

Ruataniwha Water Storage Scheme

Environmental Flow Optimisation



May 2013

Report prepared for Hawke's Bay Regional Investment Company Limited

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Report prepared for Hawke's Bay Regional Investment Company Ltd by:

Dr Olivier Ausseil, Aquanet Consulting Limited
John Hansford, Tonkin and Taylor Limited
Rob Waldron, Hawke's Bay Regional Council
Dr Roger Young, Cawthron Institute

With contributions from:

Craig Goodier, Hawke's Bay Regional Council
Thomas Wilding, Hawke's Bay Regional Council
Ian Lloyd, Golder Associates (NZ) Limited
Grant Pechey, Hawke's Bay Regional Investment Company Limited

Peer- review:

David Leong, Tonkin and Taylor Limited

EXECUTIVE SUMMARY

Context

The Tukituki River and its catchment support a number of values, including ecological (e.g. habitat for indigenous species), cultural e.g. (Mauri of the river and eel fishery), recreational (e.g. amenity, contact recreation and trout fishery) and socio-economic values (e.g. production land, industrial and residential water supply). These values are however currently limited by extended periods of low summer flows and excessive filamentous algae growth, particularly in the lower Tukituki River (“lower Tukituki corridor”). Summer low flows occur naturally in the Tukituki River, but their frequency, severity and duration are currently compounded by surface and groundwater abstraction for irrigation, industrial use and community water supply. Excessive periphyton growth is a result of a combination of nutrient enrichment and the river’s natural characteristics, in particular the extended periods of low flows. Again, this issue is likely compounded by surface and groundwater abstraction.

Surface and groundwater abstraction (primarily used for irrigation) in the Tukituki catchment has increased substantially over the last decade. This has contributed to the over-allocation of surface water in the Tukituki catchment, based on current allocation limits. If water allocation limits are altered by provision of increased regulatory minimum flows, as is proposed in the Tukituki Plan Change 6 to provide for improved ecological, recreational and cultural outcomes, the result would be a significantly reduced security of supply for existing irrigators with a consequential material economic impact on them, and reduced regional economic output.

The Ruataniwha Water Storage Scheme (RWSS) project is a proposed water storage and irrigation scheme principally servicing the Ruataniwha Plains, in Central Hawke’s Bay. The proposal is to build a dam able to contain up to 90 million cubic meters (Mm³) on the Makaroro River, a tributary of the Waipawa River, itself a tributary of the Tukituki River. The proposed dam will store winter high flows for release and use in summer when pressure on the water resource is greatest. The current proposal includes provision of water to five irrigation areas.

The study into the feasibility of the project was concluded in September 2012, with the RWSS “core” project team concluding that the project was technically, environmentally and financially feasible (HBRC, 2012a). The Hawke’s Bay Regional Council subsequently voted in favour of the project being progressed to resource consent applications. This study and report have been prepared as part of the “post-feasibility” series of studies being prepared to assist the resource consent applications.

Assessment undertaken

The aim of this study was to explore options available to the RWSS to provide additional water for irrigation or environmental purposes, over and above, but without compromising, the assumed primary irrigation and environmental flow provisions described in the Feasibility Project Description (Tonkin & Taylor, 2012).

The study was undertaken in several phases, including an initial assessment of opportunities for the RWSS to provide additional water, an assessment of possible environmental use of that water, followed by a major modelling exercise using the GoldSim modelling platform, which incorporates the major flow components of the RWSS Scheme into one integrated dynamic model.

This report also provides an assessment of the RWSS Scheme’s predicted effects on, or benefits to, river flows in the Waipawa and Tukituki rivers under different scenarios. The potential effects and benefits of the proposed environmental flow “package(s)” on aquatic ecology are assessed in the Aquatic Ecology Assessment prepared by the Cawthron Institute (Cawthron, May 2013).

Three areas for improved environmental flow have been identified as part of the preliminary assessment of “opportunities”:

1. The volume of water provisioned for irrigation in the feasibility study (95.8 Mm³) was based on a full uptake of the RWSS water, with a nominal 1 in 20 year security of supply. This means that, assuming full uptake of the water offered by the RWSS for irrigation, the live storage of the dam would be completely used up (emptied) with resulting cessation of supply to irrigators in once every 20 years on a long-term average. This also means that the volume of water available from RWSS will exceed the water demand in most non-drought years. This water can either be retained in the dam or released from the dam for other purposes, such as additional irrigation, and/or environmental flows. A preliminary assessment undertaken by Tonkin & Taylor identified that at least approximately 3.5 Mm³ will be available 9 years out of 10, with an additional 2.1 Mm³ available 6 years out of 7 (or an additional 4.4 Mm³ available 4 years out of 5), and this assuming full uptake;
2. Full uptake of the Scheme's irrigation water is not expected to occur from the start of the Scheme. Recent provisional estimates of the likely level of RWSS water uptake indicate that full uptake is likely to occur 8 to 14 years after the Scheme is operational, depending on uptake by existing irrigators (Castalia, 2012). "Excess" water will be available until the uptake is full, some of which may be able to be used for environmental purposes;
3. The "sedimentation storage" allowance of 4 Mm³ is to provide for the loss of storage volume due to sedimentation associated with the input of material from the upstream catchment. Until this volume is taken up by sediment, there is an opportunity to utilise this volume of water for environmental purposes.

It was identified that of the three areas identified above, only one (the first) would be potentially available during the whole life of the Scheme, while the other two may only be temporary. For this reason, the assessment conducted in this report primarily focused on opportunity (1), whilst recognising the additional potential associated with opportunities (2) and (3) during the early years of the Scheme.

With the key environmental issues in mind, two areas for potential improvement were identified for the purpose of this study:

- Supplementing/augmenting river flow at times when it would otherwise have dropped to very low levels, particularly during summer;
- Increasing the size, duration or frequency of flushing flows released from the dam, and/or improving the timing of their release, to optimise environmental benefit associated with reducing/removing nuisance periphyton with a particular focus on the lower Tukituki River.

The potential benefits of different levels of low flow supplementation and flushing flows are assessed in this report, as well as the volumes of water required to implement them. This analysis relied heavily on hydrological data and modelling provided by the Hawke's Bay Regional Council's Environmental Science (Hydrology) and Engineering departments.

This report also incorporates outputs from a modelling exercise undertaken by Golder Associates (NZ) Limited (Golder) using the GoldSim modelling platform. With specific regard to this report, the key objectives of the GoldSim modelling were:

- To assess the ability of the dam to release the significantly increased flushing flows recommended in this report;
- To assess the likely effects of the Scheme on downstream river flows under different "uptake" scenarios (referring here to "uptake" of Scheme water by existing water abstractors in replacement of all or part of their current takes). This meant in particular assessing the likely outcomes of "intermediary" scenarios assuming various levels of uptake by existing groundwater abstractors;

- To provide a preliminary assessment of the potential benefits of increased drainage from newly irrigated land (“irrigation water return”) on river flows. The methodology used for this preliminary assessment is presented in Appendix C.

Results

Flushing flows

Flushing flows of 50 m³/s as measured in the Tukituki River at Red Bridge would ideally be generated in order to provide significant bed sediment mobilisation and attached periphyton removal, however, there is strong evidential basis to suggest that flows much smaller than 50 m³/s, in the order of 23 to 34 m³/s (as measured at Red Bridge) are likely to provide significant benefits – if not removing the whole biomass, at least providing considerable relief and public health risk avoidance by removing the drifting/detaching algae and cyanobacteria.

Hydrodynamic modelling (MIKE11) indicates that the release of flows of 30 m³/s for 9 hours or 25 m³/s for 11 hours were likely to result in flushing flows within the 23 to 34 m³/s range along the lower Tukituki corridor down to Red Bridge, even under otherwise low river flow conditions. Modelling also shows that the environmental benefits brought by these flushing flows can be further enhanced by managing the timing of their release to “piggy-back” on natural minor fresh events (freshets) which by themselves would have had limited benefits in terms of periphyton removal.

The release of up to four flushing flows of up to 1 Mm³ each per irrigation season was modelled in GoldSim, using triggers and rules designed to “interrupt” periphyton accrual periods when they reach 30 days during the critical December to March period and encouraging piggy-backing on natural fresh events. Results show that the flushing flows were able to be supplied every year of the 36 year modelling period, up to the specified four flushing events. Piggy-backing on natural freshets allows both an increase in the size of the actual flushing flows and a reduction in the overall volume of water required to deliver the flushing flows.

Effects on downstream low flows and low flow supplementation

Results indicate that the Scheme is likely to result in significant improvement of the extreme low flows (minimum flow and Q99) in both the Waipawa and lower Tukituki Rivers under all scenarios considered. However, the Scheme may result in a reduction of MALF and an increase in the number of days below the proposed minimum flow if current water takes continue to their current level.

The Scheme is also predicted to result in benefits to low flows at Red Bridge if at least 30 % of groundwater takes (or a mix of surface and groundwater takes) stop operating in the future (presumably to utilise water provided by the Scheme). However, modelling results indicate that a higher proportion of current takes (in the order of 80% of current groundwater takes) being discontinued may be required in order to avoid residual negative effects on low flows at the Waipawa River at RDS. These results suggest that some low flow supplementation targeted at compensating for effects on low flows at RDS may be required depending on the level of uptake by current irrigators upstream or upgradient of that site.

The above conclusions do not take into account the potential benefits of increased drainage associated with additional irrigation provided by the Scheme. The preliminary assessment undertaken using the GoldSim model indicates that if this effect was fully realised, implementation of Scheme would be predicted to result in improvement of low flows (using MALF and the mean number of days below minimum flow as key indicators) under all scenarios considered at Red Bridge. Residual effects may however still occur at RDS, which reinforces the conclusion that direct mitigation may be required to mitigate potential effects at RDS. It is also noted that the release of irrigation water to service Zone M may to some extent, alleviate the need for low flow supplementation at that site.

Recommendations

Four key recommendations have been formulated in this report:

Recommendation 1: That flushing flows as described in the PD be included in the set of proposed consent conditions.

As indicated throughout this report, there is strong evidential basis to suggest that the release of “augmented” flushing flows as described in this report is likely to provide significant environmental benefits, particularly during the extended periods of summer low flows, when other means of controlling periphyton growth (such as nutrient management) are of reduced effectiveness. Being able to “interrupt” all periphyton accrual periods in the lower Tukituki River at Red Bridge before they exceed 30 days during the critical summer period provides an opportunity that would not otherwise exist to contribute to progress towards Plan Change 6’s periphyton biomass targets.

Modelling indicates that the water volumes required for both the primary and secondary flushing flows can be supplied by the dam every year. On this basis, it appears that the proposed consent conditions do not need to differentiate between primary and secondary flushing flows, and it is recommended that the proposed consent conditions require the release up to four flushing flows every year, based on the date and river flow triggers defined in this report.

It is also noted that the ability of the dam to deliver instantaneous flows of 30 m³/s may be limited when water levels in the dam reach very low levels. It is suggested that in this instance, the duration of the flushing flows should be increased proportionally to the reduction in instantaneous flows, and that, for example flushing flows of 25 m³/s for 11 hours would be likely to also achieve significant benefits. It is recommended that consent conditions allow for this level of flexibility.

Recommendation 2: That further modelling of irrigation water return be undertaken.

The increased drainage associated with the irrigation of a greater area of land is expected to result in an increase in the return of groundwater to surface water. Preliminary assessment undertaken as part of the GoldSim modelling has indicated that this positive effect may be significant when considering the low river flow range. It is acknowledged that this is only a preliminary assessment based on using average values derived from a simple water balance estimate, and it is recommended that this potential effect be more fully assessed.

Recommendation 3: That modelling be re-run if/when uptake is known

The modelling has thus far been undertaken on the basis of blanket proportional reduction of all current takes. In reality, individual takes may be stopped in the future whilst others will continue. The outcomes in terms of river flows may depend on the location and characteristics of each individual take being “replaced”. Such a level of detail cannot of course be modelled at present as it would be speculative to pre-determine which takes may or may not be “replaced”. It is our understanding that the Scheme’s commercial team will be entering in discussions with current water abstractors over the next few months. If and when formal agreements to supply water are finalised, it is suggested that it would be useful to undertake modelling on the basis of these more certain “uptake” data.

The uptake of RWSS water by existing or new irrigators within Zone M is also currently unknown, but, as noted above, the supply of water to Zone M may alleviate to some extent the need to undertake low flow supplementation at RDS (for example low flow supplementation may only be required when water is not being supplied to Zone M). Again it is suggested that this aspect be incorporated in future modelling once uptake within Zone M is known.

Recommendation 4: That provision be made to mitigate any actual effects of the RWSS on river low flows at RDS and/or at Red Bridge by targeted low flow supplementation.

As explained in this report, the implementation of the RWSS may, under some scenarios, result in negative effects on low flows, both from an ecological (as indicated by decreases in MALF) and resource use (as indicated by the number of days below PRMF) point of views. These effects may, or may not eventuate, depending primarily on the level of uptake by current water abstractors and the potential effects of the irrigation water “return”.

As per recommendations 2 and 3 above, it is recommended that further assessment be undertaken, before and during the implementation of the Scheme, in particular to incorporate actual levels of Scheme uptake when these become more certain.

It is also recommended that the Scheme release additional water as required to offset the modelled effects of the dam’s operation on the number of days below the proposed minimum flow and give further consideration to addressing the adverse effects on MALF as shown by modelling results at the time.

However, the uncertainties inherent in modelling low river flows need to be acknowledged. This is particularly the case at RDS where historical low flow data appears to have a greater level of uncertainty as pointed out in HBRC Science (May 2013a). Whilst the above approach based on modelled effects is considered suitable (and is recommended) at Red Bridge, a more certain approach, not based on modelling, may be more appropriate at RDS. A relatively simple and pragmatic way to ensure that the Scheme does not result in an increase in the number of days below the proposed minimum flows at RDS would be a consent condition requiring the Scheme to match, within given bounds, the natural inflows it receives when the flow at RDS is below, or is dropping to levels very close to, the proposed minimum flows.

In order to maintain the proposed residual flow at all times, the condition should be worded so that the rate of water discharge from the dam at those times is the larger of 1.23 m³/s and the inflow to the dam measured at the time.

It is also recommended that an upper bound be defined. Given the flow travel times to the lower catchment (approximately 12-18 hours from the dam to RDS and 30 hours to Red Bridge), situations may arise where a significant rainfall occurs in the hills, but the flow at RDS is still close to or below the proposed minimum flow. In these situations, there would be significant inflows to the dam, and also from the upper parts of the Tukituki and Waipawa River catchments. If the flow release from the dam was to fully match its inflow, the Scheme would have to release a significant flow (potentially several m³/s) for a period of up to 18 hours, in spite of that water only reaching the lower catchment at the same time as the water from the rest of the upper catchment. In effect that water would have served no purpose in terms of supplementing low flows at RDS or Red Bridge, but with consequential loss of storage. An upper bound of 1.8 m³/s, corresponding to approximately 130% of MALF at the toe of the dam is suggested.

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1. Introduction

1.1. Background

The Tukituki River is one of the Hawke's Bay largest rivers, with a catchment area of approximately 2,500 km², and a mean annual flow of 44.5m³/s in the lower river. It takes its source in the Ruahine ranges, flows through the Ruataniwha Plains and reaches the Pacific Ocean in the southern area of Hawke Bay near Haumoana.

The Tukituki River and its catchment support a number of values, including ecological (e.g. habitat for indigenous species), cultural e.g. (Mauri of the river and eel fishery), recreational (e.g. amenity, contact recreation and trout fishery) and socio-economic values (e.g. production land, industrial and residential water supply). These values are however currently limited by extended periods of low summer flows and excessive filamentous algae growth, particularly in the lower Tukituki River ("lower Tukituki corridor"). Summer low flows occur naturally in the Tukituki River, but their frequency, severity and duration are currently compounded by surface and groundwater abstraction for irrigation, industrial use and community water supply. Excessive periphyton growth is a result of a combination of nutrient enrichment and the river's natural characteristics, in particular the extended periods of low flows. Again, this issue is likely compounded by surface and groundwater abstraction.

Surface and groundwater abstraction (primarily used for irrigation) in the Tukituki catchment has increased substantially over the last two decades. This has contributed to the over-allocation of surface water in the Tukituki catchment, based on current allocation limits. If water allocation limits are altered by provision of increased regulatory minimum flows, as is proposed in the Tukituki River Catchment Plan Change (Plan Change 6") to provide for improved ecological, recreational and cultural outcomes, the result would be a significantly reduced security of supply for existing irrigators with a consequential material economic impact on them, and reduced regional economic output.

The Ruataniwha Water Storage Scheme (RWSS) project is a proposed water storage and irrigation scheme principally servicing the Ruataniwha Plains, in Central Hawke's Bay. The proposal is to build a dam able to contain up to 90 million cubic meters (Mm³) on the Makaroro River, a tributary of the Waipawa River, itself a tributary of the Tukituki River. The proposed dam will store winter high flows for release and use in summer when pressure on the water resource is greatest. The current proposal includes provision of water to five irrigation areas (zones A, B, C, D and M, refer to Figure 1).

The study into the feasibility of the project was concluded in September 2012, with the RWSS "core" project team concluding that the project was technically, environmentally and financially feasible (HBRC, 2012a). The Hawke's Bay Regional Council subsequently voted in favour of the project being progressed to resource consent applications. This study and report have been prepared as part of the "post-feasibility" series of studies being prepared to assist the resource consent applications.

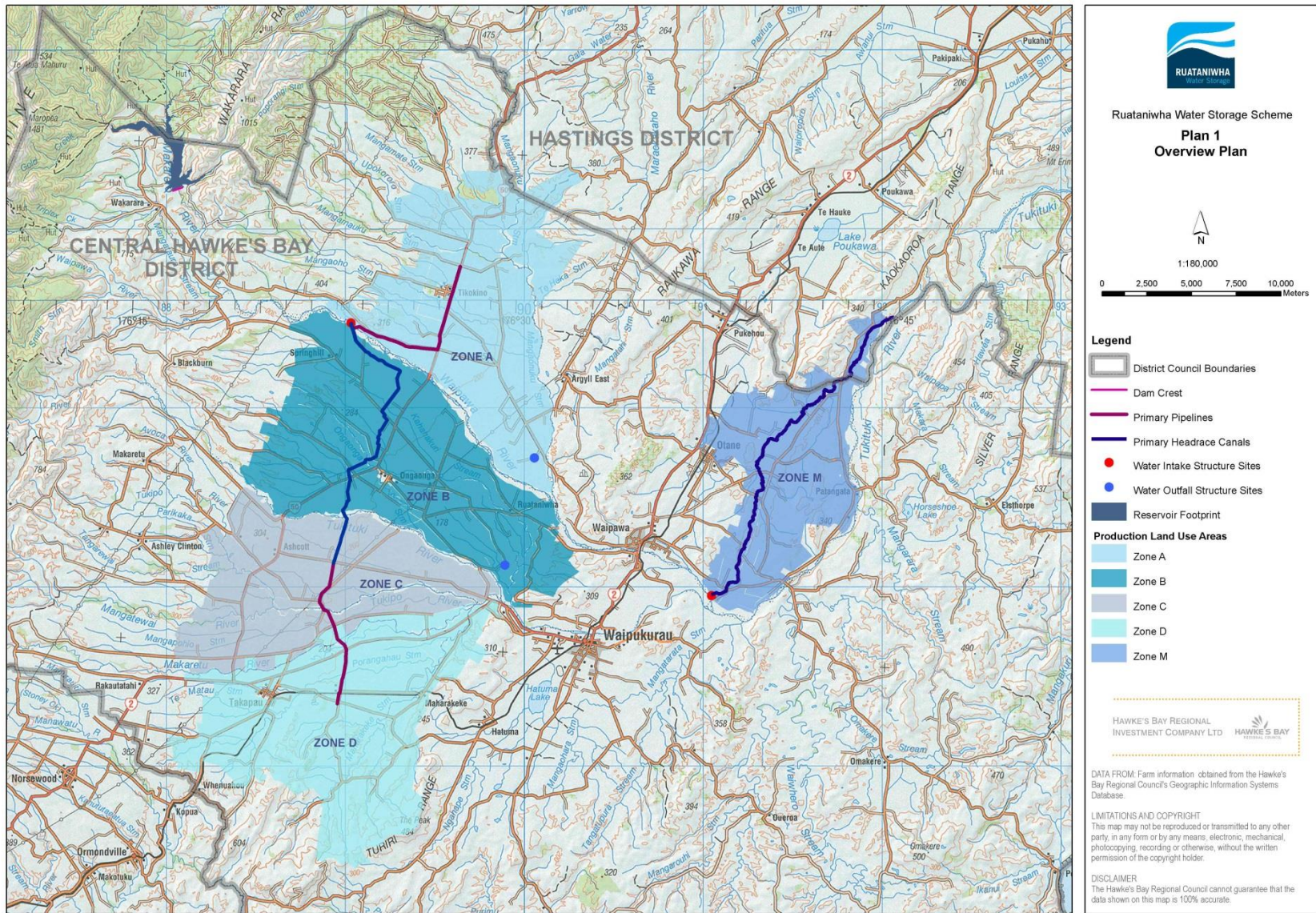


Figure 1: Location of the proposed RWSS Makaroro Dam and irrigation command areas.

1.2. Hydrology of the Tukituki catchment

The hydrology and hydrogeology of the Tukituki catchment are described in detail in a numbers of reports (e.g. Wilding and Waldron, 2012; Harper, 2013) and is broadly summarised below:

- The upper catchment, including the upper reaches of the Tukituki, Waipawa and Makaroro Rivers starts in steep mountainous country in the Ruahine ranges, then hill country. Surface flow in this part of the catchment is primarily rain-fed;
- Moving downstream, the catchment flattens and broadens out onto the Ruataniwha Plains. A significant aquifer system underlays the Ruataniwha plains. The upper parts of the Ruataniwha plains are characterised by a general water movement from the surface to the groundwater system (i.e. groundwater recharge area and “losing” river reaches).
- Further downstream, the Raukawa and Turiri ranges create a natural constriction point in the catchment, forcing the groundwater towards the surface. The surface hydrology of this part of the catchment is characterised by significant groundwater contribution to surface water bodies (springs, and “gaining” river reaches). The indicative locations of gaining and losing reaches are shown on Figure 2;
- The lower Tukituki catchment has a narrow, elongated shape, and is often referred to as the lower Tukituki corridor. The tributaries of the lower Tukituki River are generally small and do not make a significant contribution to the River’s baseflow, apart from inputs from the Papanui catchment, where a significant groundwater resource is present.

The presence of a large aquifer and a natural constriction point causing significant groundwater upwelling in a relatively small area at the bottom of the Ruataniwha Plains, and the elongated shape of the lower catchment make the Tukituki a rather unique system from a hydrology point of view.

HBRC Science (May 2013a) have modelled surface flow characteristics at three key points in the catchment under a number of scenarios, including a “naturalised” state (where all historical and current water abstractions are “turned off”), and a future state based on the current level of water abstraction continuing until 2017. They estimate that the groundwater contribution to surface river flows at 6.2 m³/s in a “naturalised” system (i.e. a modelled state where historical and current anthropogenic water abstractions are “turned off), and at 5.4 m³/s as a result of the current level of water abstractions (as in 2016, once the system reaches equilibrium). The location of the different monitoring sites and the spatial extent of the groundwater model are shown in Figure 3.

HBRC are currently proposing to raise the regulatory minimum flow, i.e. the flow below which surface water and surface water-depleting takes must stop. The proportion of time when the flow is below this proposed minimum flow as presented in Table 1 is based on these new proposed minimum flows.

There is a very important distinction to be made between the “regulatory” minimum flow, which is essentially a policy instrument and the actual minimum flow measured in the river. The regulatory minimum flow is a threshold below which some water takes are stopped, but it does not mean that the actual flow in the river will not drop below it. In fact, river flow will naturally drop below the proposed regulatory minimum flow approximately 2.5% of the time (9 days per year on average) at Red Bridge. The current level of water abstraction is modelled to cause an increase compared to the natural state to about 6.2% of the time (22 days/year on average) (Table 1 and Table 2).

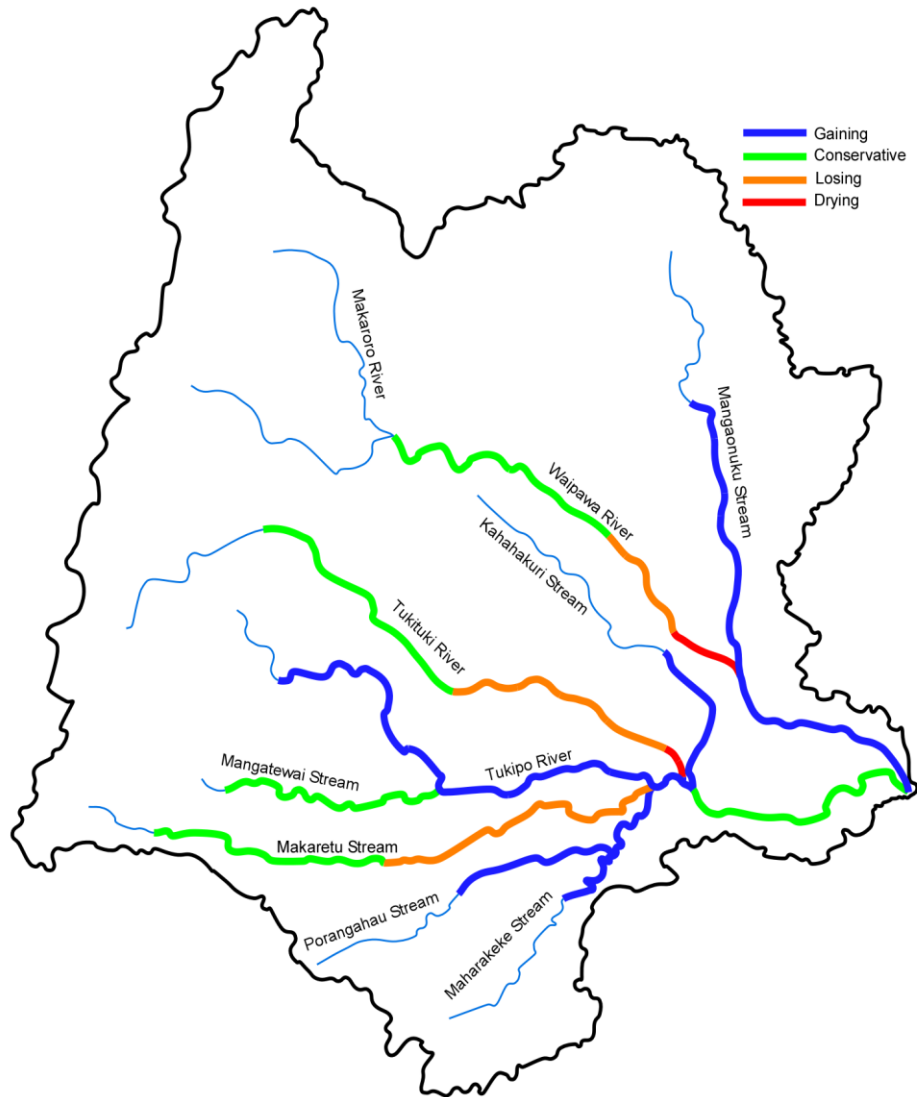


Figure 2: Indicative location of "losing" and "gaining" river reaches in the upper and middle Tukituki catchment (From Johnson 2011).

1.3. Feasibility Stage key assumptions and findings

1.3.1. Storage volumes

The proposed Makaroro Dam has a total “static” storage volume of approximately 90 Mm³. Based on the assumptions used in the September 2012 Feasibility Study, this corresponds to a useable storage capacity of 83.5 Mm³, once provision is made for sedimentation (4 Mm³), environmental flushing flow (1.5 Mm³ – see Section 1.3.2), and reservoir evaporation (1 Mm³).

This is not however the total volume of water available during an irrigation season, as water flowing from the upstream catchment will continuously bring additional water to the dam. The long term dam outflow is equal to the long term dam inflow, i.e. approximately 200 Mm³ per year on average, but varies between 122 and 290 Mm³/yr in the 39 years of hydrological record available.

Over the 39 year simulation period, at full uptake, the water supplied from the dam for irrigation varies from 24 Mm³ to 95.8 Mm³ per season (20th percentile of 68 Mm³ and 80th percentile of 87 Mm³).

1.3.2. “Feasibility Stage” environmental flow provisions

The environmental flow from the proposed Makaroro dam assumed in the feasibility stage of the project comprised:

- A minimum residual flow of 1.23 m³/s, equivalent to 90% of the 7-day MALF at the toe of the dam, equivalent to 38.8 Mm³ per year, and 19.3 Mm³ per irrigation season (assuming a November to April inclusive irrigation season);
- An additional 1.5 Mm³/year to provide for four flushing flows per season, of 10.5 m³/s (equivalent to 3 times the median flow at the toe of the dam), and of a duration of 10 hours each.

1.3.3. Feasibility Study Recommendations

As part of the Feasibility Report presented to HBRC in September 2012 the Core Project Team made the following recommendation:

“We consider that longer term Tukituki River benefits might accrue from some further analysis being undertaken associated with the most effective utilisation of the “environmental flows” assumed in the Tonkin & Taylor Ltd Feasibility Project Description. The constant residual flow from the dam of 90% of MALF combined with the proposed flushing flow volume provision of 1.5 million m³ per annum is a significant amount of water and we recommend that Cawthron and Tonkin & Taylor Ltd be jointly tasked with assessing the most effective utilisation of this water volume in terms of overall river ecology”.

This report has been prepared in response to that recommendation.

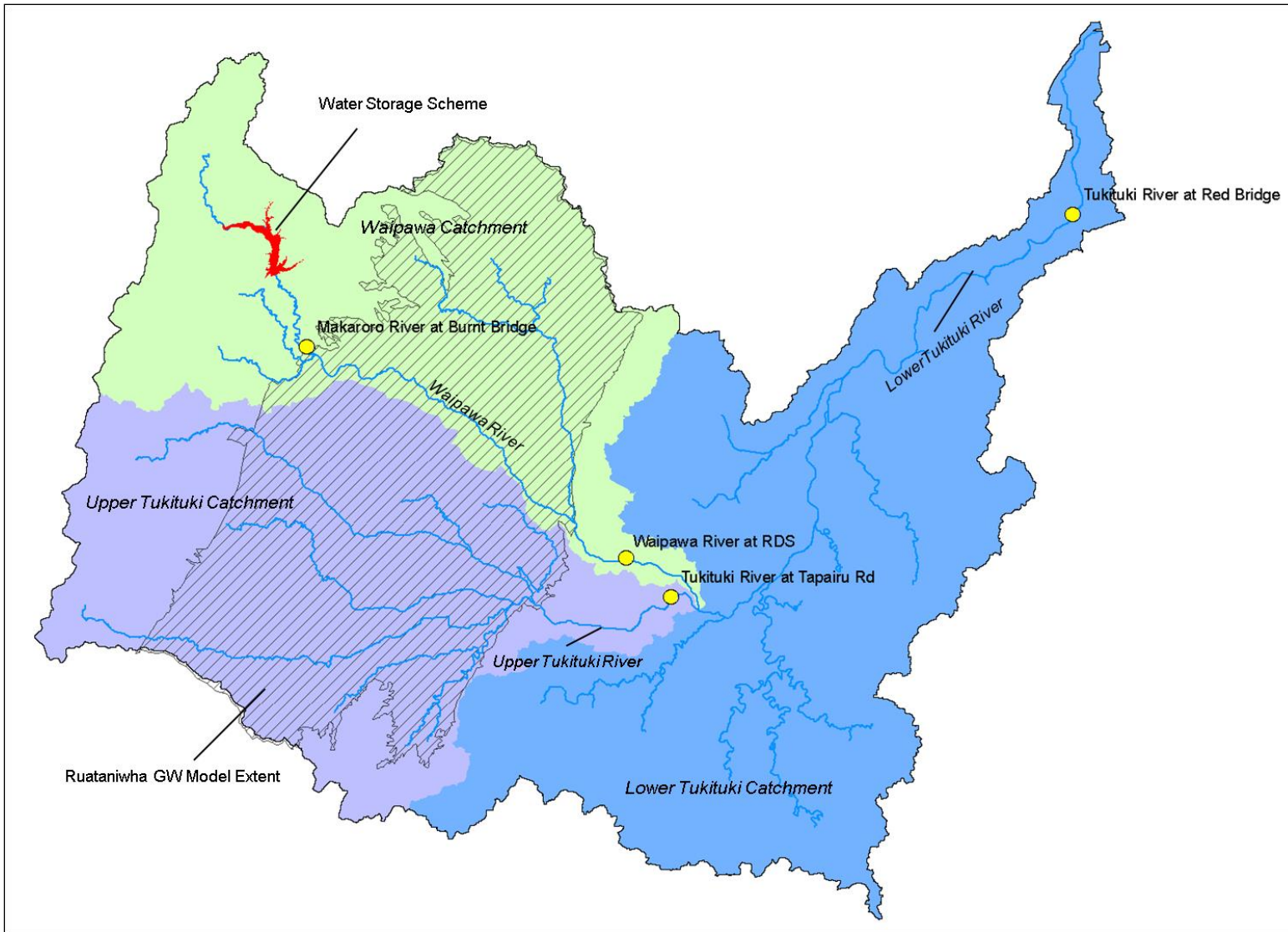


Figure 3: Location of river flow sites in the Tukituki Catchment and groundwater model boundary (HBRC Science, May 2013a).

Table 1: Summary of river flow statistics at the Tukituki at Red Bridge site modelled by HBRC Science (May 2013a).

Scenario	Mean		Min		Q ₉₉		MALF		Time ≤ Proposed Min Flow (5200 l/s)		
	l/s	% change From Scenario 2	l/s	% change From Scenario 2	l/s	% change From Scenario 2	l/s	% change From Scenario 2	% Time	No. of Days	% change From Scenario 2
Scenario 1	44,124	-	2,871	-	4,381		6,250	-	2.5%	9	-
Scenario 2	43,234	-	2,093	-	3,574		5,320	-	5.0%	18	-
Scenario 3	41,715	-4%	3,564	+ 70%	4,532	+ 27%	6,055	+ 14%	2.7%	10	- 44 %
Scenario 4	40,900	-5%	2,875	+ 37%	3,814	+ 7%	5,212	- 2%	7.2%	26	+ 44 %
Scenario 5	41,085	-5%	2,875	+ 37%	3,817	+ 7%	5,338	+ 0.3%	5.6%	20	+11 %

Table 2: Summary of river flow statistics at the Waipawa River at RDS site modelled by HBRC Science (May 2013a).

Scenario	Mean		Min		Q ₉₉		7-day MALF		Time ≤ Proposed Min Flow (2500 l/s)		
	l/s	% change From Scenario 2	l/s	% change From Scenario 2	l/s	% change From Scenario 2	l/s	% change From Scenario 2	% Time	No. of Days	% change From Scenario 2
Scenario 1	14,919	-	1,358	-	2,096		2,958	-	3.5%	13	-
Scenario 2	14,638	-	1,119	-	1,866		2,670	-	5.8%	21	-
Scenario 3	12,535	-14%	2,142	+ 91%	2,316	+ 24%	2,794	+ 5 %	3.8%	14	- 33 %
Scenario 4	12,259	-16%	1,910	+ 71%	2,101	+ 13%	2,515	- 6 %	8.6%	31	+ 48 %
Scenario 5	12,330	-16%	1,910	+ 71%	2,101	+ 13%	2,574	- 4 %	7.4%	27	+ 29 %

1.3.4. Opportunities for increased flow supply- (preliminary assessment)

The following opportunities for improved environmental flow have been identified, and constitute the “starting point” of this study:

1. The volume of water provisioned for irrigation in the feasibility (95.8 Mm³) was based on a full uptake of the RWSS water, with a nominal 1 in 20 year security of supply. This means that, assuming full uptake of the water offered by RWSS for irrigation, the live storage of the Scheme would be completely used up (emptied) with resulting cessation of supply to irrigators once every 20 years on long term average. This also means that the volume of water available from RWSS will exceed the water demand in most non-drought years. This water can either be retained in the dam or released from the dam for other purposes, such as additional irrigation, and/or environmental flows. A preliminary assessment undertaken by Tonkin & Taylor identified that approximately 3.5 Mm³ will be available 9 years out of 10, with an additional 2.1 Mm³ available 6 years out of 7 (or an additional 4.4 Mm³ available 4 years out of 5), and this assuming full uptake;
2. Full uptake of the Scheme’s irrigation water is not expected to occur from the start of the Scheme. Recent provisional estimates of the likely level of RWSS water uptake indicate that full uptake is likely to occur 8 to 14 years after the Scheme is operational, depending on uptake by existing irrigators (Castalia, 2012). “Excess” water will be available until the uptake is full, some of which may be able to be used for environmental purposes;
3. The “sedimentation storage” allowance of 4 Mm³ is to provide for the loss of storage volume due to sedimentation associated with the input of material from the upstream catchment. Until this volume is taken up by sediment, there is an opportunity to utilise this volume of water for environmental purposes.

Figure 4 and Figure 5 provide a visual summary of the different components of “excess” water that was found to be available for additional irrigation or environmental improvement as a result of the preliminary “opportunities” assessment. The key findings are:

- Using Castalia’s “baseline” uptake estimates, between 14 and 36 Mm³ may be available up until year 5 of the Scheme, and 7 to 29 Mm³ up until year 6. Whilst a certain volume appears very likely to be available during the first five years, the availability of “excess” water due to incomplete uptake should be re-evaluated after that time;
- A volume of 4 Mm³ has been allowed for sedimentation, which caters for long-term reservoir sediment infill (Tonkin & Taylor, May 2013a). Until this volume is occupied by sediment/gravel, the corresponding volume of water will either be retained in the dam throughout the irrigation season or may be released from the dam for environmental augmentation or irrigation. Whilst Tonkin & Taylor predict that the 4 Mm³ storage will take 20 years to fill based on average accumulation rates, there is considerable uncertainty about when and how quickly the sedimentation allowance will be filled by sediment and the availability of this volume of water for environmental purposes cannot be guaranteed;
- There will also be significant volumes of “excess” water potentially available on any “non-drought” year. This water will be available during the whole life of the Scheme, but its availability in any one season varies with the time-of-year and is assessed further through the GoldSim modelling (Section 3);
- It was identified that of the three areas identified above, only one (point 1. above) would be potentially available during the whole life of the Scheme, while the other two may only be temporary. For this reason, the assessment conducted in this report primarily focused on opportunity (1), whilst recognising the additional potential associated with opportunities (2) and (3) during the early years of the Scheme.

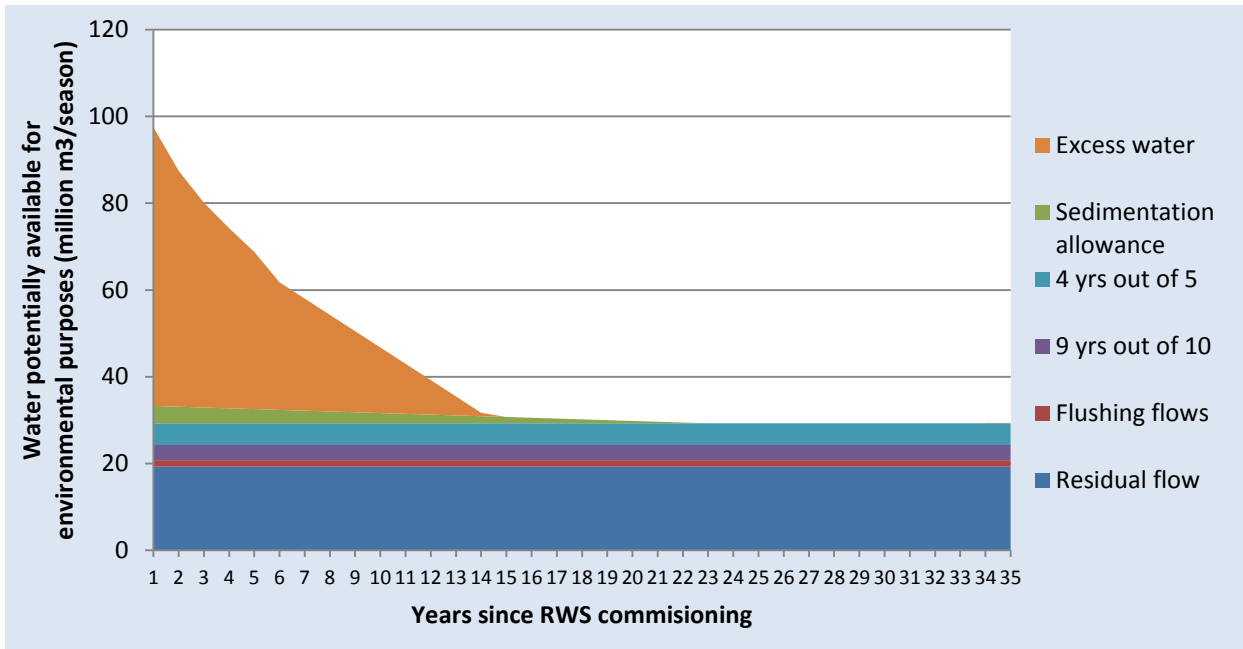


Figure 4: Components of water volumes potentially available (preliminary assessment) during the proposed 35 years consented period. The Residual flow and Flushing flow components are the assumed environmental flows proposed as part of the Feasibility Study. Water available as a result of incomplete water demand is based on Castalia’s “baseline/excluding existing consents” uptake.

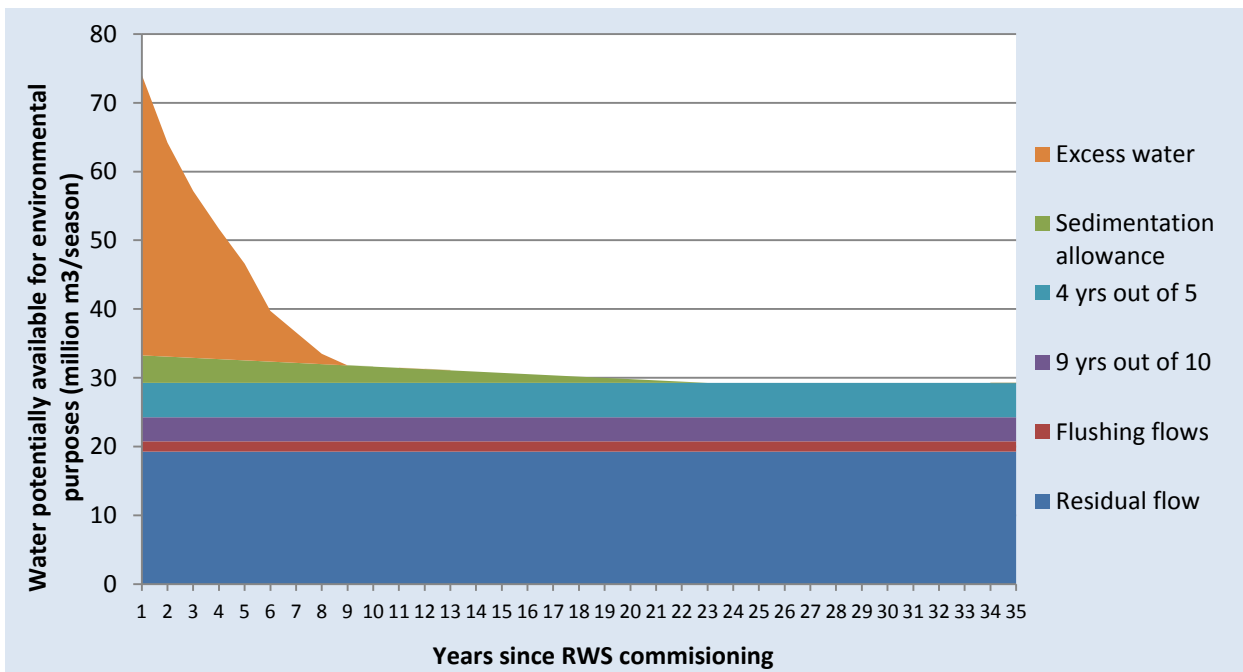


Figure 5: Components of water volumes potentially available (preliminary assessment) during the proposed 35 years consented period. The Residual flow and Flushing flow components are the assumed environmental flows proposed as part of the Feasibility Study. Water available as a result of incomplete water demand is based on Castalia’s “baseline/including existing consents” uptake.

1.4. Study Aim

The aim of this study is to explore options available to the RWSS to provide additional water for irrigation or environmental purposes, over and above, but without compromising, the assumed primary irrigation and environmental flow provisions described in the Feasibility Project Description (Tonkin & Taylor, 2012).

The study was undertaken in several phases, including an initial assessment of opportunities for the RWSS to provide additional water (as described in Section 1.3.4 above), an assessment of possible environmental use of that water (Section 2), followed by a major modelling exercise using the GoldSim modelling platform (Section 3), which incorporates the major flow components of the RWSS Scheme into one integrated dynamic model.

This report also provides an assessment of the RWSS Scheme's predicted resulting effects on, or benefits to, river flows in the Waipawa and Tukituki rivers under different scenarios. The potential effects and benefits of the proposed environmental flow "package(s)" on aquatic ecology are assessed in the Aquatic Ecology Assessment prepared by the Cawthron Institute (Cawthron, May 2013).

The findings of this study are summarised in Section 4 of this report as a recommended "environmental flow package" approach for inclusion in the suite of conditions to be put forward as part of the applications for resource consents for the RWSS.

2. Need and opportunities for environmental flow augmentation

2.1. Key environmental issues in the Tukituki catchment

As indicated earlier in this report, the Tukituki catchment currently presents two key environmental issues that are at least in part associated with river flows: extreme low flows during summer, and excessive filamentous algae growth, also predominantly during summer low flows.

Summer low flows are a feature of the Tukituki catchment, and are perceived as an issue given the competing demands of retaining water in the river to preserve ecological, recreational and cultural values and abstracting it for productive use. The summer low flows are primarily driven by the catchment's natural characteristics (particularly its climate), but their severity and duration are compounded by the current level of water abstraction (refer to Section 1.2).

The mean annual low flow (MALF) is ecologically relevant to trout and native fish because it defines the minimum space that is likely to be available on average each year. Fish health and abundance is expected to decline if flows are dropped below the MALF, with effects being more pronounced if flows are below the MALF for a prolonged period. The effects of low flow are most evident in the summer because fish have higher food requirements in summer because of the warmer water temperatures. Low flows in summer will also exacerbate the negative effects of warm water temperatures on aquatic life and the low concentrations of dissolved oxygen and variable pH that are associated with accumulations of periphyton.

Excessive periphyton growth, predominantly filamentous algae, currently occurs in the lower Tukituki River on a regular basis, particularly during extended periods of summer low flows. These excessive periphyton growths negatively impact on the river's ecological, recreational and cultural values.

Periphyton growth is controlled by a number of factors, including nutrient availability and the hydrological regime (in particular the frequency of floods or "flushing flows"). Excessive periphyton growth are often associated with nutrient enrichment; however, the hydrological regime plays a very important role, and excessive periphyton growths are still likely to occur in river systems with very low nutrient concentrations following long accrual times (i.e. the time between two "flushing" flows). Ausseil (2008) concluded that even drastic reductions in nutrient concentrations in the Tukituki River would be unlikely to totally prevent algal proliferations.

Uytendaal and Ausseil (2013) concluded that nutrient management is currently the only mechanism realistically available to control periphyton growth in the lower Tukituki River and, and have recommended in-stream DRP concentration targets to reduce the occurrence of nuisance periphyton growth. However, as explained above, the efficacy of reducing in-stream nutrient concentration to control periphyton growth is considerably reduced during extended periods of low, stable flow, particularly during late spring to early autumn. In this context, the provision of flushing flows from the proposed Makaroro Dam presents a new opportunity to aid in the reduction of nuisance periphyton growth in the Tukituki catchment, conjointly with Change 6's nutrient management provisions.

It must be clearly acknowledged that potential benefits of flushing flows would of course be limited to the reaches of rivers located downstream of the dam, i.e. the Makaroro River downstream of the dam, the Waipawa River downstream of the Makaroro confluence and down to its confluence with the Tukituki River and the Tukituki River itself downstream of its confluence with the Waipawa River.

2.2. Potential effects and benefits of the Scheme

2.2.1. Potential effects and benefits on river flows

The RWSS will result in substantial changes to the flow regime downstream of the dam, with higher summer flows in the reach downstream of the dam and lower flows in autumn and winter when the reservoir is refilling. Downstream of the irrigation intake, there will be a general reduction in median flows throughout the year. The broad-scale changes to the flow regime will result in both gains and losses in habitat for invertebrate species. The largest effect of the RWSS on the invertebrate community relates to the regular short-term fluctuations in flow that result from changes in irrigation demand during the summer and from hydro-peaking during winter (Cawthron May 2013a).

The effects of the RWSS on river flows were also investigated by HBRC Science (May 2013a). The study modelled five scenarios, including two scenarios which represent the extremes in terms of what might occur in relation to the level of water abstractions in the future with the RWSS in place.

Scenario 1 simulated a “naturalised” system, i.e. modelled what the flow would have been in the absence of any surface or ground water abstractions in the catchment. Scenario 2 assumed that the current level of surface and groundwater abstraction continued in the future until 2016.

Scenario 3 assumed that all current surface and groundwater abstractions stop when the Scheme becomes operational, and Scenario 4 assumed that all current water abstractions carry on at their current level (also with the Scheme in place). As such, Scenario 3 represented a “best case” and Scenario 4 a “worst case” from an environmental flow point of view with the Scheme in place.

Scenario 5 assumed that all surface takes and “surface depleting” groundwater takes stop when the Scheme becomes operational. As such, it represents an intermediary scenario between Scenarios 3 and 4 described above.

Scenario 3 was predicted to result in a return of the river low flow conditions to close to natural conditions, with significant increases in all low river flow statistics and a reduction in the amount of time below the proposed regulatory minimum flow when compared with Scenario 2 (current level of abstraction) (Table 1 and Table 2).

Similarly, Scenario 4 was predicted to result in improvements in the very low flow statistics (minimum flow and Q_{99}), but it was also predicted to result in decreases in other low flow statistics such as Q_{95} and MALF, and an increase in the proportion of time under the proposed regulatory minimum flow at Red Bridge compared with the current level of water abstraction (5.0% of the time under Scenario 2, up to 7.2% in Scenario 4). Decreases in MALF and increases in the proportion of time below the proposed minimum flow were also predicted under Scenario 4 (Table 1 and Table 2).

The RWSS may thus result in significant improvements in all low flow statistics at Red Bridge and RDS, including MALF and the number of days below the proposed minimum flow if all current water takes are switched off (Scenario 3). However if all current water takes were to continue at their current rate (Scenario 4) the implementation of the RWSS as proposed would result in a reduction in MALF (-2% and -6% at Red Bridge and RDS respectively) and an increase in the number of days below the proposed minimum flow at both sites.

A decrease in MALF would be of concern from an aquatic ecology point of view, as MALF defines the minimum space that is likely to be available to fish on average each year. Whilst of lesser ecological relevance, an increase in the number of days below the proposed minimum flow would be of concern as it would reduce the security of supply of existing (consented) water permits.

The Scheme can potentially compensate for the negative effects predicted under Scenario 4 by implementing targeted releases of water (low flow supplementation) as assessed in Section 2.4 below. However the requirement for the Scheme to implement low flow supplementation will obviously depend on the future status of the existing water takes, or more precisely the proportion of these takes that will continue (or cease) when the Scheme becomes operational.

It is noted that this assessment did not consider the potential effects that increased water drainage associated with the increase in irrigated land area may have on river flows, meaning that the HBRC Science (May 2013a) assessment is likely to be environmentally conservative from that point of view.

The effect and benefits of different scenarios assuming different proportions of current takes continuing in the future, and the potential effects of increased drainage from the irrigated area were assessed using the GoldSim model (Section 3), leading to the formulation of four key recommendations (Section 4.)

2.2.2. Potential effects and benefits of the Scheme on periphyton growth

The Feasibility stage land use modelling identified that the land use intensification associated with the Scheme has the potential to increase phosphorus inputs to the river with consequential increased periphyton growth, if no particular on-farm phosphorus management measures are put in place. Whilst a reduction in periphyton growth is expected after 2014 (after the upgrade of the Waipawa and Waipukurau wastewater treatment plants, as required by consent conditions), part of these benefits would have been eroded by the effects of the land use intensification enabled by the Scheme (NIWA, 2012).

The Scheme is now being progressed on the premises that properties being supplied water will have to develop and implement a phosphorus management plan, and will have to demonstrably operate on a “phosphorus neutral” (or better) basis compared with pre-irrigation phosphorus losses from that property. Compliance with the “phosphorus neutral” target will have to be demonstrated using detailed on-farm modelling.

On this basis, the Scheme will be neutral as regards the environmental effects of phosphorus discharges. That said, a “phosphorus neutral” position will make no contribution to the policy focus on reducing the occurrence of excessive periphyton growths in Proposed Plan Change 6. However, as identified above, the presence of the dam in the future could (if implemented) offer an opportunity (that would not otherwise exist) to aid in the management of nuisance periphyton growth.

2.3. Options for environmental flow improvement

The river values assessment conducted by HBRC identified that the recreational values and use, including contact recreation and trout fishery, are high in the lower Tukituki River corridor (Sharp, 2012). The environmental issues identified above are also most prevalent in the lower Tukituki River, particularly during periods of summer low flows.

With the key environmental issues in mind, two areas for potential improvement have been identified for the purpose of this study:

- Supplementing/augmenting river flow at times when it would otherwise have dropped to very low levels, particularly during summer;
- Increasing the size, duration or frequency of flushing flows released from the dam, and/or improving the timing of their release, to optimise environmental benefit associated with reducing/removing nuisance periphyton with a particular focus on the lower Tukituki River during periods of summer low flows.

A third potential area for improvement was considered at the start of the project, relating to the “smoothing” of the variability of the flow released from the dam for irrigation and hydropower in winter months. However, the study team considered that the bulk of the environmental effects due to flow variability were in this situation primarily associated with the overall amplitude of flow variations rather than the speed of change, which meant that attempting to “smooth” the flow variability was unlikely to result in significant environmental benefits unless a much higher minimum flow was maintained. This option was not considered further in this study.

2.4. Low flow supplementation

2.4.1. Principles

As explained earlier in this report, the proportion of current water abstractors stopping their current level of abstraction and using water from the RWSS has a significant bearing on the environmental flow outcomes of the Scheme’s implementation. Whilst Scenario 3 (which assumed all current water takes are stopped when the Scheme is operational) indicated significant recovery of the river’s low flows to close to natural conditions, Scenario 4 (which assumed all current water takes continue) did not result in any appreciable improvement in low flows, and even resulted in some degradation of some low flow statistics at some sites.

A basis for this study is to provide a response to the slightly negative outcome of Scenario 4 in this respect by exploring means of augmenting low river flows during the critical summer period. It is also acknowledged that Scenario 4 is a worst-case scenario, and if/as more existing water takes are phased out, the need for the Scheme to provide low flow supplementation reduces and consent requirements should ideally provide for sufficient flexibility in that regard.

Extreme summer low flows are very significant in terms of fish health and abundance because they determine the minimum habitat size available on a given year to a given fish population. As such the lower annual flows are often compared to “population bottlenecks” for fish (e.g. trout) abundance/population size. The provision of water from the dam during periods of very low flows in the river is expected to remove or improve these bottlenecks and have consequential direct benefits to fish populations.

2.4.2. Water volumes required for low flow supplementation

The volume of water required to “supplement” the river flow to a specified threshold during periods of low river flows was assessed. In other words, it means releasing enough water from the dam to ensure that the flow in the river does not fall below a given flow threshold, as illustrated in Figure 6.

The analysis included different thresholds, including the current and proposed regulatory minimum flows, the Q_{99} , Q_{98} , Q_{97} , Q_{96} and Q_{95} ¹ and the current 7-day Mean Annual Low Flow (MALF).

¹ These are flow exceedance percentiles, i.e. the flow that is statistically exceeded 99%, 98%, 97, 96% and 95% of the time respectively. Conversely, the flow is expected to drop below these thresholds 1% (3.7 days/year on average), 2% (7.3 days/year on average), 3% (11 days/year on average), 4% (14.6 days per year on average) and 5% (18.25 days/year on average).

Given the higher prevalence of environmental issues during summer and the higher recreational use during this period, the analysis was conducted on the basis of low flow supplementation during two periods December to April and December to February (inclusive).

The base flow records used for this analysis were the flow records produced by HBRC Science (May 2013a) for their Scenario 4, already described in Section 2.2.1 of this report. The analysis was conducted over the January 1972 to June 2008 period.

Summary statistics were then calculated on these results. For the purpose of this latter analysis, it was assumed that no water was supplied for low flow supplementation in any year when “excess” water volumes as estimated by Tonkin & Taylor’s preliminary analysis were less than 7.9Mm³ (Section 1.3.4). This was to account for the uncertainties associated with the capacity of the dam to provide flow supplementation water in those years.

An additional analysis was undertaken to assess the volumes of water required to compensate the Scheme’s potential effects on the number of days during which the river flow is at or below the minimum flow. The worst-case scenario, represented by Scenario 4 indicates that the Scheme’s implementation may result in an increase in the number of days the river is at or below the proposed regulatory minimum flow at Red bridge by 4 days on average. This analysis calculated the amount of water required to top up the first five days the river would have been under the proposed regulatory minimum flow in each December to April irrigation season, using the Scenario 4 modelled flow record as a basis.

2.4.3. Results

The results of this analysis are summarised in Table 3 and Table 4. These tables may be read in two different ways.

One, the volume required to achieve low flow supplementation to a given flow threshold and to a given level of confidence can be read from the table. For example, using HBRC Science’s (May 2013a)’s Scenario 4 as a baseline, up to approximately 4.0 Mm³ are required to achieve a low flow supplementation to just above the proposed regulatory minimum flow (5.2 m³/s) during the December to April period in 9 years out of 10 (90th percentile) at Red Bridge (Table 3). But if the aim is to achieve this 19 years out of 20 (95th percentile), then approximately up to 5.7 Mm³ would be required. To achieve the same level of low flow supplementation with the same level of confidence, but during the December to February period, lesser volumes of 3.1 and 4.8 Mm³ would be required.

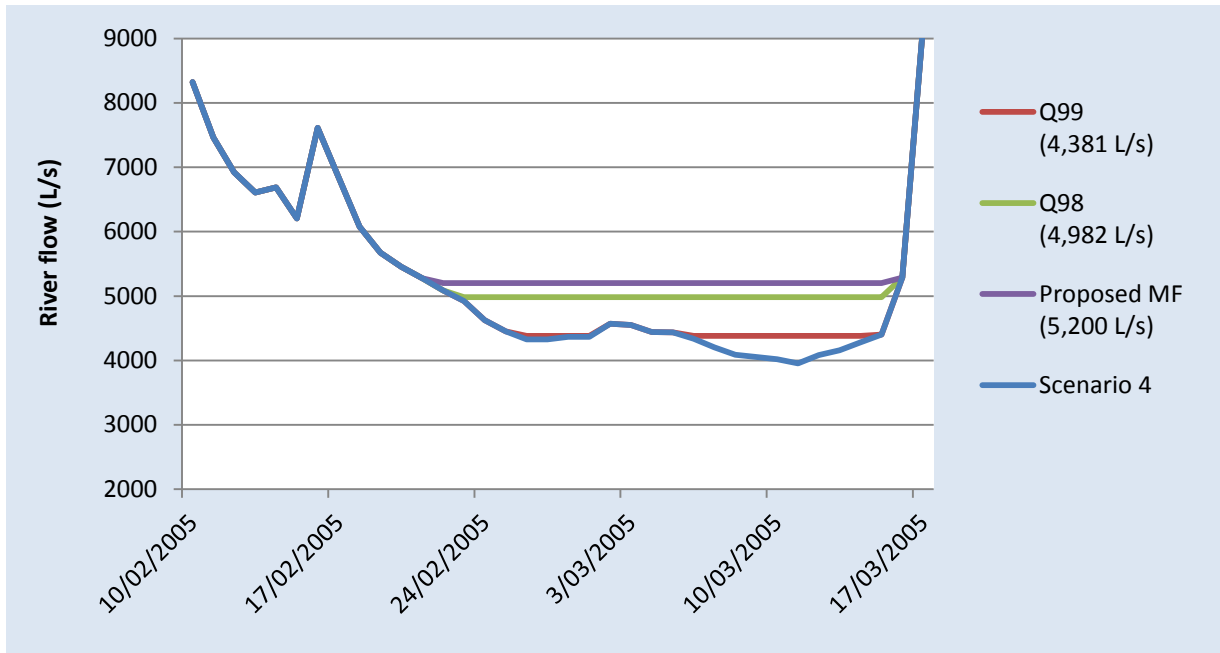


Figure 6: Illustration of low flow supplementation to different thresholds during an example low flow period at Tukituki at Red Bridge. The blue curve represents the “baseline” river flow (Scenario 4 of HBRC Science, May 2013a). The other three curves represent the resulting river flow assuming different levels of low flow supplementation. Proposed MF: Proposed Regulatory Minimum Flow.

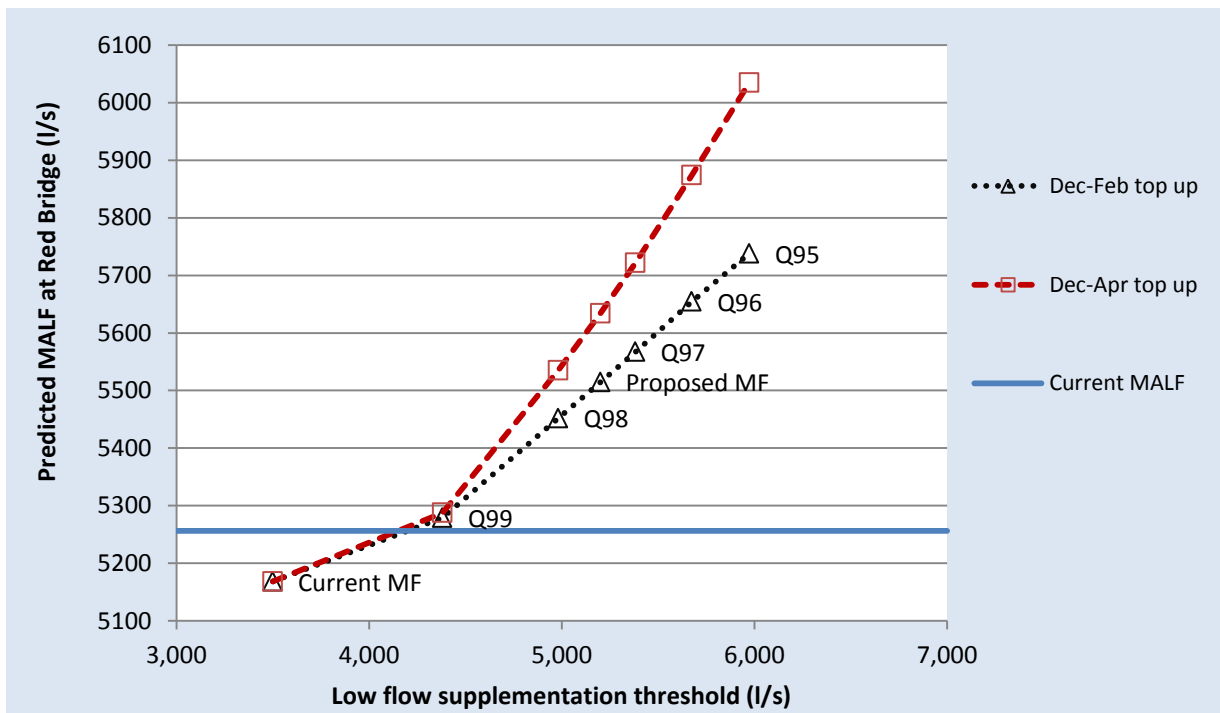


Figure 7: Predicted 7-day MALF at Red Bridge following low flow supplementation to different thresholds, using scenario 4 in HBRC Science (May 2013a) as the base scenario. The blue horizontal line represents the 7-day MALF from Scenario 2 in HBRC Science (May 2013a). Low flow supplementation triggered in December to February inclusive (black dotted line) and December to April (Red dashed line).

Conversely, the outcome achieved with a given water volume can be read from the tables. For example (still using Scenario 4 as a baseline and considering Red Bridge), 3.1 Mm³ would enable low flow supplementation to the proposed minimum flow (5.2 m³/s) during the December to February period in 9 years out of 10, or a supplementation to the Q₉₈ flow (4,982 l/s) during the December to April period in 9 years out of 10.

Regarding the Waipawa River at RDS, up to 1.9 Mm³ would be required to provide low flow supplementation to just above the proposed minimum flow with a very high level of certainty during December to February period (maximum recorded), and up to 2.0 Mm³ would be required to achieve supplementation to the same threshold 9 years out of 10 during the December to April period. A similar volume (2.1 Mm³) would also be required to achieve supplementation to the Q₉₇ (2,451 l/s) 19 years out of 20 (95th percentile) during the December to April period.

Figure 7 presents the outcomes of low flow supplementation to different thresholds on the 7-day MALF flow statistic. It indicates that low flow supplementation to a flow threshold of Q₉₉, and applied on average 4 years out of 5, results in a slight improvement in 7-day MALF at Red Bridge. As can be expected, low flow supplementation to higher thresholds (e.g. Q₉₈, Q₉₇, etc...) result in larger increases in 7-day MALF.

2.4.4. Practical Considerations

The release of flows from the Scheme to correspond with periods of low flow in the lower river will obviously require some modelling and predictive capacity, to account for travel times and inflows from different parts of the catchment. This is however not expected to be a significant obstacle to accurate low flow supplementation, as low/receding flow conditions are generally quite stable and relatively easy to forecast to a few days outlook. The model would also be able to make use of the network of flow recorders and rain gauges maintained by different organisations (e.g. HBRC and NIWA).

For the purpose of this study we have assumed that flow released from the dam is conservatively transferred along the run-of-river. The unavoidable losses due to evaporation already occur in the system before the “augmentation” water is added, and the incremental increase in losses due to the additional water was considered insignificant. The potential losses of “augmentation” water along the Waipawa River’s losing reaches located between SH50 and SH2 is potentially more significant, and it is recommended that water released for low flow supplementation purposes be transported using the infrastructure that is proposed to be built to supply water to Zone M.

Table 3: Volumes of water (in Mm³) required to supplement low river flows up to various flow thresholds during the December to April period, using Scenario 4 (from HBRC Science, May 2013a) as base scenario. PRMF: proposed regulatory minimum flow; MALF: 7-day Minimum Annual Low Flow (Naturalised MALF value in this table); Cur MF: Current regulatory minimum flow; Q₉₉: naturalised 99% flow exceedance percentile.

		Flow threshold (l/s) to which the river flow is topped up (DECEMBER-APRIL)												
		PRMF	MALF	Cur MF	Q ₉₉	Q ₉₈	Q ₉₇	Q ₉₆	Q ₉₅	Q ₉₄	Q ₉₃	Q ₉₂	Q ₉₁	Q ₉₀
		5201	6250	3500	4381	4982	5382	5675	5974	6275	6577	6886	7174	7437
Tukituki at Red Bridge	Mean	1.4	4.4	0.0	0.4	1.0	1.8	2.6	3.5	4.4	5.5	6.7	7.9	9.0
	Max	11.0	20.4	0.5	4.4	9.1	12.6	15.2	17.9	20.6	23.5	26.4	29.3	32.0
	95 th %ile	5.7	11.8	0.1	2.4	4.4	6.8	8.5	10.2	11.9	13.7	15.6	17.4	19.2
	90 th %ile	4.0	9.3	0.0	1.1	3.1	4.8	6.3	7.8	9.4	11.2	13.1	14.9	16.7
	80 th %ile	1.8	7.4	0.0	0.2	1.0	2.6	4.0	5.7	7.6	9.4	11.3	13.3	15.4
	75 th %ile	1.6	7.0	0.0	0.1	0.9	2.4	3.8	5.4	7.2	9.1	11.1	13.1	14.8
	Median	0.6	3.2	0.0	0.0	0.3	1.0	1.8	2.5	3.3	4.3	5.7	7.0	8.0
	25 th %ile	0.0	0.9	0.0	0.0	0.0	0.1	0.3	0.6	0.9	1.5	2.0	2.5	3.1
Waipawa at RDS		PRMF	MALF	Cur MF	Q ₉₉	Q ₉₈	Q ₉₇	Q ₉₆	Q ₉₅	Q ₉₄	Q ₉₃	Q ₉₂	Q ₉₁	Q ₉₀
		2500	3009	2300	2096	2314	2451	2553	2655	2772	2892	3035	3191	3333
	Mean	0.6	2.0	0.2	0.0	0.2	0.5	0.7	1.0	1.3	1.8	2.3	3.0	3.6
	Max	3.5	8.4	1.5	0.3	1.6	3.0	4.0	5.1	6.3	7.7	9.3	11.0	12.6
	95 th %ile	2.4	6.2	1.0	0.1	1.1	2.0	2.8	3.6	4.6	5.6	6.8	8.3	9.7
	90 th %ile	2.0	5.4	0.7	0.0	0.8	1.7	2.4	3.1	3.9	4.9	6.1	7.3	8.5
	80 th %ile	0.8	3.5	0.1	0.0	0.1	0.6	1.0	1.5	2.2	3.0	4.2	5.4	6.4
	75 th %ile	0.6	3.3	0.0	0.0	0.1	0.4	0.8	1.4	2.1	2.9	3.8	5.0	6.0
	Median	0.2	1.2	0.0	0.0	0.0	0.1	0.3	0.4	0.7	1.0	1.5	2.0	2.6
25 th %ile	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.7	1.0	

Table 4: Volumes of water (in Mm³) required to supplement low river flows up to various flow thresholds during the December to February period, using Scenario 4 (from HBRC Science, May 2013a) as base scenario. P RMF: proposed regulatory minimum flow; MALF: 7-day Minimum Annual Low Flow (Naturalised MALF value in this table); Cur MF: Current regulatory minimum flow; Q₉₉: 99% flow exceedance percentile.

		Flow threshold (l/s) to which the river flow is topped up												
		PRMF	MALF	Cur MF	Q ₉₉	Q ₉₈	Q ₉₇	Q ₉₆	Q ₉₅	Q ₉₄	Q ₉₃	Q ₉₂	Q ₉₁	Q ₉₀
		5201	6250	3500	4381	4982	5382	5675	5974	6275	6577	6886	7174	7437
Tukituki at Red Bridge	Mean	1.0	3.0	0.0	0.3	0.7	1.3	1.8	2.4	3.0	3.7	4.5	5.3	6.0
	Max	6.1	11.1	0.5	2.6	5.0	6.9	8.3	9.8	11.2	12.7	14.2	15.7	17.1
	95 th %ile	4.8	8.9	0.1	2.2	4.0	5.4	6.6	7.8	9.0	10.6	12.4	14.1	15.8
	90 th %ile	3.1	7.9	0.0	0.7	2.2	3.8	5.2	6.6	8.0	9.7	11.4	13.0	14.4
	80 th %ile	1.3	5.4	0.0	0.1	0.7	1.9	2.9	4.1	5.5	7.0	8.5	10.0	11.4
	75 th %ile	1.1	4.6	0.0	0.1	0.6	1.6	2.5	3.6	4.7	5.8	7.0	8.2	9.4
	Median	0.2	1.8	0.0	0.0	0.1	0.4	0.8	1.3	1.9	2.5	3.3	4.1	4.9
	25 th %ile	0.0	0.5	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.7	1.0	1.3	1.6
Waipawa at RDS		PRMF	MALF	Cur MF	Q ₉₉	Q ₉₈	Q ₉₇	Q ₉₆	Q ₉₅	Q ₉₄	Q ₉₃	Q ₉₂	Q ₉₁	Q ₉₀
		2500	3009	2300	2096	2314	2451	2553	2655	2772	2892	3035	3191	3333
	Mean	0.3	1.2	0.1	0.0	0.1	0.3	0.4	0.6	0.8	1.1	1.4	1.8	2.2
	Max	1.9	4.8	0.8	0.1	0.9	1.6	2.2	2.8	3.6	4.4	5.4	6.5	7.6
	95 th %ile	1.8	4.5	0.6	0.1	0.7	1.5	2.1	2.6	3.3	4.1	5.1	6.1	7.1
	90 th %ile	1.4	4.1	0.4	0.0	0.4	1.1	1.7	2.3	3.0	3.7	4.6	5.5	6.4
	80 th %ile	0.4	1.9	0.0	0.0	0.0	0.3	0.6	0.8	1.2	1.7	2.2	2.9	3.6
	75 th %ile	0.4	1.7	0.0	0.0	0.0	0.3	0.5	0.7	1.1	1.4	1.9	2.5	3.0
	Median	0.1	0.7	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.6	0.9	1.2	1.5
25 th %ile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	

2.5. Flushing flows

2.5.1. Principles

The size of the flushing flows assumed as part of the feasibility study (10.5 m³/s) was considered appropriate to offset the reduction in the frequency of natural flushing flows caused by the dam and the operation of the Scheme in the Makaroro River and Waipawa River. In fact, being able to make the timing of the release of the flushing flows coincide with critical periods of potential periphyton accumulation probably provides an efficient periphyton control tool for these sections of river. However, they are likely to be insufficient in themselves to provide significant algal biomass removal in the lower Waipawa and Tukituki rivers, where Cawthron (May 2013) estimate that flows of around 20 m³/s and 50 m³/s respectively are required to result in surface flushing of fine sediment and accumulated periphyton of 80% and 50% of the wetted river bed respectively. The proportion of flushed sediment is predicted to increase with the size of the flow (Figure 8).

Given the current issues caused by excessive periphyton growth in the lower Tukituki River and the potential for the land use intensification to cause an increase in in-stream nutrient loads, this section of the report looks into the opportunities for the RWSS dam to release flushing flows that might provide a means of controlling (at least partially) periphyton biomass accumulation in the lower river. This may be achieved by either or, preferably, a combination of:

- Increasing the size of flushing flows released from the dam; and/or
- Timing the release of these flows from the dam to coincide with natural minor freshes, to increase the size of the resulting flow, and ultimately the benefits in terms of periphyton biomass removal.

2.5.2. Flow release capacity from the dam.

The capacity to release large flows from the dam will depend in part on the water level in the dam – in simple terms more water height means more “head”, which in turn means a higher flow rate can pass through a given size “pipe”.

Estimates provided by Tonkin & Taylor indicate that flows of up to 20 m³/s can be generated from the dam even when the reservoir is at low levels (down to about 55.5 m below full supply level). Larger flows, up to 40 m³/s could potentially be generated when the dam is full or nearly full (i.e. down to about 19 m below full supply level, but requires the power station at the base of the dam to discharge part of the flow).

The volume of water required to release a certain flushing flow obviously varies with its size and duration. Figure 9 presents a diagram of the volume of water required for flushing flows of 10 to 40 m³/s and durations of 6 to 20 hours (assuming constant flow for the duration of the flushing flow).

Indicatively, 1 Mm³ released from the dam corresponds to a release of 30 m³/s for just above 9 hours, or 25 m³/s for just above 11 hours.

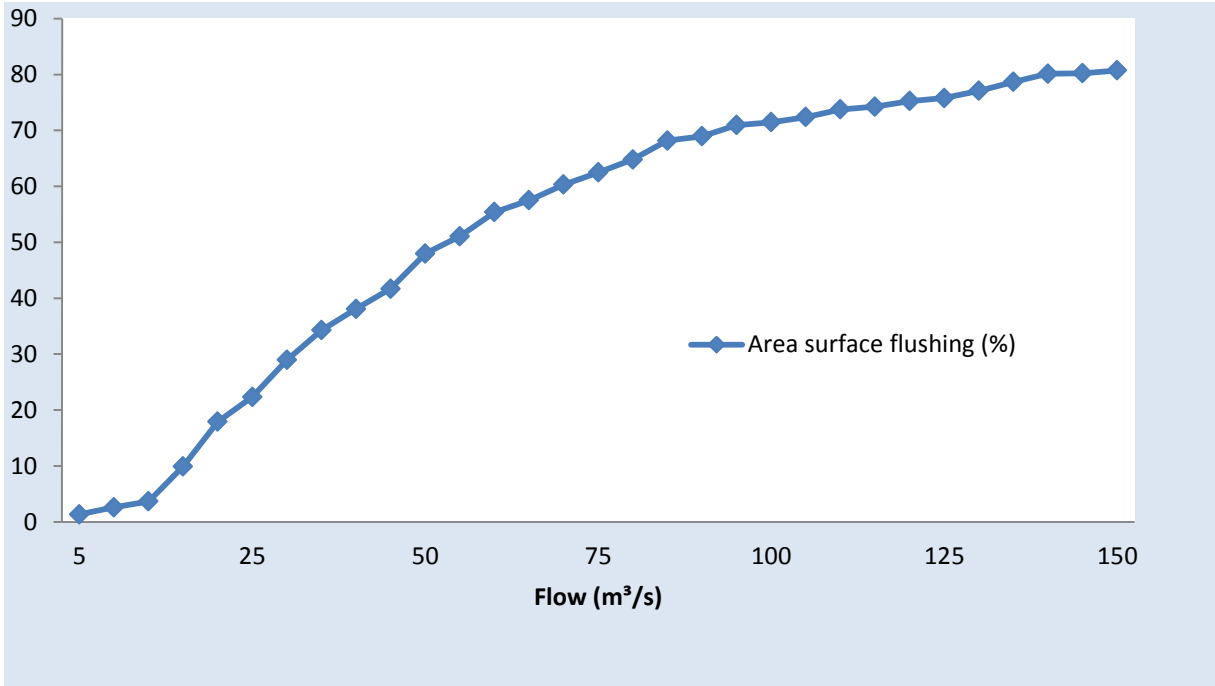


Figure 8: Percentage of surface flushing as a function of river flow at the Tukituki River at Red Bridge. (Source Cawthron Institute).

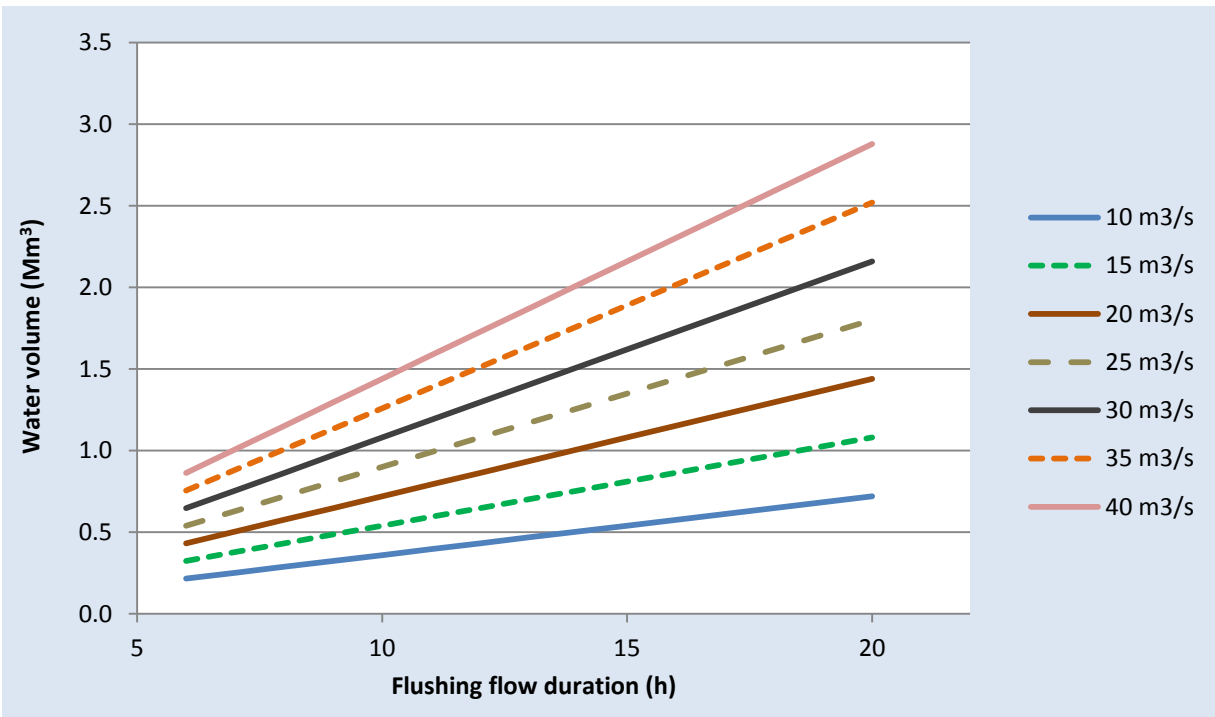


Figure 9: Water volume (in Mm³) required for the release of flows of 10 to 40 m³/s and 6 to 20 hours duration.

2.5.3. Flushing flow size and timing and periphyton removal

Although modelling suggests that flows of 50 m³/s would be required to mobilise a significant proportion of bed sediment in the lower Tukituki River at Red Bridge (Cawthron, May 2013), analysis of long-term National River Network Monitoring data (maintained by NIWA) shows that excessive filamentous algae growths (i.e. in excess of the 30% cover proposed Plan Change 6 target) were regularly observed in the lower Tukituki River at Red Bridge (58 out of 286 monthly observations made over the 1989 to 2012 period), but only rarely (three times) when the flow at the time of the observation was above 23 m³/s and never when the flow was above 34 m³/s.

Periphyton removal by flow events is of course determined not only by the flow on the day the observation is made, but also by the flow history in the 2 to 3 weeks period preceding the observation, and it is probable that some observations of low periphyton biomass made at a certain daily flow were actually driven by higher flow events in the days or weeks preceding the observation. It is recommended that the analysis presented in Figure 10 be extended to the 2 to 3 weeks period preceding each observation. Nonetheless, the fact that nuisance periphyton growths are frequent at that site, but were never observed at flows above 34 m³/s and only three times at flows over 23 m³/s, over a period of 23 years of monthly monitoring provides a strong indication that river flows in the 23 to 34 m³/s range are likely to provide significant periphyton removal benefits.

An important characteristic of periphyton growth in the lower Tukituki River is that a significant proportion of the periphyton biomass present in the river during extended periods of low, stable flows is present as poorly attached or drifting masses of filamentous algae (Adam Uytendaal, pers. comm.). Whilst this proportion of the biomass is particularly unsightly and adversely affects recreational use of the river, it is also expected to be more easily flushed out of the system than mats and filaments firmly attached to the river substrate. Further, although the abundance of *Phormidium* mats is generally low at sites across the Tukituki catchment, detached mats have occasionally been observed as deposited material on the river margins, or drifting as detached mats. A panel of experts convened by HBRC estimated that: “*the principal public health (including dogs) risks due to Phormidium are associated with the deposition of detached mats along the river margin during periods of flow recession. Even moderate-size flushing flows could substantially reduce the public health risk by removing deposited and detaching mats and reducing the potential for subsequent deposition*” (HBRC, 2013b). In this context it is expected that any significant increase in river flow/velocity during periods of otherwise stable, low flow is likely to provide some benefits in terms of periphyton biomass removal, and reduction in the potential public health risks associated with the deposition of *Phormidium* mats on the river margins.

There is also potential for the dam to augment smaller natural flow events to generate larger flushing flows in the River. The rationale is that whilst a natural minor fresh of say, 20 m³/s, may remove some of the accumulated periphyton biomass, its benefits could be greatly increased if the release of flushing flow water was timed to coincide with this natural fresh. The potential to piggy back the release of flushing flows from the dam on natural freshes was explored within the GoldSim modelling (refer to Section 3).

The Tukituki Proposed Plan Change 6 defines in-river dissolved reactive phosphorus (DRP) targets, in order to achieve in-river periphyton biomass and cover targets. The Proposed Plan Change 6 DRP targets were defined taking into account an accrual period (i.e. the time between two flushing flows) of up to 30 days. This means that Plan Change 6’s DRP concentration targets were defined at a level considered sufficiently low to control periphyton growth below periphyton biomass target levels for up to 30 days, but exceedances of the periphyton targets may occur when the accrual period (i.e. the period of low flows) extends beyond 30 days.

Based on this, it is recommended that flushing flows from the RWSS dam should, as much as possible, be released in order to “interrupt” periphyton accrual periods of 30 days or more, particularly during the key summer recreational use and periphyton growth period.

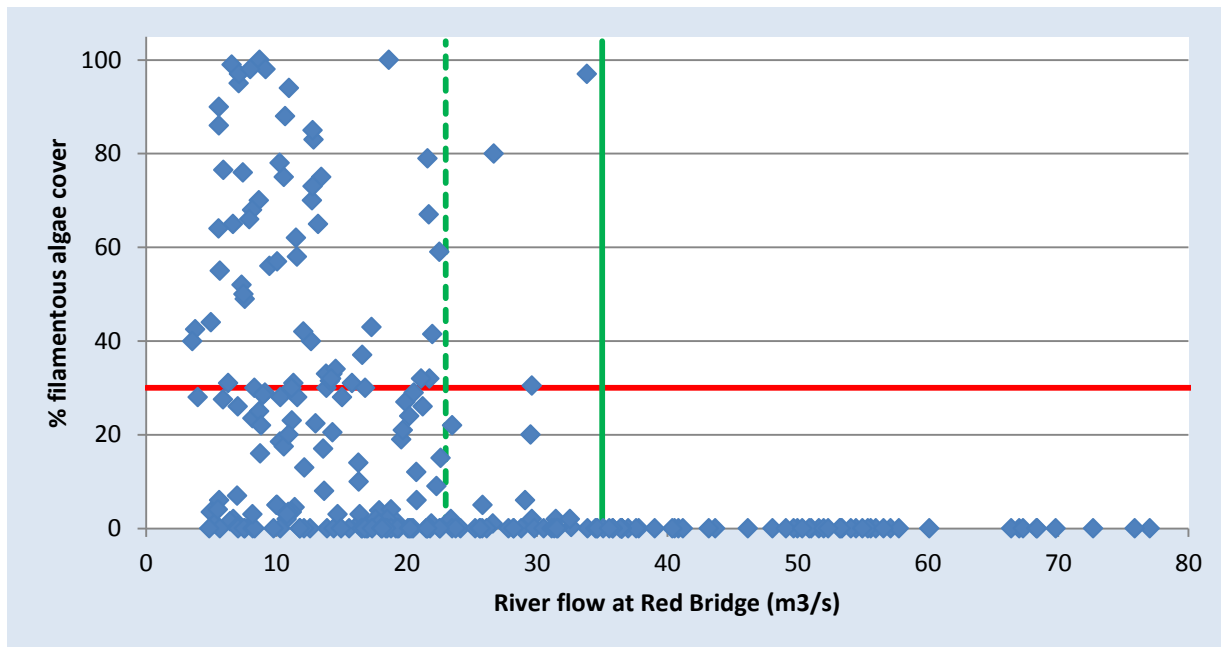


Figure 10: Visual observations of filamentous algae (FA) cover (as % of visible bed) (vertical axis) vs. river flow (horizontal axis) at the Tukituki River at Red Bridge National River Monitoring Network site over the period February 1989 to December 2012 (Data courtesy of NIWA).

2.5.4. Flushing flow travel

Modelling of the likely travel of flushing flows from the RWSS dam to the lower Tukituki River was undertaken using the Tukituki Mike11-HD hydrodynamic model (refer to Appendix A at four sites along the path of the flushing flows:

- Makaroro River at Burnt Bridge, immediately downstream of the dam;
- Waipawa River at RDS on the lower Waipawa River;
- Tukituki River at Shagrock, a short distance downstream of the confluence of Waipawa/Tukituki Rivers;
- Tukituki River at Red Bridge on the lower Tukituki River.

Modelling was undertaken assuming either (1) low flow conditions in all the reaches (nominally 2.5m³/s in the Waipawa River at RDS and 5.2 m³/s in the Tukituki River at Red Bridge) or (2) moderate flow conditions to simulate “piggy backing” over a natural fresh event (nominally 5 m³/s at RDS and 15 m³/s at Shagrock and Red Bridge). Flushing flows of 20 and 30 m³/s of durations of 9, 12 and 18 hours were modelled as well as a flow of 25m³/s for a duration of 11 hours.

Figure 11 and Figure 12 present the predicted travel of flushing flows. Results indicate that.

- there is generally little attenuation (reduction) of peak flows at RDS and Shagrock, and moderate attenuation at Red Bridge;
- for a given flow release size, attenuation of peak flows decreases when the duration of flow release from the dam increases;
- a flow release of 30 m³/s for 9 hours over low base flow conditions achieved peak flows of 35 m³/s at Shagrock and just under 30 m³/s at Red Bridge. The flow remained over 30 m³/s for 9 consecutive hours at Shagrock and over 25 m³/s for over 6 consecutive hours at Red Bridge, i.e. well within the 23 to 34 m³/s bracket defined above for flows likely to provide significant benefits;

- a flow release of 30 m³/s for 9 hours over moderate base flow conditions achieved much higher peak flows, in the order of 45 m³/s at Shagrock and 40 m³/s at Red Bridge, confirming that “piggy backing” on natural freshes is likely to achieve greater environmental outcomes for the same flow release from the dam.

Not accounted for in the MIKE11 modelling, some losses of flow may occur along the reach of the Waipawa River known as a losing reach (Figure 2). However, the flushing flows would be released over the top of existing river flows, from which losses to groundwater are already occurring, and the incremental additional losses from the additional flushing flow are expected to be relatively minor (estimated at up to 1 m³/s) (refer to Appendix B).

2.5.5. Conclusions – Flushing flows

The following points summarise the conclusions with regards to flushing flows:

- Flushing flows of 50 m³/s as measured at Red Bridge would ideally be generated in order to provide significant bed sediment mobilisation and attached periphyton removal. However, based on current design assumptions, flows that large would not physically be able to be released by the dam alone. More importantly, the volumes of water required to release would be very large;
- As much as possible, the release of flushing flows from the dam should be timed to “piggy-back” on small natural freshes to provide added periphyton removal benefits;
- Monitoring data and expert panel conclusions strongly suggest that flows much smaller than 50 m³/s, in the order of 23 to 34 m³/s (as measured at Red Bridge) are likely to provide significant periphyton removal in the lower Tukituki River;
- Flushing flows should, as much as possible, be released to interrupt accrual periods of 30 days or more to provide periphyton reduction when Plan Change 6’s in-stream DRP concentration targets may not be sufficient to maintain periphyton growth below “nuisance” levels;
- Flushing flow releases should be targeted to the summer period when recreational use of the river and risk of nuisance periphyton growth are at their highest;
- Flushing flows are likely to be only moderately attenuated, and a flow release of 30 m³/s for 9 hours is predicted to result in flows of 35 m³/s at Shagrock (where flow is predicted to remain above 23 m³/s for 9 consecutive hours) and just under 30 m³/s at Red Bridge even under low base flow conditions, i.e. well within the 23 to 34 m³/s bracket defined above for flows likely to provide significant benefits in the lower Tukituki River;
- Alternatively, a flow release of 25 m³/s for a duration of 11 hours (corresponding to approximately the same water volume as 30 m³/s for 9 hours) over low base flow conditions is predicted to result in a peak flow of 30 m³/s at Shagrock (where the flow is predicted to remain above 23 m³/s for 10 consecutive hours) and 27 m³/s at Red bridge (where it remains above 23 m³/s for 7 consecutive hours). Again these flows are well within the 23 to 34 m³/s range;
- Based on the above conclusions, the release of up to four flushing flows (one per month during the December to March period) of up to 30 m³/s for 9.25 hours was modelled in the GoldSim modelling;
- Each flow release such as described above (30 m³/s for 9 hours) requires approximately 1Mm³ of water. The actual efficiency of the proposed flushing flows is not known with certainty and should be monitored at different sites in the Makaroro, Waipawa and Tukituki Rivers, by estimating periphyton composition, cover and biomass before and after the release of flushing flows. The monitoring should specifically include an assessment of *Phormidium* abundance. The information thus collected should be used to optimise the size, duration and/or timing of the flushing flows, within the bounds of the volumes of water allocated to flushing flows. It is recommended that consent conditions relating to flushing flow release from the dam retain a degree of flexibility to allow for this testing and optimisation process during the life of the Scheme.

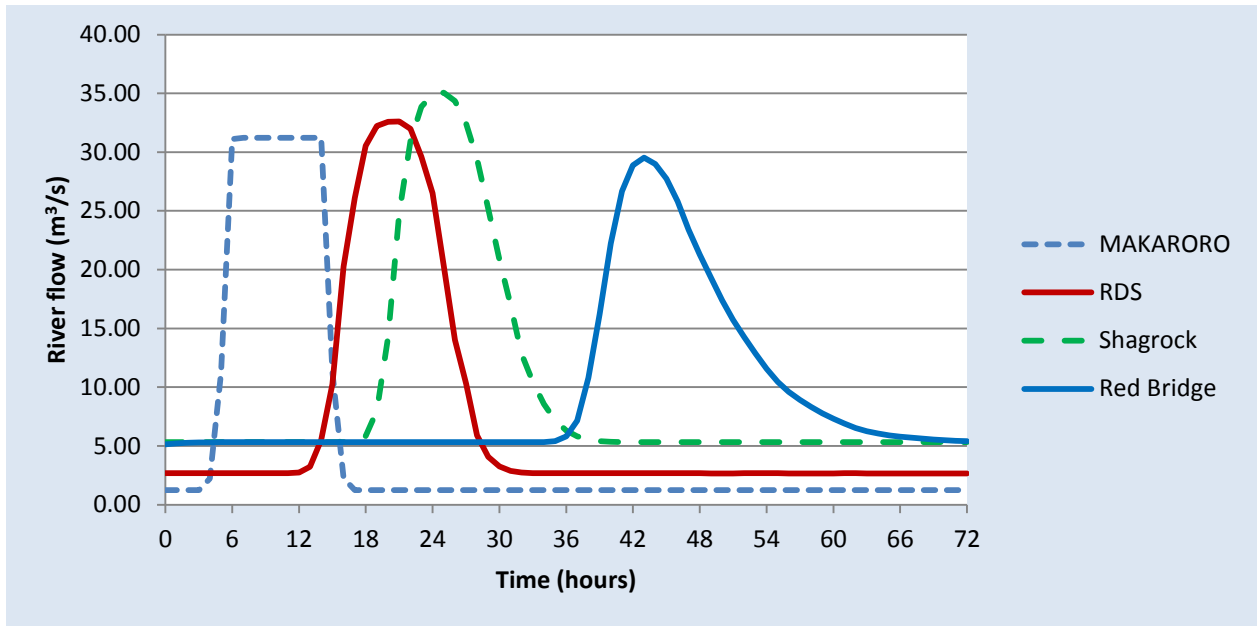


Figure 11: Predicted travel of flushing flows at different sites located downstream of the RWSS dam, assuming a low base flow in all reaches (Mike11 model).

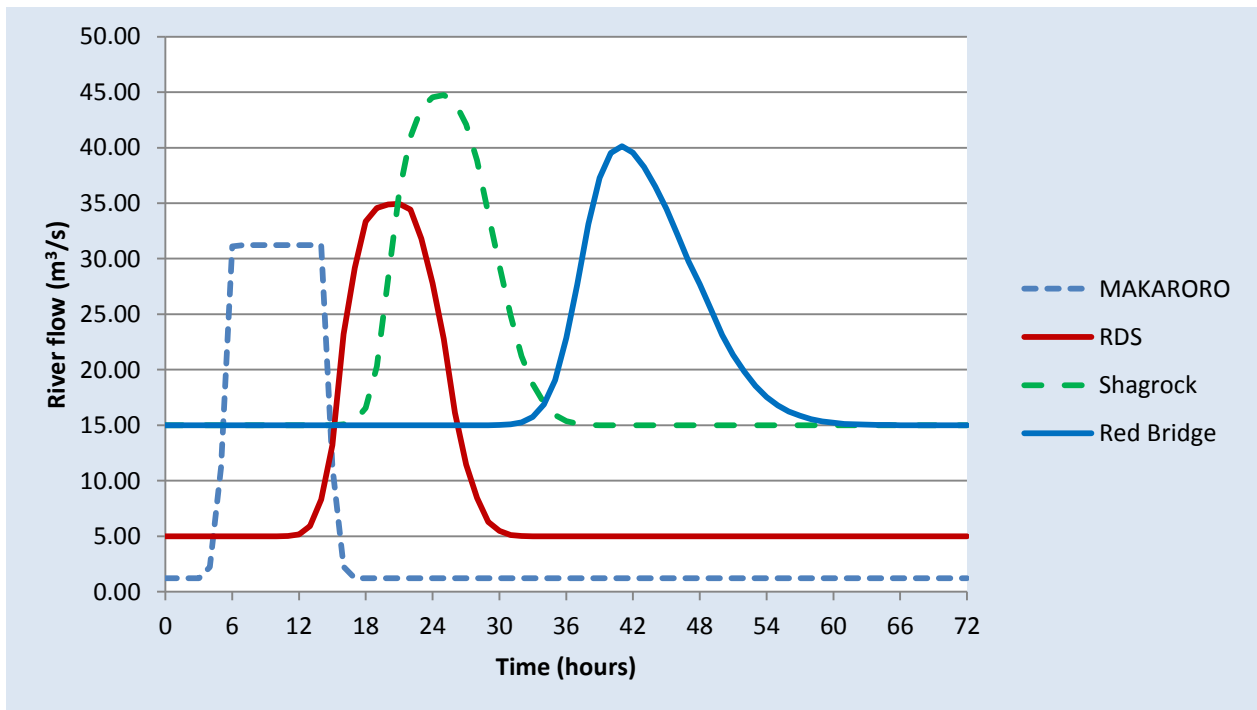


Figure 12: Predicted travel of flushing flows at different sites located downstream of the RWSS dam, assuming a moderate base flow in all reaches (Mike11 model).

2.5.6. Practical aspects

The release of flushing flows from the dam to correspond with natural minor fresh events (piggy backing) will require effective forecasting of these natural fresh events. It will require the development of a specific model incorporating rainfall and river flow real time data and forecasting, which is expected to be more challenging than the low flow forecasting referred to in Section 2.4.4, but technically feasible.

Also, the release of flushing flows would result in a relatively sudden increase in flow down the river system which may pose a risk to river users, particularly in summer. Whilst these considerations are outside the scope of this report, it is suggested that a public safety management plan may need to be prepared and implemented for the release of flushing flows.

3. GoldSim RWSS modelling

3.1. Model construction

The dam's operating regime has been modelled using the GoldSim Pro (Version 10.50) modelling platform to simulate the operation of the storage dam to harvest, store and release river flows to meet irrigation demand and an environmental flow regime. The model structure, input data and assumptions are provided in detail in the GoldSim model report prepared by Golder Associates (Appendix C). These are not repeated here, apart from key points required for clarity in this report.

The key water storage components included in the model were (in order of priority for supply, within the limits of available water):

- A primary residual flow at the toe of the dam equal to 90% of the estimated pre-dam 7-day mean annual low flow (7-day MALF), i.e. 1.228 m³/s;
- A primary flushing flow allocation of up to 2.0 million m³ per irrigation season (1 September to the following 30 April), corresponding with the release of up to two flushing flows of up to 30 m³/s in size and 9.25 hours in duration;
- A primary irrigation volume of up to 95.8 million m³ per irrigation season, corresponding to a secure primary irrigation volume of 91 million m³ delivered at the farm gate (allowing for a 5% conveyance loss from the dam to the farm gate) at full Scheme uptake;
- A secondary flushing flow provision of up to 2.0 million m³ per irrigation season, corresponding with the release of an additional up to two flushing flows of up to 30 m³/s in size and 9.25 hours in duration;
- A secondary irrigation volume of up to 28 million m³ per irrigation season. Although mainly intended for irrigation purposes, it was identified that a portion of this tranche of water may be utilised for purposes of river flow supplementation if that was necessary to mitigate any residual effect of the Scheme on low river flows. It is one of the objectives of this report to identify whether this is likely to be the case or not.

The size, timing and release triggers for the flushing flows are described in detail in the Project Description report (Tonkin & Taylor, May 2013a), and are consistent with the conclusions reached in Section 2.5.5 of this report, in particular:

- Flushing flows are released during summer season, modelled here as being December to March inclusive. Conceptually up to four flushing flows correspond to one flushing flow potentially released in each of the December to March inclusive calendar months;
- The flushing flows are released in order to interrupt accrual periods of 30 days or more, whilst allowing piggy-backing onto natural flows which are greater than 15 m³/s but less than 50 m³/s when accrual periods exceed 20 days. If no piggy-back flows occur before the accrual reaches 30 days then a flushing flow is automatically released on the 30th day of accrual.

A number of outputs were generated using the GoldSim model, including reservoir operating levels, primary and secondary irrigation volumes and reliability of supply, as well as flushing flows volumes and reliability. These outputs are summarised in the PD report and are not repeated in detail here. With specific regard to this report, the key objectives of the GoldSim modelling were:

- To assess the ability of the dam to release the significantly increased flushing flows recommended in earlier sections of this report;
- To assess the likely effects of the Scheme on downstream river flows under different “uptake” scenarios (referring here to “uptake” of Scheme water by existing water abstractors in replacement of all or part of their current takes), to complement the assessment undertaken by HBRC Science (May 2013a). This meant in particular assessing the likely outcomes of “intermediary” scenarios assuming various levels of uptake by existing groundwater abstractors;
- To provide a preliminary assessment of the potential benefits of increased drainage from newly irrigated land (“irrigation water return”) on river flows. The methodology used for this preliminary assessment is presented in Appendix C.

3.2. Modelling results – flushing flows

Key outputs relating to the release of the “augmented” flushing flows are described in the PD report (Tonkin & Taylor, May 2013a). Modelling indicates that over the 36 years record period, the operation of the Scheme according to the flushing flow thresholds and triggers results in the release of four flushing flows every year except in all years other than the 1979-1980, 1995-1996 and 1998-1999 irrigation seasons, when only three flushing flows need to be released because of natural freshes occurring at regular intervals during those years.

Water volumes released for flushing flows are presented in Table 5. A flushing flow of 30 m³/s for 9.25 hours is accounted for in GoldSim as corresponding to 0.95 Mm³, to avoid “double-accounting” for the minimum residual flow of 1.23 m³/s released at all times. As a result, two of these flushing flows represent 1.9 Mm³ and four flushing flows correspond to 3.8 Mm³. Allowing piggy-backing of the flushing flows from the dam on natural freshes means that the instantaneous flow released from the dam is sometimes less than 30 m³/s, which explains why water volumes released are often less than 3.8 Mm³ whilst 4 flushing flows are released on every year but three.

The peak flow of each flushing flow at Red Bridge was calculated by combining the flow release from the dam as modelled by GoldSim, the flow on that day at Red Bridge and the attenuation factors obtained using the Mike11 model. Figure 13 presents a frequency distribution of the peak flows at Red Bridge. Results indicate that the average and median peak flows were 37.6 m³/s and 36.3 m³/s respectively, the minimum peak flow was 27.1 m³/s, and the upper quartile (75th percentile) was 46.5 m³/s. The maximum peak flows were capped at 50 m³/s.

3.3. Modelling Scenarios – downstream flows

A large number of scenarios were modelled:

- Scenarios 2, 3, 4 and 5, were re-run with the GoldSim model, using similar assumptions and input data as HBRC Science (May 2013a) ;
- Three new scenarios, labelled Scenarios 6, 7 and 8, assuming 30, 50 and 80% respectively of current deep (i.e. non surface-depleting) groundwater takes are discontinued when the Scheme becomes operative;
- Each of the above scenarios was run excluding the potential effects of irrigation water return and then including it. Scenarios excluding the irrigation water return are annotated “a”, those including it are annotated “b”.

For each scenario, daily flow series were produced for the Tukituki River at Red Bridge and the Waipawa River at RDS, and two key statistics were calculated: MALF and the number of days below the proposed regulatory minimum flow (days<PRMF). These were compared to Scenario 2 statistics, taken here as the reference state corresponding to the current level of water abstraction.

Table 5: Annual statistics of predicted flushing flow releases from the RWSS dam per hydrological year (Source: Project Description report, Tonkin & Taylor March 2013a).

	Volume of flush flows released under the primary allocation (million m ³)	Volume of flush flows released under the secondary allocation (million m ³)	Total volume of flush flows released (million m ³)
Minimum	1.9	0.0	2.2
Median	1.9	1.8	3.8
Mean	2.1	1.4	3.5
Maximum	2.9	1.9	3.8

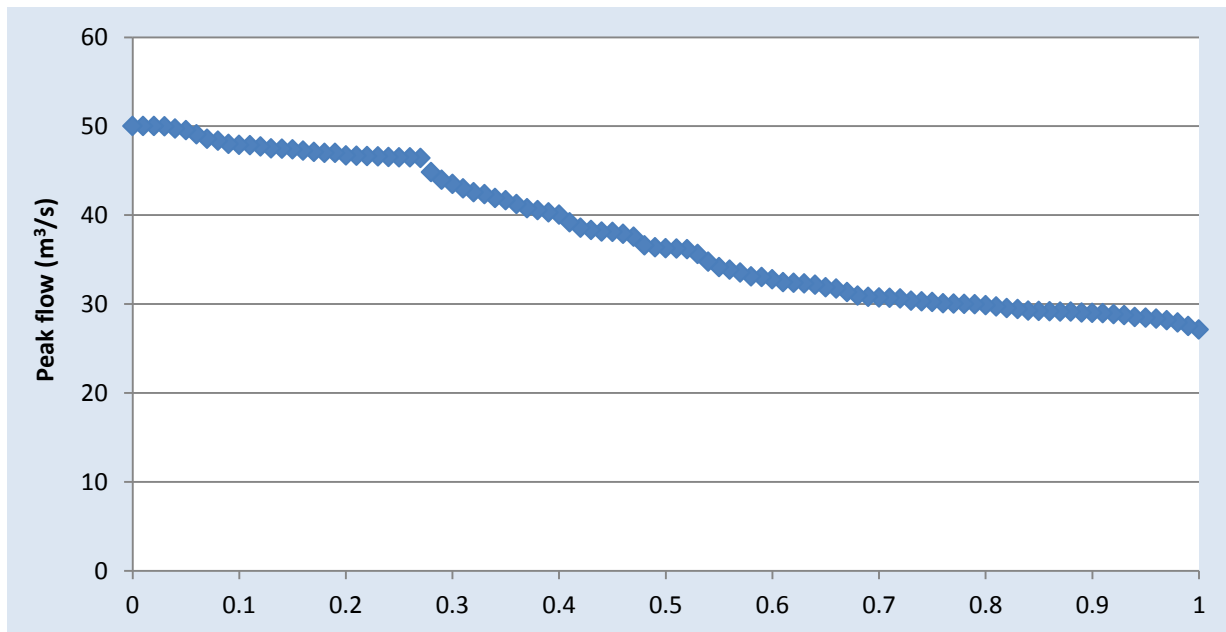


Figure 13: Frequency distribution of peak flow at the Tukituki at Red Bridge as a result of flushing flow releases modelled in GoldSim.

3.4. Modelling results – downstream flows

There was a very good level of agreement between the modelling outputs of HBRC Science, May 2013a and GoldSim for common scenarios (scenarios 2, 3 4 and 5). Subtle differences in absolute values were noted, but the direction and degree of relative change between scenarios were closely comparable.

Modelling results clearly indicate that the downstream low flow outcomes are strongly influenced by the level of “uptake” of Scheme water by existing water abstractors. Ignoring for the moment the potential benefits of increased drainage associated with irrigation, a minimum of approximately 30 % of current deep groundwater abstractions stopping (and using Scheme water instead) is required to achieve no net reduction in MALF, and no net increase in the mean days below minimum flows at Red Bridge (Figure 14 and Figure 15). A high proportion of uptake by current surface water abstractors is predicted to result in a reduction in the mean number of days below minimum flow but a slight reduction in MALF. A combination of a high level of uptake by surface water abstractors combined with a low level of uptake by groundwater abstractors would result in improvement of both MALF and days below PRMF. A similar result could of course be achieved by other permutations on the proportions of surface and groundwater “uptake”.

However, it appears that a much higher proportion of “uptake” by surface and groundwater abstractors is required to compensate for the potential effects of the Scheme at RDS. In fact, of the modelled scenarios, only Scenario 3 (100% of all takes discontinued) and Scenario 8 (80% of the groundwater takes discontinued) result in no net negative effects on MALF and mean days below PRMF. This suggests that some low flow supplementation targeted at periods of low flow at RDS may have to be provided in order to compensate for the potential effects of the Scheme on low river flows at that site, unless a high level of uptake by current irrigators upstream or upgradient of the RDS site eventuates.

The increase in drainage associated with irrigation was assessed to have a positive potential effect on low river flows, in the order of 76 l/s at RDS and 328 l/s at Red Bridge. This compares with the scale of potential effects of the Scheme on MALF under a worst-case scenario (i.e. scenario 4): 79 l/s at RDS and 108 l/s at Red Bridge respectively. Once the potential effects of return of irrigation water was accounted for, the GoldSim modelling outputs predict an improvement in MALF and days below PRMF in all scenarios considered at Red Bridge (Figure 14 and Figure 15).

At RDS however, the return of irrigation water is predicted to fully compensate for the effects of the Scheme only in Scenarios 3, 8 and 7 (50% or more uptake by current groundwater abstractors above that point) (Figure 16 and Figure 17). This again suggests that some low flow supplementation targeted at compensating for effects on low flows at RDS may be required depending on the level of uptake by current irrigators above that point.

One important point to note is that the flow modelling presented in this report does not account for flow releases to supply water to Zone M. These would flow down the Waipawa River from the confluence with the Mangaonuku Stream to the proposed Zone M intake, located a short distance upstream of the confluence with the Tukituki River. Releases of irrigation water to service Zone M will flow past the reach of the Waipawa River represented by the RDS site and should alleviate to some extent the need for additional low flow supplementation at that site.

It is also noted that whilst the increase in drainage under newly irrigated land is likely to result in increased river base flow, it may also result in localised groundwater mounding, which may in turn be associated with potential adverse effects (higher groundwater table) potentially requiring monitoring and remediation (engineered drainage) (Appendix D).

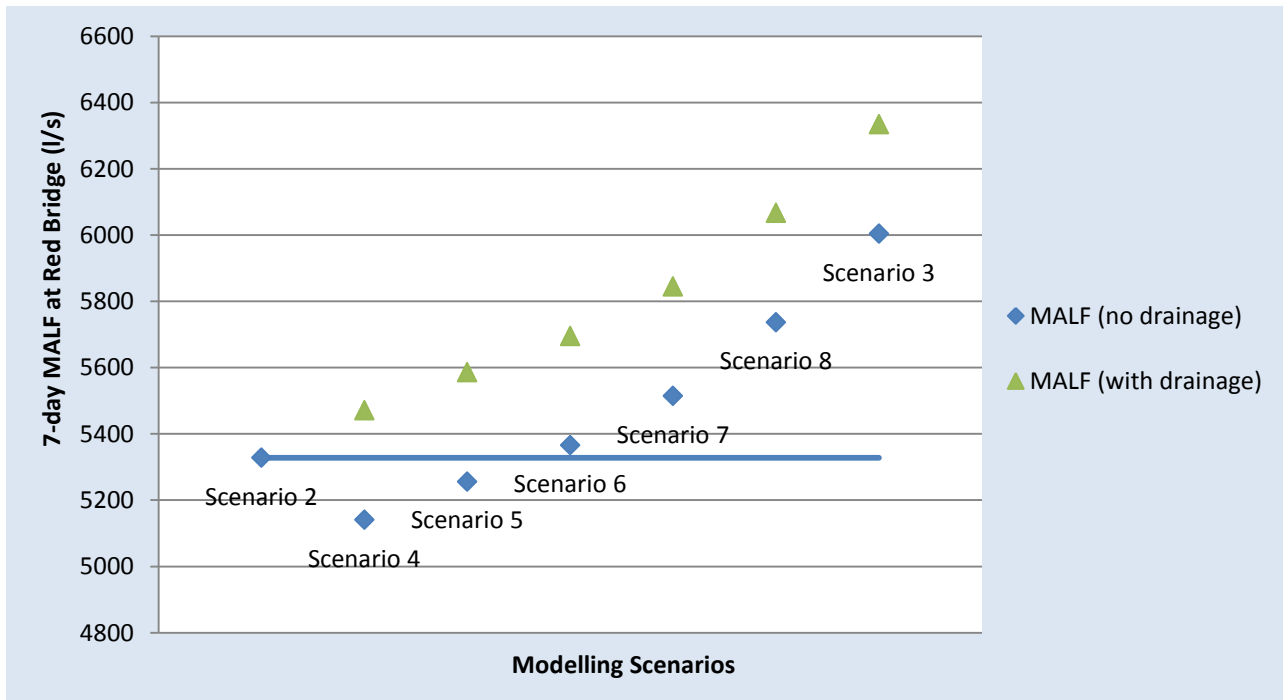


Figure 14: Predicted (as modelled by GoldSim) 7-day MALF at Tukituki River at Red Bridge under different scenarios, excluding (blue lozenges) or accounting for (green triangles) the potential effects of increased drainage associated with additional irrigation.

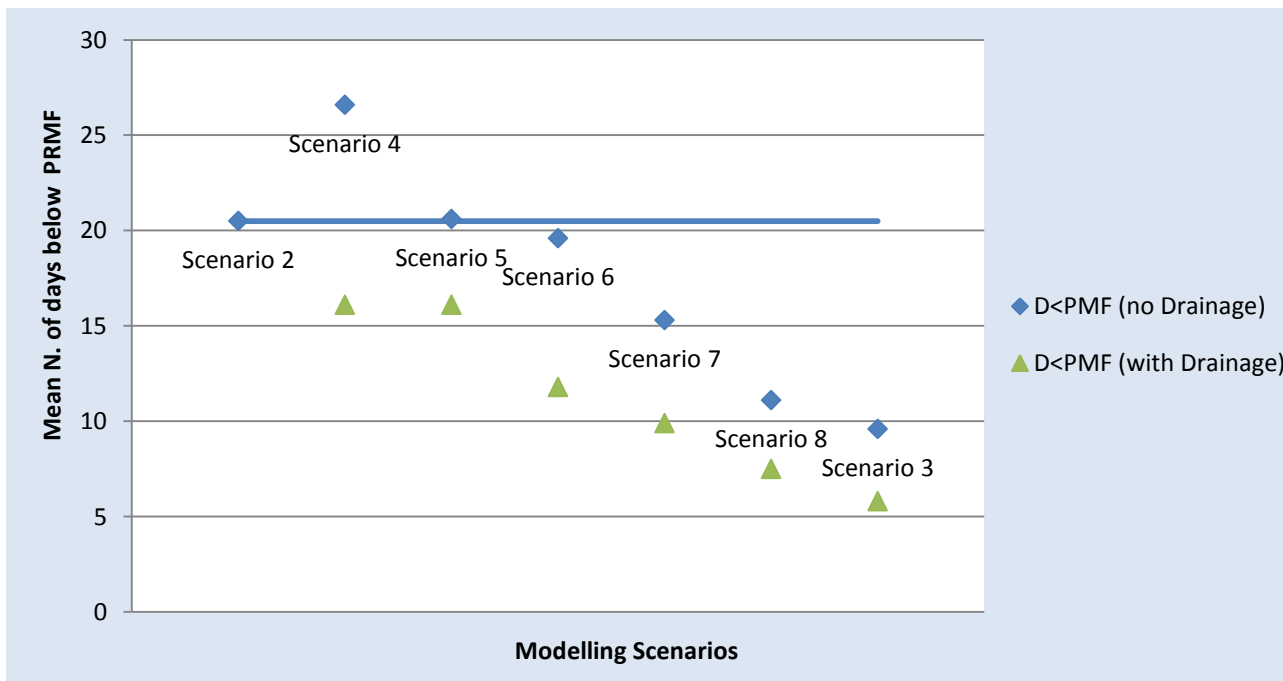


Figure 15: Predicted (as modelled by GoldSim) mean number of days below proposed regulatory minimum flow (PRMF) at Tukituki River at Red Bridge under different scenarios, excluding (blue lozenges) or accounting for (green triangles) the potential effects of increased drainage associated with additional irrigation.

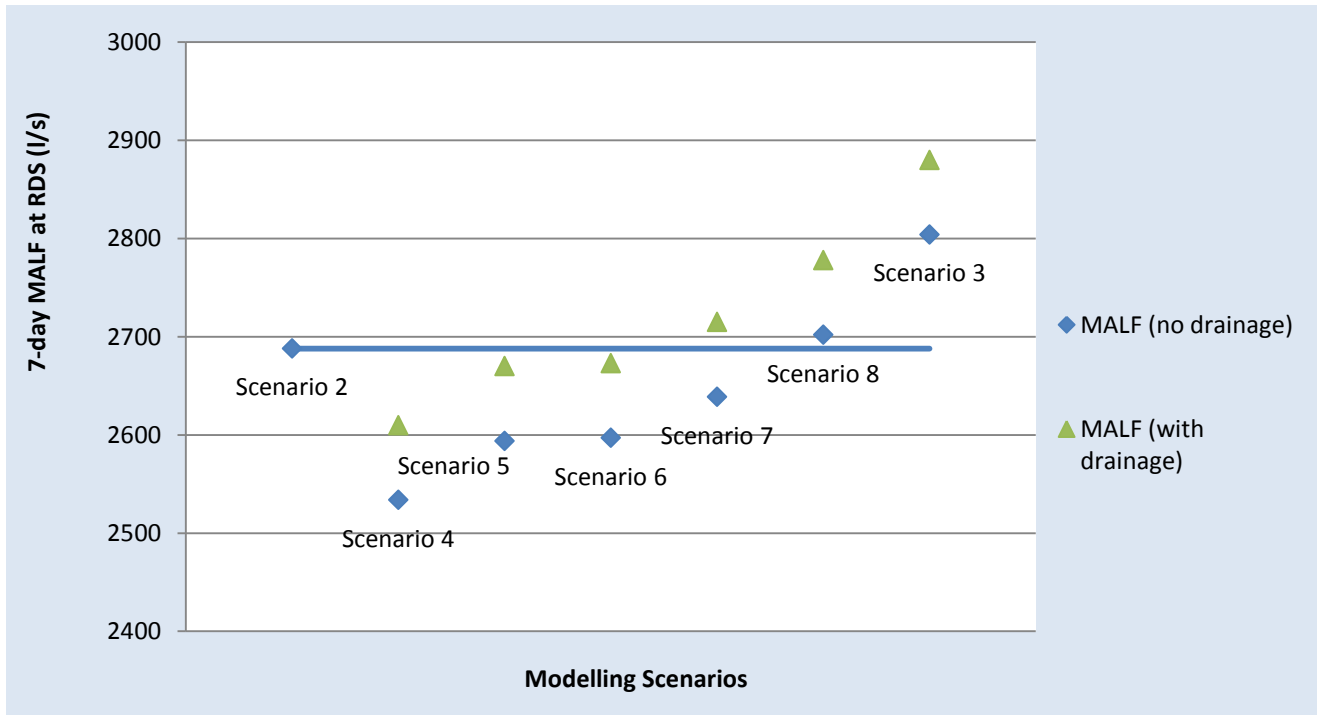


Figure 16: Predicted (as modelled by GoldSim) 7-day MALF at Waipawa River at RDS under different scenarios, excluding (blue lozenges) or accounting for (green triangles) the potential effects of increased drainage associated with additional irrigation.

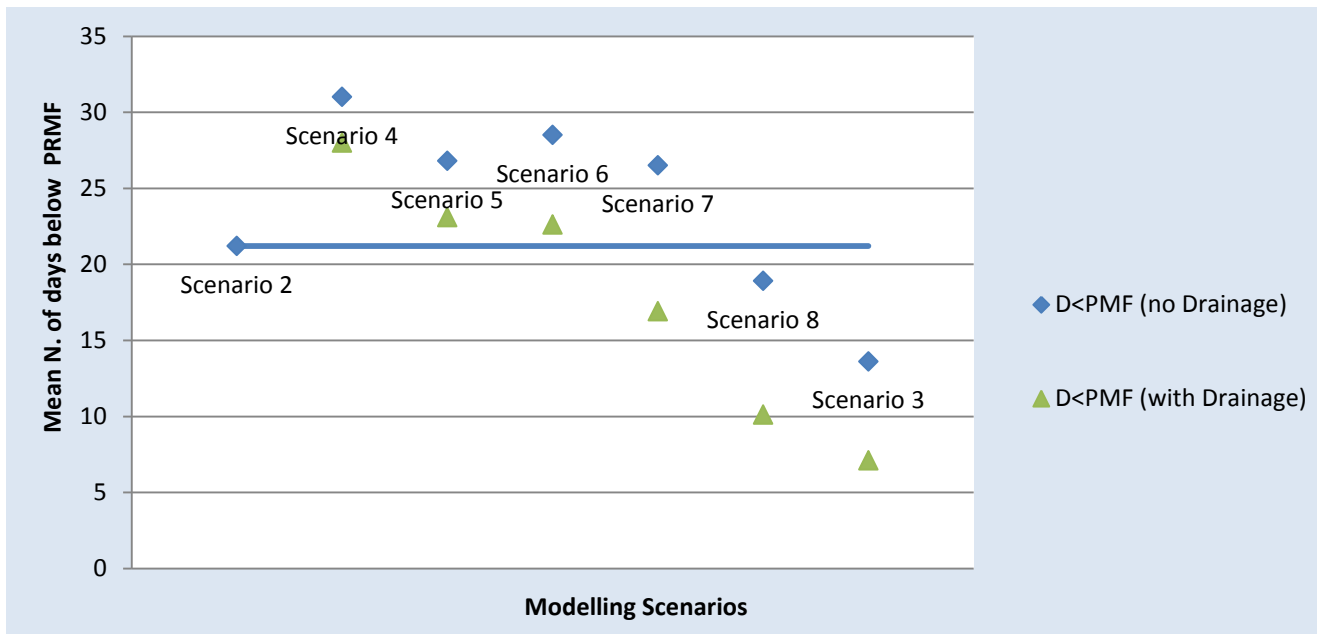


Figure 17: Predicted (as modelled by GoldSim) mean number of days below the proposed regulatory minimum flow (PRMF) at Waipawa River at RDS under different scenarios, excluding (blue lozenges) or accounting for (green triangles) the potential effects of increased drainage associated with additional irrigation.

4. Conclusions and Recommendations

4.1. Summary of results

Modelling shows that 4 “augmented” flushing flows per irrigation season can be delivered very reliably by the Scheme while maintaining primary irrigation supply and residual flow. There is strong evidential basis to suggest that they are likely to provide significant benefits – if not removing the whole biomass, at least providing considerable relief and public health risk avoidance by removing the drifting/detaching algae and cyanobacteria. Modelling also shows that the environmental benefits brought by these flushing flows can be further enhanced by managing the timing of their release to “piggy-back” on natural minor fresh events.

Results indicate that the Scheme is likely to result in significant improvement of the extreme low flows (minimum flow and Q99) in both the Waipawa and lower Tukituki Rivers under all scenarios considered. However, the Scheme may result in a reduction of MALF and an increase in the number of days below the proposed minimum flow if current water takes continue to their current level.

The Scheme is also predicted to result in benefits to low flows at Red Bridge if at least 30% of groundwater takes (or a mix of surface and groundwater takes) stop operating in the future (presumably to utilise water provided by the Scheme).

However, modelling results indicate that a higher proportion of current takes being discontinued may be required in order to avoid residual negative effects on low flows at RDS. These results suggest that some low flow supplementation targeted at compensating for effects on low flows at RDS may be required depending on the level of uptake by current irrigators upstream or upgradient of that site.

The above conclusions do not take into account the potential benefits of increased drainage associated with additional irrigation provided by the Scheme. The preliminary assessment undertaken using the GoldSim model indicates that if this effect was fully realised, implementation of the Scheme would be predicted to result in significant improvement of low flows (using MALF and the mean number of days below minimum flow as key indicators) under all scenarios considered at Red Bridge. Residual effects may however still occur at RDS, again depending on the proportion of current takes being discontinued. The proportion of current takes having to be “switched off” in order to avoid negative effects on low flow at that site was however lower than when the potential effects of increased drainage were ignored. In any case, these results reinforce the conclusion that direct mitigation may be required to mitigate potential effects at RDS. As noted above, the release of irrigation water to service Zone M may to some extent, alleviate the need for low flow supplementation at that site.

It is noted also that the nature of the flow modelling is that it relies on historical flow data. It does not, therefore, take account of the potential effects of climate change, which have to be assessed separately. Renwick (May 2013) discusses climate change mechanisms that can be expected in the Tukituki Catchment over the next 50-100 years. While noting a degree of uncertainty about how climate change effects might play out at a local scale, in broad terms, Renwick predicts changes in the seasonal distribution of flows that appear to broadly cancel out, meaning that mean and median flows are not likely to alter significantly, relative to current natural fluctuations (Renwick pers. comm.). The more significant predicted effect is an increase in the frequency and severity of droughts. The changes Renwick describes can be expected to reduce natural low flow statistics over time, including MALF. The fact that the RWSS residual flow is specified as 1.23 m³/s (rather than as a percentage of MALF) means that the residual flow will not reduce in response to the predicted effects of climate change. In this regard, the approach of not taking explicit account of climate change is therefore seen as a conservative position.

4.2. Recommendations

Recommendation 1: That flushing flows as described in the PD be included in the set of proposed consent conditions.

As indicated throughout this report, there is strong evidential basis to suggest that the release of “augmented” flushing flows as described in this report is likely to provide significant environmental benefits, particularly during the extended periods of summer low flows, when other means of controlling periphyton growth (such as nutrient management) are of reduced effectiveness. Being able to “interrupt” all periphyton accrual periods in the lower Tukituki River at Red Bridge before they exceed 30 days during the critical summer period provides an opportunity that would not otherwise exist to contribute to progress towards Plan Change 6’s periphyton biomass targets.

Modelling indicates that the water volumes required for both the primary and secondary flushing flows can be supplied by the dam every year. On this basis, it appears that the proposed consent conditions do not need to differentiate between primary and secondary flushing flows, and it is recommended that the proposed consent conditions require the release up to four flushing flows every year, based on the date and river flow triggers defined in this report.

It is also noted that the ability of the dam to deliver instantaneous flows of 30 m³/s may be limited when water levels in the dam reach very low levels. It is suggested that in this instance, the duration of the flushing flows should be increased proportionally to the reduction in instantaneous flows, and that, for example flushing flows of 25 m³/s for 11 hours would be likely to also achieve significant benefits. It is recommended that consent conditions allow for this level of flexibility.

Recommendation 2: That further modelling of irrigation water return be undertaken.

The increase drainage associated with the irrigation of a greater area of land may result in an increase in the return of groundwater to surface water. Preliminary assessment undertaken as part of the GoldSim modelling has indicated that this positive effect may be significant when considering the low river flow range. It is acknowledged that this is only a preliminary assessment based on using average values derived from a simple water balance estimate, and it is recommended that this potential effect be more fully assessed.

Recommendation 3: That modelling be re-run if/when uptake is known

The modelling has thus far been undertaken on the basis of blanket proportional reduction of all current takes. In reality, individual takes may be stopped in the future whilst others will continue. The outcomes in terms of river flows may depend on the location and characteristics of each individual take being “replaced”. Such a level of detail cannot of course be modelled at present as it would be speculative to pre-determine which takes may or may not be “replaced”. It is our understanding that the Scheme’s commercial team will be entering in discussions with current water abstractors over the next few months. If and when formal agreements to supply water are finalised, it is suggested that it would be useful to undertake modelling on the basis of these more certain “uptake” data.

The uptake of RWSS water by existing or new irrigators within Zone M is also currently unknown, but, as noted above, the supply of water to Zone M may alleviate to some extent the need to undertake low flow supplementation at RDS (for example low flow supplementation may only be required when water is not being supplied to Zone M). Again it is suggested that this aspect be incorporated in future modelling once uptake within Zone M is known.

Recommendation 4: That provision be made to mitigate any actual effects of the RWSS on river low flows at RDS and/or at Red Bridge by targeted low flow supplementation.

As explained in this report, the implementation of the RWSS may, under some scenarios, result in negative effects on low flows, both from an ecological (as indicated by decreases in MALF) and resource use (as indicated by the number of days below PRMF) point of views. These effects may, or may not eventuate, depending primarily on the level of uptake by current water abstractors and the potential effects of the irrigation water “return”.

As per recommendations 2 and 3 above, it is recommended that further assessment be undertaken, before and during the implementation of the Scheme, in particular to incorporate actual levels of Scheme uptake when these become more certain.

It is also recommended that the Scheme release additional water as required to offset the modelled effects of the dam’s operation on the number of days below the proposed minimum flow and give further consideration to addressing the adverse effects on MALF as shown by modelling results at the time.

However, the uncertainties inherent in modelling of low river flows need to be acknowledged. This is particularly the case at RDS where historical low flow data appears to have a greater level of uncertainty as pointed out in HBRC Science (May 2013a). Whilst the above approach based on modelled effects is considered suitable (and is recommended) at Red Bridge, a more certain approach, not based on modelling, may be more appropriate at RDS. A relatively simple and pragmatic way to ensure that the Scheme does not result in an increase in the number of days below the proposed minimum flows at RDS would be a consent condition requiring the Scheme to match, within given bounds, the natural inflows it receives when the flow at RDS is below, or is dropping to levels very close to, the proposed minimum flows.

In order to maintain the proposed residual flow at all times, the condition should be worded so that the rate of water discharge from the dam at those times is the larger of 1.23 m³/s and the inflow to the dam measured at the time.

It is also recommended that an upper bound be defined. Given the flow travel times to the lower catchment (approximately 12-18 hours from the dam to RDS and 30 hours to Red Bridge), situations may arise where a significant rainfall occurs in the hills, but the flow at RDS is still close to or below the proposed minimum flow. In these situations, there would be significant inflows to the dam, and also from the upper parts of the Tukituki and Waipawa River catchments. If the flow release from the dam was to fully match its inflow, the Scheme would have to release a significant flow (potentially several m³/s) for a period of up to 18 hours, in spite of that water only reaching the lower catchment at the same time as the water from the rest of the upper catchment. In effect that water would have served no purpose in terms of supplementing low flows at RDS or Red Bridge, but with consequential loss of storage. An upper bound of 1.8 m³/s, corresponding to approximately 130% of MALF at the toe of the dam is suggested.

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APPENDICES

Appendix A: MIKE11 Modelling - memo prepared by Ir. Craig Goodier, Senior Design Engineer, Hawke's Bay Regional Council

March 7, 2013

Graeme Hansen
Project Manager,
Ruataniwha Water Storage Project

Re: RWS Project: Flushing Flow Analysis using Mike11 Hydrodynamic Model

A series of 1-Dimensional computer model runs were completed using the Tukituki Mike11-HD hydrodynamic computer model. The model runs were used to simulate flushing flow releases from the proposed water storage dam.

Eighteen model runs were done for the analysis, which includes the following conditions:

Model Run	Discharge (m ³ /s)	Duration (hrs)	Base flow condition
1	20	9	Low
2	20	12	Low
3	20	18	Low
4	20	24	Low
5	30	9	Low
6	30	12	Low
7	30	18	Low
8	30	24	Low
9	20	9	High
10	20	12	High
11	20	18	High
12	20	24	High
13	30	9	High
14	30	12	High
15	30	18	High
16	30	24	High
17	25	11	Low
18	25	11	High

Base flow conditions were set as follows:

Low flow:

1. Makaroro at dam site = 1.23 m³/s
2. Waipawa upstream of Makaroro confluence = 1.44 m³/s
3. 1 and 2 combined to give 2.67 m³/s at Waipawa at RDS
4. Tukituki upstream of Waipawa confluence 2.65 m³/s
5. 3 and 4 combined to give 5.32 m³/s at Tukituki Red Bridge

High flow:

1. Makaroro at dam site = 1.23 m³/s
2. Waipawa upstream of Makaroro confluence = 3.77 m³/s
3. 1 and 2 combined to give 5 m³/s at Waipawa at RDS
4. Tukituki upstream of Waipawa confluence 10 m³/s
5. 3 and 4 combined to give 15 m³/s at Tukituki Red Bridge

The type of model used in these simulations has no infiltration losses, therefore the downstream discharges in the model are likely to be higher than what would occur in reality.

Results were examined at locations of Waipawa River at RDS, Tukituki River at Shag Rock, and Tukituki River at Red Bridge.

A plan showing the scope of the model, and the location of the test points is shown in Figure 18.

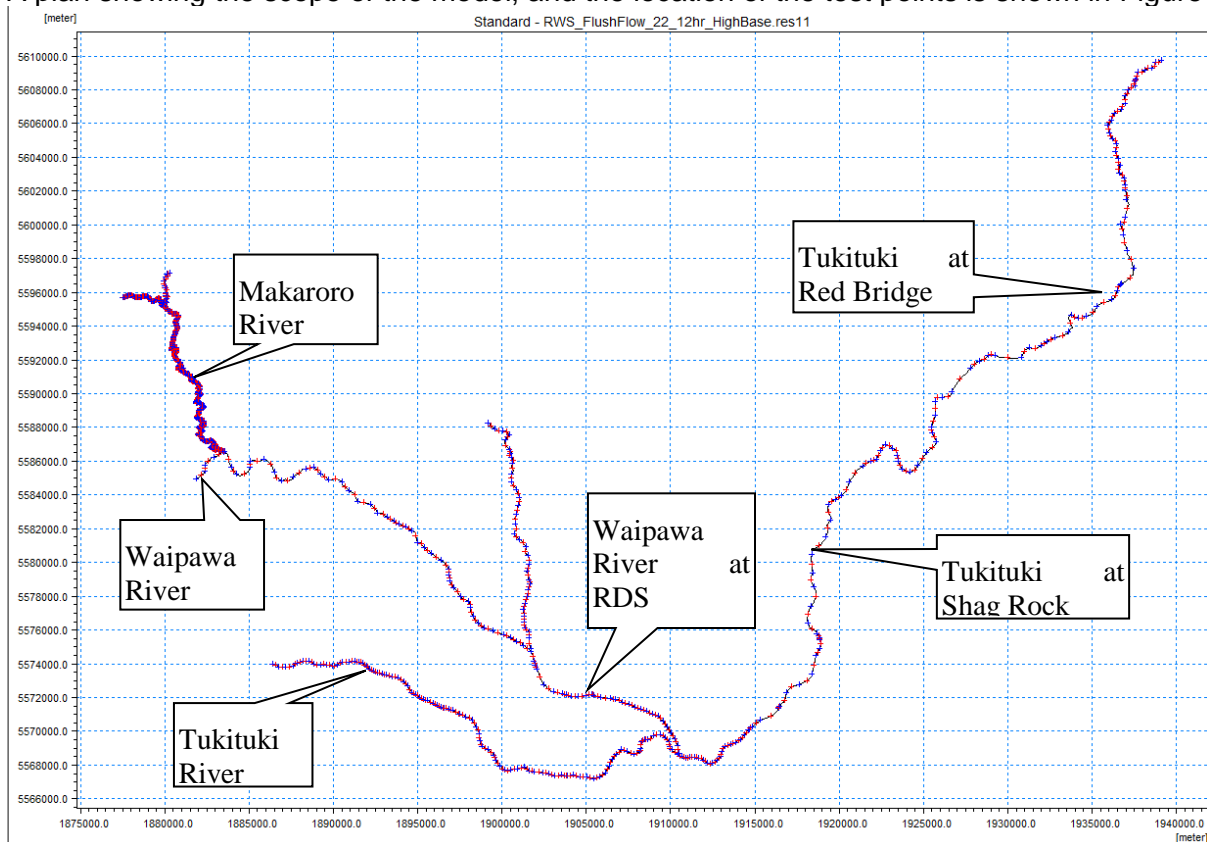


Figure 18: Hydrodynamic model schematic, showing test point locations.

Results at the selected locations (water level and discharge hydrographs) have been used in further analysis.

Results from the test locations are shown below as peak discharges, with the first table including the base flow, the second table showing the peak discharges without base flow, and the final table showing the amount of attenuation.

Peak Discharge (m3/s) (including baseflow)					
Item	Q-hr-base	Dam Site	Waipawa at RDS	Tukituki at Shag Rock	Tukituki at Red Bridge
1	20-9-low	21.2	22.6	25.2	21.5
2	20-12-low	21.2	22.6	25.3	23.8
3	20-18-low	21.2	22.6	25.3	25.1
4	20-24-low	21.2	22.7	25.3	25.3
5	30-9-low	31.2	32.6	35.1	29.5
6	30-12-low	31.2	32.7	35.3	33.0
7	30-18-low	31.2	32.7	35.3	35.1
8	30-24-low	31.2	32.7	35.3	35.3
9	20-9-high	21.2	25.0	34.9	31.9
10	20-12-high	21.2	25.0	35.0	33.7
11	20-18-high	21.2	25.0	35.0	34.9
12	20-24-high	21.2	25.0	35.0	35.0
13	30-9-high	31.2	34.9	44.7	40.1
14	30-12-high	31.2	35.0	45.0	43.1
15	30-18-high	31.2	35.0	45.0	44.9
16	30-24-high	31.2	35.0	45.0	45.0
17	25-11-low	26.2	27.6	30.2	27.5
18	25-11-high	26.2	30.0	39.9	37.7

Peak Discharge (m3/s) (not including baseflow)					
Item	Q-hr-base	Dam Site	Waipawa at RDS	Tukituki at Shag Rock	Tukituki at Red Bridge
1	20-9-low	20.0	19.9	19.8	16.1
2	20-12-low	20.0	20.0	19.9	18.4
3	20-18-low	20.0	20.0	20.0	19.8
4	20-24-low	20.0	20.0	20.0	19.9
5	30-9-low	30.0	29.9	29.7	24.2
6	30-12-low	30.0	30.0	30.0	27.7
7	30-18-low	30.0	30.0	30.0	29.7
8	30-24-low	30.0	30.0	30.0	29.9
9	20-9-high	20.0	20.0	19.9	16.9
10	20-12-high	20.0	20.0	20.0	18.7
11	20-18-high	20.0	20.0	20.0	19.9
12	20-24-high	20.0	20.0	20.0	20.0
13	30-9-high	30.0	29.9	29.7	25.1
14	30-12-high	30.0	30.0	30.0	28.1
15	30-18-high	30.0	30.0	30.0	29.9
16	30-24-high	30.0	30.0	30.0	30.0
17	25-11-low	25.0	25.0	24.8	22.1
18	25-11-high	25.0	25.0	24.9	22.7

The attenuation provided by the river system is shown in the following table.

Attenuation of Peak Discharge (m3/s)					
Item	Q-hr-base	Dam Site	Waipawa at RDS	Tukituki at Shag Rock	Tukituki at Red Bridge
1	20-9-low	0.0	0.1	0.2	3.9
2	20-12-low	0.0	0.0	0.1	1.6
3	20-18-low	0.0	0.0	0.0	0.2
4	20-24-low	0.0	0.0	0.0	0.1
5	30-9-low	0.0	0.1	0.3	5.8
6	30-12-low	0.0	0.0	0.0	2.3
7	30-18-low	0.0	0.0	0.0	0.3
8	30-24-low	0.0	0.0	0.0	0.1
9	20-9-high	0.0	0.0	0.1	3.1
10	20-12-high	0.0	0.0	0.0	1.3
11	20-18-high	0.0	0.0	0.0	0.1
12	20-24-high	0.0	0.0	0.0	0.0
13	30-9-high	0.0	0.1	0.3	4.9
14	30-12-high	0.0	0.0	0.0	1.9
15	30-18-high	0.0	0.0	0.0	0.1
16	30-24-high	0.0	0.0	0.0	0.0
17	25-11-low	0.0	0.0	0.2	2.9
18	25-11-high	0.0	0.0	0.1	2.3

Prepared by:

Ir. Craig Goodier
Senior Design Engineer,
Hawke's Bay Regional Council

Appendix B: Memo relative to flow losses along the Waipawa River, prepared by Thomas Wilding, Senior Scientist –Hydrology (HBRC).

MEMO

To: Olivier Ausseil
From: Thomas Wilding
Date: 14 December 2012
Subject: **FLOW LOSS AND GAIN FOR WAIPAWA RIVER**
File Ref:
Cc: Rob Waldron

Background

The Ruataniwha Storage team are investigating the practicality of releasing flushing flows from the proposed dam to remove nuisance algae from the river bed. The Waipawa River loses flow to groundwater between State Highway 50 and Stockade Road (yellow and red lines on Figure 1). A question arising is how much of the water released from the dam (as a flushing flow) would be lost during its passage down the Waipawa River?

Analysis of concurrent flow measurements by Johnson (2011) indicated that about 3.5 m³/s was lost to groundwater (between SH50 and Stockade Rd), and this change did not increase markedly at higher river flows. The Waipawa River appears to intersect groundwater levels at about Stockade Road, and gains flow from several groundwater-fed inflows by State Highway 2 (including the Mangaonuku Stream and Cochranes Creek). These inflows are similar in magnitude to the upstream flow losses (from Figure 13 in Johnson, 2011). Concurrent gaugings to date indicate that the losses and gains balance out (losses = gains). But groundwater-fed return flows at any point in time may show a lagged response compared to the time flow is lost upstream. Adding to this temporal separation of gains and losses, there is a spatial separation with some Waipawa losses transferred to the upper Tukituki River (via the Kahahakuri Stream – see Undereiner et al. 2009), which appear to be offset by contributions from the Mangaonuku catchment. The complexity of the groundwater interactions over space and time complicates predictions of river flow response to artificial flushing flows.

The release of flushing flows from the dam could be in the order of 11 to 20 m³/s. This release would be over and above the ambient river flows (assumed between MALF and median flow). Olivier Ausseil put forward the hypothesis that the flow release could traverse the losing/gaining reaches somewhat intact because the flow loss and gain is independent of river flow (i.e. constant loss and gain over a wide range of flows). Testing this hypothesis would require manipulation of river flows with actual releases from a dam (because of autocorrelation in observed flow data). I conducted a re-analysis of observed flow data for changing flow loss/gain with inflows to the Waipawa River to better inform decisions made prior to dam construction.

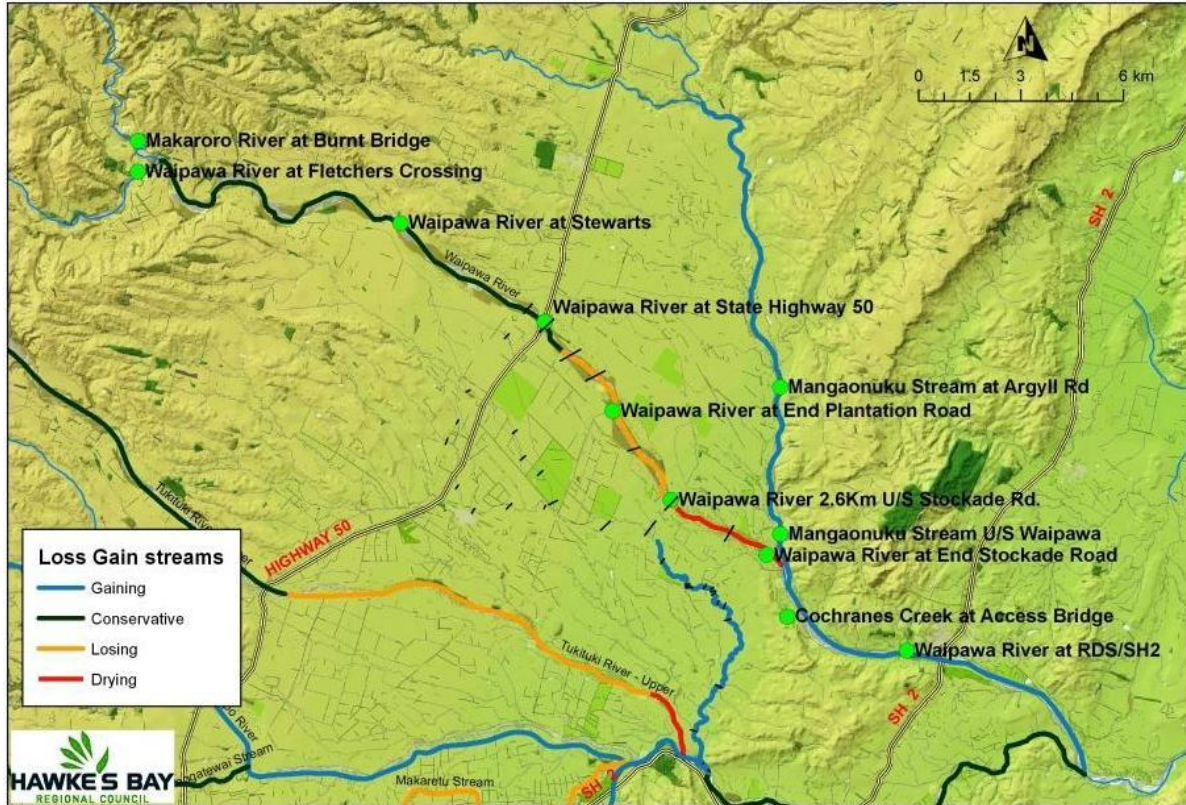


Figure 1 The Waipawa River loses flow to groundwater as it crosses the Ruataniwha Plains (e.g. yellow line represents a losing reach). Selected gauging sites are also displayed, including the concurrent gauging sites used to measure flow loss and gain (see Johnson, 2011).

Results

Concurrent gaugings (flows measured at several sites on the same day) demonstrate the flow losses observed between SH50 and Stockade Road, followed by gains measured at SH2 (Figure 2).

Looking more closely at the losses between SH50 and Stockade Road (Figure 3), suggests flow losses did increase slightly as flow increased at SH50. For example, the linear equation (from Figure 3) predicted the flow loss to groundwater increased from 3300 L/s to 4700 L/s (for inflows at SH50 of 3300 L/s to 20000 L/s respectively).

The measured flow increase between Stockade Road and State Highway 2 (Figure 4) was more consistent than upstream flow losses, but cannot be treated as static. For example, the linear equation (from Figure 4) predicted the flow gain increased from 3600 L/s to 4200 L/s (for inflows at SH50 of 3300 L/s to 20000 L/s respectively).

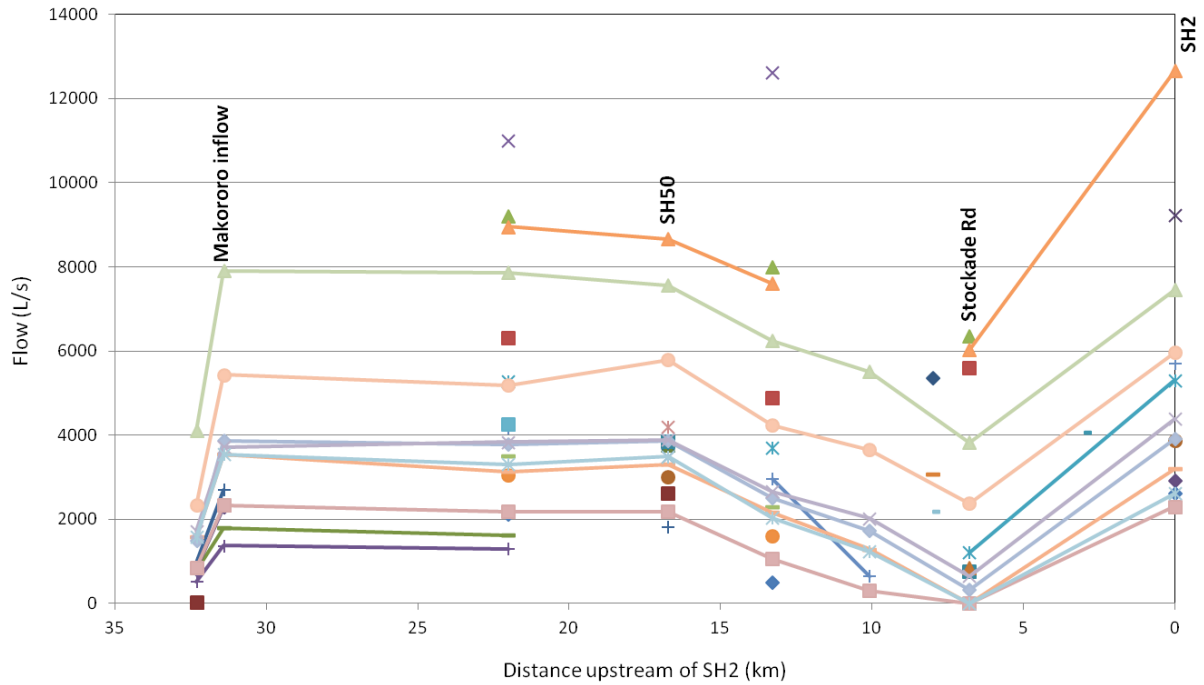


Figure 2 Flow measured during concurrent gaugings along the Waipawa River (Fletcher’s Crossing to State Highway 2). Each data line represents a single date on which flows were measured. Flows at the Makororo inflow were synthesized (sum of flows at Fletchers Crossing and Burnt Bridge).

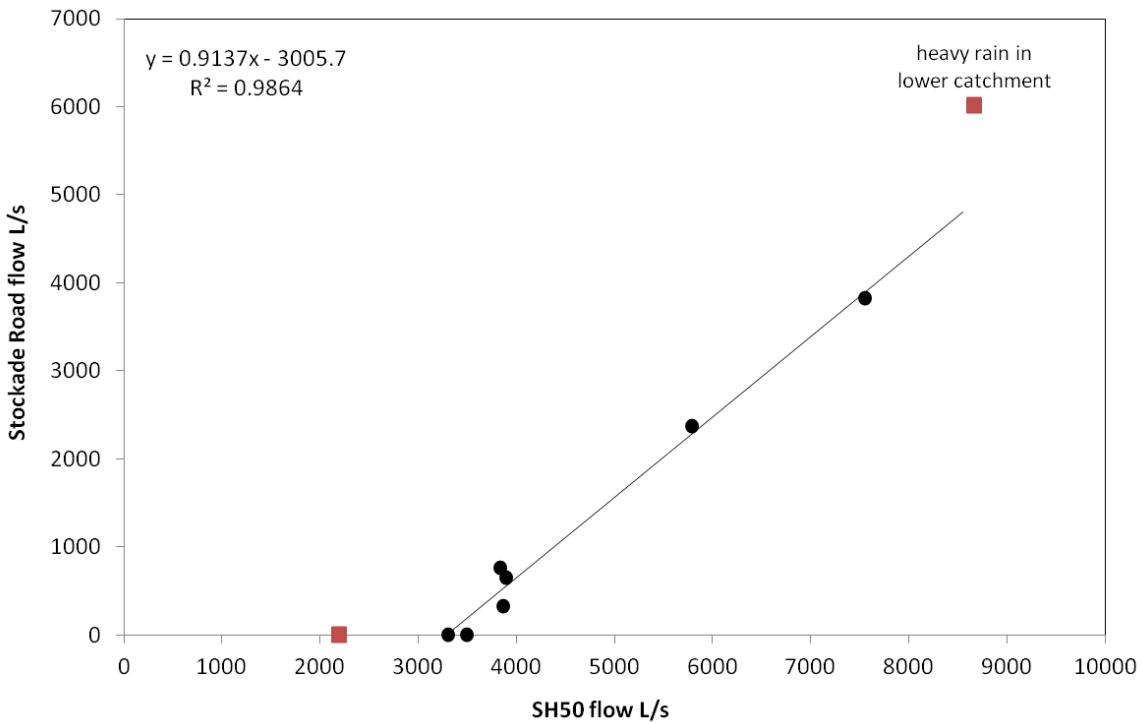


Figure 3 Flow measured during concurrent gaugings at the end of the losing reach (Stockade Road), plotted against the start of the losing reach (State Highway 50). Outliers (red points) do not contribute to the trendline. The highest flow was affected by heavy rain in the lower catchment (94 mm at Gwavas over the 4 weeks prior).

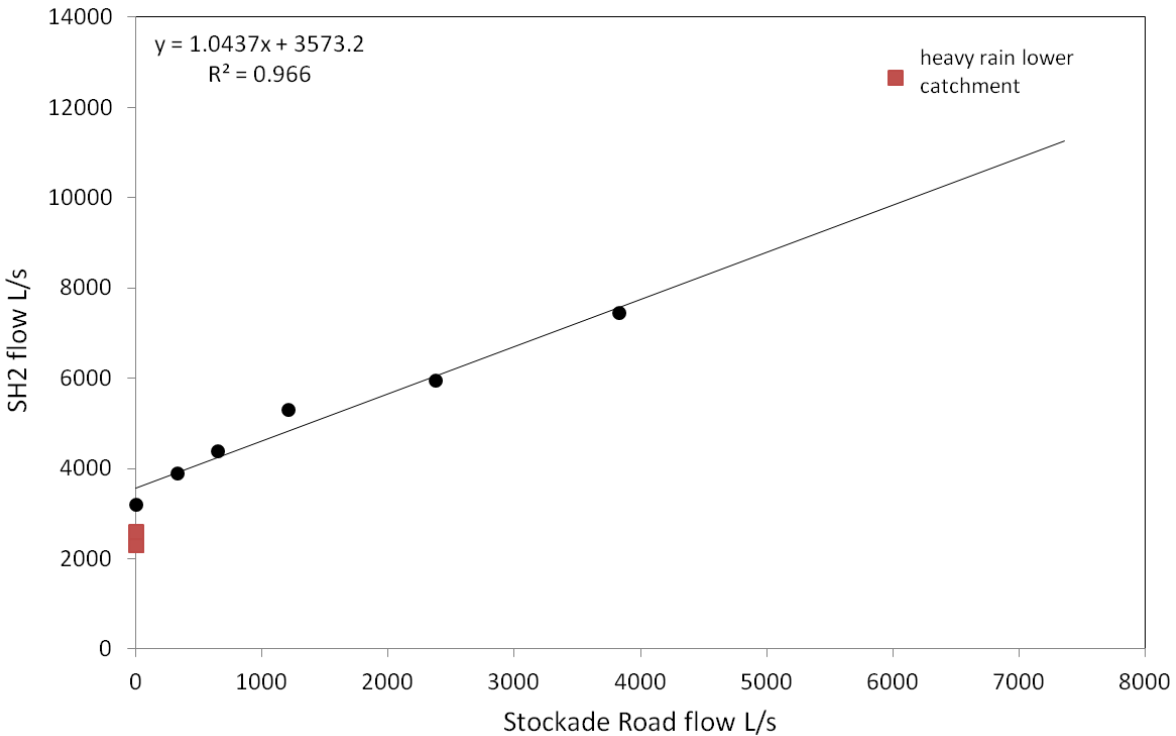


Figure 4 Flow measured during concurrent gaugings near State Highway 2 plotted against flows at the start of the gaining reach (Stockade Road). Outliers (red points) do not contribute to the trendline. The highest flow was affected by heavy rain in the lower catchment (94 mm at Gwavas over the 4 weeks prior).

The net flow change predicted by the above equations for losses and gains are summarized in Table 1. At low flows of 3300 L/s at State highway 50, a net gain of about 300 L/s is predicted at State Highway 2. At high flows of 20000 L/s, a net loss of 500 L/s is predicted because Mangaonuku inflows do not increase at the same rate as flow losses. The net loss would probably be greater during an artificial release because inflows below Stockade Road would not increase beyond antecedent inflows. For example, a net gain of 200 L/s is predicted at SH2 when ambient inflows at State Highway 50 are 5000 L/s. Releasing 15000 L/s under these conditions might then experience a net loss of 1100 L/s at SH2 (3600 gain – 4700 loss = - 1100 L/s).

There are many uncertainties in extrapolating observed flow relationships to manipulated flows. Arguably the greatest uncertainty in this analysis is estimating inflows between Stockade Road and State Highway 2. Inflows from the Mangaonuku Stream and Cochranes Creek will reflect catchment runoff, shallow aquifer levels and deep aquifer levels, rather than instantaneous flows in the Waipawa River at State Highway 50.

Table 1 Loss and gain of Waipawa River flow, predicted from observed correlations (equations in Figures 3 & 4). Numbers in red are extrapolated beyond the observed data range, so are less reliable.

SH50	Stockade predicted	predicted loss	SH2 predicted	predicted gain	predicted net change (SH50 to SH2)
3300	10	-3300	3583	3600	300
4000	649	-3400	4251	3600	200
5000	1563	-3400	5204	3600	200
6000	2477	-3500	6158	3700	200
7000	3390	-3600	7112	3700	100
8000	4304	-3700	8065	3800	100
9000	5218	-3800	9019	3800	0
10000	6131	-3900	9972	3800	-100
11000	7045	-4000	10926	3900	-100
12000	7959	-4000	11880	3900	-100
13000	8872	-4100	12833	4000	-100
14000	9786	-4200	13787	4000	-200
15000	10700	-4300	14741	4000	-300
16000	11614	-4400	15694	4100	-300
17000	12527	-4500	16648	4100	-400
18000	13441	-4600	17601	4200	-400
19000	14355	-4600	18555	4200	-400
20000	15268	-4700	19509	4200	-500

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Appendix C: GoldSim Model Report

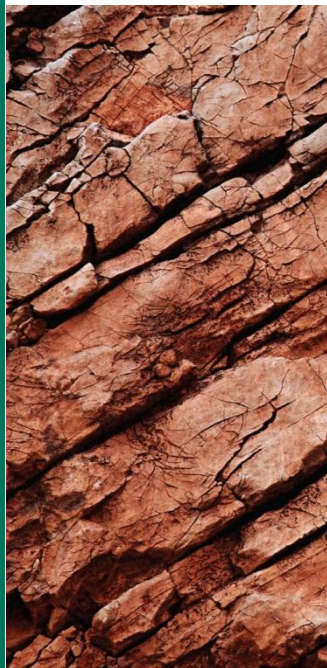


April 2013

RUATANIWHA WATER STORAGE SCHEME

GoldSim Model Report

Submitted to:
Hawkes Bay Regional Investment Company Ltd



REPORT

Report Number. 1278110104-002-R-Rev1





Summary

The Hawke's Bay Regional Investment Company Limited (HBRIC Ltd) is currently investigating the development of a water storage and irrigation scheme for the Ruataniwha Plains in the Hawke's Bay. The overall concept of the Ruataniwha Water Storage Scheme (the Scheme) is to construct a dam on the Makaroro River (dam height approximately 83 m and a total storage volume of approximately 90 M m³) to harvest and store high winter flows for release over the summer. The summer releases would be used to satisfy irrigation demand and provide for environmental flows in the Waipawa and lower Tukituki Rivers. Details of the Scheme and its potential effects are outlined in various investigations, models and reports prepared principally by Tonkin & Taylor Ltd as the lead technical advisor to the project on engineering aspects, in association with various other consultants, HBRIC Ltd and HBRC staff.

As part of the Ruataniwha Water Storage Scheme environmental flow optimisation study (Aquanet 2013), HBRIC Ltd approached both Golder Associates (NZ) Limited (Golder) and the GoldSim Technology Group and requested that a GoldSim model be developed for the scheme. The model was to focus on optimising the operation of the Scheme. The model would be used to assess the amount and availability of excess water and to aid the development of water management rules that could help to maximise the benefits (i.e. additional irrigation and/or environmental flow) to be derived from the excess water.

This report summarises the model conceptualisation, the input data used, assumptions incorporated into the model and outlines the model limitations as they pertain to the parts of the model that were used to prepare the modelling projections that have fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013). This report also documents the model review process and summarises the model projections that were used in Aquanet 2013 and Tonkin & Taylor 2013.

GoldSim is a graphical object-oriented modelling platform for developing dynamic probabilistic simulation models. GoldSim has been applied successfully as a decision support tool for a range of water balance, water quality and water resource projects, both within New Zealand and internationally.

The two main objectives of the GoldSim model of the Scheme are as follows:

- 1) To provide a water balance for the Ruataniwha water storage reservoir which appropriately simulates the performance of the proposed scheme operating regime in regard to meeting irrigation demand, environmental minimum flows and flushing flows.
- 2) To enable compliance with key performance criteria (supply reliability for water users and achievement of environmental minimum flows and flushing flows) to be evaluated at key sites downstream of the reservoir.

The GoldSim model of the Scheme was constructed with considerable flexibility to allow the rapid assessment and comparison of numerous scenarios. The input parameters to the model include a number of time series records of stream flow and other environmental and water use (i.e., irrigation) data. These inputs are derived from both the results of various specific studies and management decisions made by HBRIC Ltd regarding the scale and operation of the proposed scheme. The model predominantly covers the proposed Makaroro reservoir but extends downstream to assess flows in the Waipawa River at RDS and in the Tukituki River at Red Bridge. The model is based on a daily time step and covers 36 complete hydrological years from 1 July 1972 to 30 June 2008. A key assumption underpinning the model is that future climatic and hydrological conditions are likely to be similar to the historic data used in the simulations.

Model limitations are principally associated with the quality of the input data, the conceptualisation assumptions built into the model and the inherent difficulties in modelling natural systems. The model has been internally peer reviewed within Golder and has received an external peer review by the GoldSim Technology Group in the USA. Issues identified during the review process were discussed and where necessary the model updated accordingly. While uncertainties in the input data will transfer to uncertainties in the model projections for individual variables within a scenario, the model does allow comparisons between scenarios that can support and inform management decisions.



RUATANIWHA WATER STORAGE SCHEME - GOLDSIM MODEL REPORT

The model has two main components. The first simulates the behaviour of the reservoir projected under various management regimes. Model projections were used to develop an operational regime for the scheme, which is documented in the project description report (Tonkin & Taylor 2013), and provided much of the thinking behind the comments in the environmental flow optimisation report (Aquanet 2013). The focus of this first part of the model was to determine how water could be allocated from the reservoir and what reliability of supply could be achieved for the various competing uses.

The second component in the model is focused on projecting downstream flows using the methodologies outlined in Waldron and Baalousha (2013) which are based on Tonkin & Taylor's modelling of the Makaroro Reservoir. This part of the model was used to assess the impacts of both the transfer of existing takes and the increased recharge associated with the new irrigation and to produce the downstream flow statistics which were used within the environmental flow optimisation report (Aquanet 2013).

A technical review of the GoldSim model was performed as part of the scope of work. The review recommended seven areas for improving the robustness of the model and its use. The most important was the recommendation that the time series data (i.e., stream flow, irrigation demand and water use) referenced in the model be verified and its representativeness and accuracy assessed so that a complete assessment of the accuracy of the model projections can be completed.



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APPENDICES

APPENDIX A

Report Limitations



List of Abbreviations

HBRC	Hawkes Bay Regional Council
HBRIC LTD	Hawkes Bay Regional Investment Company Ltd
GL	Gigalitre
Golder	Golder Associates (NZ) Limited
EPA	Environmental Protection Agency
m ³	cubic metres
ha	hectares
mm/day	millimetres per day
m ³ /day	cubic metres per day
m ³ /s	cubic metres per second
PET	potential evapo-transpiration
NIWA	National Institute of Water and Atmospheric Research
M m ³	million cubic metres
ENSO	El Niño/La Niña Southern Oscillation
MALF	mean annual low flow
IPO	Interdecadal Pacific Oscillation
km	kilometres
km ²	square kilometres



1.0 INTRODUCTION

1.1 Background

The Hawke's Bay Regional Investment Company Limited (HBRIC Ltd) is currently investigating the development of a water storage and irrigation scheme for the Ruataniwha Plains in the Hawke's Bay. The investigations commenced in 2009 and a considerable amount of work has been completed. A detailed feasibility report was completed in 2012 (Hawke's Bay Regional Council (HBRC) 2012). HBRIC Ltd is applying for resource consent to construct and operate the Scheme.

The overall concept of the Ruataniwha Water Storage Scheme (the Scheme) is to construct a dam on the Makaroro River (dam height approximately 83 m and a total storage volume of approximately 90 M m³) to harvest and store high winter flows for release over the summer. The summer releases would be used to satisfy irrigation demand and provide for environmental flows in the Waipawa and lower Tukituki Rivers. Details of the Scheme and its potential effects are outlined in various investigations, models and reports prepared principally by Tonkin & Taylor Ltd as the lead technical advisor to the project on engineering aspects, in association with various other consultants, HBRIC Ltd and HBRC staff.

As part of the Ruataniwha Water Storage Scheme environmental flow optimisation study (Aquanet 2013), HBRIC Ltd approached both Golder Associates (NZ) Limited (Golder) and the GoldSim Technology Group and requested that a GoldSim model be developed for the Scheme. The model was to focus on optimising the operation of the proposed water storage. The model would be used to assess the amount and availability of excess water and to aid the development of water management rules that could help to maximise the benefits (i.e. additional irrigation and/or environmental flow) to be derived from the excess water.

1.2 Scope of Work and this Report

In early 2013 HBRIC Ltd commissioned Golder to prepare a GoldSim model for the Scheme. As part of that work, Golder was asked to provide model projections which could feed into both the project description report (Tonkin & Taylor 2013) and the environmental flow optimisation study (Aquanet 2013) for the Ruataniwha Water Storage Scheme. This report¹ summarises the model conceptualisation, the input data used, assumptions incorporated into the model and outlines the limitations of the model projections used to support the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013). This report also documents the model review process and summarises the model projections that have fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013).

Golder is currently in the process of providing HBRIC Ltd with a further report containing a description of the full model, the provision of model user guidance and recommendations for its future use.

1.3 Report Structure

This report has the following structure:

- Section 2 provides background information and briefly summarises existing models and relevant reports.

¹ This report is subject to the limitations attached in Appendix A.



- Section 3 provides a brief overview of the GoldSim model highlighting the model objectives, extent and flexibility. A summary of the conceptual model of the Scheme is presented in this section.
- Section 4 describes the details of the model including model inputs, key assumptions, model structure, projection points, model limits and boundary conditions.
- Section 5 describes the model calibration process.
- Section 6 discusses the accuracy of the model and its limitations.
- Section 7 provides a summary of the model projections.
- Section 8 provides a summary of the peer review process that has been completed on the model.
- Section 9 presents conclusions reached from the modelling and recommendations with respect to future upgrading of the model.
- Section 10 contains a list of documents referenced in this report.

2.0 BACKGROUND

2.1 Environmental Setting

The Tukituki catchment covers an area of approximately 2,500 km² in southern Hawke's Bay. The Tukituki River is approximately 80 km long. The Ruataniwha Plains are an inland gravel-filled basin located in the middle reaches of the Tukituki catchment. The plains are known to be water short and, like much of New Zealand's East Coast, suffer from summer droughts with considerable soil moisture deficits which limit crop growth. With irrigation, agricultural production can potentially be significantly increased.

The area has considerable groundwater (the Ruataniwha aquifer) and surface water resources (the Tukituki River and its major tributaries of the Waipawa, Makaroro, Makaretu and Tukipo rivers). Over summer, these resources become stressed, with low flows in the rivers and streams due to reduced summer rainfall and increased evapo-transpiration; and falling groundwater levels due to limited recharge over the summer months. Extensive periphyton growths occur in the lower Tukituki River and various reaches of the waterways tend to fall dry.

Approximately 6,000 ha are currently irrigated on the Ruataniwha Plains from a combination of groundwater and direct surface water takes. Demand for irrigation water tends to peak when the water resources are at their most stressed. The direct surface water takes and the groundwater takes that are deemed to be directly hydraulically connected to surface water bodies are subject to regulatory minimum flows and face restrictions during low river flows. The majority of the groundwater takes are not subject to minimum flow conditions and currently experience high supply reliability.

There is growing concern that:

- Water takes (particularly surface water and hydraulically connected groundwater takes) are adversely contributing to low river flows.
- Surface water resources of the area are over allocated.
- The current management regime (i.e., allocation limit and minimum flow limits) is not adequately providing for ecological and cultural outcomes.



If allocation limits are altered and the regulatory minimum flows increased, as HBRC propose in its Regional Plan 6 due to be publically notified by the Council in early May 2013, the result would be a significantly reduced security of supply for existing water users.

The Scheme is designed to help manage the effects of the increase in regulatory minimum flows in the area's waterways proposed under Regional Plan 6, while:

- 1) Maintaining water supply reliability to existing water users who choose to join the scheme.
- 2) Enabling a significant increase in the area that can be irrigated.

Aligned with development of the Scheme by HBRIC Ltd, the HBRC has adopted Proposed Plan Change 6, which will guide the management of land and water in the Tukituki catchment.

2.2 Prior Models and Reports

A large number of reports and detailed models have been produced to support development of the Scheme thus far. The following is a brief summary of the key reports and models that were used to inform and support the development of the GoldSim model.

- A Mike 11 hydraulic model to assess short term flow changes associated with the release of irrigation flows and to assist with assessment of stream bed leakage. Golder understands this model is referred to as the HBRC's Mike 11 Surface Water Hydrodynamic Model. This model was used to inform discussion on how flushing flows released from the reservoir are likely to attenuate as they move down through the system.
- Plant and Food Research's SPASMO model was used to assess irrigation demand and nutrient losses from land. The SPASMO model was used to create the irrigation demand time series used in the GoldSim model.
- Pre-feasibility and feasibility studies of the proposed scheme were based on a spreadsheet water balance model of the proposed reservoir (Tonkin & Taylor 2012). Tonkin & Taylor 2013a describe the model and associated simulations as follows:

"Simulations carried out during the Feasibility Stage were oriented at determining a basic reservoir operating regime to provide for irrigation of defined areas and to supply environmental flows. Environmental flows comprised a minimum release from the reservoir (1.228 m³/s). Releases of flushing flows were not directly simulated but an allowance of 1.5 million m³ was made in the storage for four flushing flows to be released each year coincident with the irrigation season. Generation potential was also simulated and releases were made specifically for generation when the reservoir is close to full. No allowance was made for additional environmental releases or to supply additional irrigation when surplus water is available."

- A transient groundwater model (Visual MODFLOW with the Streamflow Routing Package (SFR1)), which was developed for the Ruataniwha aquifer system. This model linked to a surface water spreadsheet based model to assess changes in flow at various locations within the Tukituki catchment (Waldron and Baalousha 2013). The surface water spreadsheet based model incorporated output from Tonkin & Taylor's spreadsheet water balance model of the proposed reservoir. The surface water spreadsheet based model and Tonkin & Taylor's spreadsheet water balance model of the proposed reservoir were used to provide much of the input data used to represent downstream flows in the GoldSim model.



Design of the Scheme is now at the feasibility stage, as summarised by Tonkin & Taylor (2013). The Scheme incorporates the findings from the above studies and models. The operation of the Scheme is designed to achieve a number of objectives including:

- Minimising or mitigating any adverse environmental effects.
- Maximising the potential benefits.
- Ensuring on-going economic viability.

As part of refining and optimising the Scheme, a report titled “Ruataniwha Water Storage Scheme Environmental Flow Optimisation” was recently prepared (Aquanet 2013). The aim of that study was to “*explore options available to the RWSS to provide additional water for irrigation or environmental purposes, over and above, but without compromising, the assumed primary irrigation and environmental flow provisions described in the Feasibility Project Description (Tonkin & Taylor 2012)*”.

The environmental flow optimisation report identified the following three opportunities for improving environmental flow:

- 1) Increased utilisation of the Scheme storage during non-drought years.
- 2) Utilisation of the full Scheme storage during scheme uptake.
- 3) Utilisation of the “sedimentation storage” prior to it filling with sediment.

In addition to the above, Golder suggest that there are two other situations which may result in excess water.

- 1) The irrigation demand is based on a modelled optimum irrigation. Actual irrigation is often different to modelled irrigation due to irrigators making conscious decisions not to irrigate or breakdown of irrigation equipment. Should land not be irrigated or if actual irrigation is less than the modelled optimum then there would be excess water available. This excess water could either be retained in the dam to reduce the amount of refilling that is required prior to the next irrigation season or released from the dam in the current season for other purposes.
- 2) Reservoir modelling work completed during feasibility level design of the project (Tonkin & Taylor 2012) included a 1.5 Mm³ allowance for environmental flows (predominantly flushing flows). The flushing flow part of this allowance is to allow flushing flows to be released from the reservoir to help to flush periphyton. During years when natural fresh events occur regularly over the summer period and/or when there is limited periphyton growth there is likely to be a reduced need to release flushing flows, which could result in excess water becoming available. This excess water could either be retained in the dam to reduce the amount of refilling that is required prior to the next irrigation season or released from the dam in the current season for other purposes.

Of the three opportunities identified by Aquanet (2013), it was concluded that only the first opportunity would be potentially available during the whole life of the Scheme. With the key environmental issues in mind, Aquanet (2013) identified two areas for potential improvement of the flow regime outlined in the feasibility report.

- 1) *Supplementing/augmenting river flow at times when it would otherwise have dropped to very low levels, particularly during summer;*
- 2) *Increasing the size, duration or frequency of flushing flows released from the dam, and/or improving the timing of their release, to optimise environmental benefit associated with reducing/removing nuisance periphyton with a particular focus on the lower Tukituki River.*



There are potential economic and environmental advantages if the Scheme can increase utilisation of its storage. In practice, increasing utilisation of the Scheme storage outside the Scheme's core environmental and irrigation supply requirements will require forecasting of future water demand and river flows. Such forecasts have a degree of risk attached, due to the difficulties in assessing future climatic conditions which drive future water demand and river flows. This risk will need to be taken into account when making management decisions. At the feasibility stage the Scheme was designed to fully supply the primary irrigator demand (approximately 95.8 M m³) during 19 years out of 20. Increased utilisation of the Scheme storage may be associated with an increased risk to supply reliability.

3.0 MODEL OVERVIEW

3.1 Model Objectives

HBRIC Ltd identified the following two-fold focus for the GoldSim modelling work:

- 1) How much excess water is available above the primary irrigation and residual flow requirements and when is the excess water available?
- 2) To what extent can excess water be used (how much/when) so as not to undermine the primary irrigator security of supply?

The above focus was translated into the following two main objectives of the Ruataniwha water storage GoldSim model:

- 1) To provide a water balance for the Ruataniwha water storage reservoir which appropriately simulates the performance of the proposed scheme operating regime in regard to meeting irrigation demand, environmental minimum flows and flushing flows.
- 2) To enable compliance with key performance criteria (supply reliability for water users and achievement of environmental minimum flows and flushing flows) to be evaluated at key sites downstream of the reservoir.

3.2 GoldSim

A water balance model was developed for the Scheme using GoldSim Pro (Version 10.50) software. GoldSim is a graphical object-oriented modelling platform for developing dynamic probabilistic simulation models. GoldSim has been applied successfully as a decision support tool for a range of water balance, water quality and water resource projects, both within New Zealand and internationally.

The GoldSim model includes numerical interpretations of the essential features of the hydrological system following commissioning of the proposed reservoir and irrigation scheme. The basis of model development includes two key components: a conceptual model and a numerical model.

The conceptual model is an idealised representation (i.e., a picture) of our understanding of the key processes of the system. A numerical model is a set of equations, which, subject to certain assumptions, quantifies the physical processes active in the system(s) being modelled. While the model itself lacks the detailed reality of the environmental system, the behaviour of a valid model approximates that of the environmental system.

A model provides a scientific means to draw together the currently available data into a numerical characterisation of the environmental system. The model represents the environmental system simulated to



a level of detail suitable to achieve the intended objectives. In this case, the model provides a projective tool to evaluate the influence the Scheme may have on flows in the Makaroro, Waipawa and Tukituki rivers downstream of the reservoir.

3.3 Model Extent

The GoldSim water balance model covers the proposed Makaroro reservoir and its associated catchment. The dam's operating regime has been modelled to simulate the operation of a water storage reservoir with the planned objectives of harvesting, storing and releasing river flows to meet irrigation demand and an environmental flow regime. In addition, the model extends to assess flows at two locations downstream of the dam (the Waipawa River at RDS and the Tukituki River at Red Bridge).

3.4 Modelled Variables

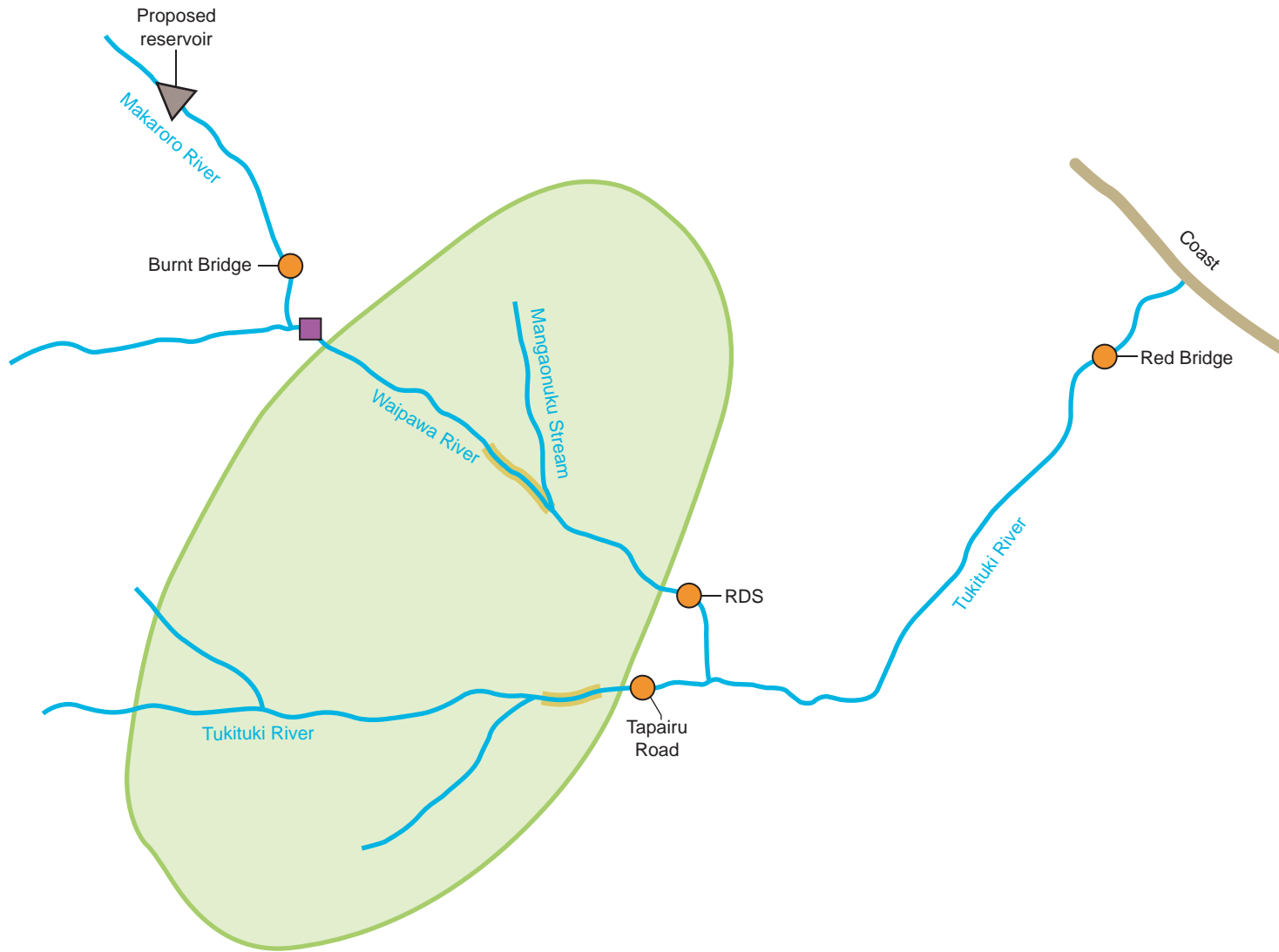
The GoldSim model, as currently structured, is capable of projecting the following conditions:

- The volume and level of water in the Makaroro Reservoir (both live storage and total storage).
- Flow from the reservoir including controlled flow released for irrigation and environmental (minimum flows and flushing flows) purposes and uncontrolled flow from the spillway. This represents flow in the Makaroro River immediately downstream of the Makaroro Reservoir.
- Supply reliability for both irrigation and environmental (minimum flows and flushing flows) uses and any shortfalls.
- Flow at the following key downstream locations:
 - The Waipawa River immediately downstream of the irrigation intake.
 - The Waipawa River at the RDS flow recording site.
 - The Tukituki River at the Red Bridge flow recording site.

3.5 Conceptualisation

The conceptual model is an idealised representation (i.e., a picture) of our understanding of the key system processes and their interrelationships.

A schematic of the proposed scheme is shown in Figure 1. The schematic was used to develop the conceptual model for the GoldSim model shown in Figure 2. The conceptual model builds on earlier reservoir modelling work completed during feasibility level design of the project (Tonkin & Taylor 2012) and utilises the results of surface water and ground water modelling work completed by Waldron and Baalousha (2013).



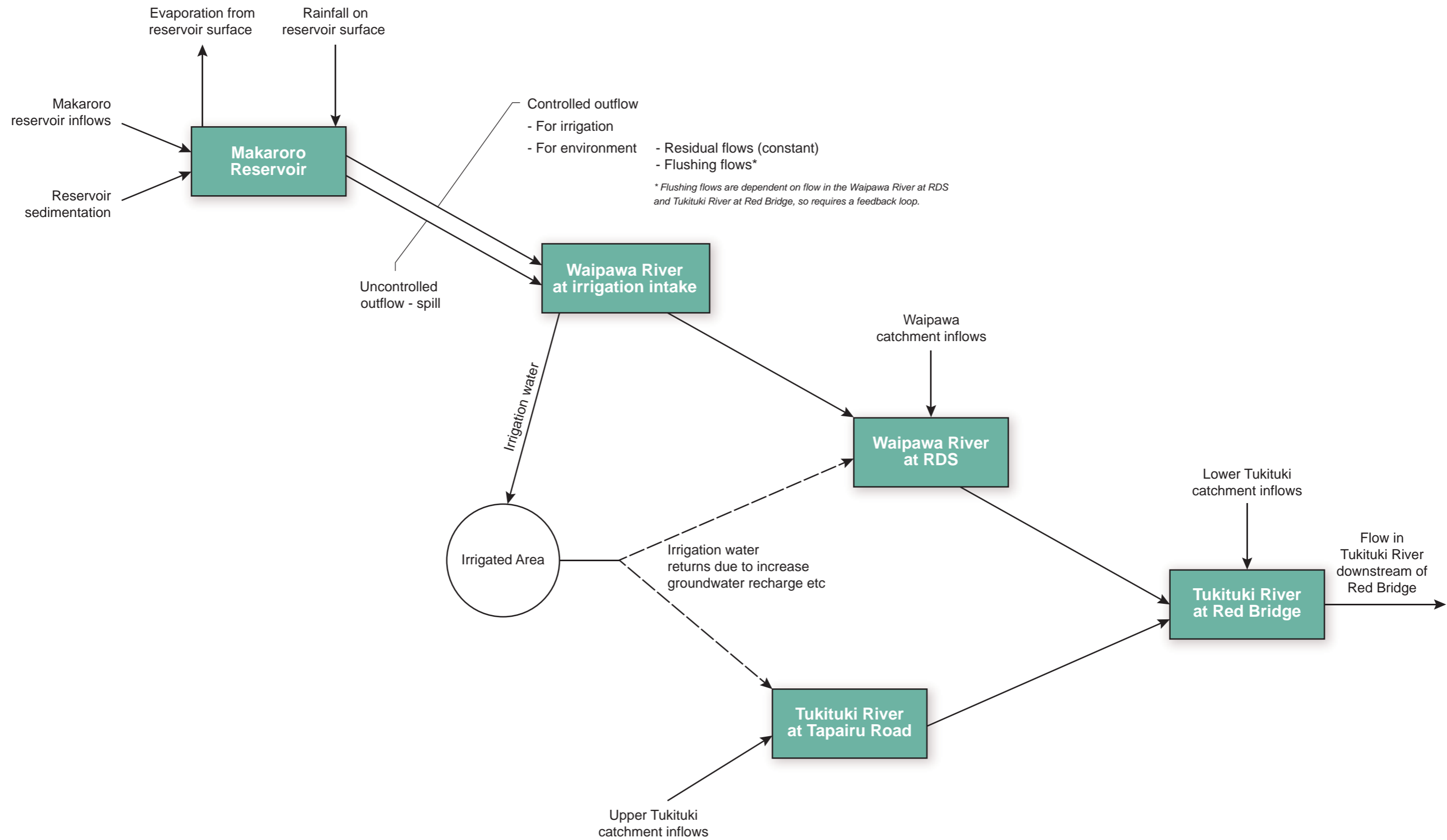
Legend

- Proposed irrigation scheme intake
- Flow recorder sites
- Key drying reaches
- Irrigation area

1. Schematic only, not to scale, not to be interpreted as an engineering design or construction drawing
2. DRAWN BY: SG REVIEWED BY: VG



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Legend
Key GoldSim nodes

1. Schematic only, not to scale, not to be interpreted as an engineering design or construction drawing
2. DRAWN BY: SG REVIEWED BY: VG





3.6 Model Functionality

The GoldSim model was constructed with a significant amount of flexibility to enable numerous scenarios to be quickly assessed. This flexibility also enables the model to be quickly refined and updated. The model has been used to guide development of the proposed operating regime. As with any multi-variable model, solutions are not unique and more than one operating regime could achieve the desired irrigation and environmental outcomes.

The adopted regime described in Tonkin & Taylor 2013 is aimed at being both practical and effective at meeting the desired irrigation and environmental outcomes. It is anticipated that the operating regime will be further reviewed, adapted and optimised following detailed design, construction and commissioning of the scheme.

In running the model scenarios that fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013) the influence of the following variables were evaluated.

- Differing reservoir sizes.
- Differing rates of irrigation uptake over time and differing rates of existing irrigators that choose to join the scheme.
- Differing rates of irrigation water returning to downstream surface flows via increased recharge due to increased irrigation.
- Differing irrigation demand and irrigation season length.
- Differing water allocation scenarios for the water that is released from the reservoir under controlled conditions, including separation of the allocation into at least the following “blocks” of water which have the following order of priority:
 - 1) A primary residual environmental flow at the toe of the dam. Refer to Section 4.3 for details.
 - 2) A primary flushing flow allocation per irrigation season (1 September to the following 30 April). The size, timing and release triggers for the flushing flows are described in detail in Section 4.5 of this report.
 - 3) A primary irrigation allocation which is used to supply water to the core primary irrigators. Refer to Section 4.4 for details.
 - 4) A secondary flushing flow allocation (refer to Section 4.5 of this report).
 - 5) A secondary irrigation allocation which is to be used to supply water to existing irrigators and to the “spot market” (refer to Section 4.6 of this report).
 - 6) A secondary residual flow allowance which can be used to supplement extreme low flows (refer to Section 4.7 of this report).

The model allows the size and priorities of the above blocks to be adjusted as well as the management associated options (i.e. flush flow triggers, minimum flow requirements and supply cut-offs to ensure certain allocations are fully supplied). The model allocates water from the reservoir on a daily basis using the priorities for the various blocks of water. It does this by first determining the volume of water in the reservoir that is available to be allocated on that day and then allocating it to the various blocks according to the stipulated priorities with the blocks with the highest priority supplied first.

Changes to the model inputs and assumptions are made using dashboards to facilitate use by HBRIC Ltd.



4.0 KEY MODEL INPUTS AND ASSUMPTIONS

4.1 Input Data

4.1.1 Introduction

The model includes a number of time series records of stream flow, climate data and water use. These data were provided to Golder and are derived from various specific studies. Input data relating to the scale, operation and management of the Scheme were determined through discussions with HBRIC Ltd.

4.1.2 Time series input data

In running the model scenarios that fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013) a total of 15 time series inputs are used in the GoldSim model. Table 1 summarises the various data series, their sources, key features and a brief outline how the data series are used within the model.

Reservoir inflows were estimated during a hydrological investigation undertaken by Tonkin & Taylor (2012) as part of the feasibility level design of the project. The inflow time series (1 January 1972 to 31 December 2010) is represented by the extended Makaroro at Burnt Bridge average daily flow record, scaled down by a factor of 0.952 for the slightly smaller catchment at the dam site (111 km² versus 122 km² at the flow recording site).

Irrigation demand data was estimated during feasibility level design of the project (Tonkin & Taylor, 2012) and is based on modelled irrigation requirements under local climatic and soil conditions. The estimated daily irrigation demand pattern for pasture production from 1 January 1972 to 31 December 2010 was used as input for the model.

River flow data for the Waipawa River at RDS and the Tukituki River at both Tapairu Road and Red Bridge were produced by Waldron and Baalousha (2013) as an output from their flow assessments. The daily time series (30 June 1969 to 30 June 2008) of naturalised flow and water take (surface water, shallow stream depleting groundwater and deep groundwater) effects were included in the model to allow projection of actual flows in the Waipawa River at RDS and in the Tukituki River at Red Bridge, both prior to and following Scheme development.

In projecting downstream flows, in order to be consistent with the methodologies outlined in Waldron and Baalousha (2013), time series of the effect of the Scheme on downstream flows from 30 June 1969 to 30 June 2008 derived from Tonkin & Taylor's spreadsheet reservoir water balance model were used as input to the GoldSim model.



Table 1: GoldSim Model summary of time series input data.

Data series	Details	Source	Comments	How data is used in the model
1. Makaroro Dam inflow series	Daily data 1/1/1972 - 31/12/2012	Spread sheet entitled RDS emailed by J Hansford of T&T to I Lloyd of Golder 21/12/2012	Data understand to represent average daily flow midnight to midnight. Data series is synthetic and is based on measured data from the recorder on the Makaroro River at Burnt Bridge.	Used as both dam inflow and as naturalised flow at the dam site.
2. Irrigation Demand data	Daily data 1/1/1972 - 31/12/2012		Data understand to represent average daily demand midnight to midnight for pasture production. The demand series includes demand in the winter and is uncapped i.e. exceed 95.8 M m ³ in some hydrological years. This is treated as raw scheme irrigation demand.	Used to calculate primary irrigation demand. The model allows an irrigation season to be specified (nominally 1 September to 30 April) and calculates irrigation season demand. Contracted demand is then calculated by capping the irrigation season demand to 95.8 M m ³ .
3. Residual flow Demand	Daily data 1/1/1972 - 31/12/2012		The data represent a constant residual flow demand of 1228 L/s, rather than being inputted as a time series it has been inputted into the GoldSim model as a fixed average daily rate.	Used for residual flow demand in the model which has the highest priority and the model is set up to ensure the residual flow demand is met 100% of the time.
4. Waipawa RDS natural flow	Daily flow 30/6/1969 - 30/6/2008 no gaps. Data understand to represent average daily flow midnight to midnight	Spread sheet entitled Scenario Modelled Synthetic Flow Records – Working V6 – Copy for Golders emailed by R Waldron of HBRC to I Lloyd of Golder 31/1/2013	RDS Scenario 1 – Naturalised DMF.	Used to determine natural inflows between the dam and RDS, i.e. Waipawa RDS natural (this series) less Makaroro Dam inflow (Series 1). Note the data indicate that occasionally dam inflows are greater than naturalised flow at RDS; this is expected to be due to a combination of differing methods used to create the synthetic input data and travel times etc.
5. Waipawa RDS impact SW and SD takes			RDS Scenario 2 – RDS SW +SD Abstraction Impact on river flows.	Used to determine the actual inflows between the dam and RDS, i.e. natural flows less effects of surface takes (including stream depleting groundwater) and groundwater takes.
6. Waipawa RDS impact GW takes full			RDS Scenario 2 – RDS S2 GW Abstraction impact on GW contribution to river flows.	A factor is applied to the level of effect to reflect the amount of surface water takes that transfer to the dam. If no takes transfer full effects are taken from natural flows. The more takes that transfer the lower the effects that are removed from the naturalised flows.
7. Waipawa RDS impact GW takes residual			RDS Scenario 3– RDS S3 GW Abstraction impact on GW contribution to river flows.	Groundwater is treated in a similar manner but there is a residual groundwater effect which occurs all the time. Series 6 represents the maximum effects while Series 7 represents the residual (minimum) effect. As with the surface water a factor is applied to the level of effect (maximum – residual effect) to reflect the amount of groundwater takes that transfer to the dam. If none transfer full effects are taken from natural flows. If all transfer only the residual effects are taken from natural flows. If part transfer then residual plus some extra effects are taken from the natural flows.
8. Tapairu Road natural flow			Tapairu Rd Scenario 1 – Naturalised DMF.	Similar to previous Waipawa at RDS time series but no consideration of the dam.
9. Tapairu Road impact SW and SD takes			Tapairu Rd Scenario 2 – Tapairu Rd SW +SD Abstraction Impact on river flows.	
10. Tapairu Road impact GW takes full			Tapairu Rd Scenario 2 – Tapairu Rd S2 GW Abstraction impact on GW contribution to river flows.	
11. Tapairu Road impact GW takes residual	Tapairu Rd Scenario 3– Tapairu Rd S3 GW Abstraction impact on GW contribution to river flows L/s.			
12. Tukituki Red Bridge natural flow	Daily flow 30/6/1969 - 30/6/2008 some gaps. Data understand to represent average daily flow midnight to midnight		Red Br Scenario 1 – Naturalised DMF.	Used to determine natural inflows between Red Bridge and both RDS and Tapairu Road, i.e. Red Bridge natural (this series) less RDS natural (Series 4) less Tapairu Road natural (Series 8). Note the data indicate that occasionally natural flow at RDS plus natural flow at Tapairu Road is greater than naturalised flow at Red Bridge, this is expected to be due to a combination of differing methods used to create the synthetic data and due to travel times etc.
13. Tukituki Red Bridge impact SW and SD takes			Red Br Scenario 2 – RDS SW +SD Abstraction Impact on river flows.	Used to determine the actual inflows between Red Bridge and both RDS and Tapairu Road, i.e. natural flows less effects of surface takes (including stream depleting GW) and GW takes, although in this case there are no GW takes. The surface water takes are assumed to be the total takes upstream of Red Bridge. The surface takes from both RDS (Series 5) and Tapairu (Series 9) are removed to prevent double counting. Note the data indicate that occasionally the sum of the surface takes from both RDS (Series 5) and Tapairu (Series 9) is greater than this series. When upstream takes effects are greater than downstream take effects the downstream catchment is assumed to contribute no take effects.
14. Effects of dam at RDS from T&T model	Average daily midnight to midnight change in flow 30/6/1969 - 30/6/2008.	Two spread sheets entitled RWS flow regime change - alternate Waipawa RDS/Tukituki Red Bridge based fully synthetic Makaroro flow. 12June2012 emailed by R Waldron of HBRC to I Lloyd of Golder 14/1/2013	Represents the projected effect on downstream flow derived from Tonkin & Taylor's modelling of the Makaroro reservoir.	Used to replicate the methodologies used in Waldron and Baalousha (2013) to project flow at RDS and Red Bridge.
15. Effects of dam at Red Bridge from T&T model				



4.1.3 Dam characteristics and operating rules

The total storage volume of the proposed Makaroro reservoir is 90 M m³, with a “live” reservoir volume of 85 M m³. Allowances of 1 M m³ per year for reservoir evaporation and losses; and 4 M m³ for sedimentation over a 20 year period (Tonkin & Taylor 2012) have been incorporated into the model.

Key dam characteristics and proposed operating rules were initially developed during feasibility level design of the project (Tonkin & Taylor 2012). The proposed operating rules were refined and optimised during the modelling process and model flexibility has been provided to enable the investigation of other combinations of rules if required.

To allow the reservoir water level to be projected the stage storage relationship contained in Table 2, which was based on information supplied by Tonkin & Taylor, was included in the model.

Table 2: Makaroro Reservoir stage storage relationship incorporated in the GoldSim model.

Total volume (M m ³)	Water level elevation (m RL HBRC datum)
0	395.00
1	410.85
3	417.72
5	422.24
10	430.07
20	439.77
40	451.68
60	459.86
90	469.19
110	474.25

4.2 Key Assumptions

The model is based on hydrological years (1 July to following 30 June) and was set up for the full period of overlapping time series data (i.e. 36 complete hydrological years from 1 July 1972 to 30 June 2008). A key assumption underpinning the model is that future climatic and hydrological conditions are likely to be similar to the historic data used in the simulations. This assumption has two key aspects, climate fluctuations and climate change.

Climate fluctuations can usually be addressed by using long historic records which include extreme events. On a seasonal and year-to-year basis, New Zealand’s climatic variability is strongly affected by the El Niño/La Niña Southern Oscillation (ENSO) (Nicholls 1992, Salinger et al. 1996, Hay et al. 1993). Recently scientists have identified a longer interdecadal variability in climate associated with the Interdecadal Pacific Oscillation (IPO) (Salinger & Mullan 1999, Salinger et al. 2001, Folland et al. 2002). Distinct shifts in climate in the mid 1940’s, late 1970’s and late 1990’s have been identified. During the period from the mid 1940’s to late 1970’s and since the late 1990’s the IPO was in a positive phase associated with increased westerly wind flow over the country, higher rainfall in the west and drier conditions in the east. During the period from the late 1970’s to late 1990’s the IPO was in a negative phase with reduced westerly wind flow conditions, lower rainfall in the west and wetter conditions in the east. Such variability reinforces the need to use as long a climatic record as possible.

The GoldSim model does not specifically consider the future effects of climate change. The predicted nature of those effects is discussed in Renwick 2013.



A time step of 1 day has been used in the model as this is consistent with the majority of the modelling that has been undertaken on the project to date. Due to the simplicity of the initial model, calculations between time steps are not expected to be required. Input data is entered into the model as 24 hour totals (mm/day or m³/day). Projection points are reported on a daily basis and represent average daily values. The daily time step means that, unless delays are specifically included in the model, all water that leaves the Makaroro Reservoir on any particular day is expected to leave the model on that day.

One of the main consequences of the daily time step is that the peak height of natural flushing flows may be underestimated by the model, i.e. flow accrual periods may be overestimated by the model. Consequently, the model may be releasing more water during flushing flows than may be necessary, which is considered environmentally conservative.

Full uptake of the primary irrigation “block” is assumed throughout the modelling period. This is considered to be an environmentally conservative assumption, as potentially more environmental water could be delivered during the uptake period without affecting the economic viability of the scheme.

Flexibility was built into the model to enable assessment of the effects that transferring different proportions of the existing takes (surface water, shallow stream depleting groundwater and deep groundwater) to the Scheme, would have on projected downstream flows. To enable projection of flows at both the Waipawa River at RDS and Tukituki River at Red Bridge, and to be consistent with Waldron and Baalousha (2013), the model separates the existing takes into the following five categories:

- 1) Surface water and shallow stream depleting groundwater takes upstream of the Waipawa River at RDS flow gauging site.
- 2) Deep groundwater takes up-gradient of the Waipawa River at RDS flow gauging site.
- 3) Surface water and shallow stream depleting groundwater takes upstream of the Tukituki River at Tapairu Road flow gauging site.
- 4) Deep groundwater takes up-gradient of the Tukituki River at Tapairu Road flow gauging site.
- 5) Surface water and shallow stream depleting groundwater takes upstream of the Tukituki River at Red Bridge flow gauging site but downstream of flow gauging sites at both the Waipawa River at RDS and Tukituki River at Tapairu Road.

The potential effect of increased irrigation on recharge can be represented in the model. The expected increase in mean annual recharge due to the new irrigation has been derived from information either provided by HBRIC Ltd or contained in NIWA 2013. The methodology used to assess the increased recharge associated with new irrigation is provided in Section 4.4.1 below.

4.3 Primary Residual Flow

The required minimum primary residual flow of 90 % of the 7-day MALF estimated for the Makaroro River at the dam site is 1,228 L/s (90 % of 1,364 L/s). This estimate of the 7-day MALF was derived by Tonkin & Taylor (2012) and discounts the extreme average daily low flows in the historical Burnt Bridge record of 520 L/s on 19 April 1979 and 670 L/s on 22 December 1984 because the flows on these two days appear anomalous. Inclusion of these two data points would result in a slightly lower 7-day MALF at the Burnt Bridge site of 1,390 L/s and a corresponding 90 % 7-day MALF at the dam site of about 1,191 L/s. The 7-day MALF from the adjusted Burnt Bridge record between 1976 and 1991 is very similar at 1,380 L/s (Tonkin & Taylor 2012).

The primary residual flow requirement is given the highest priority within the model. The proposed operating regime has been developed to ensure that the residual flow is provided 100% of the time during the 36



hydrological years that are modelled. During extreme years when inflows are low and demand high, the model indicates the live storage in the reservoir would be completely emptied. During such times the ability to fully supply the residual flow requirement has the potential to be compromised. To overcome this, the model has been set up to cut back irrigation supplies when the live volume in the reservoir falls below 2.5 M m^3 (i.e. less than approximately 3% of the maximum live storage) thereby ensuring that the simulated residual flow is provided 100% of the time. The 2.5 M m^3 trigger value was determined through increasing the trigger until the model projected that the primary residual flow would be provided 100% of the time. The model has flexibility to adjust the 2.5 M m^3 irrigation cut back trigger to evaluate other scenarios.

4.4 Primary Irrigation Water

A primary irrigation volume of up to 95.8 M m^3 , corresponding to a contracted primary irrigation volume of 91 M m^3 delivered at the farm gate and an allowance for conveyance/operational losses (of approximately 5 %) at full scheme uptake has been defined. As outlined above, irrigation demand was estimated during feasibility level design of the project (Tonkin & Taylor 2012) and is based on irrigation modelling of local climatic and soil conditions for pasture production by Plant and Food Research.

Daily irrigation demand from 1 January 1972 to 31 December 2010 is used in the model. The model enables differing irrigation seasons and irrigation caps to be specified. The model calculates the irrigation demand which will be covered by the scheme (referred to in the model as “contracted irrigation demand”) by initially determining the daily irrigation demand that occurs within the irrigation season and then capping that value at 95.8 M m^3 per irrigation season. An irrigation season of 1 September to the following 30 April and a primary irrigation cap of 95.8 M m^3 was assumed for all the scenarios that were assessed. Figure 3 shows the cumulative full irrigation demand, irrigation season demand and contracted irrigation demand per irrigation season as projected by the GoldSim model. Limiting the “contracted irrigation demand” though stipulating an irrigation season and applying a primary irrigation cap will result in the irrigators experiencing some on-farm shortfalls even if the Scheme fully supplies the contracted irrigation demand.



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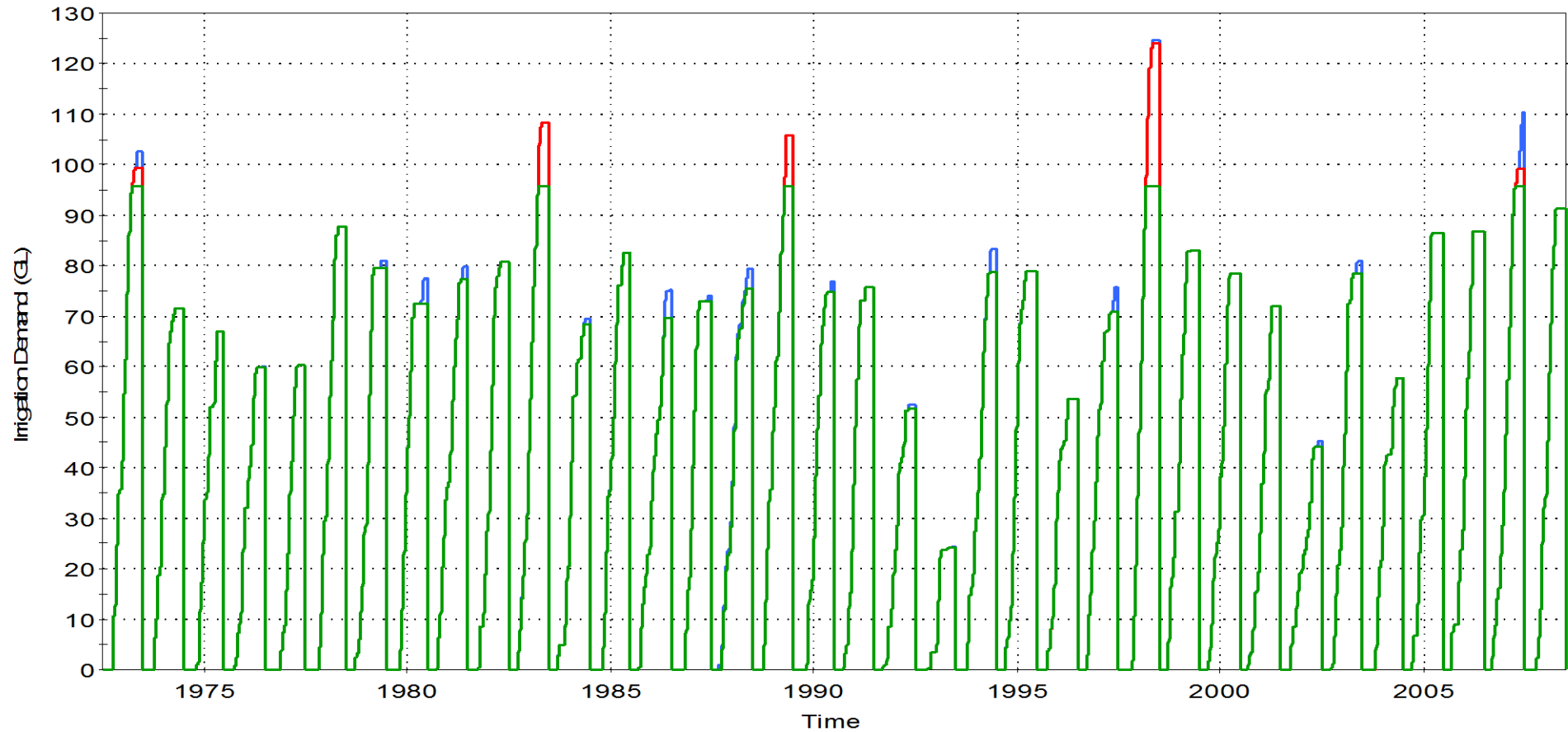


Figure 3: Cumulative irrigation demand plot per irrigation season showing total demand in blue, demand over the irrigation season 1 September to 30 April in red, and irrigation season demand capped at 95.8 M m³ in green (i.e. contracted irrigation).

Note 1 GL (gigalitre) = 1 M m³ (million cubic metres)



4.4.1 Increased drainage due to irrigation

Increased irrigation is expected to correspondingly result in increased recharge, potentially higher groundwater levels and greater spring flows. NIWA (2013) confirmed the potential for increased recharge and suggested a potential increase in mean annual drainage due to irrigation of 18 % to 24 % of the irrigation application, depending on the climate soil and irrigation rate. This increased drainage due to irrigation has not been included in the groundwater model (Waldron and Baalousha 2013) but is expected to lead to higher groundwater levels, greater spring flows and increase baseflow in the area's waterways. To fully assess the potential positive effect of increased recharge on downstream surface water flows the increased drainage associated with irrigation should be included in a groundwater model. However, to allow a preliminary assessment, the potential increase in baseflow associated with new irrigation was incorporated into the GoldSim model using the methodology outlined below and information either provided by HBRIC Ltd or contained in NIWA 2013.

- For each of the three key flow sites (Waipawa River at RDS and the Tukituki River at both Tapairu Road and Red Bridge) HBRIC Ltd have estimated the area that is currently irrigated and the area which will potentially be irrigated in each sub-catchment under the Scheme. HBRIC Ltd then classified the sub-catchment areas according to the two soil types and two climate stations assessed in NIWA 2013.
- For each sub-catchment area the relative increase in mean annual drainage from the current situation to full scheme development has been determined using the projected increase in mean annual drainage outlined in NIWA 2013.
- Using the assumption that all the increased drainage will eventually resurface via springs as baseflow in the area's waterways, the potential increased baseflow associated with increased drainage in each sub-catchment has been calculated for the three key river sites. As the Ruataniwha Plains are a gravel-filled basin with all flow exiting the basin via a gorge cut by the Tukituki River it is considered a reasonable assumption that the increased drainage associated with the irrigation will resurface as baseflow. Baseflow will fluctuate over the year due to recharge events, groundwater levels, and the hydrogeological properties of the groundwater system. Ideally the potential size and timing of increased spring/drain flows should be assessed within the groundwater model. However, to provide a preliminary assessment it is considered appropriate to assume that the increased baseflow will be a constant rate over the year.
- As the amount of increased drainage will depend on scheme uptake the GoldSim model links the increased drainage to the rate of irrigation uptake. In running the model scenarios that fed into the environmental flow optimisation report (Aquanet 2013) full scheme uptake was assumed.

The assessment of the potential increase in baseflow associated with new irrigation that has been included in the GoldSim model is considered preliminary and Golder recommends that the potential impacts of increased recharge due to new irrigation should be addressed more formally through use of a groundwater model.

4.5 Flushing Flows

Two "blocks" of water have been defined for flushing flows:

- 1) A primary flushing flow allocation of up to 2 M m³ per irrigation season;
- 2) A secondary flushing flow allocation, also of up to 2 M m³ per irrigation season.



The primary flushing flows are given a higher level of priority than the primary irrigation water. The secondary flushing flows are given a lower level of priority than the primary irrigation water, but a higher level of priority than the secondary irrigation water.

When flushing flows are released they combine with the primary residual flow releases to give a maximum combined flow of 30 m³/s for a duration of 9.25 hours which equates to a maximum volume of approximately 1 M m³ per flushing flow. The annual allocation limit of 2 M m³ for both primary and secondary flushing flows therefore corresponds to two flushing flows under each allocation. The total number of flushing flows released under both the primary and secondary allocation per irrigation season is capped at four, with a maximum combined volume of 4 M m³.

The following rules and triggers have been included in the model to ensure that flushing flows are released:

- When the accrual period, between natural flow events that exceed 50 m³/s in the Tukituki River at Red Bridge, approaches or reaches 30 days.
- Between 15 December and the end of the irrigation season on 30 April.
- Where possible, the flushing flows from the dam are released to coincide with natural minor freshes in order to maximise environmental benefit. In the model this is achieved by “piggy backing” onto natural flows that are greater than 15 m³/s but less than 50 m³/s. When the accrual period mentioned above exceeds 20 days the model looks for potential “piggy back” flows. If no piggy back flows occur before the accrual reaches 30 days then a flushing flow is automatically released on the 30th day of accrual. The rate of flow released during a “piggy back” event is the lesser of 30 m³/s and the difference between 50 m³/s and the flow recorded in the river, and is released for 9.25 hours, (i.e. if a 30 m³/s natural flow is recorded, 20 m³/s is released from the reservoir).

One of the key objectives of the model is to assess the release of flushing flows and provide guidance on an operating regime that would suitably release flushing flows. Flexibility has been built into the model that allows all the flushing flow control and trigger values outlined above (i.e. flush flow size, duration, number of releases, accrual triggers etc.) to be altered and differing scenarios assessed. The values outlined above were developed jointly with HBRIC Ltd and HBRC staff by running a number of flushing flow scenarios. While the scenarios run focussed on releasing flows relative to conditions in the Tukituki River at Red Bridge the model has the flexibility to also trigger flushing flows based on conditions in the Waipawa River at RDS.

When assessing both the triggering of flushing flows and the size of “piggy back” flushing flow releases the model uses downstream flows projected by the model. A description of how the model projects downstream flows is provided in Section 4.8. When assessing flushing flows the model considers flows today and if a flushing flow is triggered the flow will be released from the reservoir the following day. The model does not consider the effect of releasing flushing flows when projecting downstream flow statistics.

HBRC’s Mike 11 Surface Water Hydrodynamic Model indicates that flows released from the reservoir will attenuate as they flow down through the river system. The GoldSim model as it is currently structured does not consider attenuation of flows released from the reservoir as they move down through the river system. Not incorporating attenuation is expected to lead to a slight underestimation of the volume required to be released from the reservoir and an overestimation of resulting downstream flows. Golder recommends that consideration be given to updating the GoldSim model to incorporate a preliminary assessment of flow attenuation which utilises the findings of the HBRC’s Mike 11 Surface Water Hydrodynamic Model and recognises the daily timestep of the GoldSim model.



4.6 Secondary Irrigation Water

A block of potentially available secondary irrigation water has been identified, which essentially corresponds to inflows into the reservoir once the other blocks have been provided for. One of the key objectives of the model was to assess the volumes of water that may be available within this secondary irrigation block, and how often and when in the season any secondary irrigation water may become available.

The model achieves the above by determining when in the irrigation season the combined storage remaining in the reservoir and the volume already supplied to the primary irrigators surpasses a certain critical “ring-fenced” volume. Any subsequent inflows into the reservoir, which are not required to meet residual and flushing flow releases requirements, are then potentially available for secondary irrigation. To ensure the supply reliability of the primary irrigators is not compromised by the secondary irrigators, a critical “ring-fenced” volume of at least the maximum allocation assigned to the primary irrigation block (namely 95.8 M m³) is required. To accommodate periods when reservoir inflows are insufficient to meet the residual and flushing flow release requirements, there is a need to further increase the critical “ring-fenced” volume. The modelling process found that a critical “ring-fenced” volume of 105% of the maximum allocation assigned to the primary irrigation block (namely 1.05 x 95.8 M m³) was sufficient to ensure the residual flow and flushing flow requirements were met and the supply reliability of the primary irrigators was not significantly compromised by the supply of secondary irrigation water. The model assumes that all potentially available secondary irrigation water is released from the reservoir and used on the same day it is projected to become available.

Including the secondary irrigation allocation increases the overall volume of water that is harvested from the river system and as a result leads to lower reservoir levels, which extends the period during which the reservoir is refilling, in turn resulting in lower downstream flows during the re-filling period. To prevent over-harvesting of water a seasonal cap of 28 M m³ was placed on the secondary irrigation allocation.

4.7 Secondary Residual Flow

The model is set up with functionality to consider an allocation block for secondary residual flow which can be used to further increase the primary residual flows. The secondary residual flow allocation is targeted at increasing particularly low flows to ensure that flows do not drop below a certain threshold level. The model achieved this by considering projected flow in both the Waipawa River at RDS and the Tukituki River at Red Bridge and if that flow is below a certain threshold then water is released from the dam to increase downstream flow back up to the threshold. Functionality was built into the model to allow the threshold values to be altered and for the assessment to consider both sites individually and together. The trigger was initially set for both sites at their respective Q99 values (1,864 L/s for Waipawa River at RDS and 3,577 L/s for the Tukituki River at Red Bridge). Initial scenario runs for the environmental flow optimisation report (Aquanet 2013) indicated that the Scheme was projected to generally improve extreme low flows in both the Waipawa River at RDS and the Tukituki River at Red Bridge and as such secondary residual flow releases were not expected to be required. This was confirmed by running one scenario which included secondary residual flows.

4.8 Downstream Flows

The model projects flow at the following locations:

- 1) Immediately downstream of the dam, which includes both controlled releases (to meet residual, flushing flow requirements and irrigation demand), and spills which occur when the reservoir is full.



- 2) The Waipawa River at RDS which is downstream of the proposed irrigation intake and the model assumes all the irrigation water (including any required in Zone M) is abstracted from the Waipawa River upstream of RDS.
- 3) The Tukituki River at Red Bridge which represents the downstream end of the model.

The projected flow series generated from the GoldSim model have been input into Hilltop hydrological software to enable statistical analysis of the flow series. Between GoldSim and Hilltop the following key flow statistics were reported:

- Days below a specified minimum flow (2,500 L/s in the Waipawa River at RDS and 5,200 L/s in the Tukituki River at Red Bridge), both per hydrological year and then the following statistics from the annual values: minimum, mean, maximum, median and a 1 in 10 year drought.
- The following flow statistics for the full period that the model was run (namely 36 years): median, mean, Q99 and 7d-MALF.

Flow duration curves and various typical hydrographs can be readily produced from the Hilltop files but are not included in this report.

In running the model scenarios that fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013) downstream flows in the Waipawa River at RDS and in the Tukituki River at Red Bridge were projected using the methodologies outlined in Waldron and Baalousha (2013). Waldron and Baalousha (2013) assessed the likely effects of the implementation of the Scheme on river flows at three locations (Waipawa River at RDS and the Tukituki River at both Tapairu Road and Red Bridge) under the following three scenarios:

- That the current level of surface and groundwater abstraction in the catchment continues when the scheme is implemented. This is referred to as Scenario 4 in Waldron and Baalousha 2013 and represents the situation where none of the existing irrigators transfer to the Scheme.
- That the current level of surface water and shallow stream depleting groundwater abstraction in the catchment stop when the scheme is implemented but all current deep groundwater abstractions in the catchment continue. This is referred to as Scenario 5 in Waldron and Baalousha 2013 and represents the situation where none of the existing groundwater irrigators transfer to the Scheme but all of the existing surface water and shallow stream depleting groundwater irrigators transfer to the Scheme.
- That all current water abstractions in the catchment stop when the Scheme is implemented. This is referred to as Scenario 3 in Waldron and Baalousha 2013 and represents the situation where all of the existing irrigators transfer to the Scheme.

To feed into the environmental flow optimisation report (Aquanet 2013) Golder were asked to use the GoldSim model to assess the likely outcomes of three intermediary scenarios (between the three assessed by Waldron and Baalousha) assuming different levels of Scheme water uptake by existing irrigators. The effect that groundwater abstraction in particular will have on river flows will be influenced by many factors including but not limited to: the location of the takes, the hydrogeological characteristics of the pumped aquifer and the degree of connection between the aquifer and the surface water streams. The effects are also expected to vary in time due to changing groundwater levels, recharge rates and delays due to the movement of the cone of depression associated with groundwater pumping. These changes are complex to project and intermediary scenarios should ideally be assessed using the Waldron and Baalousha groundwater model. However, to allow a preliminary assessment of the three intermediary scenarios a methodology was incorporated into the GoldSim model that assumed that the effect of the implementation of the Scheme on river flows varied linearly between the scenarios assessed by Waldron and Baalousha (2013). Golder recommends that the potential effect of the implementation of the Scheme on river flows



under the three intermediary scenarios should be addressed more formally through use of the Waldron and Baalousha groundwater model.

Both the Waldron and Baalousha model and the GoldSim model are based on a blanket assessment of existing takes transferring to the Scheme. In reality, existing takes will each make their own individual decision whether or not to join the scheme. The outcomes in terms of river flows are likely to depend on the location and characteristics of each individual take being transferred or not to the Scheme. Such a level of detail cannot be modelled at present as it would be speculative to pre-determine which takes may or may not transfer to the Scheme. Golder recommends that, once there is a better understanding of which existing takes will and will not transfer to the Scheme, the likely effects of the implementation of the Scheme on river flows be reassessed through use of the Waldron and Baalousha groundwater model and linked surface water model.

4.9 GoldSim Model Setup and Dashboards

The GoldSim model was set up so that all balances and calibration graphs are generated within the model. All the input data that the model requires have been incorporated into the model and there is no importing of data. Similarly all output graphs from the scenario runs are generated within the GoldSim model. Detailed analysis of the projected flow series output (including determining percentiles etc.) is not possible within GoldSim. The projected flow series generated from the GoldSim model were exported into Hilltop hydrological software for statistical analysis of the projected flow series.

The model was developed to allow numerous alternative scenarios to be rapidly developed, assessed and compared. To facilitate this, the models functionality was incorporated into various dashboards. The GoldSim model has been set up with two dashboards (Irrigation and Dam dashboard and Environmental dashboard) to simplify calibration and running of the model, and a Results dashboard for viewing the results. The dashboards allow all inputs to be easily changed allowing rapid assessment of various scenarios. The dashboard facility within the GoldSim allows model users to easily change variables and run scenarios while ensuring that the user does not alter the model logic or coding.

In running the model scenarios that fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013) the following dashboard functionality was used.

The Irrigation and Dam Dashboard

- Reservoir variables including storage volume size.
- Irrigation variables for primary and secondary irrigation including irrigation season length, irrigation uptake, allocation caps etc.
- Allocation priorities.

The Environmental Dashboard

- Flushing flow variables including triggers, allocation limits and management options.
- Increased drainage variables including areas irrigated, expected mean increase in drainage and mean irrigation depths.
- Variable associated with the transfer of existing water takes to the Scheme.
- Minimum flows and residual flow requirements.



The Results Dashboard

- Provides various summary graphs and a link to the statistical analysis section which summarises the key results.

5.0 MODEL CALIBRATION AND VERIFICATION PROCESS

5.1 Introduction

The model is a simplistic water balance model which uses various supplied time-series. The model does not project any variables which can be calibrated against measured data sets. As such model calibration and verification is limited to ensuring that the model correctly accounts for mass and that the model calculations are correct.

5.2 Model Balances

Two mass balances are included in the model. The first covers the reservoir part of the model and the second covers the overall model. Total inflow into the reservoir has been compared to total projected outflow and projected changes in storage (Figure 4). The mass balance for the reservoir part of the model shows an exact match which confirms that the reservoir part of the model is correctly conserving mass. Because the model projects downstream flow using the methodology outlined in Waldron and Baalousha (2013) it was not possible to undertake a mass balance for the whole model.

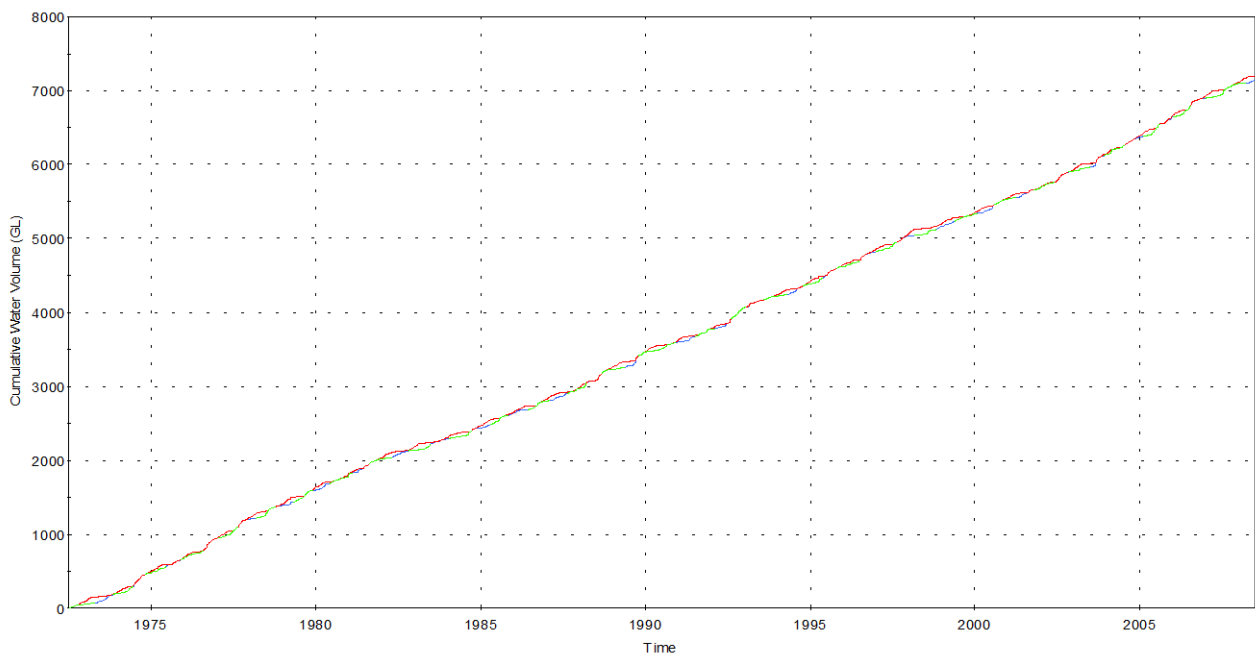


Figure 4: Reservoir mass balance showing total inflow in blue, total outflow in red and total outflow plus change in storage in green (dashed and overlies the blue inflow line).

Note 1 GL (gigalitre) = 1 M m³ (million cubic metres)



6.0 MODEL LIMITATIONS

6.1 Introduction

As with all models the accuracy of model projections is limited by a combination of the following two principal factors:

- 1) The accuracy of the input data.
- 2) The accuracy of the model itself and how representative the model is of the actual system and the physical processes being modelled.

Interpretation of model projections requires care and needs to fully consider the model limitations. Ideally interpretation of model projections should be done by people who are fully conversant with both the system being modelled and the model itself, taking into account its objectives, structure, inputs and underlying assumptions. Care is required when modifying or running the model and Golder recommends that running of the model and interpretation of model projections only be undertaken by people who are fully conversant with the model and its underlying assumptions. The model scenarios that fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013) were all run and analysed by Golder and the associated results are presented in this report (predominantly Section 7.0).

The model limitations are principally associated with the quality of the input data, the conceptualisation assumptions built into the model and the inherent difficulties in modelling natural systems.

6.2 Accuracy of the Model Inputs

Almost all the model input data has been supplied to Golder by HBRIC Ltd, HBRC or its consultants. The input data principally consists of the time series data summarised in Table 1 and various management decisions regarding operation of the scheme. Golder has not verified the input data and has not been supplied with information regarding its accuracy. An assessment of the overall accuracy of the model projections is therefore not possible. To improve confidence in the model projections and to allow an assessment of the likely uncertainty band associated with the projections Golder recommends that the data referenced in the model be verified and its representativeness and accuracy assessed.

6.3 Accuracy of the Model

As outlined in Section 5.2 the model suitably conserves mass. The model is essentially a mass balance which tracks water volumes. As the overall model conserves mass, it can be assumed that no calculation errors are present within the model. Similarly the model has been through a thorough peer review process (described in Section 8.0) which did not identify any calculation errors.

6.4 Summary

While uncertainties in the input data will transfer to uncertainties in the model projections for individual variables within a scenario, the model does allow comparisons between scenarios. Such comparisons can support and inform management decisions.



7.0 MODELLED PROJECTIONS

7.1 Introduction

The model projections from the scenarios that fed into the environmental flow optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013) are summarised in this section. Most for the scenarios are associated with a key base scenario the criteria for which are summarised in Table 3.

Table 3: Base scenario criteria.

Item	Value	Comment
Maximum Live Storage in the Reservoir	85 M m ³	
Residual Environmental Flow	1,228 L/s	Supply of the residual environmental flow is given the highest priority.
Primary flushing flow allocation during the flushing flow season from 15 December to 30 April. Flushing is based on a maximum 30 day accrual between flows that exceed 50m ³ /s in the Tukituki River at Red Bridge. 'Piggy backing' on freshes that exceed 15 m ³ /s is encouraged when accrual is between 20 and 29 days. When accrual reaches 30 days a flushing flow is released.	2 M m ³	Allows for approximately two flushing flow events where the flow released from the dam (flushing and residual) equals 30 m ³ /s for a duration of 9.25 hrs. Primary flushing is given the second highest priority.
Irrigation season	1 September to 30 April	
Maximum primary irrigation supply	95.8 M m ³	Primary irrigation supply is given the third highest priority
Total primary irrigation shortfall	19.3 M m ³	A shortfall in core irrigation supply occurs during three irrigation seasons
Live storage volume at which primary irrigation supply ceases	2.5 M m ³	This ensures that the residual environmental flow is always supplied.
Secondary flushing flow allocation	2 M m ³	Results in a total flushing flow allocation of 4 M m ³ . Secondary flushing is given the fourth highest priority.
Maximum number of flushing releases	4	Limits the total number of flushing flows that are released under both the primary and secondary allocations.
Secondary irrigation cap.	28 M m ³	Secondary irrigation is controlled under a management regime determined by HBRIC Ltd, which determines the potential availability of secondary irrigation water and assumes that all potentially available secondary irrigation water is released from the reservoir and used on the same day it is projected to become available.
Ring fenced live storage volume to maintain primary irrigation supply reliability	1.05 x 95.8 M m ³	

7.2 Primary Residual Flow

Under the modelled scenarios, the primary residual flow was continuously supplied throughout the 36 hydrological year modelling period. As outlined above, irrigation supplies need to be cut back when the live volume in the reservoir falls below 2.5 M m³ to ensure that the primary residual flow is provided 100 % of the time. If irrigation supplies are not cut back when the live volume in the reservoir falls below 2.5 M m³ then



the model projects that the primary residual flow will not be fully supplied during the 1972-1973 and 1997-1998 irrigation seasons.

7.3 Primary Irrigation Water

Under the modelled scenarios, which include supply of both primary and secondary irrigation water, the model projects that irrigation demand is fully supplied up to the maximum contracted volume of 95.8 M m³ every irrigation season over the 36 seasons modelled except three (1972-1973, 1982-1983 and 1997-1998). The projected cumulative volume of primary irrigation water that is supplied each irrigation season and the project shortfall in supply is shown in Figure 5 and summarised below. The shortfalls shown in Figure 5 and described below are in addition to the on-farm shortfalls associated with stipulating an irrigation season and applying a primary irrigation cap (Section 4.4).

- In the 1972-1973 irrigation season, a shortfall of approximately 3.9 M m³ is projected, which represents approximately 4 % of the 91.9 M m³ that is supplied during that season (i.e. $3.9/91.9 = 4\%$). The shortfall occurs over two periods. Approximately half of the shortfall occurs during 6-13 March 1973 with the remainder occurring during 24-29 March 1973.
- In the 1982-1983 irrigation season, a shortfall of approximately 10.9 M m³ is projected which represents approximately 13 % of the 84.9 M m³ that is supplied during that season (i.e. $10.9/84.9 = 13\%$). The shortfall occurs over an approximately two week period 2-17 March 1983.
- In the 1997-1998 irrigation season, a shortfall of approximately 6.3 M m³ is projected which represents approximately 7 % of the 89.5 M m³ that is supplied during that season (i.e. $6.3/89.5 = 7\%$). The shortfall occurs over a two week period 23 February-2 March 1998.

All three shortfalls in primary irrigation supply occur relatively late in the season, are relatively short in duration and irrigators are expected to be able to manage around them without incurring significant production losses.

In all three cases the shortfall occurs because the live volume in the reservoir has been drawn down to 2.5 M m³ at which time irrigation is curtailed to ensure sufficient volume remains to fully supply the residual flow requirements. Low reservoir volumes are predominantly due to drawdown to meet irrigation demand that season although the low reservoir volume during the 1982-1983 irrigation season was in part due to the reservoir not fully replenishing over the previous winter. If secondary irrigation is excluded then the model projects the same shortfall during the 1972-1973 and 1997-1998 irrigation seasons and a reduced shortfall of 0.8 M m³ during the 1982-1983 irrigation season. If secondary irrigation is excluded and primary irrigation supplies are not curtailed when the live volume in the reservoir falls below 2.5 M m³ then the model projects reduced shortfalls which only occur during the 1972-1973 (shortfall of 1.2 M m³) and 1997-1998 (shortfall of 4.0 M m³) irrigation seasons.

7.4 Flushing Flows

The model projects a strong demand for flushing flows and the 2.0 M m³ primary allocation for flushing flows is fully utilised in all of the 36 irrigation seasons modelled. In all but 6 seasons (1979-1980, 1995-1996, 1996-1997, 1998-1999, 2003-2004 and 2005-2006) the total volume of water released from the dam for flushing flows exceeds 3.0 M m³. The maximum number of four flushing flows are released in all years other than the 1979-1980, 1995-1996 and 1998-1999 irrigation seasons, when only three flushing flows are released. The projected cumulative volume of flushing flow water released from the reservoir each irrigation season is shown in Figure 6 and summary statistics are provided in Table 4.



7.5 Secondary Irrigation

The model projects a significant volume of secondary irrigation water is potentially available, with the full 28 M m³ allocation projected to be available during 16 of the 36 seasons modelled. Under the secondary irrigation management option that was modelled much of this potentially available secondary irrigation water only becomes available late in the irrigation season. There are three years where no secondary irrigation water is available (1972-1973, 1982-1983 and 1997-1998) and a further three years (1983-1984, 1993-1994 and 2007-2008) when the projected volume available is less than 5 M m³. The cumulative volume of secondary irrigation water which is projected to be potentially available per irrigation season is presented in Figure 7 along with the projected cumulative primary irrigation volume. Summary statistics for the projected potentially available secondary irrigation volume are provided in Table 5.



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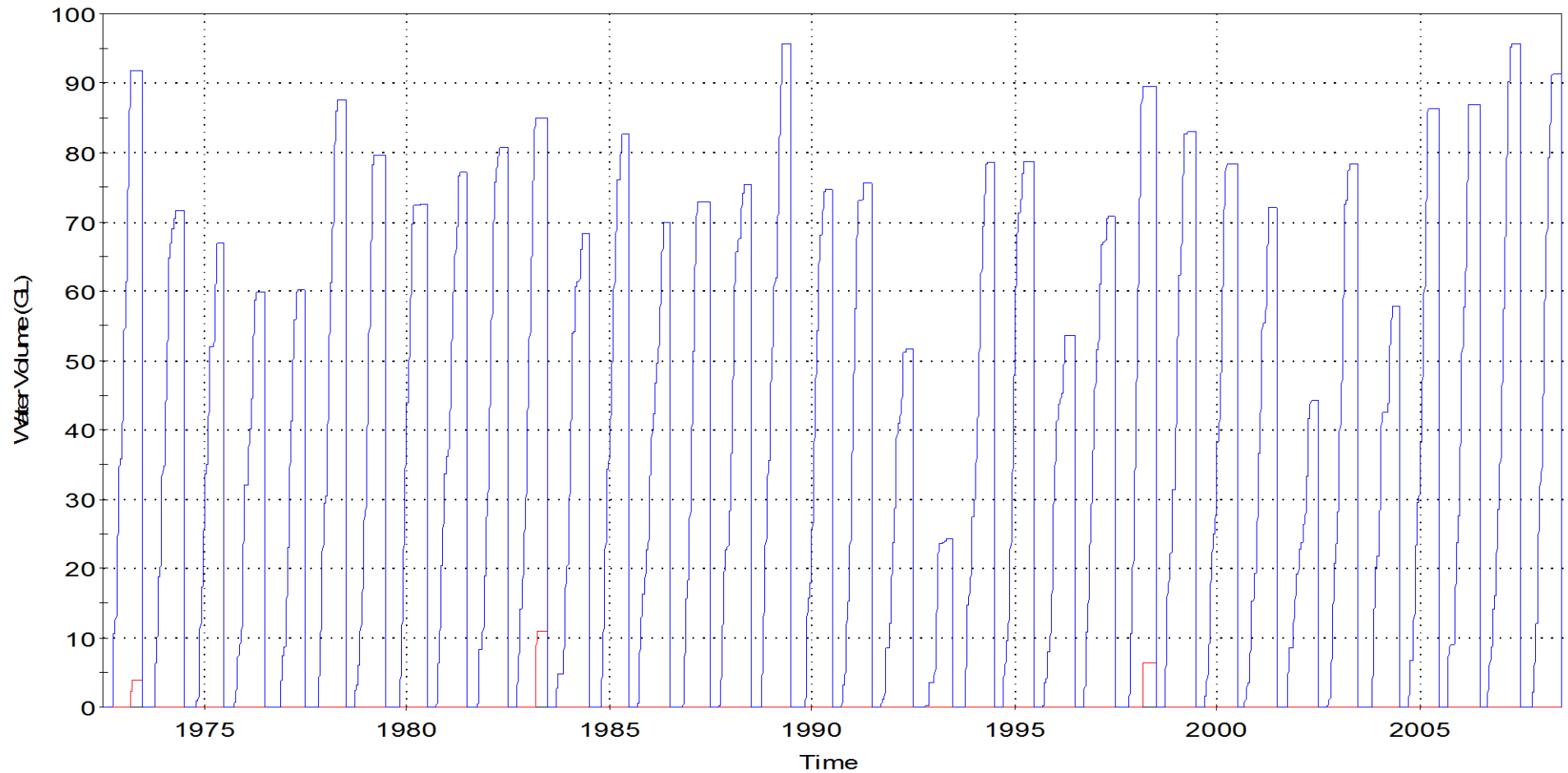


Figure 5: Projected cumulative primary irrigation volume supplied (blue) and shortfall in supplying agreed demand (red) per irrigation season.

Note 1 GL (gigalitre) = 1 M m³ (million cubic metres)



Table 4: Annual statistics for projected flushing flow releases from the Makaroro Reservoir.

Hydrological year	Volume of flushing flows released under the primary allocation (M m ³)	Volume of flushing flows released under the secondary allocation (M m ³)	Total volume of flushing flows released (M m ³)
1972 - 1973	1.9	1.8	3.7
1973 - 1974	1.9	1.9	3.8
1974 - 1975	2.7	1.0	3.7
1975 - 1976	2.8	1.0	3.8
1976 - 1977	1.9	1.9	3.8
1977 - 1978	1.9	1.4	3.3
1978 - 1979	1.9	1.9	3.8
1979 - 1980	1.9	0.6	2.5
1980 - 1981	2.6	0.9	3.5
1981 - 1982	1.9	1.9	3.8
1982 - 1983	1.9	1.9	3.8
1983 - 1984	1.9	1.9	3.8
1984 - 1985	1.9	1.1	3.0
1985 - 1986	1.9	1.9	3.8
1986 - 1987	1.9	1.9	3.8
1987 - 1988	1.9	1.9	3.8
1988 - 1989	1.9	1.9	3.8
1989 - 1990	2.4	0.7	3.1
1990 - 1991	1.9	1.8	3.7
1991 - 1992	2.8	1.0	3.8
1992 - 1993	1.9	1.9	3.8
1993 - 1994	1.9	1.9	3.8
1994 - 1995	1.9	1.9	3.8
1995 - 1996	1.9	1.0	2.9
1996 - 1997	1.9	0.8	2.7
1997 - 1998	1.9	1.9	3.8
1998 - 1999	2.2	0.0	2.2
1999 - 2000	2.9	1.0	3.8
2000 - 2001	1.9	1.5	3.4
2001 - 2002	1.9	1.9	3.8
2002 - 2003	2.5	1.0	3.5
2003 - 2004	2.6	0.0	2.6
2004 - 2005	2.8	1.0	3.8
2005 - 2006	2.6	0.3	2.9
2006 - 2007	1.9	1.9	3.8
2007 - 2008	1.9	1.9	3.8
Minimum	1.9	0.0	2.2
Median	1.9	1.8	3.8
Mean	2.1	1.4	3.5
Maximum	2.9	1.9	3.8

Notes: The model sometimes projects releases slightly more than the 2.0 M m³ primary caps due to the way it assesses the flushing flow allocation caps. When below the allocation cap the model will release a flushing flow even if releasing will exceed the cap.
Flushing flow volume excludes residual flow releases which occur concurrently.

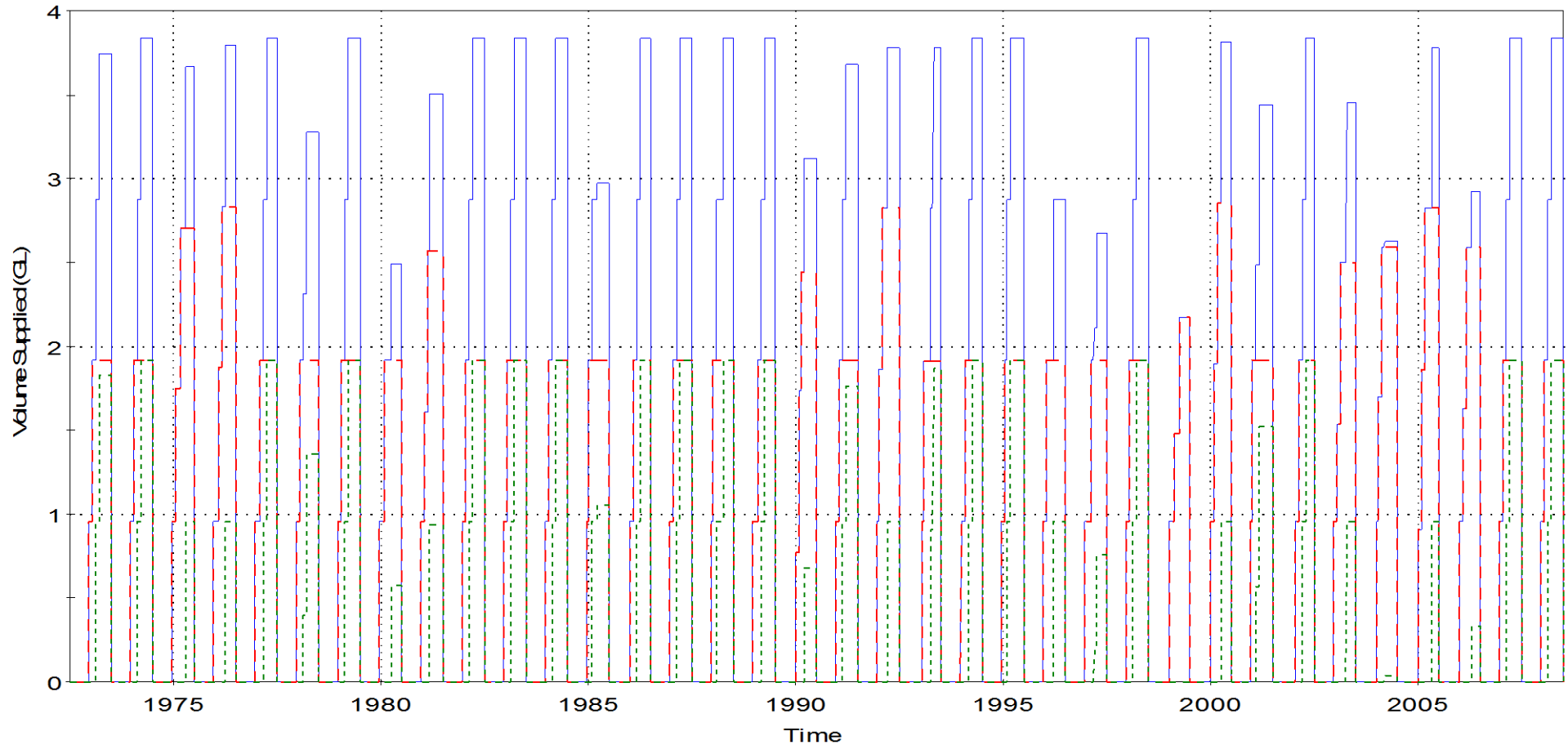


Figure 6: Projected flushing flow volumes released per irrigation season. The red dashed line represents flushing flows released from the dam under the primary allocation. The green dotted line represents flushing flows released under the secondary allocation.

Note: Flushing flow volume excludes residual flow releases which occur concurrently. 1 GL (gigalitre) = 1 M m³ (million cubic metres)



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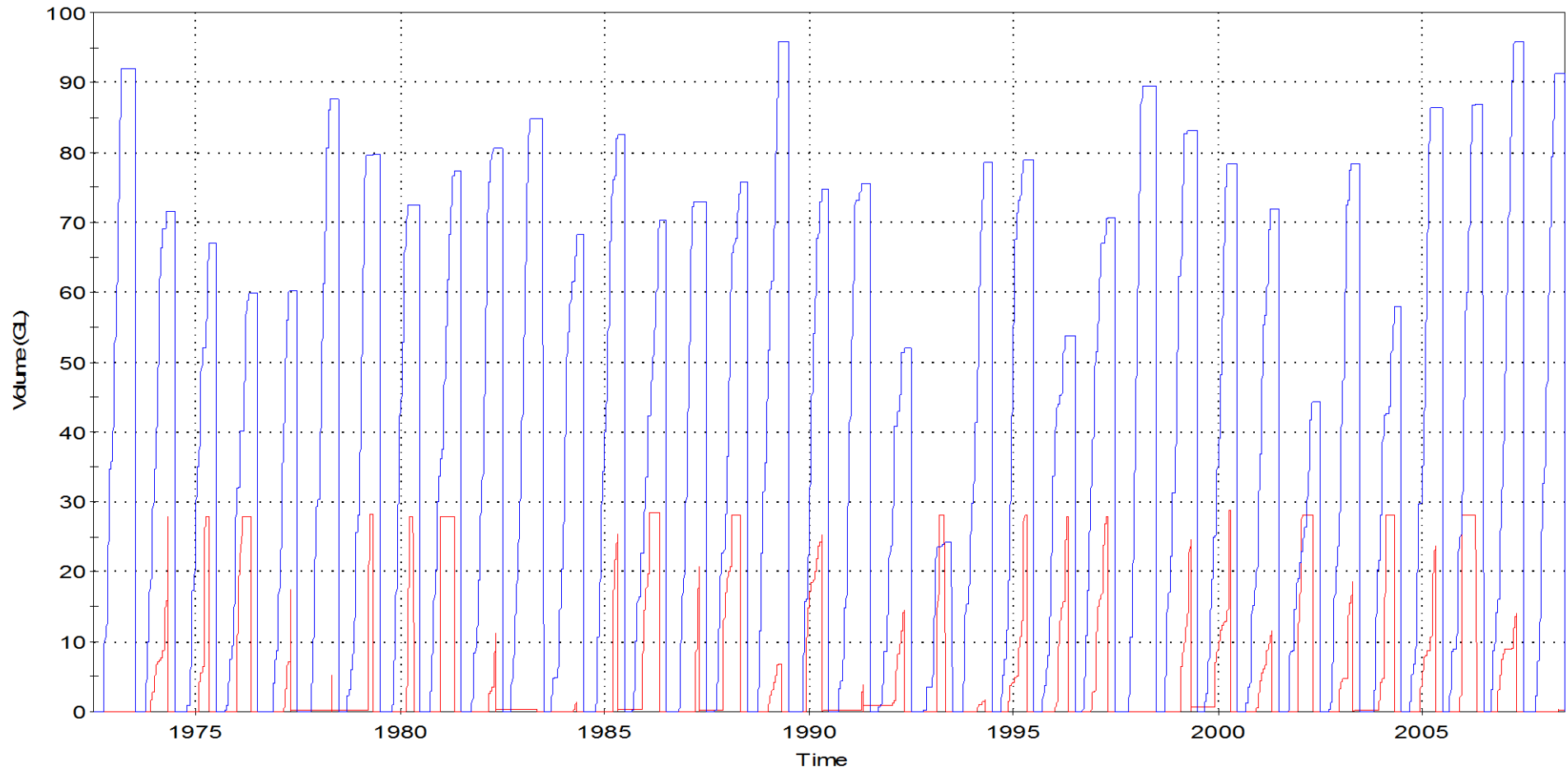


Figure 7: Projected cumulative primary (blue) and secondary (red) irrigation volumes supplied per irrigation season.

Note 1 GL (gigalitre) = 1 M m³ (million cubic metres)



Table 5: Annual statistics for projected secondary irrigation water that is potentially available.

Hydrological year	Volume of secondary irrigation water potentially available (M m ³)
1972 - 1973	0.0
1973 - 1974	28.0
1974 - 1975	28.0
1975 - 1976	28.0
1976 - 1977	17.5
1977 - 1978	5.3
1978 - 1979	28.0
1979 - 1980	28.0
1980 - 1981	28.0
1981 - 1982	11.6
1982 - 1983	0.0
1983 - 1984	1.5
1984 - 1985	25.9
1985 - 1986	28.0
1986 - 1987	21.0
1987 - 1988	28.0
1988 - 1989	6.7
1989 - 1990	25.4
1990 - 1991	5.3
1991 - 1992	13.6
1992 - 1993	28.0
1993 - 1994	1.8
1994 - 1995	28.0
1995 - 1996	28.0
1996 - 1997	28.0
1997 - 1998	0.0
1998 - 1999	25.6
1999 - 2000	28.0
2000 - 2001	11.5
2001 - 2002	28.0
2002 - 2003	18.7
2003 - 2004	28.0
2004 - 2005	23.7
2005 - 2006	28.0
2006 - 2007	14.2
2007 - 2008	0.3
Minimum	0.0
Median	25.5
Mean	18.8
Maximum	28.0



7.6 Reservoir Storage and Operating Levels

Storage volumes within the reservoir are projected to fluctuate considerably, although generally storage volumes tend to increase over the winter months as flows are harvested and the reservoir refills. Stored volumes tend to decrease over the summer irrigation season as the reservoir is drawn down to supply irrigation demand. Projected reservoir fluctuations over the 36 hydrological years that were modelled are shown in Figure 8 (live storage), Figure 9 (total storage) and Figure 10 (water level) with annual summary statistics provided in Table 6 and average monthly summary statistics provided in Table 7 (live storage), Table 8 (total storage) and Table 9 (water level). The reservoir is projected to refill and spill every winter over the 36 modelled years except three (1982, 1998 and 1999). The 1998 winter was particularly poor for refilling, with the reservoir only reaching 48 M m³ (i.e. 56% full) by the start of the 1998-1999 irrigation season.

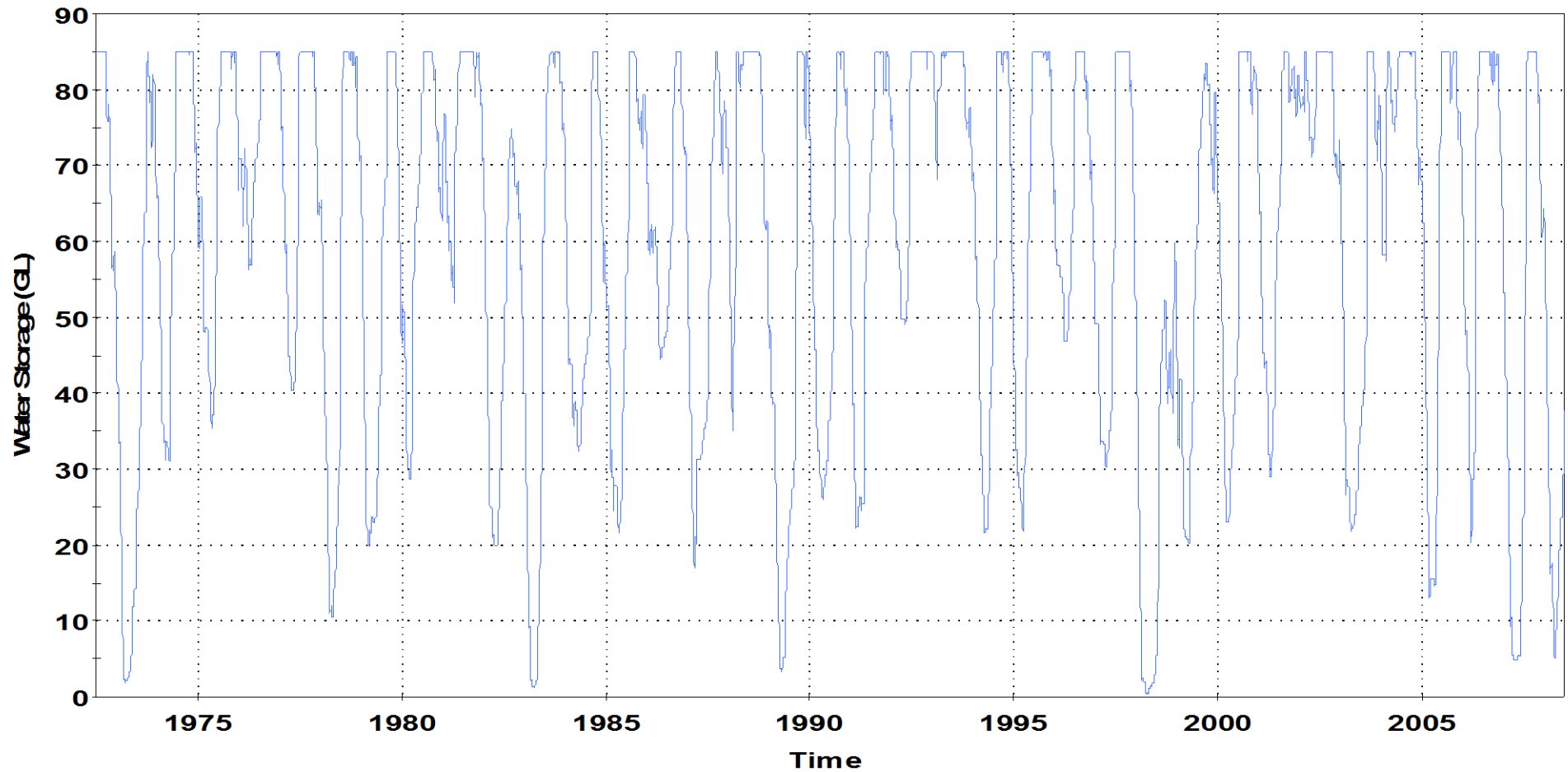


Figure 8: Projected live storage volume in the Makaroro Reservoir.

Note 1 GL (gigalitre) = 1 M m³ (million cubic metres)

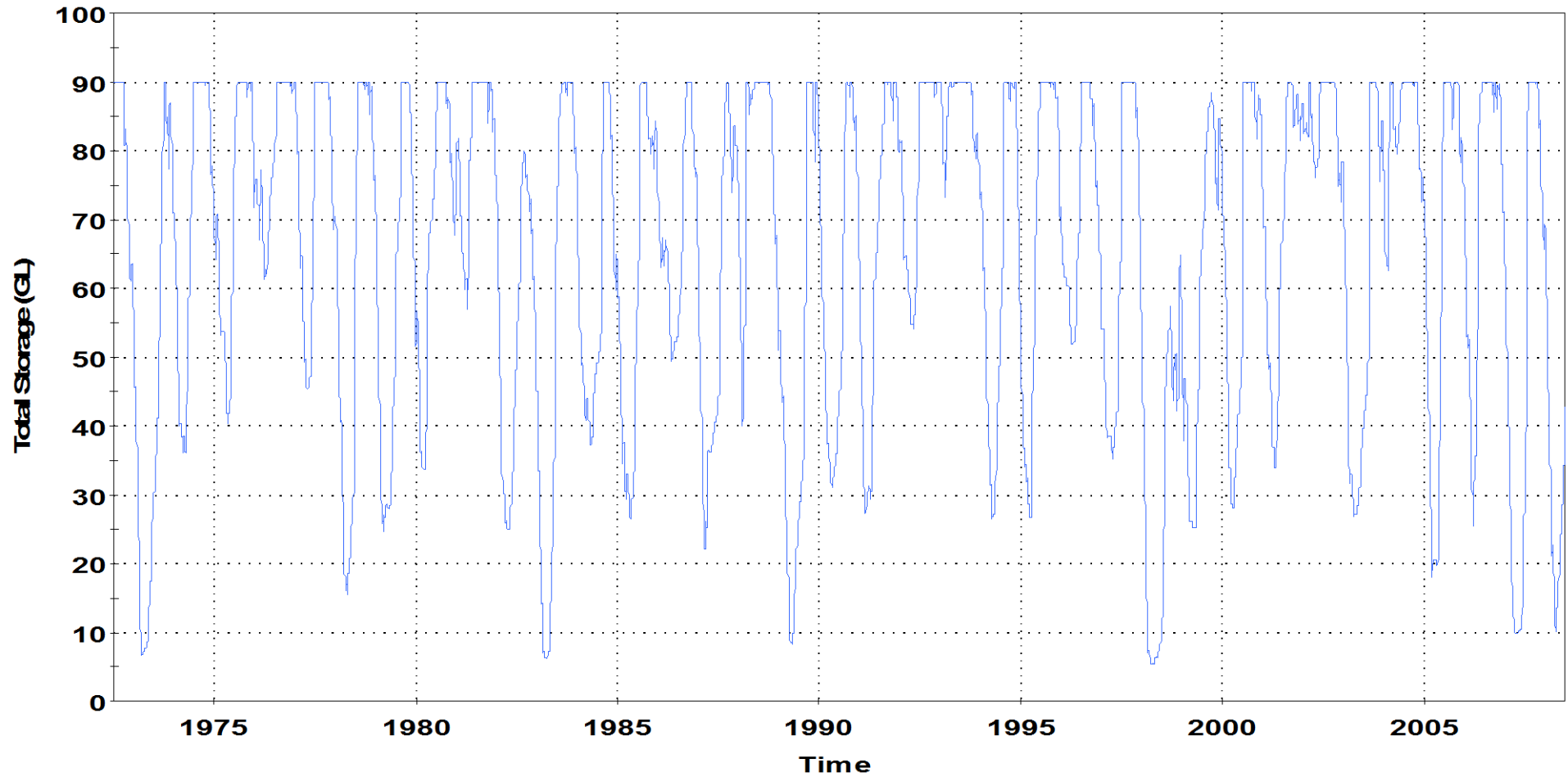


Figure 9: Projected total storage volume in the Makaroro Reservoir.

Note 1 GL (gigalitre) = 1 M m³ (million cubic metres)

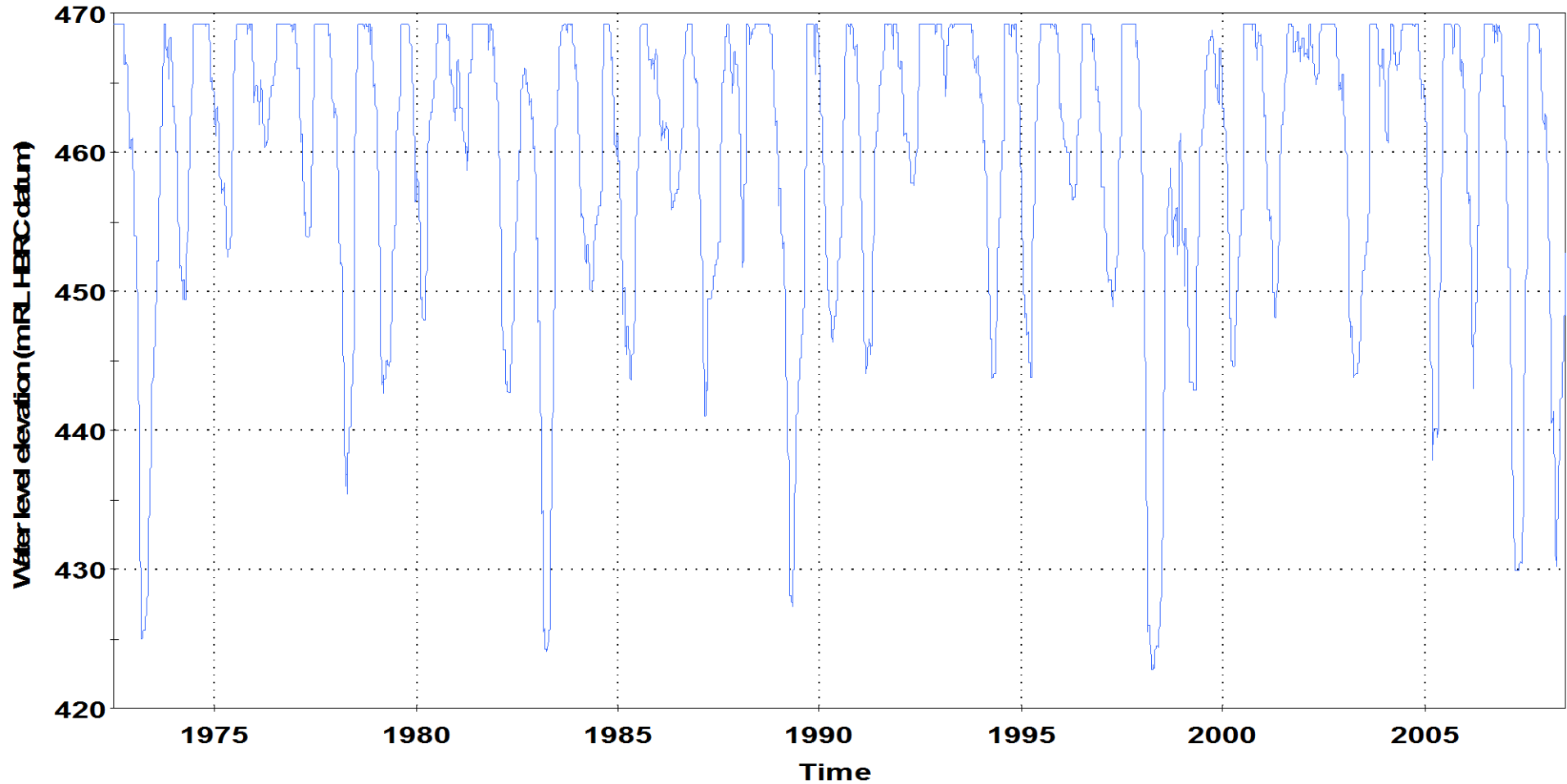


Figure 10: Projected water level in the Makaroro Reservoir.



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Table 6: Projected annual statistics for the Makaroro Reservoir.

Hydrological year	Live Storage (GL*)			Total Storage (GL*)			Water Level (m RL HBRC datum)		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
1972 - 1973	1.7	45.1	85.0	6.7	50.1	90.0	424.9	451.5	469.2
1973 - 1974	24.9	56.1	85.0	29.9	61.1	90.0	445.7	459.2	469.2
1974 - 1975	35.4	66.6	85.0	40.4	71.6	90.0	451.9	463.1	469.2
1975 - 1976	56.3	74.6	85.0	61.3	79.6	90.0	460.3	466.0	469.2
1976 - 1977	40.4	71.1	85.0	45.4	76.1	90.0	453.9	464.6	469.2
1977 - 1978	10.5	55.5	85.0	15.5	60.5	90.0	435.4	457.6	469.2
1978 - 1979	19.8	56.7	85.0	24.8	61.7	90.0	442.6	458.6	469.2
1979 - 1980	28.7	61.6	85.0	33.7	66.6	90.0	447.9	461.3	469.2
1980 - 1981	51.9	74.7	85.0	56.9	79.7	90.0	458.6	466.0	469.2
1981 - 1982	20.0	58.3	85.0	25.0	63.3	90.0	442.7	459.2	469.2
1982 - 1983	1.2	40.7	75.0	6.2	45.7	80.0	424.1	450.4	466.1
1983 - 1984	32.3	61.6	85.0	37.3	66.6	90.0	450.1	461.2	469.2
1984 - 1985	21.5	51.2	85.0	26.5	56.2	90.0	443.7	457.1	469.2
1985 - 1986	44.4	65.8	85.0	49.4	70.8	90.0	455.5	463.0	469.2
1986 - 1987	17.1	52.8	85.0	22.1	57.8	90.0	441.0	457.7	469.2
1987 - 1988	35.0	71.4	85.0	40.0	76.4	90.0	451.7	464.8	469.2
1988 - 1989	3.3	49.5	85.0	8.3	54.5	90.0	427.3	454.3	469.2
1989 - 1990	22.3	51.6	85.0	27.3	56.6	90.0	444.1	457.0	469.2
1990 - 1991	22.2	55.8	85.0	27.2	60.8	90.0	444.1	458.8	469.2
1991 - 1992	49.0	71.0	85.0	54.0	76.0	90.0	457.4	464.8	469.2
1992 - 1993	68.1	83.5	85.0	73.1	88.5	90.0	464.0	468.7	469.2
1993 - 1994	21.5	60.7	85.0	26.5	65.7	90.0	443.7	460.5	469.2
1994 - 1995	21.8	60.4	85.0	26.8	65.4	90.0	443.8	460.4	469.2
1995 - 1996	46.9	69.2	85.0	51.9	74.2	90.0	456.6	464.2	469.2
1996 - 1997	30.2	59.1	85.0	35.2	64.1	90.0	448.8	460.3	469.2
1997 - 1998	0.3	44.8	85.0	5.3	49.8	90.0	422.8	449.4	469.2
1998 - 1999	5.2	37.6	60.5	10.2	42.6	65.5	430.3	451.8	461.6
1999 - 2000	23.0	57.4	83.5	28.0	62.4	88.5	444.6	459.5	468.7
2000 - 2001	29.0	64.1	85.0	34.0	69.1	90.0	448.1	462.1	469.2
2001 - 2002	63.5	79.4	85.0	68.5	84.4	90.0	462.5	467.4	469.2
2002 - 2003	21.8	57.4	85.0	26.8	62.4	90.0	443.8	458.9	469.2
2003 - 2004	34.7	72.2	85.0	39.7	77.2	90.0	451.5	465.0	469.2
2004 - 2005	13.0	59.3	85.0	18.0	64.3	90.0	437.9	459.4	469.2
2005 - 2006	20.3	67.6	85.0	25.3	72.6	90.0	442.9	463.1	469.2
2006 - 2007	4.9	50.5	85.0	9.9	55.5	90.0	429.9	454.0	469.2
2007 - 2008	5.1	49.8	85.0	10.1	54.8	90.0	430.2	455.0	469.2
Minimum	0.3	37.6	60.5	5.3	42.6	65.5	422.8	449.4	461.6
Mean	26.3	60.1	84.0	31.3	65.1	89.0	444.6	459.9	468.9
Maximum	68.1	83.5	85.0	73.1	88.5	90.0	464.0	468.7	469.2
Value exceeded 95% of the time	1.6	43.8	81.3	6.6	48.8	86.3	424.7	451.2	468.1
Value exceeded 90% of the time	4.1	47.3	85.0	9.1	52.3	90.0	428.6	452.9	469.2
Value exceeded 75% of the time	16.1	52.5	85.0	21.1	57.5	90.0	440.2	457.5	469.2
Median	22.3	59.2	85.0	27.3	64.2	90.0	444.1	459.9	469.2

Notes: * 1 GL (gigalitre) = 1 M m³ (million cubic metres)



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Table 7: Average monthly projected live storage volume in the Makaroro Reservoir (GL*).

Hydrological Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Mean
1972 - 1973	85.0	85.0	84.9	77.2	62.5	56.0	39.2	17.8	2.4	2.6	7.3	17.7	45.1
1973 - 1974	28.9	45.8	68.8	81.9	78.4	71.5	59.0	40.0	33.3	32.9	55.3	76.9	56.1
1974 - 1975	85.0	85.0	85.0	85.0	81.6	70.0	62.8	55.9	48.6	41.1	37.6	60.2	66.6
1975 - 1976	81.1	85.0	85.0	84.6	84.8	76.2	70.6	67.0	63.3	58.4	66.7	72.4	74.6
1976 - 1977	81.8	85.0	85.0	85.0	85.0	84.7	78.4	63.5	50.3	41.7	44.1	67.4	71.1
1977 - 1978	85.0	85.0	85.0	84.9	79.3	65.5	57.1	37.6	20.7	12.1	16.8	34.4	55.5
1978 - 1979	75.3	85.0	84.8	84.7	82.5	72.1	54.8	29.3	21.1	23.1	25.8	39.3	56.7
1979 - 1980	60.8	74.2	85.0	84.9	78.1	57.5	48.1	34.1	29.2	50.3	64.7	72.2	61.6
1980 - 1981	83.6	85.0	84.9	81.6	72.6	65.3	74.5	64.1	57.3	63.0	78.5	85.0	74.7
1981 - 1982	85.0	85.0	85.0	82.9	83.4	74.8	59.1	34.3	23.6	20.3	24.9	38.3	58.3
1982 - 1983	51.5	69.9	73.5	68.8	63.4	50.7	29.7	10.0	1.8	2.9	15.1	48.4	40.7
1983 - 1984	74.5	83.9	84.3	84.7	83.2	74.9	58.1	44.0	37.4	36.3	34.2	42.0	61.6
1984 - 1985	45.6	63.6	84.9	83.7	71.9	58.2	50.3	34.5	27.4	24.4	25.2	43.8	51.2
1985 - 1986	62.6	85.0	84.2	77.1	75.2	76.5	63.7	60.0	60.2	51.7	45.2	47.5	65.8
1986 - 1987	52.2	65.9	83.2	85.0	77.8	68.8	47.4	26.2	23.4	31.3	33.5	36.1	52.8
1987 - 1988	49.3	73.1	83.5	78.2	74.5	73.8	55.5	41.7	75.0	82.4	83.9	85.0	71.4
1988 - 1989	85.0	85.0	85.0	82.8	69.0	57.5	44.4	36.1	18.2	4.3	6.2	18.0	49.5
1989 - 1990	24.6	34.4	76.3	85.0	80.1	82.7	64.9	47.4	34.0	27.9	28.4	33.7	51.6
1990 - 1991	42.7	68.4	84.8	84.7	80.3	69.1	45.4	27.0	25.1	25.4	51.7	63.6	55.8
1991 - 1992	73.4	82.8	85.0	83.7	84.3	79.6	72.9	60.2	56.7	49.8	51.5	72.0	71.0
1992 - 1993	85.0	85.0	85.0	85.0	84.6	85.0	81.6	73.0	82.0	84.9	85.0	85.0	83.5
1993 - 1994	85.0	85.0	85.0	81.9	75.5	72.9	64.5	52.0	33.6	23.5	26.5	41.7	60.7
1994 - 1995	58.3	85.0	84.3	84.9	82.3	62.2	37.8	29.0	24.4	35.1	60.6	79.3	60.4
1995 - 1996	85.0	85.0	84.9	84.8	83.9	72.3	60.3	56.3	52.7	47.0	52.5	65.4	69.2
1996 - 1997	84.1	85.0	84.7	79.8	71.0	60.1	48.6	37.4	33.5	31.7	36.1	54.8	59.1
1997 - 1998	82.5	85.0	85.0	85.0	80.6	62.9	36.1	9.9	1.5	0.6	1.4	3.2	44.8
1998 - 1999	14.9	43.6	49.4	41.9	42.1	55.0	39.4	35.4	21.7	20.4	34.3	53.8	37.6
1999 - 2000	66.2	77.6	82.1	78.5	69.3	76.7	62.2	46.4	27.1	25.4	33.8	42.0	57.4
2000 - 2001	77.1	85.0	84.8	84.0	80.4	78.6	62.9	47.2	40.8	29.9	38.1	58.5	64.1
2001 - 2002	68.9	83.8	84.8	80.1	81.3	80.3	78.7	81.8	81.2	73.1	74.2	84.8	79.4
2002 - 2003	85.0	85.0	85.0	83.9	73.3	71.3	60.2	38.0	27.2	22.4	23.9	31.0	57.4
2003 - 2004	37.2	52.1	85.0	84.9	77.5	76.8	64.0	67.2	84.2	77.2	77.4	84.2	72.2
2004 - 2005	85.0	85.0	84.9	85.0	78.2	70.1	60.0	37.6	16.7	15.5	25.9	66.0	59.3
2005 - 2006	85.0	85.0	81.6	84.6	80.1	73.8	55.9	45.2	26.5	30.8	75.9	84.8	67.6
2006 - 2007	85.0	85.0	83.6	83.5	82.5	69.1	51.1	29.6	11.1	4.9	5.3	11.9	50.5
2007 - 2008	48.8	84.8	85.0	84.9	78.4	64.6	54.6	30.8	14.4	7.1	16.6	26.8	49.8
Minimum	14.9	34.4	49.4	41.9	42.1	50.7	29.7	9.9	1.5	0.6	1.4	3.2	
Mean	67.9	77.5	82.6	81.6	76.9	69.9	57.1	43.0	35.8	33.6	40.7	53.5	
Maximum	85.0	85.0	85.0	85.0	85.0	85.0	81.6	81.8	84.2	84.9	85.0	85.0	
Exceeded 95%	27.9	45.2	72.3	75.0	63.2	55.7	37.4	15.9	2.2	2.8	6.0	16.3	
Exceeded 90%	40.0	57.8	79.0	77.7	69.2	57.5	39.3	26.6	12.8	4.6	11.2	22.4	
Exceeded 75%	52.0	74.0	84.1	81.8	74.2	64.2	48.5	33.2	21.5	20.4	25.1	37.8	
Median	76.2	85.0	84.9	84.3	78.9	71.4	58.5	39.0	28.3	30.4	35.2	54.3	

Notes: * 1 GL (gigalitre) = 1 M m³ (million cubic metres)



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Table 8: Average monthly projected total storage volume in the Makaroro Reservoir (GL*).

Hydrological Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Mean
1972 - 1973	90.0	90.0	89.9	82.2	67.5	61.0	44.2	22.8	7.4	7.6	12.3	22.7	50.1
1973 - 1974	33.9	50.8	73.8	86.9	83.4	76.5	64.0	45.0	38.3	37.9	60.3	81.9	61.1
1974 - 1975	90.0	90.0	90.0	90.0	86.6	75.0	67.8	60.9	53.6	46.1	42.6	65.2	71.6
1975 - 1976	86.1	90.0	90.0	89.6	89.8	81.2	75.6	72.0	68.3	63.4	71.7	77.4	79.6
1976 - 1977	86.8	90.0	90.0	90.0	90.0	89.7	83.4	68.5	55.3	46.7	49.1	72.4	76.1
1977 - 1978	90.0	90.0	90.0	89.9	84.3	70.5	62.1	42.6	25.7	17.1	21.8	39.4	60.5
1978 - 1979	80.3	90.0	89.8	89.7	87.5	77.1	59.8	34.3	26.1	28.1	30.8	44.3	61.7
1979 - 1980	65.8	79.2	90.0	89.9	83.1	62.5	53.1	39.1	34.2	55.3	69.7	77.2	66.6
1980 - 1981	88.6	90.0	89.9	86.6	77.6	70.3	79.5	69.1	62.3	68.0	83.5	90.0	79.7
1981 - 1982	90.0	90.0	90.0	87.9	88.4	79.8	64.1	39.3	28.6	25.3	29.9	43.3	63.3
1982 - 1983	56.5	74.9	78.5	73.8	68.4	55.7	34.7	15.0	6.8	7.9	20.1	53.4	45.7
1983 - 1984	79.5	88.9	89.3	89.7	88.2	79.9	63.1	49.0	42.4	41.3	39.2	47.0	66.6
1984 - 1985	50.6	68.6	89.9	88.7	76.9	63.2	55.3	39.5	32.4	29.4	30.2	48.8	56.2
1985 - 1986	67.6	90.0	89.2	82.1	80.2	81.5	68.7	65.0	65.2	56.7	50.2	52.5	70.8
1986 - 1987	57.2	70.9	88.2	90.0	82.8	73.8	52.4	31.2	28.4	36.3	38.5	41.1	57.8
1987 - 1988	54.3	78.1	88.5	83.2	79.5	78.8	60.5	46.7	80.0	87.4	88.9	90.0	76.4
1988 - 1989	90.0	90.0	90.0	87.8	74.0	62.5	49.4	41.1	23.2	9.3	11.2	23.0	54.5
1989 - 1990	29.6	39.4	81.3	90.0	85.1	87.7	69.9	52.4	39.0	32.9	33.4	38.7	56.6
1990 - 1991	47.7	73.4	89.8	89.7	85.3	74.1	50.4	32.0	30.1	30.4	56.7	68.6	60.8
1991 - 1992	78.4	87.8	90.0	88.7	89.3	84.6	77.9	65.2	61.7	54.8	56.5	77.0	76.0
1992 - 1993	90.0	90.0	90.0	90.0	89.6	90.0	86.6	78.0	87.0	89.9	90.0	90.0	88.5
1993 - 1994	90.0	90.0	90.0	86.9	80.5	77.9	69.5	57.0	38.6	28.5	31.5	46.7	65.7
1994 - 1995	63.3	90.0	89.3	89.9	87.3	67.2	42.8	34.0	29.4	40.1	65.6	84.3	65.4
1995 - 1996	90.0	90.0	89.9	89.8	88.9	77.3	65.3	61.3	57.7	52.0	57.5	70.4	74.2
1996 - 1997	89.1	90.0	89.7	84.8	76.0	65.1	53.6	42.4	38.5	36.7	41.1	59.8	64.1
1997 - 1998	87.5	90.0	90.0	90.0	85.6	67.9	41.1	14.9	6.5	5.6	6.4	8.2	49.8
1998 - 1999	19.9	48.6	54.4	46.9	47.1	60.0	44.4	40.4	26.7	25.4	39.3	58.8	42.6
1999 - 2000	71.2	82.6	87.1	83.5	74.3	81.7	67.2	51.4	32.1	30.4	38.8	47.0	62.4
2000 - 2001	82.1	90.0	89.8	89.0	85.4	83.6	67.9	52.2	45.8	34.9	43.1	63.5	69.1
2001 - 2002	73.9	88.8	89.8	85.1	86.3	85.3	83.7	86.8	86.2	78.1	79.2	89.8	84.4
2002 - 2003	90.0	90.0	90.0	88.9	78.3	76.3	65.2	43.0	32.2	27.4	28.9	36.0	62.4
2003 - 2004	42.2	57.1	90.0	89.9	82.5	81.8	69.0	72.2	89.2	82.2	82.4	89.2	77.2
2004 - 2005	90.0	90.0	89.9	90.0	83.2	75.1	65.0	42.6	21.7	20.5	30.9	71.0	64.3
2005 - 2006	90.0	90.0	86.6	89.6	85.1	78.8	60.9	50.2	31.5	35.8	80.9	89.8	72.6
2006 - 2007	90.0	90.0	88.6	88.5	87.5	74.1	56.1	34.6	16.1	9.9	10.3	16.9	55.5
2007 - 2008	53.8	89.8	90.0	89.9	83.4	69.6	59.6	35.8	19.4	12.1	21.6	31.8	54.8
Minimum	19.9	39.4	54.4	46.9	47.1	55.7	34.7	14.9	6.5	5.6	6.4	8.2	
Mean	72.9	82.5	87.6	86.6	81.9	74.9	62.1	48.0	40.8	38.6	45.7	58.5	
Maximum	90.0	90.0	90.0	90.0	90.0	90.0	86.6	86.8	89.2	89.9	90.0	90.0	
Exceeded 95%	32.9	50.2	77.3	80.0	68.2	60.7	42.4	20.9	7.2	7.8	11.0	21.3	
Exceeded 90%	45.0	62.8	84.0	82.7	74.2	62.5	44.3	31.6	17.8	9.6	16.2	27.4	
Exceeded 75%	57.0	79.0	89.1	86.8	79.2	69.2	53.5	38.2	26.5	25.4	30.1	42.8	
Median	81.2	90.0	89.9	89.3	83.9	76.4	63.5	44.0	33.3	35.4	40.2	59.3	

Notes: * 1 GL (gigalitre) = 1 M m³ (million cubic metres)



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Table 9: Average monthly projected water level in the Makaroro Reservoir (m RL HBRC datum).

Hydrological Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Mean
1972 - 1973	469.2	469.2	469.1	466.8	462.2	460.1	453.3	440.8	426.0	426.4	432.1	441.0	451.5
1973 - 1974	448.1	456.0	464.1	468.2	467.1	465.0	461.1	453.7	450.6	450.3	459.7	466.7	459.2
1974 - 1975	469.2	469.2	469.2	469.2	468.1	464.5	462.3	459.9	457.2	454.2	452.7	461.3	463.1
1975 - 1976	468.0	469.2	469.2	469.1	469.1	466.5	464.7	463.6	462.4	460.9	463.5	465.3	466.0
1976 - 1977	468.2	469.2	469.2	469.2	469.2	469.1	467.2	462.5	457.9	454.4	455.4	463.7	464.6
1977 - 1978	469.2	469.2	469.2	469.2	467.4	463.1	460.3	452.7	442.9	437.0	440.8	450.1	457.6
1978 - 1979	466.2	469.2	469.1	469.1	468.4	465.2	459.5	448.1	443.4	444.6	446.2	453.4	458.6
1979 - 1980	461.6	465.8	469.2	469.2	467.0	460.5	457.0	450.9	448.2	457.6	462.9	465.2	461.3
1980 - 1981	468.8	469.2	469.2	468.1	465.3	463.1	465.9	462.7	460.6	462.3	467.2	469.2	466.0
1981 - 1982	469.2	469.2	469.2	468.5	468.7	466.0	461.0	450.7	444.9	442.9	445.7	452.9	459.2
1982 - 1983	458.4	464.5	465.6	464.1	462.5	458.1	448.4	434.8	425.0	426.6	439.0	456.5	450.4
1983 - 1984	465.9	468.8	469.0	469.1	468.6	466.1	460.7	455.3	452.7	452.1	451.1	454.6	461.2
1984 - 1985	456.0	462.3	469.2	468.8	465.1	460.8	457.9	451.1	447.2	445.4	445.8	455.2	457.1
1985 - 1986	462.2	469.2	468.9	466.7	466.2	466.5	462.6	461.4	461.5	458.5	455.9	456.8	463.0
1986 - 1987	458.7	463.3	468.6	469.2	467.0	464.2	456.7	446.4	444.8	449.5	450.8	452.1	457.7
1987 - 1988	457.3	465.5	468.7	467.1	465.9	465.7	459.7	454.4	466.0	468.4	468.9	469.2	464.8
1988 - 1989	469.2	469.2	469.2	468.5	464.2	460.5	455.5	451.9	441.4	428.8	431.1	441.5	454.3
1989 - 1990	445.5	450.7	466.5	469.2	467.7	468.5	462.9	456.7	450.9	447.4	447.8	450.8	457.0
1990 - 1991	454.8	464.0	469.1	469.1	467.7	464.2	455.9	446.9	445.8	446.0	458.3	462.5	458.8
1991 - 1992	465.6	468.5	469.2	468.8	469.0	467.5	465.4	461.5	460.4	457.7	458.4	465.2	464.8
1992 - 1993	469.2	469.2	469.2	469.2	469.1	469.2	468.1	465.5	468.3	469.2	469.2	469.2	468.7
1993 - 1994	469.2	469.2	469.2	468.2	466.2	465.4	462.8	458.6	450.7	444.9	446.6	454.4	460.5
1994 - 1995	460.8	469.2	469.0	469.1	468.4	462.1	452.6	448.1	445.4	450.9	461.5	467.4	460.4
1995 - 1996	469.2	469.2	469.1	469.1	468.8	465.3	461.5	460.3	458.9	456.6	458.8	463.1	464.2
1996 - 1997	468.9	469.2	469.1	467.6	464.9	461.4	457.2	452.6	450.8	449.7	452.1	459.6	460.3
1997 - 1998	468.4	469.2	469.2	469.2	467.8	462.3	451.6	434.0	424.6	423.1	424.4	427.3	449.4
1998 - 1999	438.2	455.2	457.6	454.5	454.6	459.7	453.4	451.4	443.8	443.0	450.9	459.2	451.8
1999 - 2000	463.3	466.9	468.3	467.2	464.3	466.6	462.1	456.3	447.0	445.9	450.9	454.5	459.5
2000 - 2001	466.7	469.2	469.1	468.9	467.8	467.2	462.3	456.7	454.0	448.6	452.8	460.9	462.1
2001 - 2002	464.2	468.8	469.1	467.7	468.0	467.7	467.2	468.2	468.0	465.5	465.8	469.1	467.4
2002 - 2003	469.2	469.2	469.2	468.8	465.6	464.9	461.4	452.6	447.0	444.2	445.0	449.3	458.9
2003 - 2004	452.6	458.1	469.2	469.2	466.9	466.6	462.7	463.6	468.9	466.8	466.8	468.9	465.0
2004 - 2005	469.2	469.2	469.2	469.2	467.1	464.6	461.3	452.4	440.7	440.0	446.0	463.1	459.4
2005 - 2006	469.2	469.2	468.1	469.1	467.7	465.7	459.9	455.8	446.6	449.2	466.4	469.1	463.1
2006 - 2007	469.2	469.2	468.8	468.7	468.4	464.3	458.2	448.4	435.8	429.9	430.4	436.2	454.0
2007 - 2008	455.9	469.1	469.2	469.2	467.2	462.8	459.4	449.0	438.8	432.1	440.3	446.8	455.0
Minimum	438.2	450.7	457.6	454.5	454.6	458.1	448.4	434.0	424.6	423.1	424.4	427.3	
Mean	463.2	466.7	468.4	468.1	466.6	464.5	460.0	453.9	449.4	448.1	451.7	457.5	
Maximum	469.2	469.2	469.2	469.2	469.2	469.2	468.1	468.2	468.9	469.2	469.2	469.2	
Exceeded 95%	447.4	455.8	465.2	466.1	462.4	460.0	452.3	439.3	425.7	426.5	430.9	439.8	
Exceeded 90%	453.7	460.2	467.3	466.9	464.3	460.5	453.4	446.7	437.3	429.4	435.6	444.2	
Exceeded 75%	458.6	465.8	468.9	468.2	465.8	462.7	457.2	450.3	443.7	443.0	445.8	452.7	
Median	466.4	469.2	469.1	469.0	467.3	465.0	460.8	453.2	447.7	448.9	451.6	459.4	



7.7 River Flow

7.7.1 Base Scenario

The projected flow immediately downstream of the reservoir under the base scenario (Table 3) is reported together with the projected changes due to the development of the reservoir. The projected flows immediately downstream of the reservoir under the base scenario are summarised in Table 10, Table 11 and Table 12. Flow duration curves (i.e. cumulative probability curves of the flow distribution) are shown in Figure 11.

Compared with the inflow duration curve, the projected dam outflow duration curve clearly reflects the effect of storage regulation. There is a step in the outflow duration curve at approximately 11,140 L/s, which indicates that the dam outflow is projected to be sustained constantly at this flow for significant periods (about 8 % of the time). At the low flow end, the dam outflow is projected to be maintained at the environmental residual flow of 1,228 L/s for prolonged periods (i.e. some 33 % of the time). During very low flow periods, the managed outflow regime is projected to be higher than the pre-existing flow regime. This flow augmentation effect is projected to occur for about 3% of the time (11 days per year) on average, but up to 6 % of the time (22 days) during a dry year such as 1972-1973.



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Table 10: Projected mean monthly dam outflows – comprising irrigation supply, environmental, residual and spill flow.

Hydrological Year	Jul (m ³ /s)	Aug (m ³ /s)	Sep (m ³ /s)	Oct (m ³ /s)	Nov (m ³ /s)	Dec (m ³ /s)	Jan (m ³ /s)	Feb (m ³ /s)	Mar (m ³ /s)	Apr (m ³ /s)	May (m ³ /s)	Jun (m ³ /s)	Mean (m ³ /s)
1972- 1973	6.96	3.76	5.41	6.42	8.15	5.51	9.01	11.04	2.67	1.23	1.23	1.23	5.18
1973- 1974	1.23	1.23	1.24	4.90	5.67	8.61	8.36	8.07	5.38	7.30	1.23	10.52	5.28
1974- 1975	16.54	10.53	15.03	8.05	7.89	6.55	5.48	9.07	10.27	6.61	1.23	1.23	8.20
1975- 1976	1.89	4.93	7.40	7.06	5.84	10.71	9.81	7.08	8.27	1.65	1.23	1.23	5.60
1976- 1977	3.74	15.13	22.84	11.91	10.16	5.97	7.94	8.30	9.12	7.11	1.23	4.10	8.94
1977- 1978	12.26	17.42	16.93	8.07	7.82	5.04	9.74	7.16	8.98	4.01	1.23	1.23	8.34
1978- 1979	9.23	7.05	3.90	3.88	7.05	5.72	11.49	9.69	12.01	1.84	1.23	1.23	6.19
1979- 1980	1.23	2.79	15.37	9.31	7.75	10.28	6.37	9.16	10.22	1.49	1.23	1.23	6.35
1980- 1981	5.21	4.89	5.21	6.47	6.22	14.89	5.94	7.22	4.98	3.75	2.06	12.52	6.61
1981- 1982	7.37	10.17	8.61	4.76	5.83	5.93	10.53	11.32	3.20	5.23	1.23	1.23	6.25
1982- 1983	1.23	1.23	3.43	4.38	6.77	8.14	10.13	8.23	1.59	1.23	1.23	1.23	4.04
1983- 1984	1.23	1.35	3.41	6.35	6.12	6.30	10.59	3.99	3.07	4.30	1.23	1.23	4.10
1984- 1985	1.23	1.23	12.21	6.35	8.02	5.93	6.52	9.36	10.88	5.92	1.23	1.23	5.80
1985- 1986	2.25	8.88	5.70	4.47	3.68	10.79	7.63	7.40	4.63	6.64	1.23	1.23	5.37
1986- 1987	1.23	1.23	13.97	6.34	7.63	6.77	10.24	8.62	5.11	6.05	1.23	1.23	5.76
1987- 1988	1.23	1.23	3.23	6.75	7.47	8.81	11.06	7.63	8.44	3.73	1.71	3.80	5.42
1988- 1989	17.82	13.42	13.72	7.72	7.83	7.60	6.30	6.81	9.32	3.23	1.23	1.23	8.04
1989- 1990	1.23	1.23	18.11	10.39	8.07	9.39	10.85	7.84	6.19	4.10	1.23	1.23	6.63
1990- 1991	1.23	1.30	4.44	5.19	4.49	10.95	8.94	6.79	1.65	4.47	1.23	1.23	4.31
1991- 1992	1.23	5.75	3.19	5.73	10.44	6.60	6.55	5.76	6.38	3.28	1.23	1.52	4.80
1992- 1993	22.10	10.84	10.70	20.49	7.36	8.22	7.73	11.97	4.97	4.14	5.72	4.88	9.94
1993- 1994	2.88	4.40	5.79	6.90	2.51	5.99	5.89	9.58	6.29	4.04	1.23	1.23	4.70
1994- 1995	1.23	6.84	4.82	6.35	10.33	11.25	8.25	5.79	4.79	7.87	1.23	4.17	6.07
1995- 1996	15.17	7.98	5.31	7.30	6.05	8.86	7.89	4.59	6.23	5.25	1.23	1.23	6.46
1996- 1997	17.85	7.98	6.41	6.04	7.15	10.18	6.96	6.22	5.73	2.76	1.23	1.23	6.67
1997- 1998	7.18	7.20	9.49	12.43	8.03	11.49	11.49	8.88	1.59	1.23	1.23	1.23	6.79
1998- 1999	1.23	1.23	5.19	5.67	4.74	6.68	9.75	9.54	4.28	6.83	1.23	1.23	4.76
1999- 2000	1.23	1.23	2.35	6.19	5.04	8.77	6.84	9.77	6.24	6.72	1.23	1.23	4.72
2000- 2001	9.39	5.21	6.32	10.83	2.48	7.89	8.95	5.82	6.86	3.37	1.23	1.23	5.82
2001- 2002	1.23	6.70	5.17	2.86	3.65	8.77	7.79	5.77	6.30	3.67	1.23	8.63	5.14
2002- 2003	19.28	11.69	4.63	6.26	5.68	6.75	8.99	11.13	6.88	3.01	1.23	1.23	7.24
2003- 2004	1.23	2.35	24.29	8.12	7.84	5.90	11.14	10.82	7.45	4.15	1.23	7.36	7.60
2004- 2005	10.02	11.31	5.74	10.06	8.56	5.90	10.14	11.41	8.41	4.12	1.23	3.55	7.53
2005- 2006	17.44	4.65	4.75	14.76	7.38	16.35	9.82	7.45	6.87	1.36	1.23	10.29	8.57
2006- 2007	27.03	10.65	4.90	3.47	8.09	7.51	9.73	10.07	7.94	2.46	1.23	1.23	7.88
2007- 2008	1.23	7.88	7.18	8.13	8.05	5.37	10.41	9.99	6.24	2.03	1.23	1.23	5.74
Minimum	1.23	1.23	1.24	2.86	2.48	5.04	5.48	3.99	1.59	1.23	1.23	1.23	4.04
Mean	6.98	6.19	8.23	7.51	6.83	8.23	8.76	8.31	6.37	4.06	1.39	2.83	6.30
Maximum	27.03	17.42	24.29	20.49	10.44	16.35	11.49	11.97	12.01	7.87	5.72	12.52	9.94



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Table 11: Mean monthly reservoir inflows, i.e. the pre-existing flow regime at the Makaroro Dam site.

Hydrological Year	Jul (m ³ /s)	Aug (m ³ /s)	Sep (m ³ /s)	Oct (m ³ /s)	Nov (m ³ /s)	Dec (m ³ /s)	Jan (m ³ /s)	Feb (m ³ /s)	Mar (m ³ /s)	Apr (m ³ /s)	May (m ³ /s)	Jun (m ³ /s)	Mean (m ³ /s)
1972- 1973	6.96	3.76	4.20	2.70	2.07	2.75	1.63	1.24	1.50	1.77	4.44	6.16	3.28
1973- 1974	5.26	10.28	10.34	3.56	6.29	2.85	2.17	1.70	5.22	12.06	8.98	18.14	7.23
1974- 1975	16.54	10.53	15.03	8.10	3.20	2.77	6.28	2.40	9.62	2.18	4.31	13.80	7.93
1975- 1976	5.14	4.93	7.40	7.15	6.06	5.45	8.40	8.44	2.81	3.83	4.39	3.04	5.58
1976- 1977	7.37	15.13	22.84	11.91	10.24	5.87	3.05	3.13	3.73	5.48	5.92	16.66	9.28
1977- 1978	12.26	17.42	16.93	7.42	3.11	2.69	2.00	2.08	1.35	4.96	4.37	16.61	7.62
1978- 1979	18.71	7.05	4.04	3.94	4.05	2.09	1.38	1.66	12.24	2.40	4.56	6.71	5.79
1979- 1980	8.57	10.38	15.37	8.60	2.32	2.79	3.76	3.96	11.87	12.74	3.09	5.88	7.44
1980- 1981	7.36	4.89	4.84	3.39	2.68	16.21	5.02	3.08	3.78	10.84	6.31	12.52	6.76
1981- 1982	7.37	10.17	8.61	4.93	3.34	2.57	1.50	2.95	1.81	4.77	5.24	6.35	4.98
1982- 1983	8.39	5.15	2.52	2.98	2.35	2.08	1.62	1.94	1.25	4.03	7.53	17.55	4.79
1983- 1984	6.63	2.44	2.74	7.22	3.88	2.57	1.91	1.81	2.60	1.73	3.90	2.97	3.38
1984- 1985	2.67	14.66	13.55	3.50	1.83	3.37	2.22	3.68	10.41	3.55	5.10	9.56	6.19
1985- 1986	14.24	8.88	3.75	2.82	3.56	8.50	3.65	6.85	4.10	1.80	1.96	2.08	5.19
1986- 1987	4.70	9.30	16.13	6.17	2.50	2.34	1.43	1.18	10.16	6.06	2.68	2.37	5.44
1987- 1988	12.69	5.35	4.91	2.69	9.63	3.91	2.33	10.80	21.26	3.27	2.65	3.80	6.94
1988- 1989	17.82	13.42	13.68	4.64	2.14	1.79	3.43	2.35	2.25	1.16	5.09	4.46	6.06
1989- 1990	3.08	11.76	31.60	10.41	8.31	6.05	2.58	2.31	2.86	1.94	2.95	4.24	7.34
1990- 1991	8.22	11.75	3.78	5.42	3.16	1.95	1.34	1.52	2.89	5.48	12.77	4.99	5.31
1991- 1992	4.41	8.44	3.26	3.90	14.86	3.14	2.25	3.96	3.02	2.69	4.56	11.99	5.52
1992- 1993	22.10	10.84	10.70	20.49	7.94	8.22	3.27	14.84	6.93	4.15	5.78	4.88	10.01
1993- 1994	2.88	4.40	5.79	3.10	3.54	2.73	1.86	2.34	1.63	1.75	6.83	6.01	3.57
1994- 1995	14.28	7.15	4.97	6.61	6.31	1.89	1.80	4.17	2.71	16.18	9.94	10.18	7.18
1995- 1996	15.17	7.98	5.43	7.17	5.75	3.01	4.23	3.95	3.08	5.61	5.95	8.17	6.31
1996- 1997	20.38	7.98	5.45	3.51	3.92	3.51	4.65	2.31	5.26	3.27	3.46	9.79	6.16
1997- 1998	16.22	7.20	9.49	12.21	4.25	1.98	1.08	1.08	0.84	1.54	1.46	2.56	5.03
1998- 1999	13.33	5.15	3.52	5.47	6.23	6.60	7.86	2.73	2.67	6.66	8.67	9.00	6.52
1999- 2000	6.26	3.85	3.04	2.22	7.83	3.87	2.52	1.53	2.05	9.54	3.91	5.07	4.30
2000- 2001	23.52	5.21	7.03	8.23	4.24	2.88	3.07	1.77	2.70	2.01	10.33	5.20	6.41
2001- 2002	7.52	9.28	4.07	2.76	2.96	9.42	6.74	8.49	2.78	2.45	5.09	9.50	5.91
2002- 2003	19.28	11.69	5.49	4.08	2.69	6.24	1.65	2.18	4.87	2.67	2.84	4.37	5.72
2003- 2004	3.05	19.82	24.29	7.87	4.18	5.02	5.79	19.26	5.49	2.30	3.74	8.68	9.06
2004- 2005	10.02	11.31	6.25	10.18	2.79	5.00	2.49	1.86	5.21	3.80	12.14	20.00	7.63
2005- 2006	17.44	4.65	3.82	15.93	4.27	12.41	3.06	2.13	4.01	11.99	11.83	10.89	8.60
2006- 2007	27.03	10.65	3.93	4.21	4.23	2.61	1.50	1.35	3.21	2.21	1.41	8.16	5.93
2007- 2008	23.55	8.59	7.18	7.75	2.92	3.20	1.66	0.94	1.97	3.04	6.05	7.37	6.23
Minimum	2.67	2.44	2.52	2.22	1.83	1.79	1.08	0.94	0.84	1.16	1.41	2.08	3.28
Mean	11.68	8.93	8.78	6.48	4.71	4.45	3.09	3.83	4.73	4.78	5.56	8.33	6.29
Maximum	27.03	19.82	31.60	20.49	14.86	16.21	8.40	19.26	21.26	16.18	12.77	20.00	10.01



Table 12: Projected change in monthly mean flows below the dam site when the scheme is in full operation.

Hydrological Year	Jul (m ³ /s)	Aug (m ³ /s)	Sep (m ³ /s)	Oct (m ³ /s)	Nov (m ³ /s)	Dec (m ³ /s)	Jan (m ³ /s)	Feb (m ³ /s)	Mar (m ³ /s)	Apr (m ³ /s)	May (m ³ /s)	Jun (m ³ /s)
Mean Inflow	11.68	8.93	8.78	6.48	4.71	4.45	3.09	3.83	4.73	4.78	5.56	8.33
Mean Outflow	6.98	6.19	8.23	7.51	6.83	8.23	8.76	8.31	6.37	4.06	1.39	2.83
Difference outflow-inflow	-4.70	-2.74	-0.55	1.03	2.12	3.78	5.67	4.48	1.64	-0.72	-4.17	-5.50

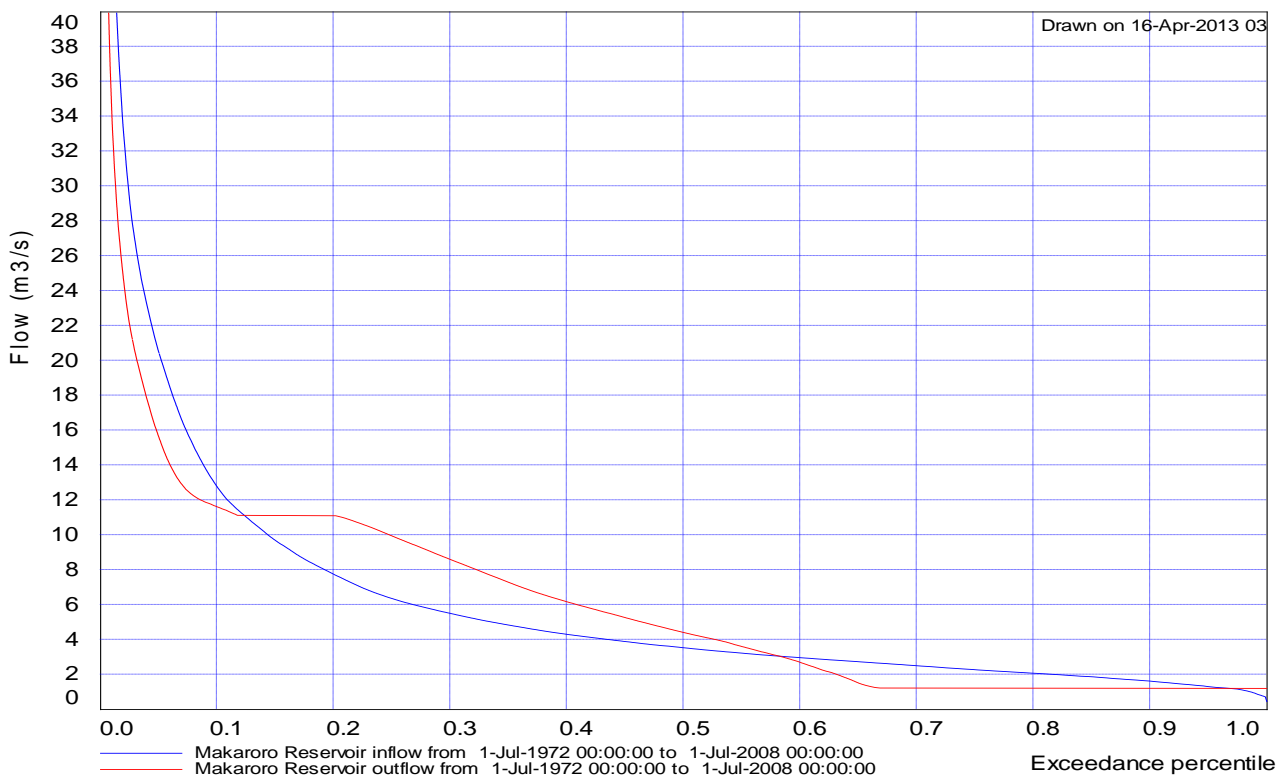


Figure 11: Makaroro Dam site projected outflow (red) versus inflow (blue) duration curves.

7.7.2 Additional scenarios

To allow consideration of the potential effects of the transfer of existing takes to the scheme, the increased recharge associated with irrigation and the potential effect of a secondary residual flow allowance, a total of 14 scenarios were modelled with the projected flows reported for both the Waipawa River at RDS and Tukituki River at Red Bridge. A summary of the scenarios is provided in Table 13 and the projected downstream flow statistics are provided in Table 14 and Table 15. This assessment was undertaken using downstream flows projected by the GoldSim model using the methodologies outlined in Waldron and Baalousha (2013) which uses Tonkin & Taylor’s modelling of the Makaroro Reservoir.



Table 13: Scenario summary for considering the transfer of existing takes and the increased recharge associated with irrigation.

Scenario Name	Key Criteria	Comment
No dam	Dam removed	Represents the current situation with the current takes
Scenario 4	Base reservoir scenario plus existing takes.	As per Scenario 4 in Waldron and Baalousha (2013). Represents worst case scenario – i.e. no existing takes transfer to the scheme and no consideration of increased drainage due to new irrigation.
Scenario 5	Base reservoir scenario plus existing groundwater takes. All existing surface and stream depleting takes transfer to the scheme.	As per Scenario 5 in Waldron and Baalousha (2013). No consideration of increased drainage due to new irrigation.
30 % GW	Base reservoir scenario plus existing surface and stream depleting takes and assuming 30% of existing groundwater takes transfer to the scheme.	The 30% of the groundwater takes that transfer to the scheme are assumed to be evenly distributed throughout the scheme command area. No consideration of increased drainage due to new irrigation.
50 % GW	Base reservoir scenario plus existing surface and stream depleting takes and assuming 50% of existing groundwater takes transfer to the scheme.	The 50% of the groundwater takes that transfer to the scheme are assumed to be evenly distributed throughout the scheme command area. No consideration of increased drainage due to new irrigation.
80 % GW	Base reservoir scenario plus existing surface and stream depleting takes and assuming 80% of existing groundwater takes transfer to the scheme.	The 80% of the groundwater takes that transfer to the scheme are assumed to be evenly distributed throughout the scheme command area. No consideration of increased drainage due to new irrigation.
Scenario 3	Base reservoir scenario with all existing takes (surface, stream depleting and groundwater) transferred to the scheme.	As per Scenario 3 in Waldron and Baalousha (2013). Represents a mid-range scenario – i.e. all existing takes transfer to the scheme but no consideration of increased drainage due to new irrigation.
Scenario 4 plus secondary residual	Scenario 4 above but allowing for supplementation of flows below Q99 back up to Q99	No consideration of increased drainage due to new irrigation.
Scenario 4 incl. drainage	As per Scenario 4 with consideration of increased drainage due to new irrigation.	
Scenario 5 incl. drainage	As per Scenario 5 with consideration of increased drainage due to new irrigation.	
30 % GW incl. drainage	As per Scenario 30% GW with consideration of increased drainage due to new irrigation.	
50 % GW incl. drainage	As per Scenario 50% GW with consideration of increased drainage due to new irrigation.	
80 % GW incl. drainage	As per Scenario 80% GW with consideration of increased drainage due to new irrigation.	
Scenario 3 incl. drainage	As per Scenario 3 with consideration of increased drainage due to new irrigation.	Represents a best case scenario – i.e. all existing takes transfer to the scheme and consideration of increased drainage due to new irrigation.

Notes: The model projections for the un-shaded cells (the first 8 Scenarios) are presented in Table 14. The model projections for the shaded cells (the last 6 scenarios) are presented in Table 15.



Table 14: Flow statistics and statistics for days when projected average daily flow is less than the minimum, return irrigation water excluded.

Hydrological year	Waipawa at RDS - days below 2500L/s								Tukituki at Red Bridge - days below 5,200 L/s							
	No dam Scenario 2	Base Scenario 4	Scenario 5	30% GW	50 % GW	80 % GW	Scenario 3	Scenario 4 with secondary residual	No dam Scenario 2	Base Scenario 4	Scenario 5	30% GW	50 % GW	80 % GW	Scenario 3	Scenario 4 with secondary residual
1972 - 1973	17	34	25	31	30	18	9	34	68	79	67	65	55	46	42	79
1973 - 1974	0	0	0	0	0	0	0	0	5	12	5	6	3	2	2	12
1974 - 1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975 - 1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976 - 1977	46	61	53	59	55	44	32	61	16	21	18	14	12	6	4	21
1977 - 1978	43	57	50	54	53	40	18	57	37	43	37	33	26	21	18	43
1978 - 1979	76	84	79	84	83	74	70	84	52	56	52	53	50	47	45	56
1979 - 1980	19	32	26	29	27	21	10	32	7	13	8	8	0	0	0	13
1980 - 1981	13	21	18	16	15	10	8	21	0	0	0	0	0	0	0	0
1981 - 1982	0	0	0	0	0	0	0	0	24	36	22	24	15	11	7	36
1982 - 1983	111	125	116	121	119	109	96	125	38	46	37	38	33	12	3	46
1983 - 1984	65	74	72	74	72	62	60	74	38	49	38	33	26	18	15	49
1984 - 1985	20	32	28	32	31	15	7	32	52	62	52	45	38	35	34	62
1985 - 1986	19	44	37	35	29	12	4	44	2	5	2	0	0	0	0	5
1986 - 1987	65	76	71	75	75	65	57	76	47	59	51	49	40	32	30	59
1987 - 1988	6	9	9	7	7	2	0	9	19	22	18	17	15	11	8	22
1988 - 1989	24	49	41	40	29.5	11	4	49	38	49	36	33	17	0	0	49
1989 - 1990	0	0	0	0	0	0	0	0	0	6	0	1	0	0	0	6
1990 - 1991	15	53	30	38	33	25	3	53	35	53	36	28	19	13	12	53
1991 - 1992	0	4	0	4	3	0	0	4	2	5	2	2	1	0	0	5
1992 - 1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993 - 1994	9	41	28	35	33	7	2	41	19	34	24	15	6	0	0	34
1994 - 1995	0	2	0	0	0	0	0	2	13	21	11	15	8	4	2	21
1995 - 1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996 - 1997	0	0	0	0	0	0	0	0	7	11	7	7	5	5	5	11
1997 - 1998	111	129	125	120	116	100	87	129	101	102	101	100	95	89	84	102
1998 - 1999	2	6	3	5	4	4	0	6	4	11	0	9	0	0	0	11
1999 - 2000	17	29	29	27	21	10	0	29	9	24	14	10	5	1	0	24
2000 - 2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001 - 2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002 - 2003	0	3	3	0	0	0	0	3	17	21	17	16	14	9	6	21
2003 - 2004	0	4	3	2	2	0	0	4	0	2	0	0	0	0	0	2
2004 - 2005	21	31	21	29	27	19	10	31	19	22	20	20	17	12	10	22
2005 - 2006	5	9	6	7	6	2	0	9	0	3	0	0	0	0	0	3
2006 - 2007	26	56	46	54	45	9	0	56	43	56	41	40	27	15	10	56
2007 - 2008	32	51	44	48	37	22	14	51	26	33	27	26	22	10	7	33
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	21.2	31.0	26.8	28.5	26.5	18.9	13.6	31.0	20.5	26.6	20.6	19.6	15.3	11.1	9.6	26.6
Maximum	111	129	125	121	119	109	96	129	101	102	101	100	95	89	84	102
Median	11	25	19.5	21.5	18	8	0	25	14.5	21	15.5	14.5	7	3	2	21
90 th percentile i.e. 1 in 10 dry year	65	75	71.5	74.5	73.5	63.5	58.5	75	49.5	57.5	51.5	47	39	33.5	32	57.5
Flow Statistics L/s																
Median	8,538	6,418	6,493	6,475	6,513	6,570	6,682	6,418	20,801	18,912	19,088	19,105	19,236	19,432	19,764	18,912
Mean	14,639	12,273	12,344	12,331	12,369	12,426	12,535	12,273	43,158	40,790	40,975	40,987	41,117	41,314	41,629	40,790
Q99	1,871	2,085	2,085	2,151	2,187	2,269	2,306	2,085	3,602	3,765	3,766	3,986	4,140	4,369	4,488	3,765
7-Day MALF	2,688	2,534	2,594	2,597	2,639	2,702	2,804	2,534	5,328	5,141	5,256	5,366	5,515	5,737	6,004	5,141



Table 15: Flow statistics and statistics for days when projected average daily flow is less than the minimum, return irrigation water included.

Hydrological year	Waipawa at RDS - days below 2500L/s							Tukituki at Red Bridge - days below 5,200 L/s						
	No dam Scenario 2 incl. drainage	Base Scenario 4 incl. drainage	Scenario 5 incl. drainage	30% GW incl. drainage	50 % GW incl. drainage	80 % GW incl. drainage	Scenario 3 incl. drainage	No dam Scenario 2 incl. drainage	Base Scenario 4 incl. drainage	Scenario 5 incl. drainage	30% GW incl. drainage	50 % GW incl. drainage	80 % GW incl. drainage	Scenario 3 incl. drainage
1972 - 1973	17	30	20	24	14	4	0	68	57	57	47	43	33	28
1973 - 1974	0	0	0	0	0	0	0	5	4	4	2	2	2	2
1974 - 1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975 - 1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976 - 1977	46	59	47	49	41	24	6	16	13	13	8	4	3	2
1977 - 1978	43	53	49	46	35	8	3	37	29	29	22	19	17	9
1978 - 1979	76	84	76	76	73	56	41	52	50	50	47	46	43	40
1979 - 1980	19	28	21	24	18	6	1	7	3	3	0	0	0	0
1980 - 1981	13	15	14	13	9	2	1	0	0	0	0	0	0	0
1981 - 1982	0	0	0	0	0	0	0	24	17	17	12	8	0	0
1982 - 1983	111	120	113	114	104	78	66	38	33	33	21	5	0	0
1983 - 1984	65	73	68	68	61	52	48	38	26	26	20	16	12	10
1984 - 1985	20	32	22	20	10	1	0	52	40	40	34	34	31	30
1985 - 1986	19	33	22	19	10	0	0	2	0	0	0	0	0	0
1986 - 1987	65	75	69	70	62	49	40	47	41	41	31	30	21	13
1987 - 1988	6	7	7	5	0	0	0	19	15	15	11	10	5	0
1988 - 1989	24	40	33	21	9	0	0	38	26	26	3	0	0	0
1989 - 1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990 - 1991	15	37	17	28	11	1	0	35	20	20	13	12	7	0
1991 - 1992	0	3	0	1	0	0	0	2	1	1	0	0	0	0
1992 - 1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993 - 1994	9	35	18	18	4	1	0	19	8	8	0	0	0	0
1994 - 1995	0	0	0	0	0	0	0	13	8	8	4	2	1	0
1995 - 1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996 - 1997	0	0	0	0	0	0	0	7	5	5	5	5	4	4
1997 - 1998	111	119	113	111	93	67	47	101	95	95	92	87	75	67
1998 - 1999	2	5	0	4	4	0	0	4	0	0	0	0	0	0
1999 - 2000	17	26	26	17	8	0	0	9	6	6	1	0	0	0
2000 - 2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001 - 2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002 - 2003	0	0	0	0	0	0	0	17	14	14	10	6	4	0
2003 - 2004	0	2	2	0	0	0	0	0	0	0	0	0	0	0
2004 - 2005	21	28	20	26	18	6	0	19	18	18	12	11	7	5
2005 - 2006	5	7	2	6	1	0	0	0	0	0	0	0	0	0
2006 - 2007	26	50	36	23	3	1	0	43	28	28	15	10	3	0
2007 - 2008	32	46	36	31	22	8	3	26	23	23	13	7	1	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	21.2	28.0	23.1	22.6	16.9	10.1	7.1	20.5	16.1	16.1	11.8	9.9	7.5	5.8
Maximum	111	120	113	114	104	78	66	101	95	95	92	87	75	67
Median	11	20.5	15.5	15	4	0	0	14.5	8	8	3.5	2	0	0
90th percentile i.e. 1 in 10 dry year	65	74	68.5	69	61.5	50.5	40.5	49.5	40.5	40.5	32.5	32	26	20.5
Flow Statistics L/s														
Median	8,538	6,494	6,568	6,551	6,497	6,646	6,757	20,801	19,241	19,418	19,435	19,566	19,761	20,094
Mean	14,639	12,349	12,420	12,406	12,445	12,502	12,611	43,158	41,120	41,305	41,317	41,447	41,644	41,959
Q99	1,871	2,162	2,162	2,230	2,282	2,332	2,378	3,602	4,099	4,101	4,326	4,464	4,683	4,855
7-Day MALF	2,688	2,610	2,670	2,673	2,715	2,778	2,880	5,328	5,471	5,586	5,695	5,845	6,067	6,334



8.0 MODEL PEER REVIEW

The model has received the following three-stage peer review in line with Golder's internal review procedures and HBRIC Ltd's request that the model receive an external review by the GoldSim Technology Group in the USA.

- 1) A detailed review of the model calculations was undertaken by a GoldSim modeller in Golder's Christchurch Office, who had not previously been involved in the project. This calculation review was undertaken in an informal manner with any identified concerns discussed and addressed.
- 2) The revised model was subsequently externally peer reviewed by Mr Jason Lillywhite, a water resources specialist at GoldSim Technology Group in the USA. Mr Lillywhite is an experienced modeller of natural water systems including reservoirs. This review involved a process where the principal modeller who created the model explained the model to the external reviewer via an interactive computer linked session. The external reviewer subsequently reviewed the model and provided comments, which were subsequently discussed and where necessary addressed.
- 3) The third stage of the model review was conducted by Mr Charles Voss an experienced senior GoldSim reviewer from Golder's Redmond Office in the USA. This review involved a high level strategic review of the model and a technical review of this model report. Review comments received from Mr Voss were discussed and, where necessary, addressed.

A final version of the model titled *ruataniwha_V45 post review final* was prepared and provided to HBRIC Ltd on 9 April 2013. This report documents the *ruataniwha_V45 post review final* version of the model and the projections documented in this report have been derived using that version of the model.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The GoldSim model of the Ruataniwha Water Storage Scheme has been constructed with considerable flexibility to allow the rapid assessment and comparison of numerous scenarios. While uncertainties in the input data will transfer to uncertainties in the model projections for individual variables within a scenario, the model does allow comparisons between scenarios. Such comparisons can support and inform management decisions.

The model is comprised of two components. The first projects how the reservoir is expected to function under various management regimes. Projections were used to develop an operational regime for the scheme, which is documented in the project description report (Tonkin & Taylor 2013), and provided much of the thinking behind the comments in the environmental flow optimisation report (Aquanet 2013). The objective of the reservoir component of the model was to evaluate alternative allocation regimes from the reservoir and assess the reliability of supply for the various competing uses. The second component is used to project down stream flows using the methodologies outlined in Waldron and Baalousha (2013) which are based on Tonkin & Taylor's modelling of the Makaroro Reservoir. The model predictions were used to assess the impacts of both the transfer of existing takes and the increased recharge associated with the new irrigation and to produce the downstream flow statistics which were used within the environmental flow optimisation report (Aquanet 2013).

The model has been internally peer reviewed within Golder and has received an external peer review by the GoldSim Technology Group. Issues identified during the review process were discussed and where necessary the model updated accordingly.

During the model construction, use, documentation and review processes as they pertain to the parts of the model that were used to prepare the modelling projections that have fed into the environmental flow



optimisation report (Aquanet 2013) and the project description report (Tonkin & Taylor 2013) the following seven recommendations were identified, which are aimed at improving the robustness of the model and its use.

- 1) The GoldSim model contains a large number of time series data (i.e., stream flow, irrigation demand and water use). The reliability of the model projections and the associated uncertainty depends in part on the accuracy of the data. It is recommended that the time series data referenced in the model be verified and its representativeness and accuracy assessed so that a complete assessment of the accuracy of the model projections can be completed.
- 2) An assessment of the potential increase in baseflow associated with new irrigation has been included in the GoldSim model. This assessment is considered preliminary and it is recommended that the potential impacts of increased recharge due to new irrigation be addressed more formally through use of a groundwater model.
- 3) When assessing flushing flows the current GoldSim model does not consider attenuation of flows as they move down through the river system. It is recommended that consideration be given to updating the flushing flow part of the GoldSim model to incorporate a preliminary assessment of flow attenuation which utilises the findings of the HBRC's Mike 11 Surface Water Hydrodynamic Model and recognises the daily timestep of the GoldSim model.
- 4) The model projects a significant volume of secondary irrigation water is potentially available although much of it only becomes available late in the irrigation season when irrigation demand is likely to be lower. Golder recommends that further work be undertaken to assess the usefulness of the potentially available secondary irrigation water and particularly when and how it would be utilised.
- 5) Waldron and Baalousha (2013) assessed the likely effects of the implementation of the Scheme on downstream river flows under three scenarios of existing takes transferring to the Scheme. Their assessment was based on projections from a groundwater model. A preliminary assessment of three intermediary scenarios (between the three assessed by Waldron and Baalousha) has been undertaken using the GoldSim model. Golder recommends that the potential effect of the implementation of the Scheme on river flows under the three intermediary scenarios be addressed more formally through use of the Waldron and Baalousha groundwater model. Similarly, once there is a better understanding of which existing takes will and will not transfer to the Scheme, the likely effects of the implementation of the Scheme on river flows should be reassessed through use of the Waldron and Baalousha groundwater model and linked surface water model.
- 6) The GoldSim model of the Makaroro Reservoir includes consideration of all the proposed releases from the reservoir other than those for hydroelectricity generation. It is recommended that consideration be given to updating the GoldSim model to incorporate the hydroelectricity generation part do the proposed Scheme.
- 7) Currently the model is solely deterministic in that it is based on a historical climatic record. GoldSim has the ability to convert a historical record to a full stochastic time series. To fully assess the implications of future climate scenarios on the scheme in a more robust manner the GoldSim model should be expanded to support stochastic assessments.



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APPENDIX A

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Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australia & NZ	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

AUCKLAND

Tel +64 9 486 8068
 Fax +64 9 486 8072

Level 2
 Nielsen Centre
 129 Hurstmere Road
 Takapuna
 Auckland 0622

PO Box 33-849
 Takapuna 0740

TAURANGA

Tel +64 7 928 5335
 Fax +64 7 928 5336

78 Maunganui Road
 Tauranga 3116

PO Box 13611
 Tauranga Central
 Tauranga 3141

HAMILTON

Tel +64 7 928 5335
 Fax +64 7 928 5336

Ruakura AgResearch Centre
 Room 31 in the Homestead
 East Street
 Hamilton 3214

PO Box 19-479
 Hamilton 3244

NELSON

Tel +64 3 548 1707
 Fax +64 3 548 1727

Level 3
 295 Trafalgar Street
 Nelson 7010

PO Box 1724
 Nelson 7040

CHRISTCHURCH

Tel +64 3 377 5696
 Fax +64 3 377 9944

Level 1
 214 Durham Street
 Christchurch 8011

PO Box 2281
 Christchurch 8140

DUNEDIN

Tel +64 3 479 0390
 Fax +64 3 474 9642

Level 9A
 John Wickliffe House
 265 Princes Street
 Dunedin 9016

PO Box 1087
 Dunedin 9054



Appendix D: Groundwater mounding briefing paper

23 April 2013

Project No. 1378310035-001-LR-Rev0

Grant Pechey
Hawke's Bay Regional Investment Company Limited
Private Bag 6006
Napier, 4142
New Zealand

RUATANIWHA WATER STORAGE SCHEME - GROUNDWATER MOUNDING BRIEFING PAPER

Dear Grant

Thank you for your request, on behalf of the Hawke's Bay Regional Investment Corporation Limited (HBRIC Ltd), for a short briefing paper on the potential groundwater level mounding issues that could arise from the development of the Ruataniwha Water Storage Scheme (the Scheme). In response to your request, Golder Associates (NZ) Limited (Golder) has undertaken a desk based assessment and we present this letter¹ as our briefing paper. The objective of this letter is to provide HBRIC Ltd with guidance on the relative significance of the potential groundwater mounding issues and direction on how best to proceed with investigating and managing the issues. This letter provides strategic high level advice and does not address detailed site specific issues.

During a meeting on Friday 25 January 2013 between Olivier Ausseil (Aquanet Consulting Limited), Howard Williams (Golder), and Dougall Gordon and Rob Christie (Hawke's Bay Regional Council HBRC), the scope of the briefing paper was discussed. Subsequent telephone discussions and email exchanges between Olivier Ausseil and Ian Lloyd of Golder (6th and 7th March 2013), confirmed that HBRIC Ltd require a short briefing paper which includes comments on the following topics:

- 1) Brief explanation of mounding, how irrigation development can influence groundwater levels and the potential effects (positive and negative) that can occur due to mounding.
- 2) Examples of the mounding issues associated with existing (and proposed) irrigation schemes, including an outline of how such issues have been investigated, managed and examples of mitigation options that have been used.
- 3) Overview comments on the potential mounding and associated issues that could arise from the development of the Scheme.
- 4) Guidance on how the potential issues identified in the three earlier points could be further investigated and managed.

These numbered topics are addressed in the following sections.

¹ This report is provided subject to the limitations attached.



1.0 MOUNDING

Mounding is the localised increase in the elevation of either the water table in an unconfined aquifer or water pressures in a confined aquifer. Mounds are usually the result of increased recharge to the aquifer but can also be caused by restricting outflow from the aquifer i.e. a groundwater dam effect. In the context of irrigation it is mounding of the water table due to increased recharge that is the issue.

It is generally recognised that surface water sourced irrigation schemes produce mounds of groundwater beneath them as a result of the additional recharge associated with the irrigation. This increase in recharge has two contributing factors:

- 1) Increased rainfall-related recharge due to the higher soil moisture levels associated with irrigation;
- 2) Irrigation-related recharge as the irrigation is unlikely to be 100% efficient and some leakage from the distribution network would be expected.

These mounds are connected to the active process where water moves through the unsaturated zone to the underlying aquifer. These mounds attenuate (relax) as they move outwards from the point of recharge causing spatial and temporal increases in groundwater levels. The spatial distribution of the increase of groundwater levels is coincident and peripheral to the footprint of the irrigated area. An analogy to a groundwater mound would be the ripples seen on dropping an object into water; the effect is most marked close to the source and less as the effect moves away.

The size and extent of groundwater mounds associated with surface water sourced irrigation schemes is controlled by many variables including but not limited to:

- The area's climatic conditions.
- Details of the irrigation i.e. extent, type, timing and characteristics (particularly uniformity, application rates, application depths and return periods).
- Properties of the soils being irrigated.
- Land use of the area being irrigated and particularly the crop being irrigated.
- The characteristics of the groundwater system, particularly: the extent of the system, the aquifer properties, how much water is stored within it, the characteristics of how water moves through it, natural groundwater levels and fluctuations, and the proximity and nature of discharge points from the groundwater system.

Although the greatest increase in water recharged to the aquifer system would likely be within the footprint of the irrigated areas, any increased recharge will also likely influence groundwater levels down-gradient of the irrigated area.

Rivers and streams play a role in absorbing the mounding by increasing their flow. Groundwater progressively stored as mounding and higher down-gradient groundwater levels over the summer irrigation season can lead to an increased extent of wet areas, increasing flow to the river systems and higher water levels in groundwater bores, especially during and following the irrigation season. Whether an increase in surface flow occurs each irrigation year will be dependent upon the variables listed above. Close to the irrigated areas, the mounding and any increased surface water flow may be distinctly seasonal. Further away, down-gradient, the seasonal mounding and related effects may become smoothed, and the seasonality of flows may be more subtle.

Some of these effects may be considered positive: increased spring and stream flow during the irrigation season, increased water levels within existing wetlands and groundwater bores, increased area where crops can access the water table thereby reducing the need for irrigation. Other effects may be considered negative, and include: raised groundwater levels to depths just below, or at the ground surface in areas where this effect had not previously been experienced. Potential issues related to such a rise in groundwater levels include reduction in septic tank efficiency, 'floating' of septic and underground fuel storage tanks, nuisance (excessive) flows in drains and natural water bodies such that they may be under-designed for flood events. Higher water tables increase the risk of soil becoming water logged, which

reduces its strength and increases the risk of soil structure damage i.e. pugging due to stock and can affect the species that will grow in the area as many crops and trees do not like saturated conditions in the root zone. There are also potential ecological issues that need to be considered such as increased spring and stream flow can lead to predator species gaining access to areas they previously could not access. Furthermore, there are often water quality issues associated with increased drainage.

2.0 EXAMPLES OF MOUNDING AND RELATED ISSUES

During the consent hearings for Canterbury's Central Plains Water Scheme (CPW), the applicant provided maps which predicted that the scheme would result in groundwater mounding of up to 10 m above pre-scheme levels (Lewthwaite 2007; Weir 2008). Similarly, mounding is predicted to occur beneath the proposed Hurunui Water Project (PDP 2012b). Canterbury Regional Council groundwater level and surface flow monitoring data indicates that mounding occurs beneath the Waimakariri Irrigation Limited (WIL) scheme (Dodson et al. 2012; PDP 2012a; PDP 2012c), beneath the Rangitata Diversion Race (RDR) scheme (Davey 2006; Dommissie 2005, 2007), and beneath the relatively small Northbank scheme on the true left bank of the Rakaia River (Williams 2009). Furthermore, groundwater level monitoring under the Morven-Glenavy Irrigation Scheme indicated that groundwater levels rose up to 6 m as a result of construction and commissioning of the scheme and drainage was required to reduce high groundwater levels in a number of locations (CRC 2009). Similar issues were experienced during commissioning of the Amuri Irrigation Scheme in North Canterbury (Weeber and Smith 2010).

In all these examples, groundwater level increases take the form of summer, rather than winter maxima in groundwater levels and increased flows in surface drainage within and down-gradient of each irrigation scheme. In the case of CPW, groundwater model results were developed for mounding during and after a 'dry' year when significant volumes of water were used for irrigation and the ambient groundwater levels were low. In addition, groundwater model results were developed for mounding during and after a 'wet' year when although less water was used for irrigation the ambient groundwater levels were already high (Weir 2007). The 'wet' year results produced more mounding simply because groundwater levels were already high. Note that just because there has been a 'wet' winter or antecedent wet period over a number of years (e.g. mid 1970s in Canterbury) does not necessarily mean that the summer use of water irrigation is low. In the decision on CPW's consent applications the hearing commissioners expressed concern about the levels of mounding that were expected (CRC 2010).

In the case of the RDR scheme, raised groundwater levels and increased spring flows associated with irrigation have been relied upon by down-gradient groundwater and surface water (i.e. abstraction from spring fed drains) users. While the conversion of border dyke irrigation to spray within the RDR scheme has increased irrigation efficiencies, it has reduced the degree and timing of irrigation-related recharge to groundwater (Davey 2006).

Referring to the Waimakariri Irrigation Limited scheme, PDP (2012c) states: "*Long term groundwater plots in the most recent WIL..... monitoring report show that groundwater levels in bores from the upper part of the scheme have remained largely unaffected by increased recharge from irrigation, however bores from the lower part of the scheme display groundwater levels that fluctuate within their typical range but no longer experience the low groundwater levels that previously occurred before the scheme began. Groundwater levels generally appear to increase in winter months and decrease in summer months, although summertime groundwater levels have increased since the commencement of the scheme. This increase in summertime groundwater levels is considered to be a positive effect.*"

Engineered drainage is the principal remedial action that is considered when mounding results in unacceptably high water table levels. Drainage is well understood and there are numerous examples throughout New Zealand of drainage successfully reducing high water table levels. Many of the existing large irrigation schemes (Morven-Glenavy Irrigation Scheme, RDR, Amuri Irrigation Scheme) have extensive drainage networks which target areas of high water table levels. Management of or limiting irrigation in the immediate vicinity of sensitive areas is also a potential option for dealing with localised mounding issues.

3.0 POTENTIAL FOR MOUNDING

The potential for mounding is strongly related to the increase in land surface recharge and the properties of the aquifer system. There are currently approximately 6,300 ha of irrigated land in the Tukituki catchment above Red Bridge and this area is expected to increase to approximately 30,900 ha when the Scheme is fully operational (HBRC 2013). This approximately 24,600 ha increase in irrigation is likely to significantly increase groundwater recharge. NIWA (2013) confirmed the potential for increased recharge and estimated a potential increase in mean annual recharge due to irrigation of 18 % to 24 % of the irrigation application, depending on the climate soil and irrigation rate.

This increased recharge due to irrigation has not been included in the groundwater model (Waldron and Baalousha 2013) but given that the Scheme is located within a geological basin Golder would expect any increased recharge to resurface at the down-gradient boundary of the basin. To fully assess the potential for mounding associated with the Scheme the increased recharge associated with the increased irrigation should be included in a groundwater model. Given the size of the Scheme, the conclusions of NIWA (2013) regarding the expected increased recharge and the observation that mounding occurs beneath and/or down-gradient of most existing large irrigation schemes, Golder considered that it is highly likely that the Scheme will result in groundwater mounding beneath and down-gradient of the irrigated area and increased flows from springs located within or down-gradient of the irrigated area.

Whether or not the expected higher groundwater levels and increased spring flows will have a positive or negative effect is more difficult to assess and requires consideration of the existing natural and anthropogenic environment as these effects are likely to be very location specific. Increasing water table levels to at or close to the ground-surface are likely to be considered positive in an area set aside for a wetland but are likely to result in a desire to install drainage in areas of high intensity agriculture. Given the size of the Scheme, Golder expects that there are likely to be locations where the expected higher groundwater levels and/or increased spring flows will be considered a negative and remedial action will be required.

4.0 INVESTIGATION AND MANAGEMENT OF MOUNDING

The following actions are suggested as next steps in the assessment of mounding and down-gradient groundwater effects associated with the Ruataniwha Water Storage Scheme and are listed in order of decreasing priority:

- 1) Map current wetland and 'wet' areas under the current (pre-scheme) situation. Mapping of currently wet areas that are prone to waterlogging will be helpful in designing a monitoring programme and indicating which areas might need future remedial drainage to deal with excess water after the scheme is commissioned. In part, this mapping can be informed from the groundwater model (Baalousha 2012), that has indicated within which areas (red ellipses) groundwater pressures are causing streams to gain (Figure 1) and where groundwater flow directions are generally upward (Figure 2). It would be useful to overlay a soil map (i.e. Figure A.2 in Baalousha 2009) and a slope map (i.e. Figure A.3 in Baalousha 2009) of these areas in order to assess the likelihood of water logging and pugging. Visual examination indicates that some of the areas where groundwater is rising and streams are gaining coincide with Class 2 soil which is categorised as relatively poor draining in character, and with low slope. It would also be helpful to produce an additional map that indicates the vertical differential elevation between the topography and the groundwater level.
- 2) Plant and Food Research's SPASMO model has been used to assess irrigation demand and nutrient losses from land for the Scheme (Green *et al.* 2013). The SPASMO model has provided projections of drainage and runoff under both the current land use regime and the projected landuse regime when the scheme is operational. To build on the preliminary assessment undertaken in NIWA 2013 the projections from the SPASMO model should be used to complete a more thorough assessment of the potential change in recharge (drainage) associated with the scheme.
- 3) A transient numerical groundwater flow model has been developed for the Ruataniwha Basin to explore changes to the aquifer system in terms of aquifer storage, aquifer-spring interactions and aquifer-river interactions. The model is documented in various reports including (Baalousha, 2009 and 2010). The model has been used to assess the potential impact of the Scheme on the area's groundwater and

surface water resources (Waldron and Baalousha 2013). In assessing the potential impact of the Scheme the potential increased recharge associated with the increased irrigation was not specifically modelled. The SPASMO model projections of drainage and runoff under both the current landuse regime and the projected landuse regime when the scheme is operational should be fed into the transient numerical groundwater flow model to assess any mounding, down-gradient groundwater pressure and spring/stream flows effects associated with development of the Scheme. This analysis using the groundwater model would highlight areas where groundwater mounding due to the Scheme may be an issue.

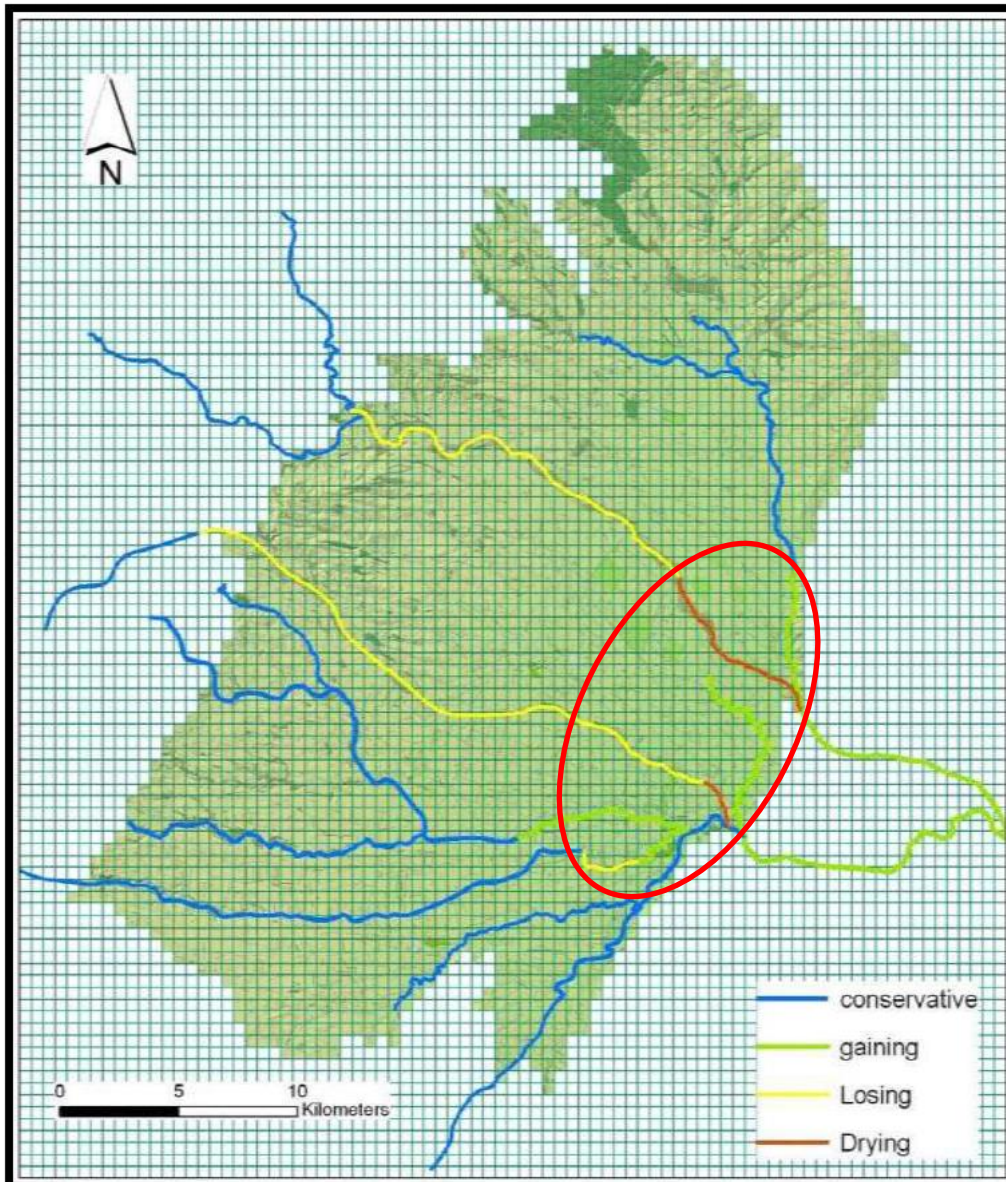


Figure 1: Gain and loss river patterns in the Ruataniwha Basin (Modified from Figure 14 of Baalousha 2010). Red ellipses indicate areas where increased groundwater levels may induce increased surface flows and upward groundwater flow.

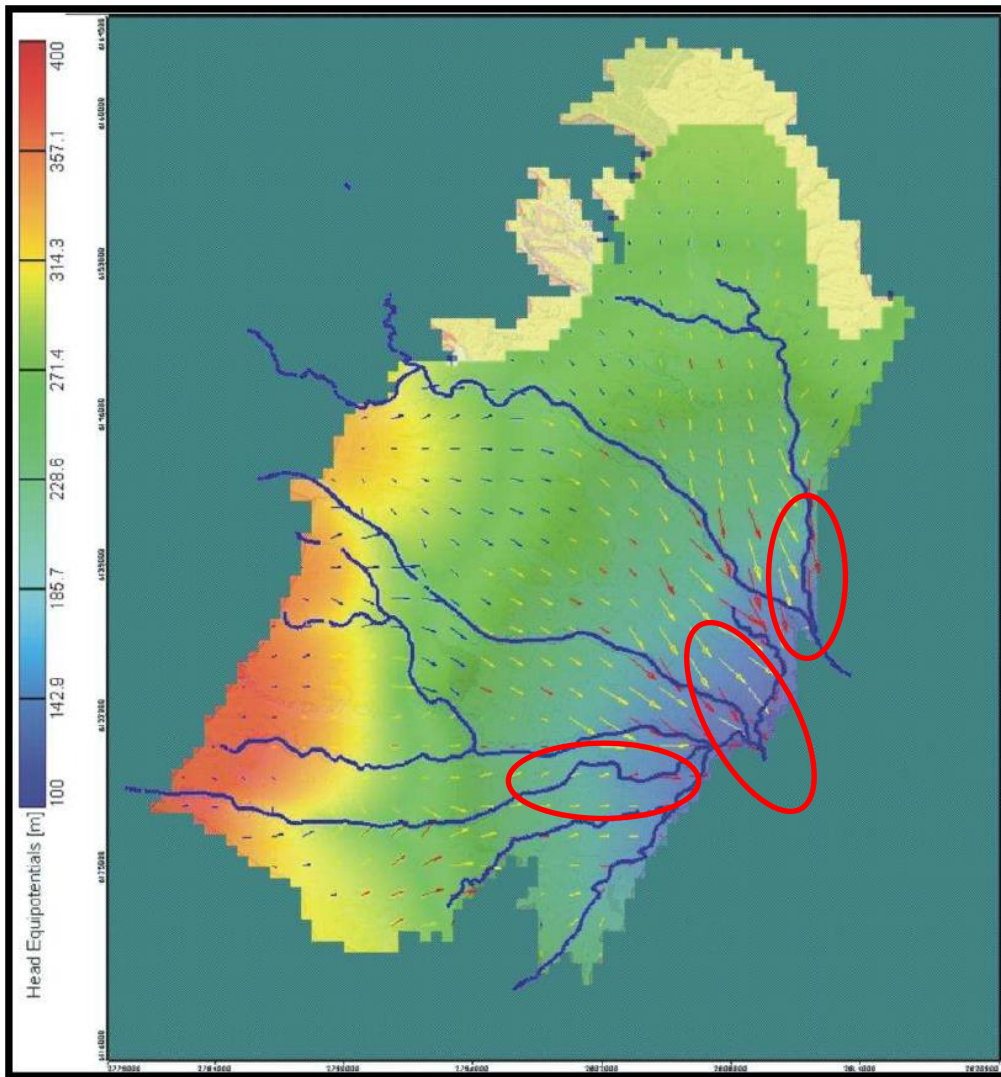


Figure 2: Calibrated head and vector map (yellow arrows indicate downward groundwater movement, red arrows indicate upward movement and blue arrows indicate horizontal movement). Red ellipse indicates zone of patchy upward groundwater flow (Modified from Figure 23 of Baalousha 2009).

- 4) Design, install and commission a monitoring system of piezometers in the shallow strata within the groundwater system and flow gauges within the area's spring fed streams. Changes in groundwater level and the flow in spring fed stream are straightforward to monitor, using bores and flow gauges. However, in order to assess the effects of the Scheme, it is considered important to install monitoring bores and gauges in appropriate locations prior to the commissioning of the Scheme so that background data can be collected. It is against these background data that the positive and negative effects of the Scheme will be measured, so the more background data that is collected (i.e. dry and wet years), the more robust any subsequent determination of the Scheme's effects will be. Development of the monitoring programme should consider the results of items 1 and 3 and areas targeted for monitoring should focus on the margins of existing "wet" areas (item 1) and areas where the groundwater model projects mounding due to the Scheme may be an issue (item 3). This monitoring should continue during commissioning and operation of the Scheme to assess potential changes in groundwater levels and to provide a trigger for any potential remedial actions. Golder notes that the timeframe for any mounding to become noticeable may vary considerably and could occur very rapidly after scheme commissioning or may take months or years to become noticeable and it may take a considerable period for any groundwater mounds to fully develop.

- 5) Prepare a groundwater mounding and drainage management plan which outlines options that will be considered and implemented should the groundwater level monitoring determine that the Scheme has result in adverse groundwater mounding. The plan should include immediate staged actions to be taken if trigger groundwater levels or flows are breached. The management plan should refer to the results of the earlier steps and particularly focus on area where the groundwater model projects mounding due to the Scheme may be an issue. Such plans have been prepared for many of the recent large irrigation schemes including CPW (Lewthwaite 2007), the Waimakariri Irrigation Limited scheme (PDP 2012a) and the Hurunui Water Project (PDP 2012b).

Concluding Comments

Golder considered that it is highly likely that the Scheme will result in groundwater mounding beneath and down-gradient of the irrigated area and increased flows from springs located within or down-gradient of the irrigated area. Given the size of the Scheme, Golder expects that there are likely to be locations where the expected groundwater mounding and/or increased spring flows will be considered a negative effect and remedial action will be required.

Engineered drainage is the principal remedial action that is considered when mounding results in unacceptably high water table levels. Drainage is well understood and there are numerous examples throughout New Zealand of drainage successfully reducing high water table levels.

Golder recommends that HBRIC Ltd take a proactive approach to addressing potential mounding issues associated with the Scheme. The groundwater model should be used to identify areas where mounding due to the Scheme may be an issue. A management plan should then be developed that targets those areas and outlines options that will be considered and implemented should groundwater mounding become an issue.

Golder trust that this letter appropriately outlines the potential groundwater level mounding issues that could arise from the development of the Ruataniwha Water Storage Scheme and provides HBRIC Ltd with guidance on how to proceed with investigating and managing the identified issues. Should you have any questions regarding the content of this letter, please contact either of the two undersigned.

Yours Sincerely

GOLDER ASSOCIATES (NZ) LIMITED



Howard Williams
Senior Hydrogeologist



Ian Lloyd
Senior Water Resource Engineer

hw/il/kc

CC: Olivier Ausseil of Aquanet Consulting Limited,
Dougall Gordon, Rob Christie and Grant Pechey of Hawke's Bay Regional Council

Attachments: Reference list
Report limitations

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