in Zone 1	Extent of area flooded
		m³/s	Mm³	mRL	ha
Base Case 0	Base 0	700	7.4	1.9	525
Base Case 1	Base 1	700	3.9	1.1	387
Base Case 2	Base 2	700	2.4	0.7	332
Base Case 3	Base 3	700	0.0	-1.8	0
Base Case 4	Base 4	700	0.0	-1.8	0
Murupara Diversion, Case 0	Option 1	700	5.8	1.6	455
Whirinaki Dam, Case 0	Option 2a	700	1.8	0.5	298
Galatea MAR, Case 0	Option 2b	700	2.4	0.7	335
Galatea MAR, Case 0	Option 2c	700	3.2	0.9	365
Galatea MAR, Case 0	Option 2d	700	1.3	0.3	251
Horomanga Dam, Case 0	Option 3	700	4.7	1.3	416

B 1.1 Zone 2

Zone 2 is a more optimised layout of the Zone 1 impoundment area. This storage solution requires an extra spillway. Both spillways, the existing and proposed, should be design together to work for different scenarios, possible requiring a variable gate or invert level. The assessment results for Zone 2 are shown in Table 33.

Table 33 Optimised Scenario – Zone 2

Scenario	Id	Cap	Top of Hydrograph	Level in Zone 2	Extent of area flooded
		m³/s	Mm³	mRL	ha
Base Case 0	Base 0	700	7.4	2.9	393
Base Case 1	Base 1	700	3.9	1.9	298
Base Case 2	Base 2	700	2.4	1.3	229
Base Case 3	Base 3	700	0.0	-1.3	0
Base Case 4	Base 4	700	0.0	-1.3	0
Murupara Diversion, Case 0	Option 1	700	5.8	2.4	369
Whirinaki Dam, Case 0	Option 2a	700	1.8	1.0	207
Galatea MAR, Case 0	Option 2b	700	2.4	1.3	231
Galatea MAR, Case 0	Option 2c	700	3.2	1.6	266
Galatea MAR, Case 0	Option 2d	700	1.3	0.8	189
Horomanga Dam, Case 0	Option 3	700	4.7	2.2	339

B 1.3 Zone 3

Zone 3 (Figure 63) is an alternative option but it has not enough storage for most options, specially the base case, so it can't be a solution on itself. Table 34 shows levels required and only a maximum level of 3mRL feasible at this location (Reid's top bank level). The only exception is if this option goes together with Option 2c.

Figure 63 Map of Zone 3

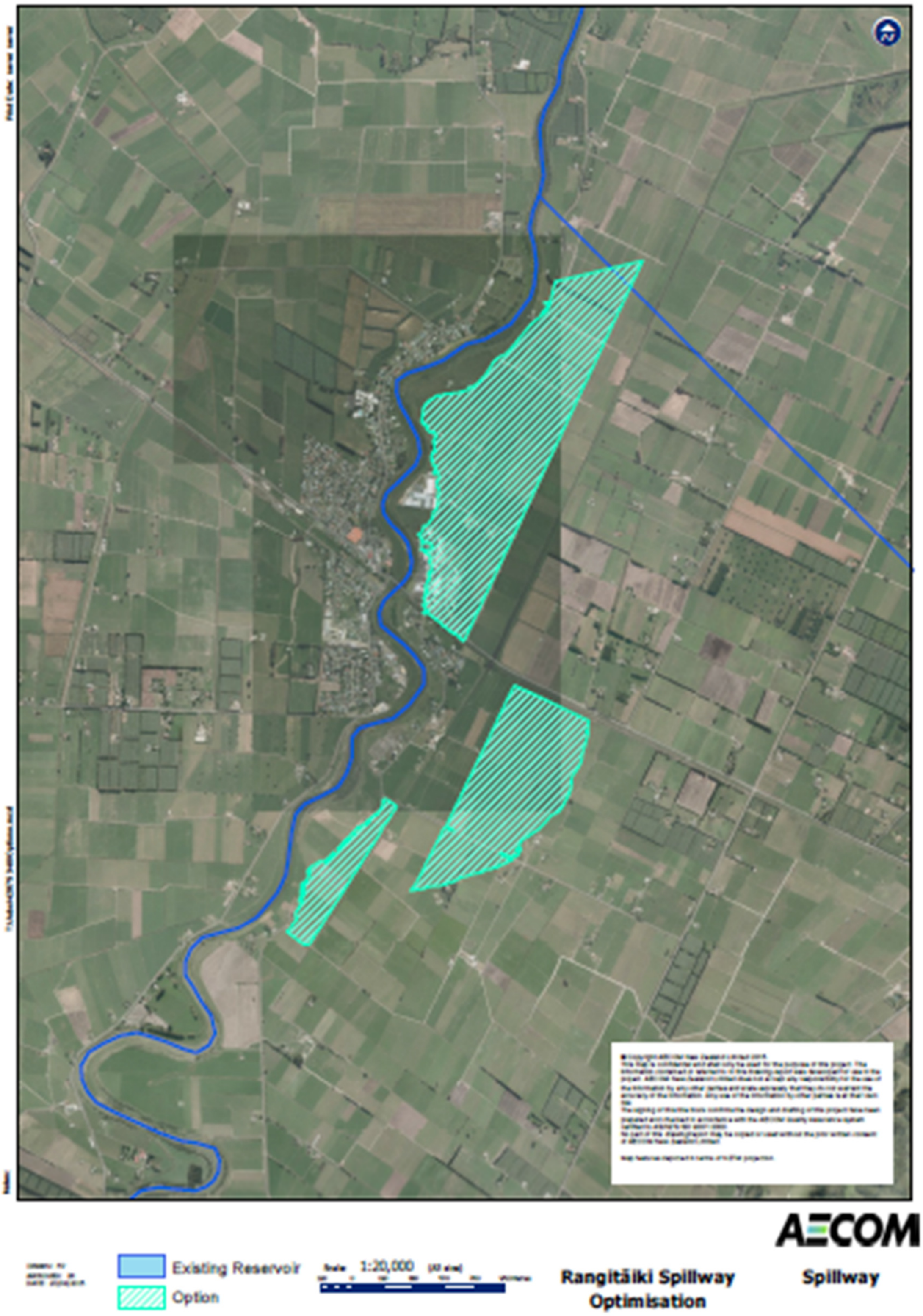


Table 34 Scenario of Zone 3

Scenario	Level in Zone 3	Extent of area flooded
	mRL	ha
Base Case 0	5.7	270
Base Case 1	4.3	226
Base Case 2	3.6	205
Base Case 3	0.2	0
Base Case 4	0.2	0
Murupara Diversion, Case 0	5.1	262
Whirinaki Dam, Case 0	3.3	194
Galatea MAR, Case 0	3.6	206
Galatea MAR, Case 0	4.0	216
Galatea MAR, Case 0	3.0	179
Horomanga Dam, Case 0	4.6	244

B 1.4 Zone 4

Zone 4 has more potential as a spillway can be built upstream of the current spillway, so the flows can be effectively controlled with the design. The maximum level required can be confined in the lower areas limited by the ground and road (SH2), and the Edgecumbe settlement can be isolated from the flooding zone with a bund.

Figure 64 summarizes the results and Table 35 shows maximum water levels. The maximum level required for the Base Case 0 scenario is about 3.68mRL, and that is just about the level of the SH2. Bund protection for Edgecumbe and the SH2 would be required to ensure the flood stays in the designated area. The cannel shown in the figure going north from the flooded area discharges into the Tarawera River, so some release can be provided as the water levels rise. Upgrades in this channel would allow a more efficient performance of the system (Figure 65). This zone would be flooded only for floods larger than the 65yr event approximately (as for lower frequencies the flows are carried by the Rangitāiki River and Reid's Canal if the event is larger than the 40yr event).

Figure 64 Base Case 0 Flood Extent

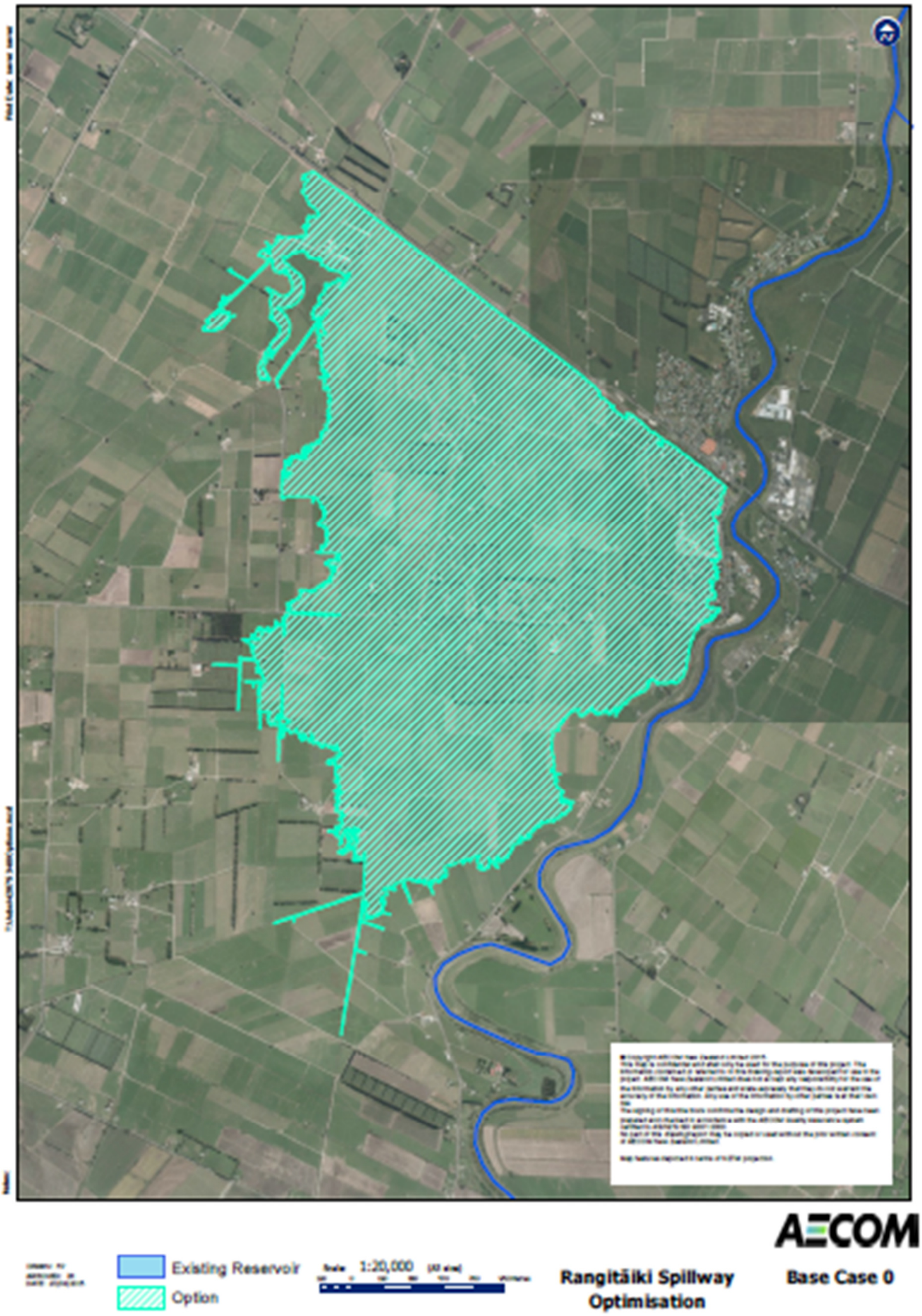


Table 35 Scenario of Zone 4

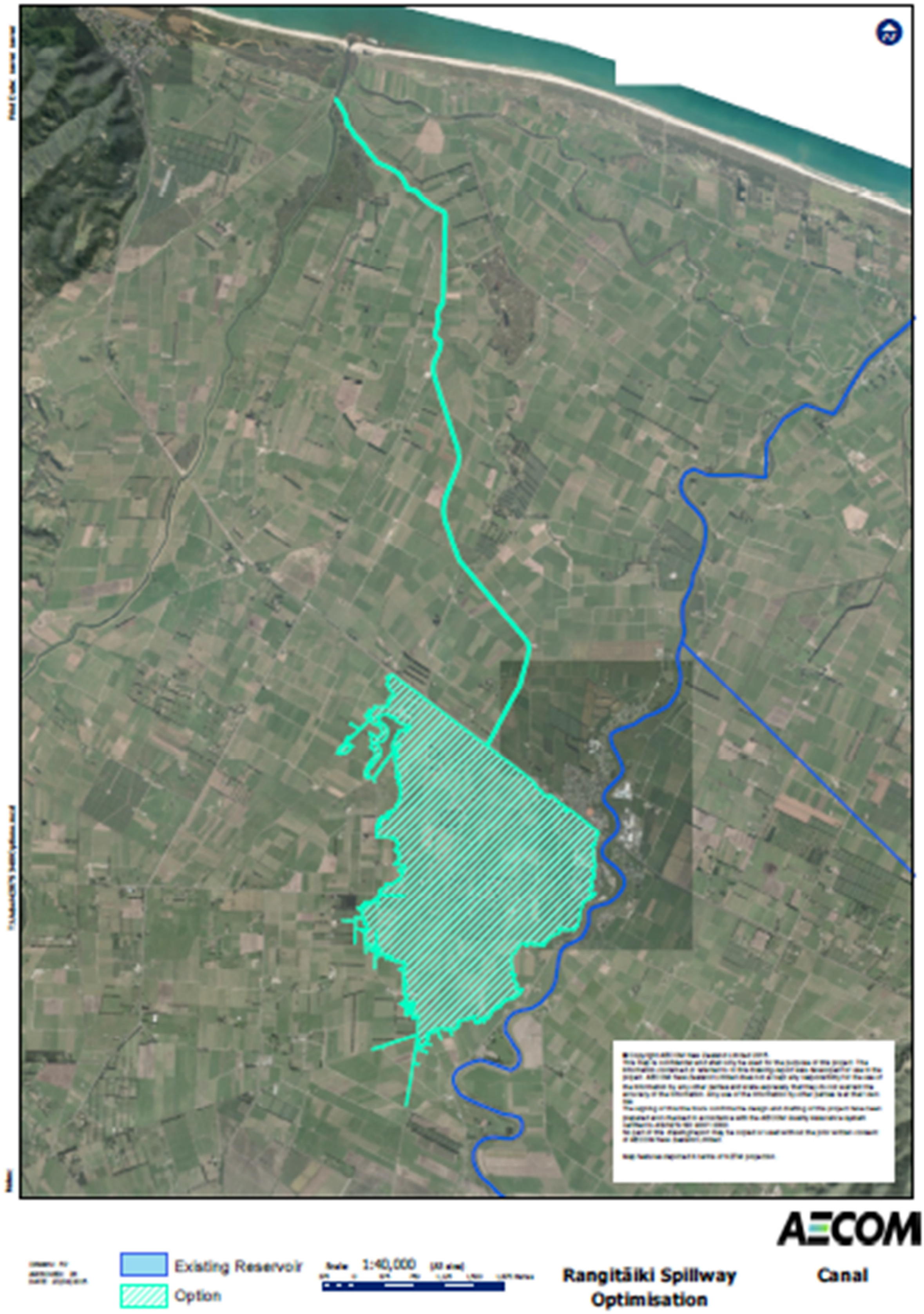
Scenario	Level in Zone 4	Extent of area flooded
	mRL	ha
Base Case 0	3.68	651
Base Case 1	3.02	489
Base Case 2	2.68	372
Base Case 3	0.55	0
Base Case 4	0.55	0
Murupara Diversion, Case 0	3.40	583
Whirinaki Dam, Case 0	2.50	312
Galatea MAR, Case 0	2.69	377
Galatea MAR, Case 0	2.88	444
Galatea MAR, Case 0	2.35	258
Horomanga Dam, Case 0	3.21	535

A 1.5 Spillway and Diversion to Tarawera River and Whakatane River

A spillway and channel to the Whakatane River seems impracticable due of the topography of the plains, but a diversion to Tarawera River might be possible. Figure 65 shows the alignment across the plains between the Rangitāiki and Tarawera rivers. A spillway can be built upstream of the existing spillway and discharge towards the Tarawera through the local draining channel. Certainly the channel would require an upgrade to ensure the capacity of the extra 100m³/s flow. Also, as the channel discharges into the mouth of the Tarawera River, the exit will not be possible unless the tide is very low and the Tarawera River water level allows discharge. For this reason storage might be required to detain the waters before being discharge.

However there seems little logical in contemplating such expenditure on channel upgrades when bunding of flood areas are a less expensive option and meet the objectives.

Figure 65 Spillway and Diversion to Tarawera River



Appendix C

Cost Estimates

Appendix C Cost Estimates

C 1.1 Dam Costs

The costs for dam construction are provided in Table 36. They do not include any land purchase costs.

Table 36 Dam Costs

				Whirinaki		Murupara		Horomanga	
Comparitive schedule of costs				Crest RL	296.1	Crest RL	319.8	Crest RL	291
Item	Description	Unit	Rate ($NZD)	Quantity	Amount ($NZD)	Quantity	Amount ($NZD)	Quantity	Amount ($NZD)
Zoned Earth Embankment	Strip Dam footprint	m^2	4	42,421	$169,685	95,607	$382,428	44,792	$179,168
	Excavate to foundation	m^3	8	130,737	$1,045,895	294,388	$2,355,102	138,368	$1,106,948
	Treat foundation	m^2	5	41,398	$206,990	93,421	$467,106	43,642	$218,209
	Core of dam	m^3	30	364,409	$10,932,263	736,764	$22,102,912	352,432	$10,572,959
	Transition zone	m^3	100	13,171	$1,317,054	29,812	$2,981,244	13,833	$1,383,339
	Shoulders Fill	m^3	20	690,773	$13,815,455	1,386,987	$27,739,749	665,020	$13,300,399
	Sub-Total				$27,487,341		$56,028,542		$26,761,022
Dam Appertenant Structures	Valve Tower Structure including bridge	LS	0	1	$0	1	$0	1	$0
	Valve Tower M&E	LS	0	1	$0	1	$0	1	$0
	Spillway	LS	2000000	1	$2,000,000	1	$2,000,000	1	$2,000,000
	Sub-Total				$2,000,000		$2,000,000		$2,000,000
Total Construction Cost					$29,487,341		$58,028,542		$28,761,022
Engineering	Engineering	%	10%		$2,948,734		$5,802,854		$2,876,102
Consents	Consents	%	8%		$2,358,987		$4,642,283		$2,300,882
Total Cost of Dam					$34,795,062		$68,473,680		$33,938,006
	20% contingency				$ 41,754,074.82		$ 82,168,415.54		$ 40,725,606.81

C 1.2 Bund Costs

Storage Bunds Cost Estimates

Note: P&G costs, design, consenting etc not included, will typically add up to 10% to 25% of project cost. These are pure capital costs only.

1. Storage Bunds

Typical Bund Cross Section		
Height	2.5	m
Width at Base	15	m, assuming 1:3 side slopes
Cross Section area	18.75	m2
Base area of bund	15	m2 per m of bund
Bund Material (clay) will be imported from Awakeri Quarry		
Volume of Material per truck load	7.7	m3 at 2.6t/m3, 4 axle 20t truck load
Cost of Clay Fill	30	$ per m3
Vehicle Costs		
Work Day	10	hours
Fuel Cost including truck and driver	150	$ per hour assuming 150km return trip per truck from Awakeri Quarries, so four trucks required at all times
Placement of Fill	120	$/hour Excavator + Driver
	120	$/hour Dozer + Driver
	15	m3 per hour Work rate (assumed)
	2	Number of truck deliveries per hour, based on dozer work rate
	8.2	m bund per 10hr day
Total Cost per day		
	$ 4,615	Cost of fill material
	$ 8,400	Cost of vehicles including fuel
	$ 13,015	Total cost per day

2. Cost per Storage Bund

	Length (m)	Total Number of Days	**Cost**	20% Contingency
Zone 1	0	0	**$ -**	
Zone 2	2500	305	**$ 3,965,625**	$ 4,758,750.00
Zone 3	450	55	**$ 713,813**	$ 856,575.00
Zone 4	4000	487.5	**$ 6,345,000**	$ 7,614,000.00

C 1.3 Weir Costs

				Weir	
Comparitive schedule of costs				Crest RL	296.1
Item	Description	Unit	Rate ($NZD)	Quantity	Amount ($NZD)
Zoned Earth Embankment	Strip Dam footprint	m^2	4	250	$1,000
	Excavate to foundation	m^3	8	750	$6,000
	Treat foundation	m^2	5	250	$1,250
	Core of dam	m^3	30	2,100	$63,000
	Transition zone	m^3	100	83	$8,333
	Shoulders Fill	m^3	20	2,250	$45,000
	Sub-Total				$124,583
	Spillway	LS	20000	1	$20,000
	Sub-Total				$20,000
Total Construction Cost					$144,583

C 1.4 Weirs and Gates

Gated Weir Cost Estimates

Note: P&G costs, design, consenting etc not included, will typically add up to 10% to 25% of project cost. These are pure capital costs only.

1. Cost of Land

	100	ha area of land	
$	50,000	$/ha agricultural rate	
$	5,000,000	Total land cost	

2. Clear Land, Stockpile and Re-use Fill

	8	$ per m3 clearance rate cut and stockpile for reuse	This assumes double handing of cut material. Could be cheaper if cut to fill method is used.
	8	$ per m3 re-place and compact stockpile material	Rates can vary from $4/m3 to $20/m3 depending on the project, scale of work, location etc. Have used $8 as representative
	2,000,000	m3 fill to clear assuming 2m depth over 100 ha	
$	32,000,000	Total clearance and replace fill material cost	

3. Gates and Weirs

Awaiting details from Richard Scott

Weir	$	140,000	See weir tab
Four gates including actuators etc	$	800,000	LS from Central Plains scheme, assume four gates in series

4. Annual Maintenance Costs

$	47,000	Per annum. Assume 5% annual maintenance cost

Weir + 20%	$44,568,000	
Gates + 20%	$45,360,000	
		$ 4,536

C 1.5 Power Generation Losses Analysis

The flood operation procedure takes less than 4 days for the July 2004 event. By considering an extreme scenario, the power losses would be:

Power Generated: $P = C*H*Q*\rho*T/10^6$ [MW.hr]

Where: C is the efficiency (80% in this exercise)
H is the head [m]
Q is the flow [m^3/s]
ρ is the density: 1000 [kg/m^3]
T time of generation [hrs]

The extreme case is that during an average of 4 days the generation is with a minimum Head = 53.0m (70.0-17 mRL), compared with a maximum Head = 57.2 (76.2 – 19 mRL). This result is a difference of about 430MW.hr. At $25/MW.h it is about NZ$100,000.00 for the flood event.