Combined Irrigation and Flood Storage in
Upper Rangitāiki Catchment

Bay of Plenty Regional Council

13-Jan-2017

Doc No. 1

Combined Irrigation / Flood Control Storage in Upper Rangitāiki

Initial Feasibility Study

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Initial Feasibility Study

Client: Bay of Plenty Regional Council

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Executive Summary

Bay of Plenty Regional Council (BOPRC) has commissioned AECOM New Zealand Limited (AECOM) to look at the benefits of combining storage in the Upper Rangitāiki catchment for economic development, primarily through the provision of irrigation water for agricultural production, and flood mitigation to reduce flood risk in the Lower Rangitāiki catchment. The work is to build on an earlier study that considered a range of options to optimise flood management of the Rangitāiki spillway. In the previous study a number of water storage options that delivered flood control benefits were identified. The purpose of this investigation is to establish if multi-purpose storage delivering multiple benefits is possible.

Previous flood studies

The previous flood studies have involved looking at all possible options and then considered which of them offered realistic management options during a large (100year) flood event. Modifications to the operating rules at Matahina Dam during a large flood event provided the greatest potential improvements in downstream flood conditions. However, this solution is dependent on flood forecasting and real time management of a flood event. There are inherent risks in relying solely on this approach.

Other Upper Rangitāiki catchment management options were considered including construction of on line storages, or the raising of existing storages on the Horomanga, Whirinaki and Rangitāiki Rivers. Off line storage and water harvesting was also considered including multiple subcatchment dams and diversion to managed aquifer recharge (MAR) in the Galatea Basin. Land use management controlling the hydrologic impacts and out of catchment diversion were the other options considered. Of these other options that were considered on line and off line storage within or near the Galatea basin provided the greatest benefit for downstream flood control.

Previous irrigation studies

A number of studies considering hydroelectric generation potential and irrigation have been conducted in the catchment since 1982. For irrigation a range of scheme options were identified but storage was required to ensure irrigation reliability because of allocation rules. However, the high volume of storage (17Mm^3) and associated dam cost reduced the scheme economic feasibility.

Current focus and the changing environment

Since these studies the environment has changed and issues that may further impact irrigation development are:

- NPS on freshwater which requires the setting of limits that may alter allocable flows.
- Climate change that could change rainfall inputs.
- Community awareness of sustainability has increased along with the understanding of the need to address multiple values within the catchment.

Options for consideration

All options from the flood study were considered for fatal flaws and whether the storage could be combined for irrigation as well as flood management. On line storage dams were discounted because of the size, cost and impacts. This included raising Aniwhenua where large areas of land would be inundated. Off line water harvesting storage dams were considered the most likely option to be successful and further work was undertaken to optimise storage for irrigation demand and flood attenuation. Local farmers also suggested an off line pumped storage scheme should be considered. However, the storage volume was less than 20% of the volume required. While it may have some merits for a stand-alone irrigation scheme it did not provide a multi-purpose outcome.

Preferred option

The preferred option for detailed analysis is the off line water harvesting options in the Galatea Basin which uses the irrigation pipe network to disperse surface water across the basin to groundwater. The irrigation pipes would be installed for run of river take. The ponds have been conceptualised as being cut and fill on the low terrace on the edge of the flood plain along the right bank of the Whirinaki River.

In a large flood the amount of water to be captured from the river exceeds infiltration and so harvesting ponds are required to act as an attenuation buffer between river flood flows and the rate water can infiltrate the ground. Further, if this water is to be applied as managed aquifer recharge and provide storage for irrigation then it needs to be spread across the Galatea Basin.

For an irrigation scheme water would be taken from the river through a gallery and then piped across the basin. Harvested flood water could be fed into the piped system and then surcharged to strategically placed infiltration basins across the area to optimise groundwater recharge.

Option optimisation

The preferred option has been optimised by assessing inputs and demands and then estimating storage volumes. For flood storage the volumes above the thresholds used in the flood study have been applied. For irrigation storage volume has been determined based on water / supply modelling using GoldSim and the following assumptions/inputs:

- Water supply from the Whirinaki and Rangitāiki rivers has been based on an allocation of 5% and 10% of the 5 year 7 day low flow; and on diversion of 10% of the flow above median flow on the Whirinaki River.
- Pond weir levels will be fixed for flood control but the weir crest will be controlled by a moveable gate for irrigation water capture above median flow.
- Groundwater availability and storage volume has been derived from records and published information on thickness of the unsaturated zone and porosity. Additional losses from managed aquifer recharge back to streams have been estimated.
- Irrigation demand has been based on NIWA VCS data and soils information. Thresholds for irrigation application and system efficiency and capacity have been applied to estimate the demand for water.
- Various design criteria for managed aquifer recharge has been adopted.

Optimised pond sizes have been based on a maximum water depth of 3m. For irrigation alone the pond base area needs to be 36.5ha; and for flood control the area needs to be 156ha to meet the goals of the previous flood study.

Performance

The three ponds required for flood management have been optimised to perform as outlined in the flood study. That means there is also a requirement to include flood forecasting and management of water levels within Lake Matahina.

For irrigation to be reliable three water sources are required; river takes, natural groundwater take and groundwater take from water harvesting through MAR, with the majority of the supply coming from MAR. This is similar to previous studies that indicated storage of water is required to ensure irrigation reliability.

Cost estimate

The cost estimate is high level with a 20% contingency and only considers components that are common to both irrigation and flood management. Three ponds with a fixed inlet control are required for flood control and for irrigation one pond with a variable inlet control because of the proportional take of the median flow needs control. Further the assumption that water depth is limited to 3m impacts cut and fill volumes so it has been assumed that there could be a need for imported fill and this is a significant proportion of the cost estimate. In reality detailed design would aim to minimise importing material. Infiltration basins to disperse water in a MAR scheme for irrigation have not been included, and neither has any estimate of bores and pumps for water extraction as these are viewed as being solely irrigation requirements and have no flood control benefit.

The cost estimates are:

- Flood control only - $34.8M
- Irrigation only - $15.8M

- Combined flood and irrigation use $39M.

Benefits

Water harvesting and MAR bring a number of benefits compared to a more conventional on line high dam storage. These include:

- River flow is not impeded during floods so inundation extents are unchanged.
- Sediment transport in the river is unlikely to change and so gravel movement is not impacted.
- Only a small proportion of the irrigation take comes from the run of river flows and so while necessary for irrigation changing allocable thresholds could be managed although costs may increase.
- The increased recharge of groundwater with MAR would dilute any contaminants.
- Flood management is improved with the off line storage although it is expensive. Optimising cut and fill volumes for ponds, even if the water depth increase, could reduce the overall cost, given that $10.7M has been estimated for imported fill.
- There is resilience and opportunity for climate change adaption within the concept through modification of pond size, number of ponds and location of ponds.
- Environmental impacts are potentially minimised with no obstruction in the rivers, no mechanical intakes that impact fish passage, and low visual impacts.

Conclusion

It has been shown that a multi-use scheme is possible but is dependent on confirmation of the assumptions and the acceptance of the cost used in the assessment.

Review & Update

Following receipt of the draft report BOPRC requested a review of groundwater aspects by internal staff and AECOM to consider the potential impacts of the consent conditions for Matahina dam that limit water abstraction upstream of the dam to flows greater than 160m^3/s at Matahina.

The groundwater review raised matters of groundwater flow and residence time for any managed aquifer recharge based irrigation scheme. AECOM have commented on this and indicated the estimated residence time is greater than two annual irrigation cycles and the modelling shows that the groundwater storage is recharged 39 years out of 40 years.

The flow abstraction threshold at Matahina dam was shown to impact on the groundwater availability. Under the assumed modelled regime it was found that the available groundwater storage would be depleted 7 years out of 40 years. This may mean an irrigation scheme would be uneconomic.

The groundwater review and the AECOM assessment of consent impacts are provided in Appendices A and B.

1.0 Introduction

1.1 Purpose

Bay of Plenty Regional Council (BOPRC) has commissioned AECOM New Zealand Limited (AECOM) on 2 June 2016 to look at the benefits of combining storage in the Upper Rangitāiki catchment for economic development, primarily through the provision of irrigation water for agricultural production, and flood mitigation to reduce flood risk in the lower Rangitāiki catchment. The work is to build on an earlier study that considered a range of options to optimise the Rangitāiki spillway. In the previous study a number of storage options that delivered flood control benefits were identified. The purpose of this additional investigation is to establish if a multi-purpose storage delivering multiple benefits is possible.

1.2 Background

1.2.1 Flood Study

BOPRC commissioned AECOM (formerly URS NZ Ltd) to assess alternative flood mitigation options in the Rangitāiki Catchment upstream of Reid's Spillway as part of the larger Rangitāiki Floodway Project. The aim of the project was to reduce the flows during large flood events (1% AEP) at the spillway. The objective of the work was to show whether alternative, upper catchment options could create additional benefits for the Rangitāiki Floodway Project. A further objective was to possibly reduce the need for further structural works currently planned downstream of the spillway as part of the Rangitāiki Floodway Project. The work built on options that were identified in an earlier phase of the River Scheme Sustainability Project.

The outcome of the project identified that modifications to the operating rules at Matahina Dam during a large flood event could lead to the greatest improvements in downstream flood conditions. However, this solution is dependent on flood forecasting and real time management of a flood event. There are inherent risks in relying solely on this approach.

Other upper Rangitāiki catchment management options were considered including construction of on line storages, or the raising of existing storages on the Horomanga, Whirinaki and Rangitāiki Rivers. Off line storage and water harvesting was also considered including multiple subcatchment dams and diversion to managed aquifer recharge (MAR) in the Galatea Basin. Land use management controlling the hydrologic impacts and out of catchment diversion were the other options considered. Of these other options that were considered on line and off line storage within or near the Galatea basin provided the greatest benefit for downstream flood control.

Further investigation of these options and whether they can be beneficially linked to irrigation is the objective of this project.

1.2.2 Previous Studies

Hydro generation potential within the Rangitāiki catchment and the possibility of a community irrigation scheme in the Galatea Basin have been the subject of many investigations over many decades. In 1982 the Ministry of Works and Development undertook an assessment of local hydro-electric potential in the Bay of Plenty Catchment Commission region. This was followed in 1984 and 1985 by the Ministry of Works and Development reports on the feasibility of pastoral irrigation at Galatea. A further pre-feasibility study for the Galatea Murupara Irrigation scheme was undertaken by Aqualinc in 2004 and this was followed by a feasibility study in 2006.

A range of scheme options were identified from these studies and included:

- Run of river supply supplemented with storage and delivered under pressure in pipelines or gravity supply along a canal.
- Run of river supply supplemented by groundwater.
- Run of river supply and water from Lake Aniwhenua.
- The gravity run of river supply option with hydro generation.

The storage required is up to 17Mm^3 and a potential dam site was identified on the Mangawiri Stream. However *the key study finding was that the proposed scheme was constrained by current water allocation rules which limit surface water allocations to a maximum of 10% of the one in five year low flow (Q5). The impact of this constraint is the need to incorporate storage in the water supply system to improve water supply and reliability during periods of low flow. However, the high volume of storage (17Mm^3) and associated dam cost reduced the scheme economic feasibility*[1].

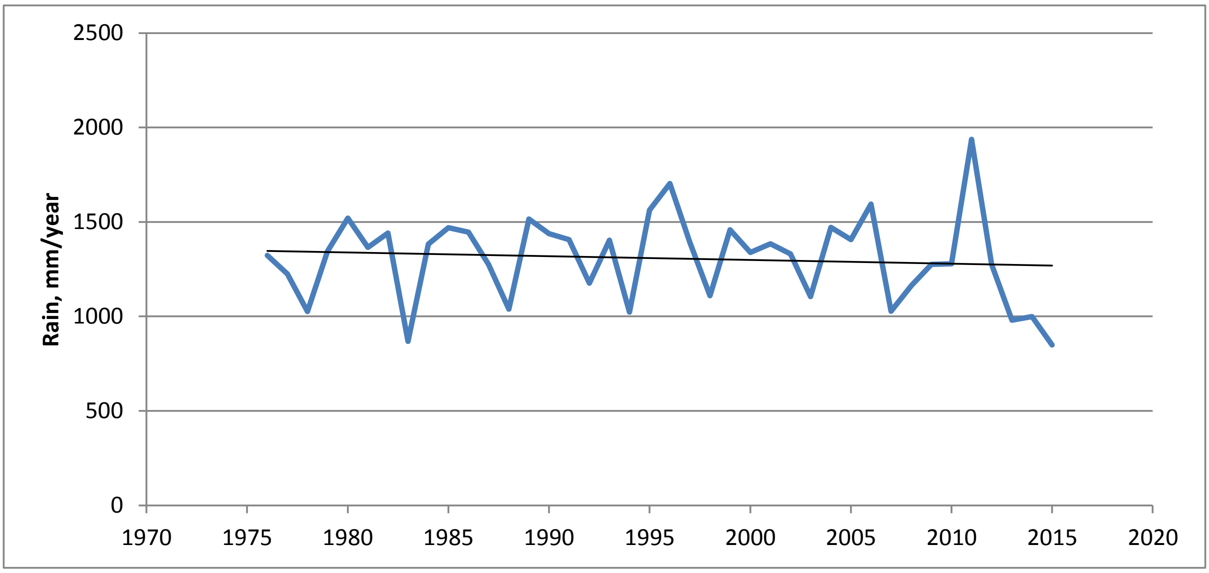
Groundwater resources in the Rangitāiki catchment have been documented by GNS in 2014 and include extensive coverage of the Galatea basin. The overall conclusion being that within the basin rainfall exceeds evapotranspiration and so the groundwater should have significant annual recharge.

1.2.3 Changing Environment

Since these studies have been undertaken a number of factors have changed to the extent that a different baseline environment needs to be considered for any future flood management and irrigation development within the catchment. This changing environment includes:

- NPS on freshwater which requires the setting of limits which will eventually incorporate water quantity and quality limits. These limits are likely to be higher than those that existed at the time of previous studies. For example the previous irrigation feasibility work was based on a take of 10% of the 5yr low flow. This could be reduced to 5% in the future reducing the amount of run of river water supply.
- Climate change is well documented but within the catchment a decreasing trend over decades has been identified and so there could be less rainfall recharging soil moisture and groundwater. Annual rainfall totals show a negative trend of about 2mm/year. However, this trend may be heavily influenced by the lower rainfall totals in recent years.

Figure 1 Annual Rainfall Trend



- Community awareness of sustainability has increased along with the understanding of the need to address multiple values within the catchment. It is now less acceptable for a dominant resource to be used by some in a way that excludes the availability for others.

1.3 Scope of this Project

This project is an initial consideration of the potential to combine storage for irrigation and flood control. A combined irrigation / flood control storage scheme may bring positive economic benefits to the catchment. The objective of this proposed work is to provide an initial assessment of the feasibility of developing a win-win outcome through the combined use of storage for flood control and economic

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[1] Galatea Murupara Irrigation Feasibility Study Phase 1 Prefeasibility Report. Report #4978/6, 2004, Aqualinc Research Ltd

development by irrigation in the Upper Rangitāiki catchment. The work is to build on the previous flood study that identified on line and off line storage opportunities and establish whether they could be incorporated into a multi-purpose flood control and irrigation scheme.

The broad scope of the proposed work is to address storage in the Upper Rangitāiki catchment, including the following aspects:

- Irrigation storage and supply options;
    - In a corridor along the foot of the eastern hills,
    - From groundwater sources, and
    - From water harvesting from the Rangitāiki River, its tributaries and Lake Aniwhenua.
- Irrigation demand volumes and reliability of supply for irrigation.
- How flood control storage and irrigation storage will operate and interact.
- Assessment of downstream flood impacts in the 100 year storm.
- Provision of high level cost estimate of storage for irrigation and flood water.
- Provision of a qualitative assessment of thresholds and risks such as climate change, environmental issues and constructability risks.

2.0 Approach

2.1 Option Identification

The approach to option identification was to:

- Consolidate the options from the flood study, and
- Visit the site and discuss options with stakeholders including the irrigator representatives, BOPRC and TrustPower.

2.1.1 Flood Study Options

Flood study options that have been considered for inclusion in this assessment are those identified in the middle and upper Rangitāiki from Aniwhenua upstream:

- New dam on the Whirinaki River.
- New dam on the Horomanga Stream.
- Additional storage associated with Aniwhenua or the reaches downstream of Aniwhenua.
- Off line water harvesting dams.
- Diversion of Whirinaki Flows to a managed aquifer recharge (MAR) scheme across the Galatea Basin.

2.1.2 Stakeholder Options

In addition to the flood study options there were other issues that stakeholders flagged.

The irrigators asked that a small tributary be considered for storage potential including the option for operating such storage as a pumped storage hydro generation scheme.

BOPRC and TrustPower identified potential issues with the flood calibration of the flow record in the Whirinaki catchment. Both stakeholders identified the issue from an assessment of runoff volumes; TrustPower from downstream flows and volumes in their storage, while BOPRC identified issues from additional rainfall monitoring in recent flood events. While there may be a calibration issue that needs to be resolved it has been excluded from this study as this study is based on comparisons with previous work. Consequently principles and concepts will still apply but the magnitude of any infrastructure may alter if the flow calibration is revised.

2.2 Fatal Flaw Identification

The approach to excluding any option was both qualitative and quantitative. The primary question being does it serve both irrigation and flood management or is it exclusively beneficial to just one of those activities. Potential flaws were tabulated and then the decision made on whether to exclude a particular option.

2.3 Dynamic Modelling

To establish the benefit of a particular option and the relative merits for flood control and irrigation requires the understanding of dynamic processes and interactions. The requirement is to balance the supply, and its timing, of water from natural sources; the volume of flood attenuation required; and the demand for irrigation water. To optimise the size of storages a simulation model that takes the time series data from many years of record and integrates the different factors has been adopted as the preferred approach to resolving the merits of different options.

2.3.1 GoldSim

GoldSim is the software that is used to undertake the dynamic modelling. Wikipedia describes GoldSim as *dynamic, probabilistic simulation software developed by GoldSim Technology Group. This general-purpose simulator is a hybrid of several simulation approaches, combining an extension of system dynamics with some aspects of discrete event simulation, and embedding the dynamic simulation engine within a Monte Carlo simulation framework.*

While it is a general-purpose simulator, GoldSim has been most extensively used for environmental and engineering risk analysis, with applications in the areas of water resource management, mining, radioactive waste management, geological carbon sequestration, aerospace mission risk analysis and energy.

GoldSim provides a visual and hierarchical modelling environment, which allows users to construct models by adding "elements" (model objects) that represent data, equations, processes or events, and linking them together into graphical representations that resemble influence diagrams. Influence arrows are automatically drawn as elements are referenced by other elements. Complex systems can be translated into hierarchical GoldSim models by creating layer of "containers" (or sub-models). Visual representations and hierarchical structures help users to build very large, complex models that can still be explained to interested stakeholders (e.g., government regulators, elected officials, and the public).

Though it is primarily a continuous simulator, GoldSim has a number of features typically associated with discrete simulators. By combining these two simulation methods, systems that are best represented using both continuous and discrete dynamics can often be more accurately simulated. Examples include tracking the quantity of water in a reservoir that is subject to continuous inflows and outflows, as well as sudden storm events; and tracking the quantity of fuel in a space vehicle as it is subjected to random perturbations.

Because the software was originally developed for complex environmental applications, in which many inputs are uncertain and/or stochastic, in addition to being a dynamic simulator, GoldSim is a Monte Carlo simulator, such that inputs can be defined as distributions and the entire system simulated a large number of times to provide probabilistic outputs.

With these features GoldSim is the ideal software to simulate water supply and demand for the continuous seasonal irrigation demand, the daily river flows and the random occurrence of extreme flood events.

3.0 Flood Storage

3.1 Flood Study Outputs

The flood study analysis compared each identified potential flood control measure option with a base case under five different operating rules at Matahina Dam. The options from the flood study are tabulated in Table 1 along with a comment on the relevance to this study which is considering the combined benefits of irrigation and flood control.

Table 1 Flood Study Assessed Control Options

Option #	Option Description	Relevance
1a	Out of catchment diversion u/s of Murupara	No benefit for irrigation as water lost from catchment
1b	Land use change u/s of Murupara	No benefit for flood control
1c	New dam u/s of Murupara on Rangitāiki	Potential benefit for irrigation and flood control
2a	New dam on Whirinaki	Potential benefit for irrigation and flood control
2b	Galatea MAR – weir control	Potential benefit for irrigation and flood control
2c	Galatea MAR – gated optimised flow	Potential benefit for irrigation and flood control
2d	Galatea MAR – hydrograph control	Potential benefit for irrigation and flood control
3	Horomanga Dam	Potential benefit for irrigation and flood control
4a	Matahina Dam raising	Only beneficial for flood control
4b	New Dam downstream of Aniwhenua	Potential benefit for irrigation and flood control
4c	New Dam below Matahina Dam	Only beneficial for flood control
4d	Multiple Sub-catchment Dams	Potential benefit for irrigation and flood control

In the following sections the options that are considered to be potentially beneficial to flood control and irrigation are further considered to identify if any fatal flaw exist, for flood control or irrigation, or alternatively whether that option merits consideration when combined with irrigation.

3.2 On Line Storage

3.2.1 New dam upstream of Murupara on Rangitāiki

In the flood study this dam is of negligible benefit and so the only beneficiaries would be irrigators. With one dominant beneficiary this defeats the purpose of trying to develop a multi benefit scheme for flood control and irrigation. Further on line dams create a barrier to natural flow and so justification and compensatory measures to mimic a natural environment are complex and difficult. This option as a combined water resource management measure has therefore been excluded from further assessment.

3.2.2 New dam on Whirinaki or Horomanga

The flood study identified that a dam would only provide a potential reduction of around 50% of the ultimate target for flood control in the lower Rangitāiki catchment. The dams would be very high to provide the flood storage required to attenuate flows and this would leave insufficient storage for multiple use options. Such a large dam would modify the river regime and impact sediment transport. As these rivers are major sources of bedload the reservoir would become infilled such as is happening in Aniwhenua and there would be a decrease in benefit to both the irrigators and for flood control.

In addition to the hydrologic and hydraulic considerations there are numerous other factors that would make consenting and construction of these dams exceedingly difficult. Such factors include seismic risk with the fault line along the east of the Galatea basin. The impoundment would cross into the Urewera National Park and have major flora and fauna impacts. The storage area would be mostly empty for much of the time because of the need to provide for flood storage but this could impact terrestrial ecology and increase slope stability risk. Aquatic ecology would be impacted and fish passage impeded. Other social, cultural, visual, and economic values are also likely to be negatively impacted.

These options were not considered further due to the low flood management benefit and the lack of live storage for irrigation water storage.

3.2.3 New dam downstream of Aniwhenua

The irrigators advised that there preference was to minimise pumping and so a dam downstream of Aniwhenua would be at odds with this objective as all irrigation water would require pumping. Further, the flood study identified that such a dam only provides a potential reduction of around 50% of the ultimate target for flood control and so there would be insufficient storage for multiple use options.

Raising Aniwhenua dam was given some consideration but discounted because of the extent of flooding, the impact on infrastructure and the ongoing sedimentation. The extent of flooding for a 2, 4 and 6m increase in dam height is shown in Figure 2, Figure 3 and Figure 4.

Figure 2 Flood extent from 2m raising of Aniwhenua Dam

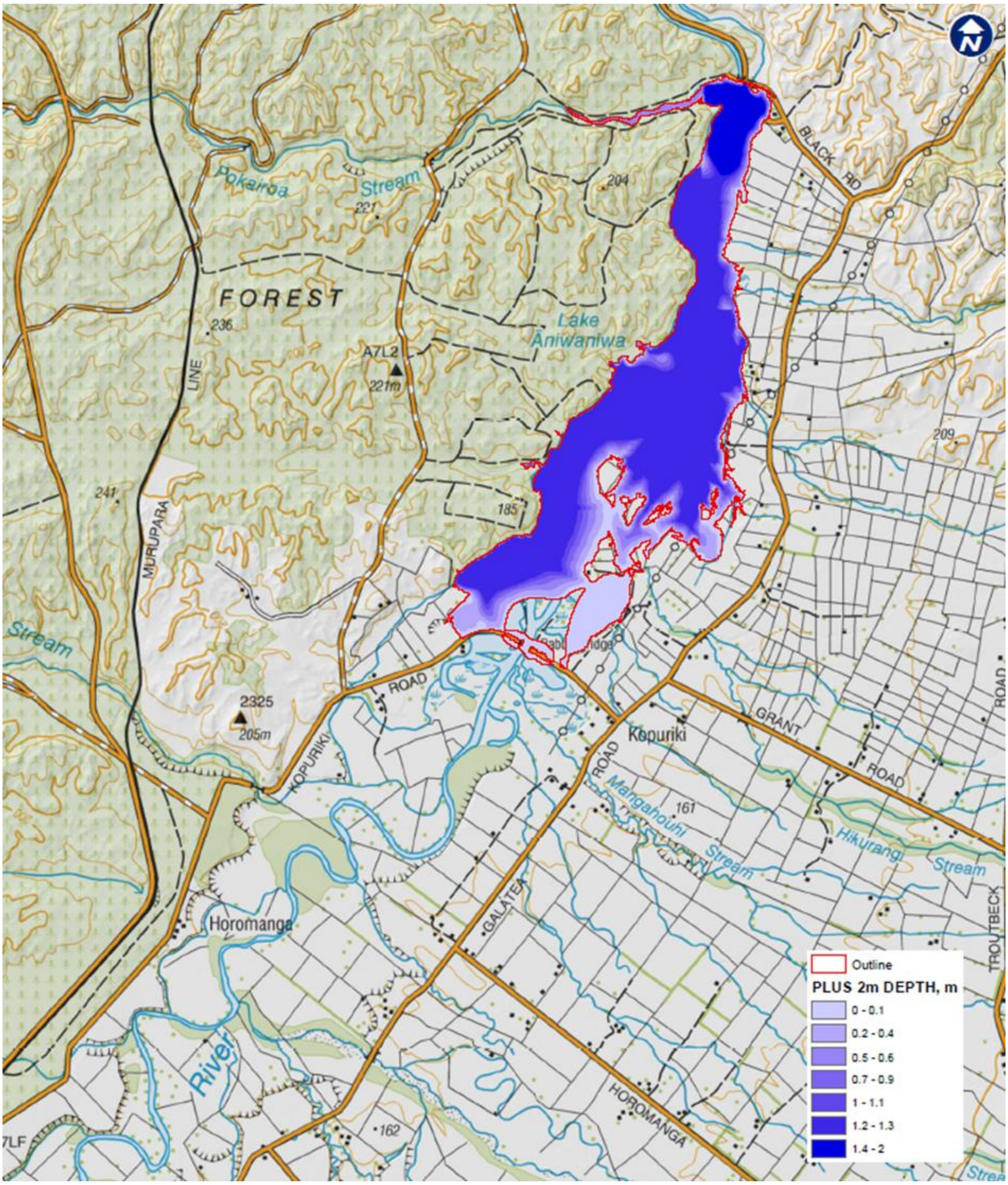


Figure 3 Flood extent from 4m raising of Aniwhenua Dam

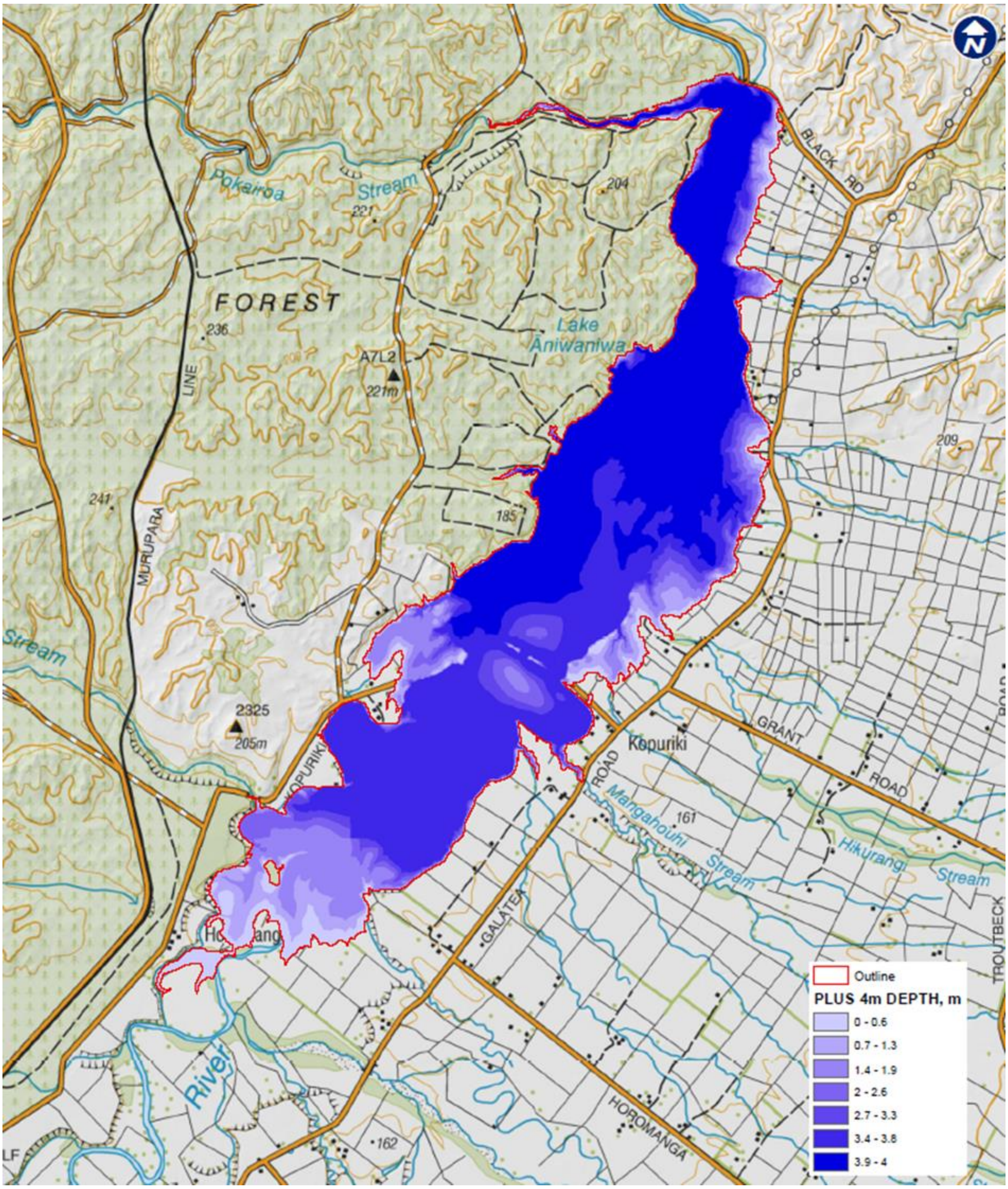
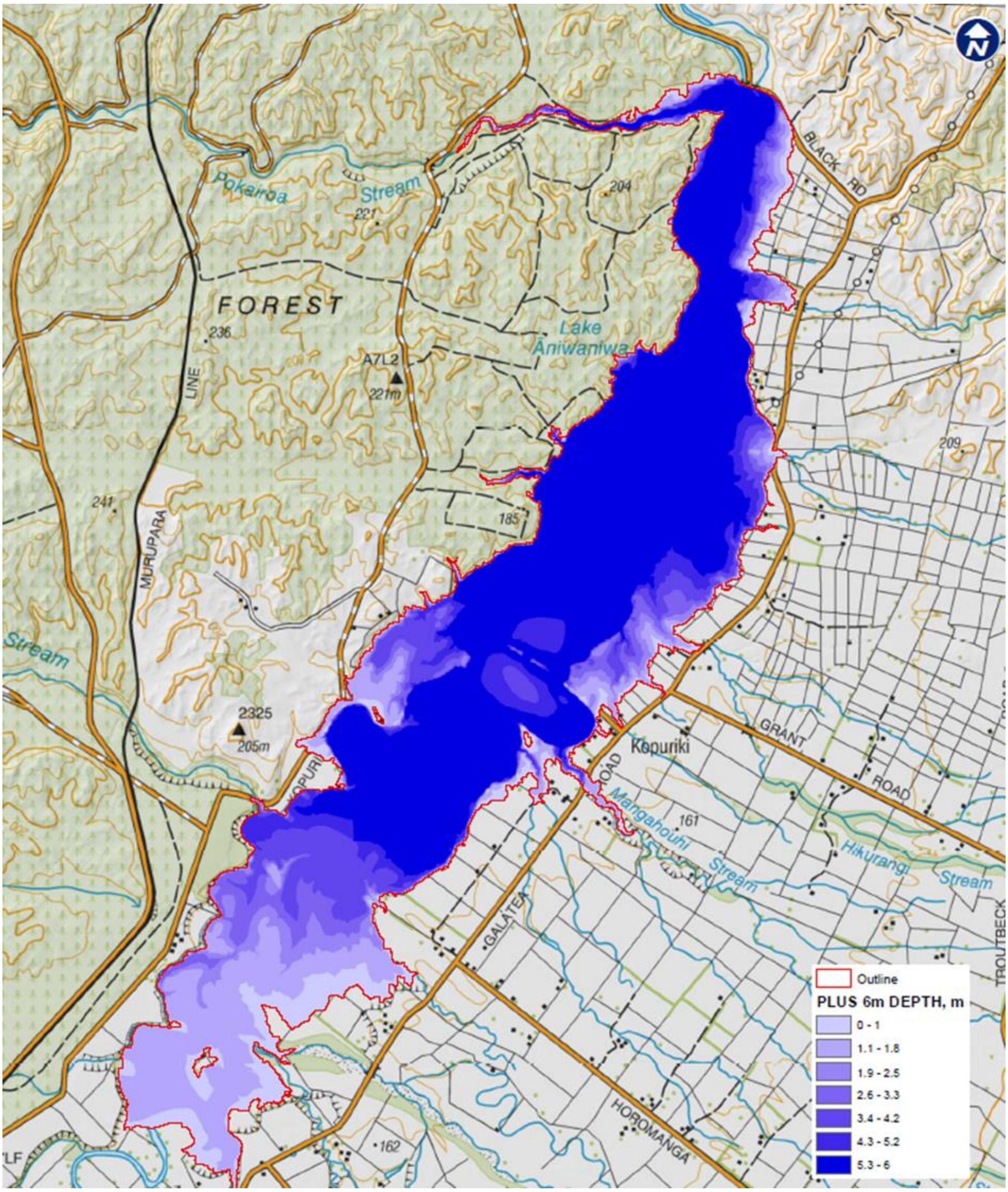


Figure 4 Flood extent from 6m raising of Aniwhenua Dam



3.3 Off Line Water Harvesting

3.3.1 Multiple Sub-catchment Dams

The flood study identified this would require numerous dams with optimised control to be effective. Further any on line storage locations would increase storage volume required. While theoretically possible it would be difficult to control and likely to be very expensive. Including irrigation storage would only increase storage volume requirements and the complexity of management.

Given there are other options and the operational aspects would be so complex this option has not been the subject of further consideration.

3.3.2 Managed Aquifer Recharge – Galatea Basin

Previous irrigation feasibility assessments have indicated that storage of water is required for irrigation reliability. This requirement for storage may increase with the NPS on freshwater. The flood study has shown that water storage is required in the middle catchment to provide attenuation. MAR provides an opportunity for both as long as the flood waters can be diverted and there is sufficient groundwater storage available.

The flood study indicated that a peak flow of approximately 100m^3/s was required to reduce the peak flow and a storage volume of up to 15.8Mm^3 is required. To divert this amount of water during a flood, harvesting storages near the river are required because the transfer to groundwater can't accommodate such a high instantaneous inflow.

The potential location of these water harvesting storages has been considered along the banks of the Whirinaki River downstream of the Troutbeck Road bridge. For this assessment all storages have been located on the right bank but storage could also be located on the left bank. Because of the magnitude of the Q100 year flood in the Whirinaki the bunds for these storages cannot be located in the flood plain as it would elevate flood levels. Consequently it is likely that the storages would need to be cut into the terrace. To achieve this and minimise the water depth in the storage to less than 3m deep three storage ponds of approximately 40ha to 50ha each are required.

Flood water would flow into these storages over a weir into a settling basin and then into a larger pond. The water would exit the storage by two means:

- The base of the storage would be designed as a MAR infiltration basin with enhanced drainage network in the base of the storage. This water has been assumed to infiltrate at an average of 0.75m^3/s/ha.
- For MAR to be effective water needs to recharge across the Galatea Basin. An irrigation scheme would use a piped network with an intake capacity of approximately 5m^3/s. This pipe would be used to shift the harvested water to smaller infiltration basins placed strategically across the Galatea Basin.

GoldSim has been used to establish the size of the harvesting ponds and the smaller infiltration basins. The model has taken the flood overflow from the flood study model and then assumed continuous infiltration and piped outflows as described in (Figure 5). From this the volume has been optimised and then the three ponds conceptually designed to match topographic limitations (Figure 6). Final design would require river water levels to be established with hydraulic modelling so the spill levels for the ponds can be determined with accuracy.

Figure 5 Water Harvesting Pond Size Optimisation

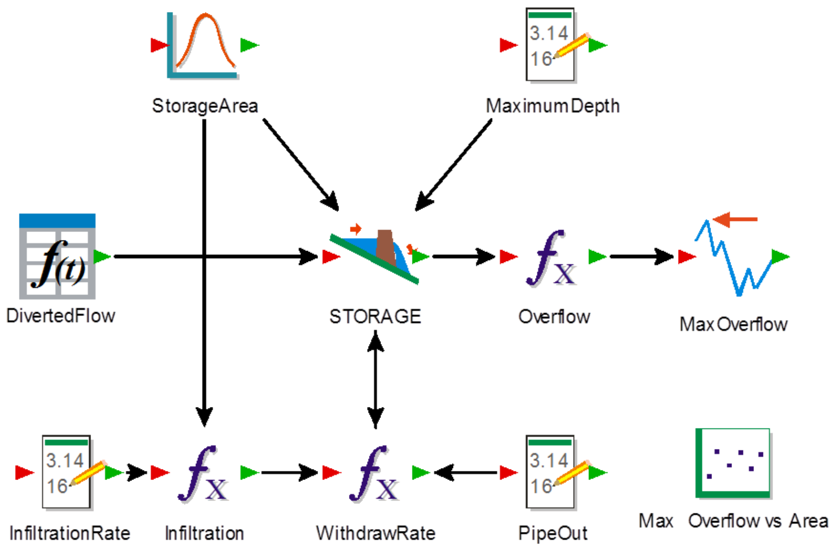
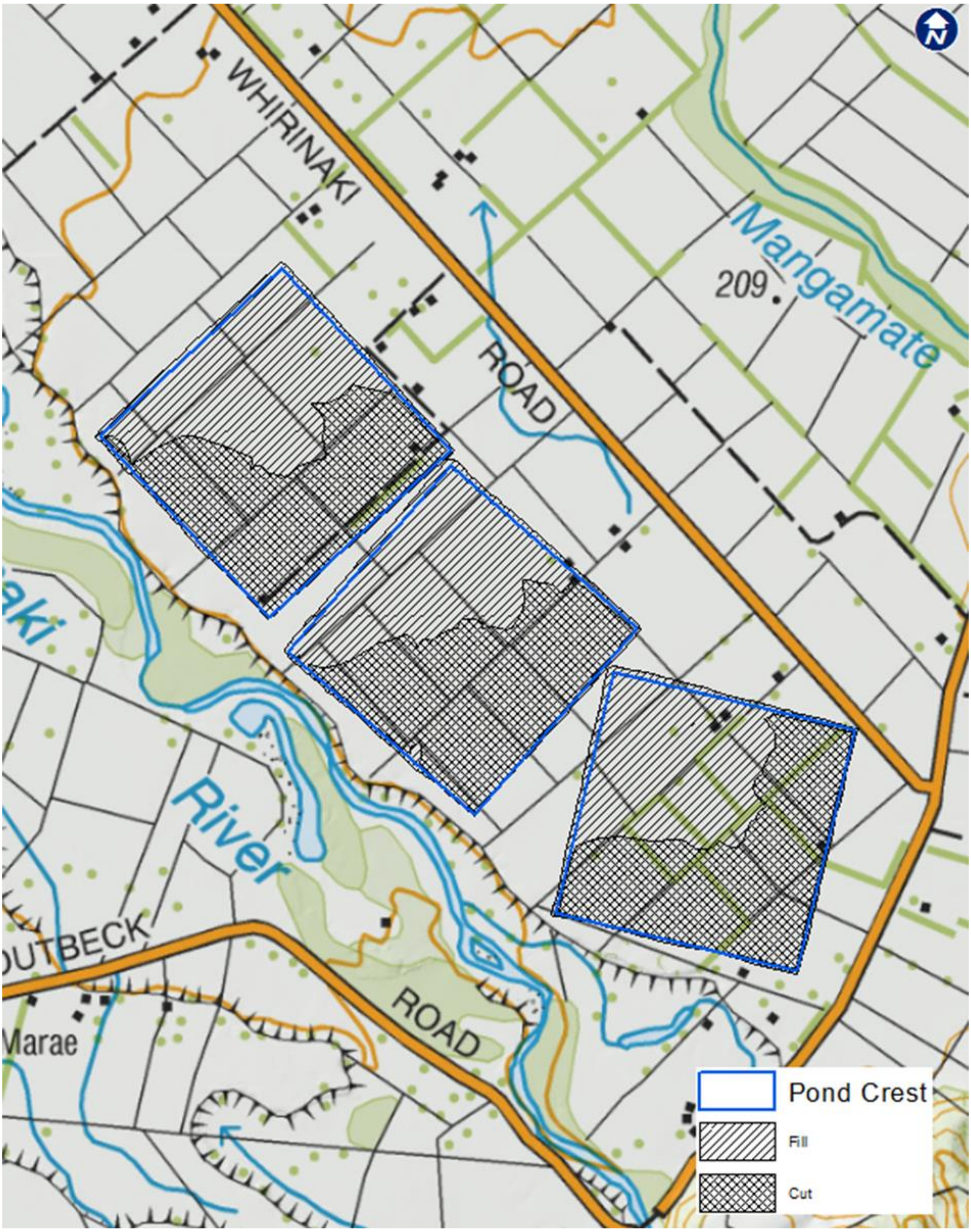


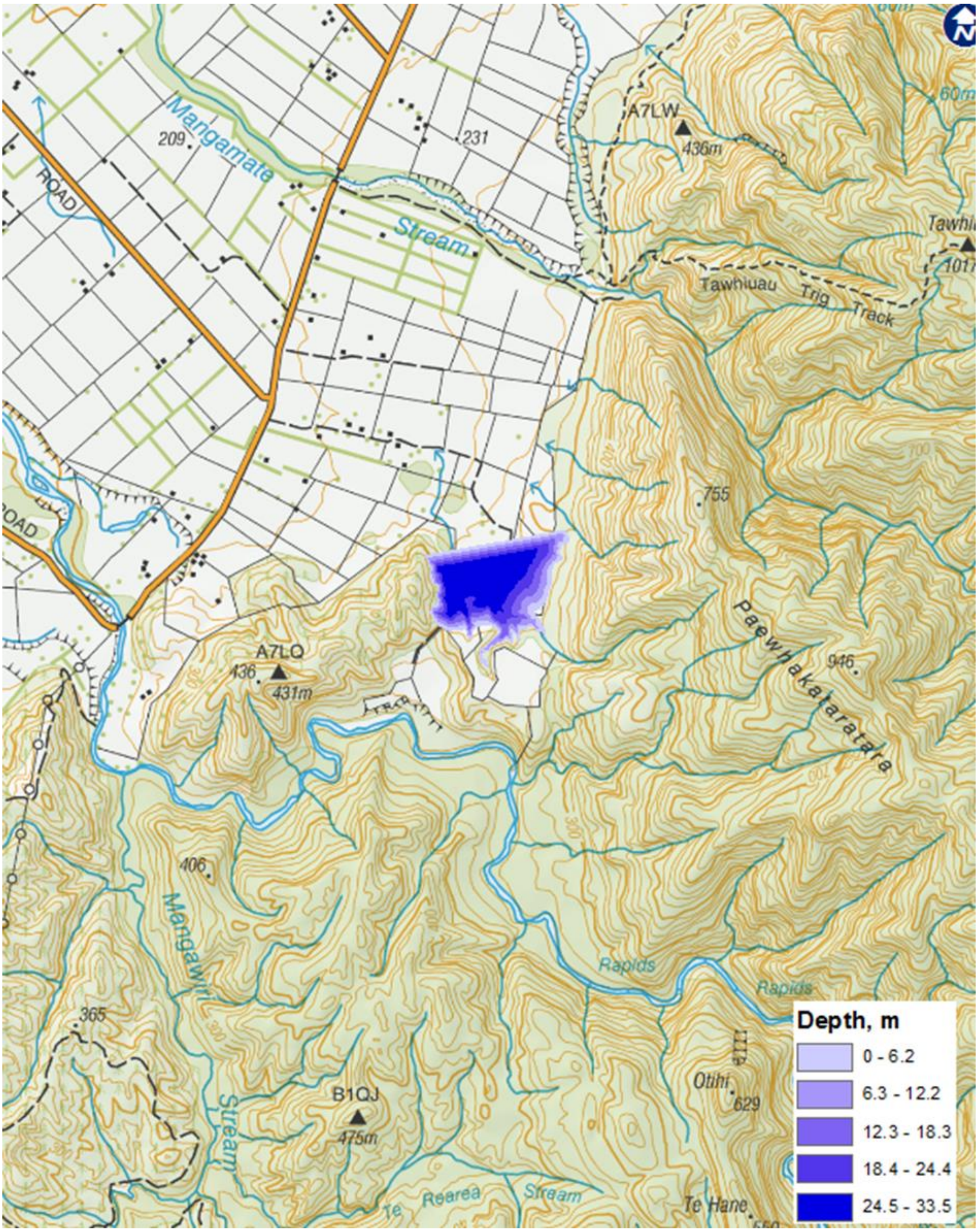
Figure 6 Water Harvesting Pond Layout



3.3.3 Pumped Storage Reservoir

Irrigation stakeholders asked that a potential pumped storage location be considered. One has been identified near where the stakeholders indicated. Like the larger on line dams it has potential issues with seismic risk and landscape considerations. It also requires more embankment material than the volume of water stored which is 3Mm^3 of water. Given the pumping requirements and the sizing of any delivery pipe it is considered that such storage has little merit for flood control. While there may be benefits to irrigators it has not been considered further because it will not have a multi-purpose function.

Figure 7 Pumped Storage Location and Dam Alignment



4.0 Irrigation Storage

4.1 Storage Requirement

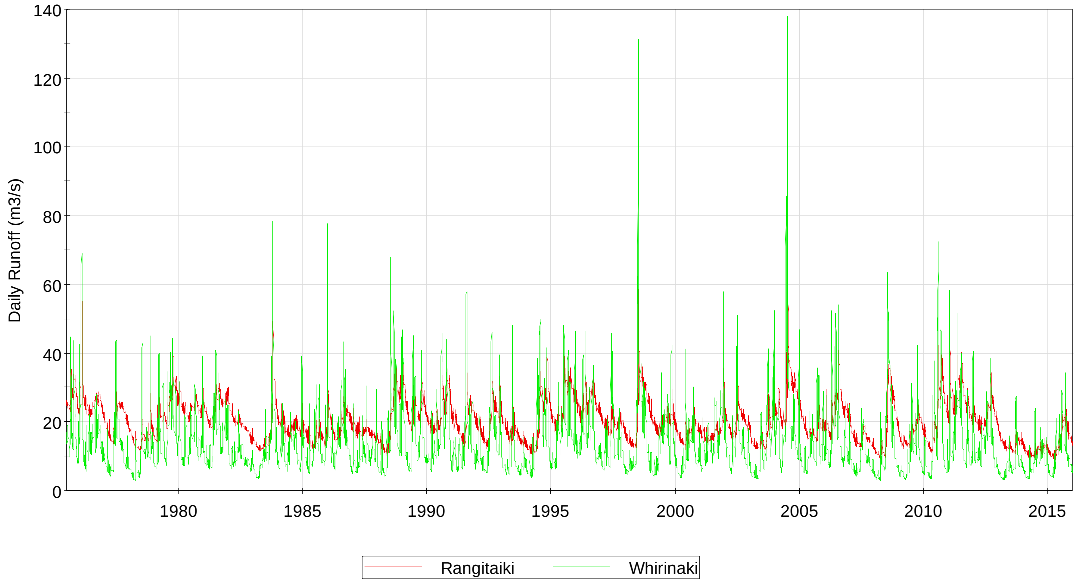
Early irrigation studies indicated that some storage may be required to support irrigation demand. This study investigates the magnitude of the storage volume and assesses that storage in relation to irrigation reliability. The storage volume is a balance between water supply and irrigation demand.

4.2 Water Sources

4.2.1 Surface water

Previous work has indicated abstraction of water from the Rangitāiki River upstream of the Whirinaki confluence and the Whirinaki River itself. This study considers abstraction from these rivers because of the availability of continuously recorded flow data at these locations. Flow records for both locations are shown in Figure 8. The Whirinaki record shows that the flow is more variable than in the Rangitāiki with higher and lower flows.

Figure 8 Daily Runoff in the Rangitaiki and Whirinaki Rivers



Only a proportion of this river water is available for abstraction and so within the GoldSim model some abstraction rules were established for specific scenarios:

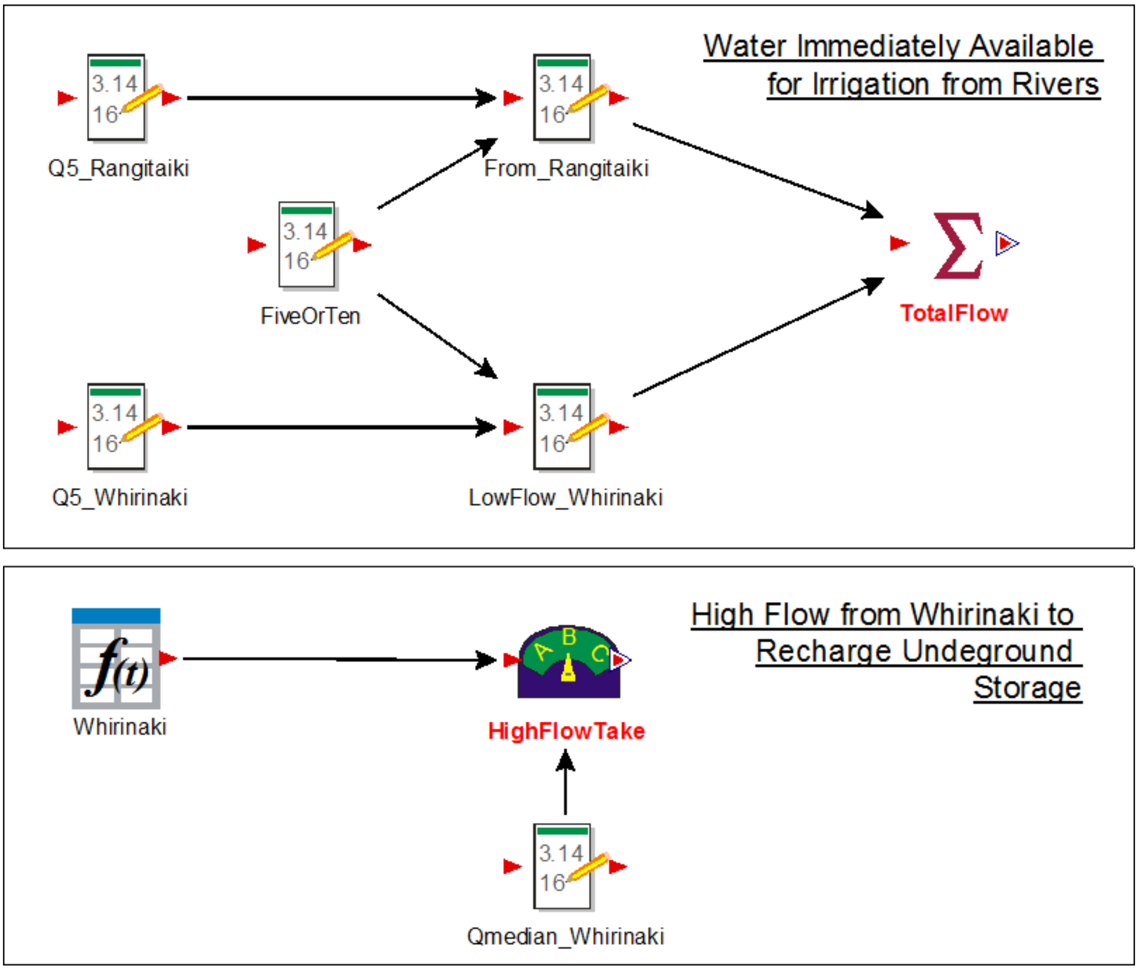
- Run of river abstraction based on a limit to the proportion of the one in five year low flow (Q_5) 7 day low flow. Two scenarios were considered – 5% and 10% of the Q5 low flow.
- Water harvesting when up to 10% of the flow above median flow could be harvested to storage.

The configuration of the two options in the GoldSim model is shown in Figure 9.

The flow values that have been used in the modelling are:

- Rangitāiki Q_5 7 day low flow 12.2 m^3/s
- Whirinaki Q_5 7 day low flow 3.89 m^3/s
- Whirinaki median flow 11.44 m^3/s.

Figure 9 Water abstraction scenarios



4.2.2 Groundwater

4.2.2.1 Geological/Hydrogeological Description

The Galatea Basin comprises a floodplain of the Rangitāiki River within the low lying areas of the river valley, covering an area of approximately 150 km^2 (White and Tschritter, 2015[2]). Within the Galatea Basin, the Rangitāiki has confluences with a number of tributaries, including the Whirinaki and the Horomanga, before entering Lake Aniwhenua.

The surficial geology of the upper catchment of the Rangitāiki, prior to the Galatea Basin, entails flat pumice covered plains, which are very absorbent and therefore able to regulate run off to the extent that flood flows are only two or three times larger than normal flow (Environment Bay of Plenty, 2008[3]).

The Galatea Basin itself however comprises surficial Holocene alluvial sediments of the Tauranga Group; in the southern central part of the basin, bore logs indicate the Tauranga group extends to at least 116.5m below ground level (m bgl) (White and Tschritter, 2015).

The Ikawhenua Ranges to the east are separated from the Galatea Basin by the Waiohau Fault system. The Whirinaki and Horomanga tributaries originate in the Ikawhenua Ranges, which is comprised of greywacke rock; consequently high run off gives rise to relatively large flood flows to the main channel (Environment Bay of Plenty, 2008).

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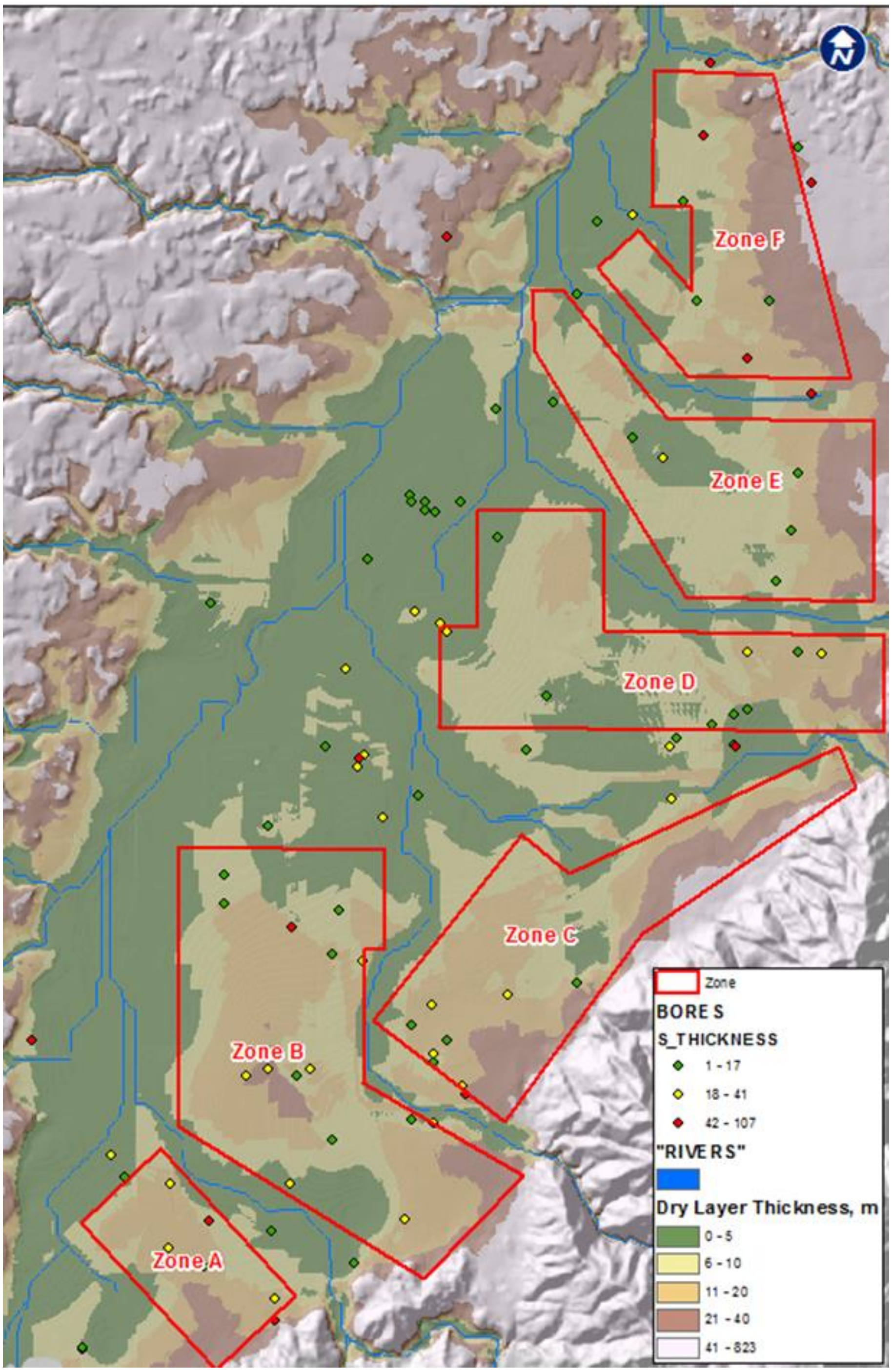
[2] White, P.A. and Tschritter, C. 2015. Groundwater resource investigations in the Upper Rangitaiki River Catchment, Bay of Plenty Region. Stage 1 – preliminary groundwater allocation assessment. GNS Science Consultancy Report 2014/283. 65p.

[3] Environment Bay of Plenty. 2008. Rangitaiki Tarawera Floodplain Management Strategy Stage 1. River & Drainages Publication 2008/01.

A large number of boreholes have been advanced across the Galatea Basin, with a range of depths from shallow to over 100m bgl, and they provide an indication of the aquifer materials and groundwater levels across the basin. Groundwater levels are typically deeper in elevated areas, particularly towards the eastern extent of the basins, where outwash gravels are deposited from the Ikawhenua Ranges.

Figure 10 indicates the interpreted unsaturated thickness spatially within the basin. This was derived using information provided in bore logs and water level measurements held by BOPRC. Unsaturated zone thickness ranges from approximately 0 – 5 m adjacent to the Rangitāiki River and its tributaries, to 21 – 40 m thickness at topographic highs, such as between the tributaries at the eastern boundary of the basin.

Figure 10 Interpreted unsaturated thickness in the basin



4.2.2.2 Groundwater resource – availability, allocation and use

The groundwater resources within the Galatea Basin are used extensively for agriculture. The groundwater available for allocation (GAA) in the basin is the largest within the Upper Rangitāiki River catchment and calculated from estimates of groundwater recharge to be 0.8 m^3/sec (69,000m^3/day). BOPRC records indicate that there are 27 consented bores in the Galatea Basin, having a combined consented allocation of 0.43m^3/sec (37,000m^3/day). A further 88 bores are assumed to take less than 15m^3/day, as a permitted use, with these contributing an additional 1,300 to the groundwater take.

The groundwater allocation is therefore approximately 55% of the GAA (White and Tschritter, 2015). However, estimated use is only approximately 0.21m^3/sec (18,000m^3/day).

4.2.2.3 Managed Aquifer Recharge

Directing excess surface water to ground as managed aquifer recharge (MAR), has the potential to provide in-ground water storage and improve water availability in the medium to long term. Areas with notable thickness of unsaturated materials, appropriate permeability and distance from groundwater discharge zones may be suitable for this purposeful recharge of groundwater.

A review of the borehole logs and groundwater levels, provided by BOPRC, allowed the unsaturated zone thickness to be estimated, as presented in Figure 10. A number of distinct areas, located between the tributaries of the Rangitāiki River, were identified as having the large thickness of unsaturated deposits, providing potential for MAR; these zones, labelled A – F are also presented on Figure 10.

For each zone, the volume of unsaturated aquifer that has the potential to be saturated utilising managed aquifer recharge infiltration methods has been estimated based upon the dry layer thickness. An averaged thickness was taken for each thickness range, minus two metres to allow for a small unsaturated zone to remain at the surface. For example, for a dry layer thickness range of 21m – 40m, the average thickness of 30m, minus 2m for unsaturated zone, gave a value of 28m to be utilised in calculations. The interpreted thickness of unsaturated zone was then multiplied by the estimated surface area occupied by each thickness range. The volumes generated were then multiplied by a typical alluvium literature value of porosity (0.25) to generate an estimate of the volume of the unsaturated pore space. The predicted volumes of unsaturated alluvium aquifer and unsaturated pore space within the aquifer for each of the zones are presented in Table 2.

Table 2 Volumes of Unsaturated Alluvial Aquifer and Unsaturated Pore Space with Potential to be saturated by Infiltration

Zone	Volume of Unsaturated Alluvial Aquifer (m^3)	Volume of Unsaturated Pore Space (m^3)
A	42,000,000	11,000,000
B	85,000,000	21,250,000
C	80,000,000	20,000,000
D	39,000,000	9,750,000
E	42,000,000	10,500,000
F	65,000,000	16,250,000
TOTAL	**353,000,000**	**88,750,000**

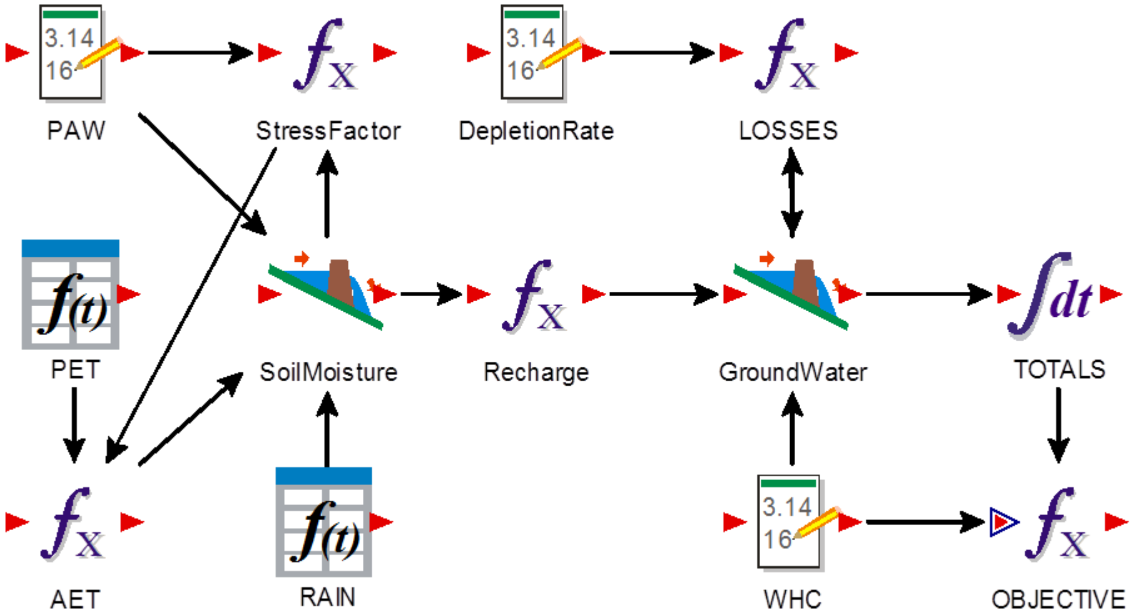
If this unsaturated zone is managed recharge then there will be a dynamic environment where water infiltrates but with the hydraulic properties of the zone there will also be a depletion or discharge to natural channels. The area of these zones is 62.2km^2 giving 1.43m^3 storage/m^2. To replicate this process in the GoldSim model the following assumptions were made:

- Storage recharge equals overflow rate of the soil reservoir.
- Losses *(L)* from storage are proportional to amount of water *(h)* in the storage: $L = \alpha \cdot h^{1.5}$.

- Under natural conditions *h* fluctuates near an average of 0.5*1.43m.

The model for parameter optimisation is outlined in Figure 11.

Figure 11 Unsaturated zone parameter optimisation

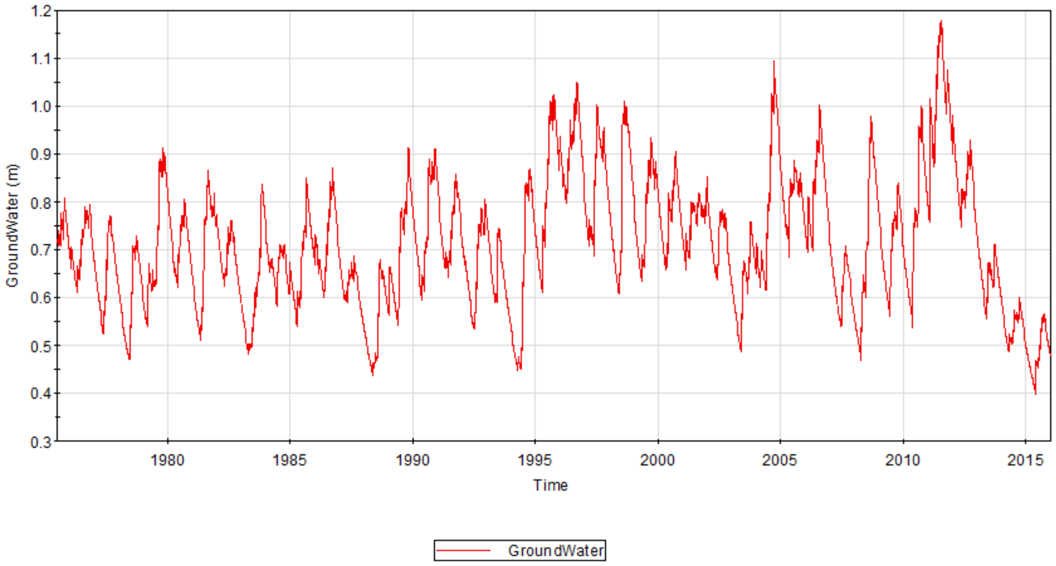


The components of the model are defined as:

- Plant available water (PAW) – A weighted average across the basin set at 145mm.
- Initial PAW set at 100% assuming soil wet on 1st July 1975.
- Water holding in saturated zone set at 1.43m.

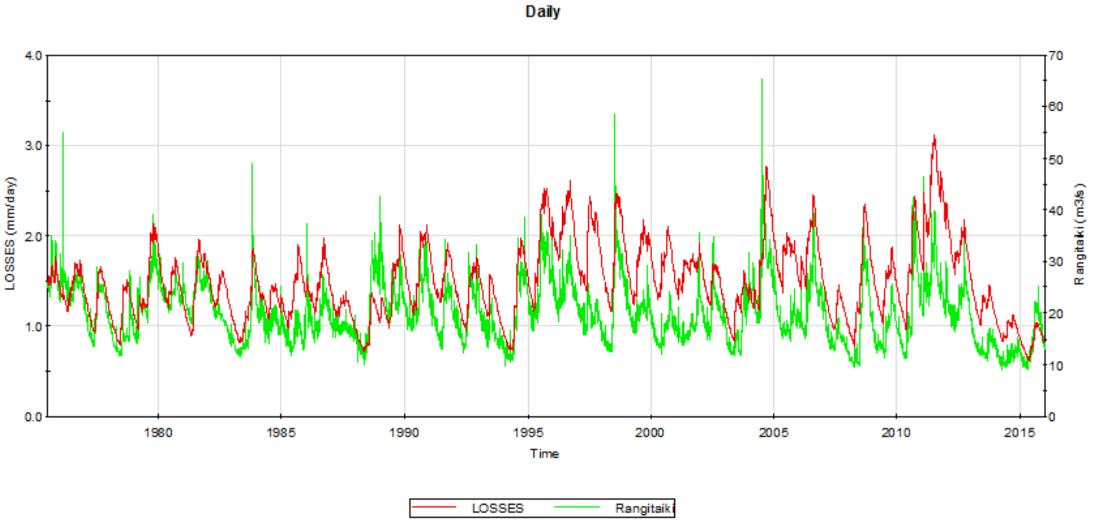
An optimised value of 0.00243m/day for depletion rate was obtained for model operation that generated a “natural” water holding in the unsaturated zone as shown in Figure 12.

Figure 12 Natural water holding in unsaturated zone



The losses in model are essentially discharge to streams and/or infiltration into deeper horizons. A significant correlation of 0.73 was found between their monthly values and Rangitāiki river runoff which indicates the optimisation is replicating the natural environment. The losses from the unsaturated zone and the Rangitāiki river flows are shown in Figure 13.

Figure 13 Daily losses from unsaturated zone vs runoff in Rangitaiki River



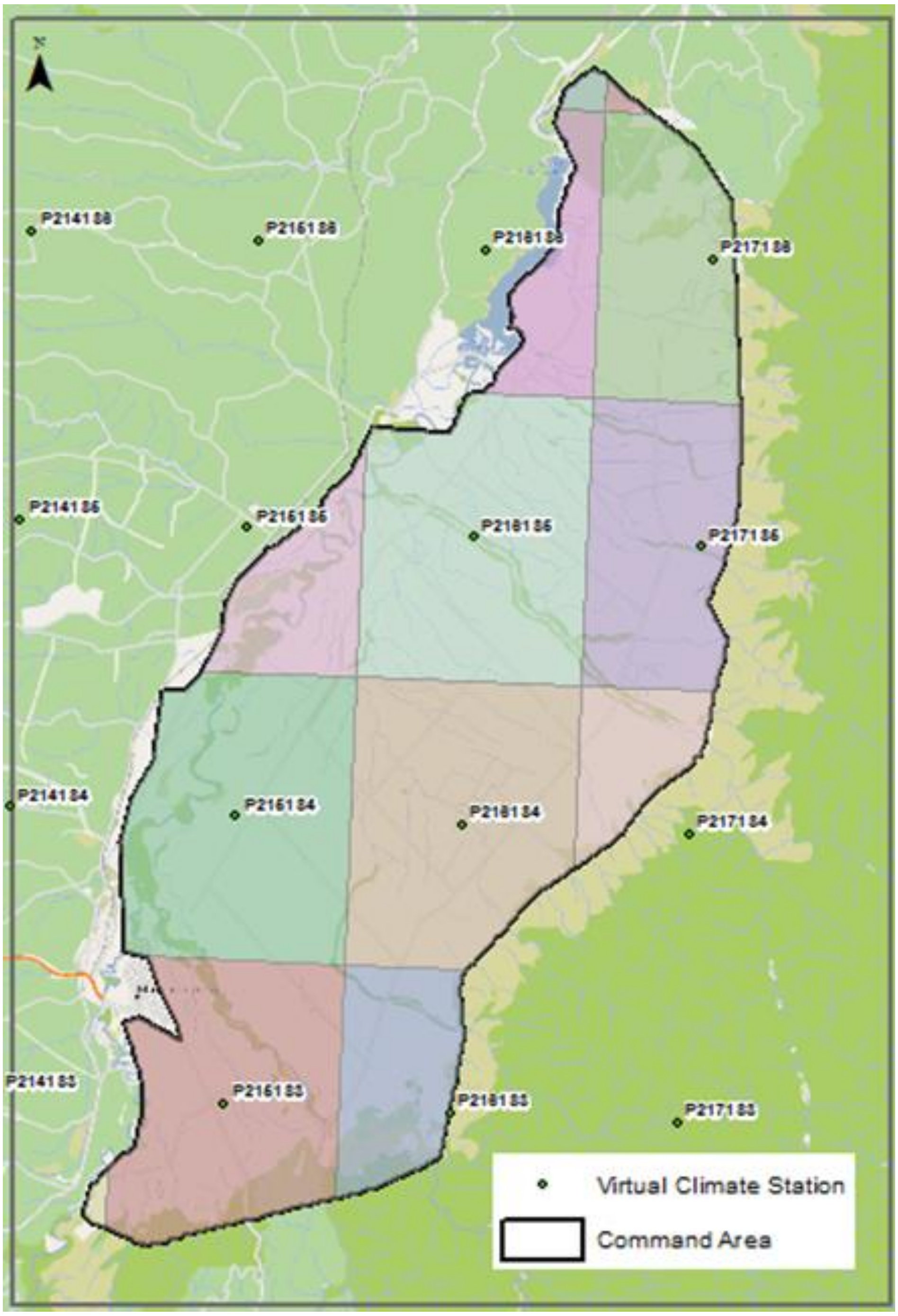
4.3 Irrigation Demand

Irrigation demand is estimated using a soil water balance model. This model is based on rainfall, evapotranspiration and the buffering effect of moisture stored in the soil. It takes into account the daily fluctuations in rainfall, evapotranspiration and the level of soil moisture. Based on a soil moisture threshold irrigation requirement is determined. The ability of the water supply to maintain the soil moisture above this threshold is a reflection on the reliability of the irrigation system.

4.3.1 Climate and Soils

The rainfall and evapotranspiration data has been sourced by BOPRC from NIWA. A total of 40 calendar years, from 1/01/1975 to 1/01/2016, of daily data has been provided for this assessment. The data comes from virtual climate stations that are spaced on a grid across the country. Only 15 stations have relevance to the Galatea basin as shown in Figure 14.

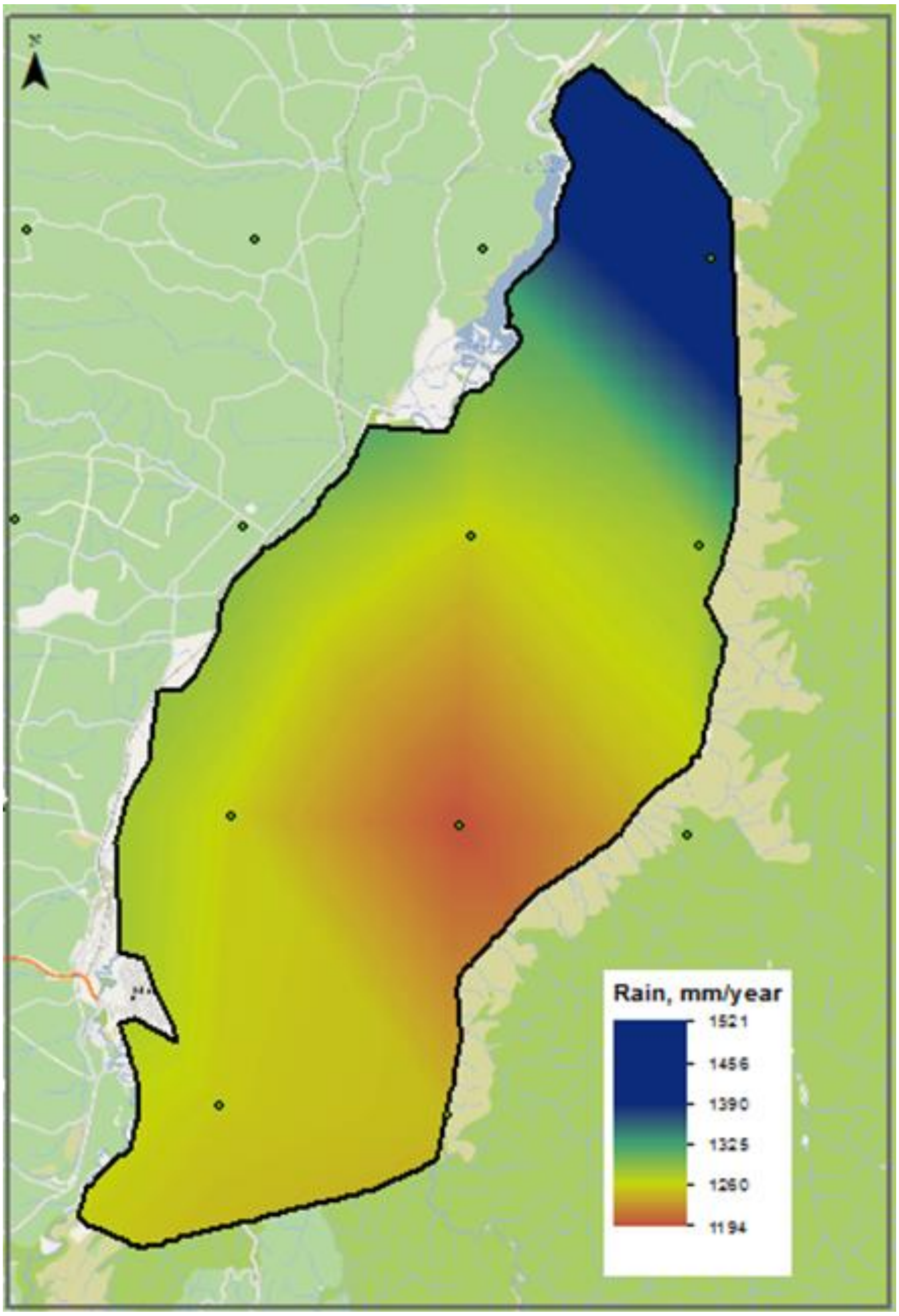
Figure 14 VCS locations in relation to Galatea Plain



Acronyms have been used for the climate and soil parameters as follows;

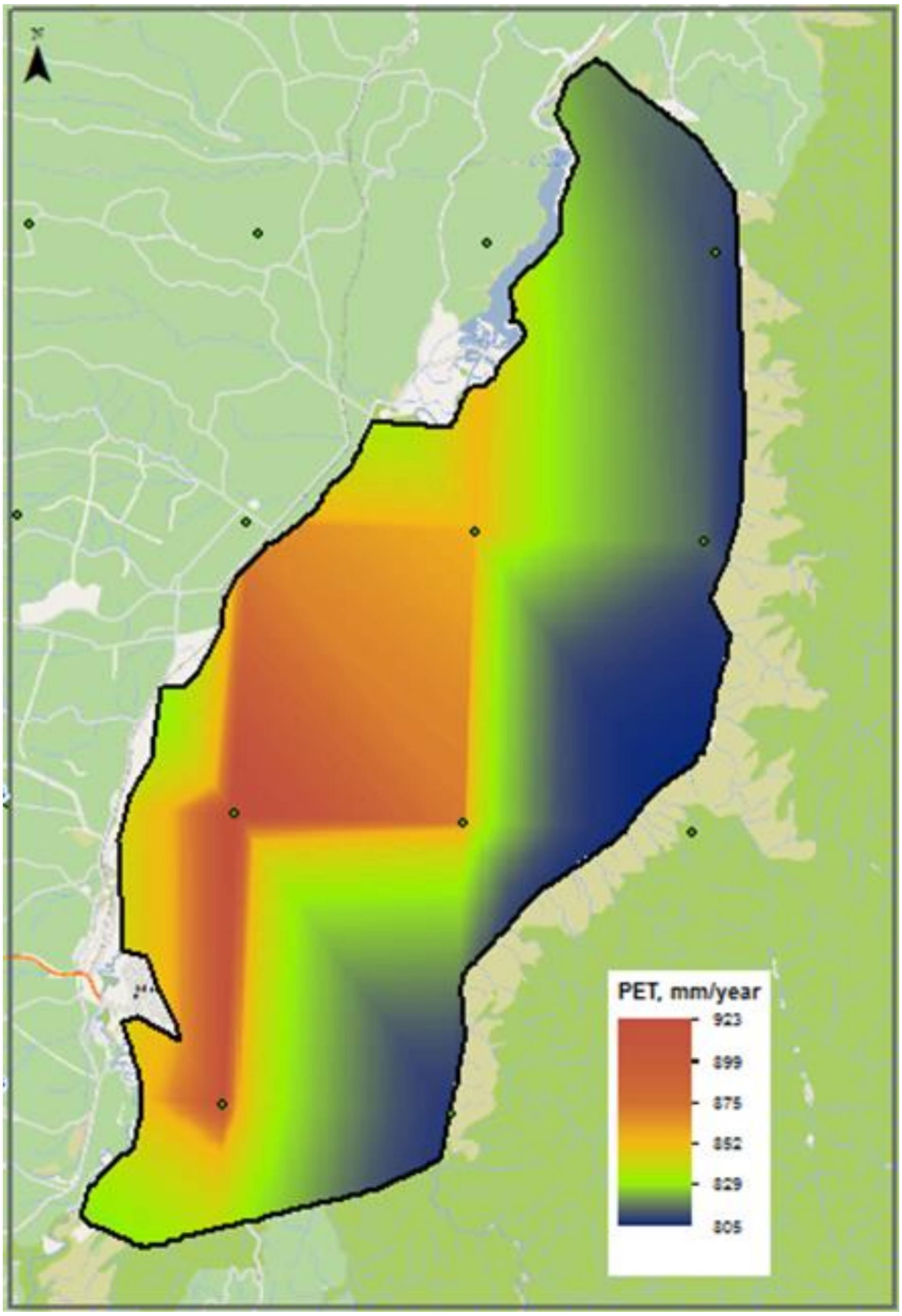
- PET – potential evapotranspiration
- VCS – virtual climate station
- PAW – plant available water
- AET – actual evapotranspiration.

Figure 15 Average Annual Rainfall



Average annual rainfall varies from 1190mm to 1520mm and while the gradation across the area is obvious, so too is the clustering around each of the station locations.

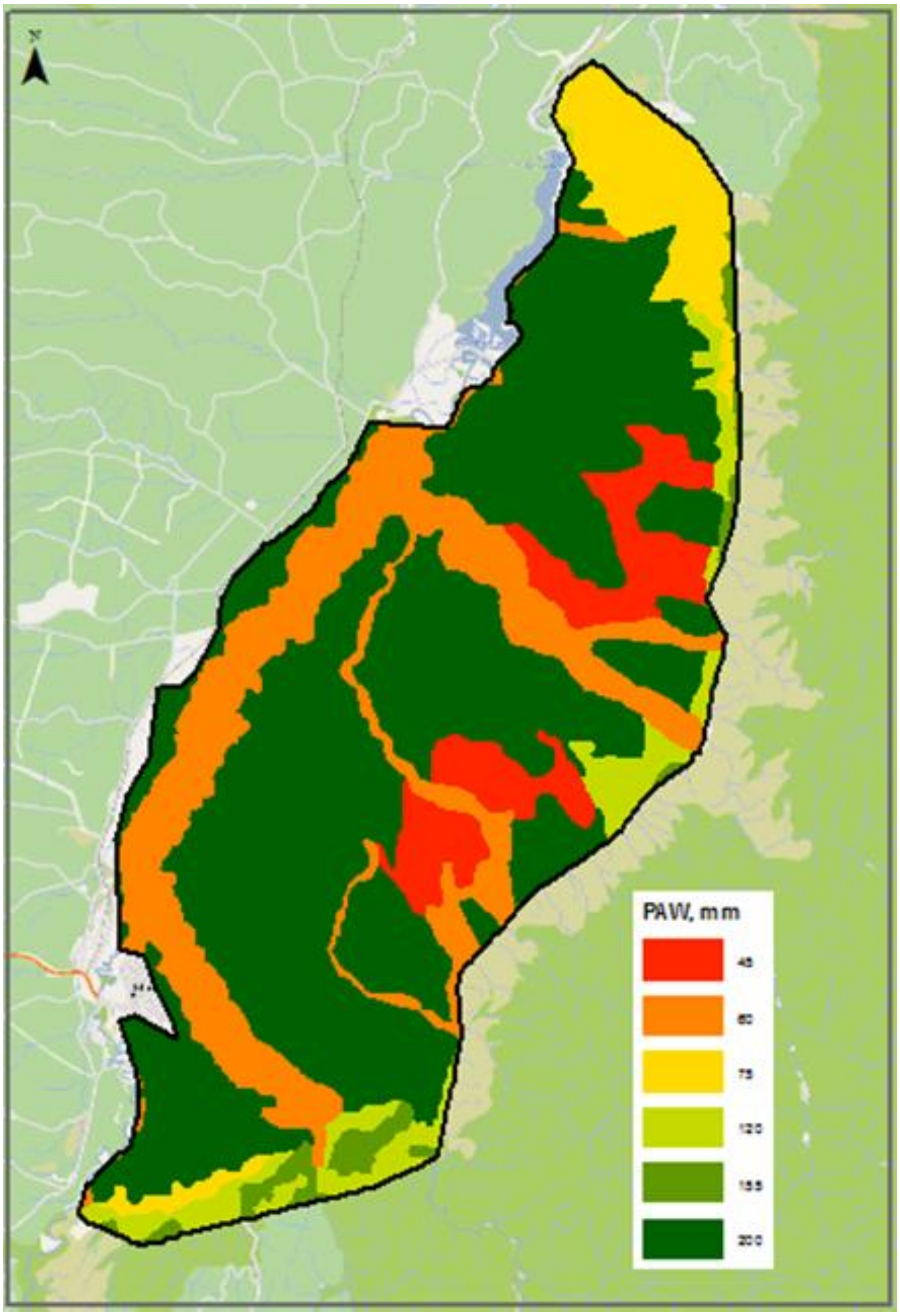
Figure 16 Average Annual Potential Evapotranspiration



PET ranges from 800mm to 920mm/year. The effect of the grid station base on totals can be clearly observed. For this assessment the data has not been further manipulated but for more detailed design, refinement is required with a finer interpolation mesh being required.

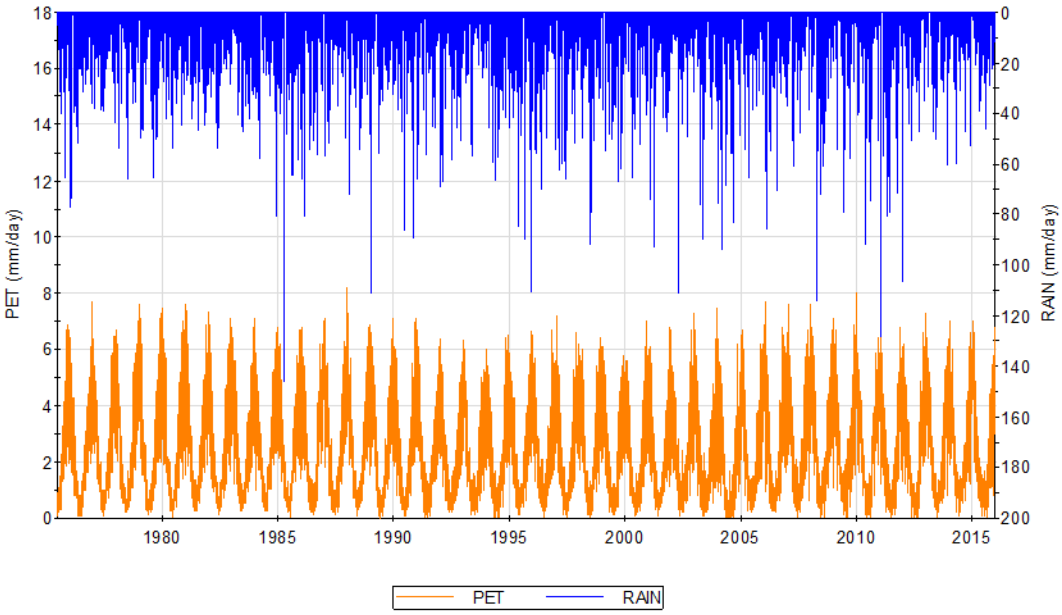
The magnitude of PAW can have a significant effect on the irrigation demand. PAW varies across the basin as shown in Figure 17.

Figure 17 Distribution of PAW



At this stage it is unknown how irrigation demand would be distributed across the irrigation command area so the data has been synthesised to provide averages and a single synthetic climate station record for the basin. A PAW of 145mm has been applied to model soil. This was calculated as individual PAWs weighted by area. A similar approach was applied to climatic data. Daily rain and PET from individual VCS were weighted according to their area of influence. Figure 18 shows rain and PET variations for such a synthetic station.

Figure 18 Daily rain and PET for synthetic climate station



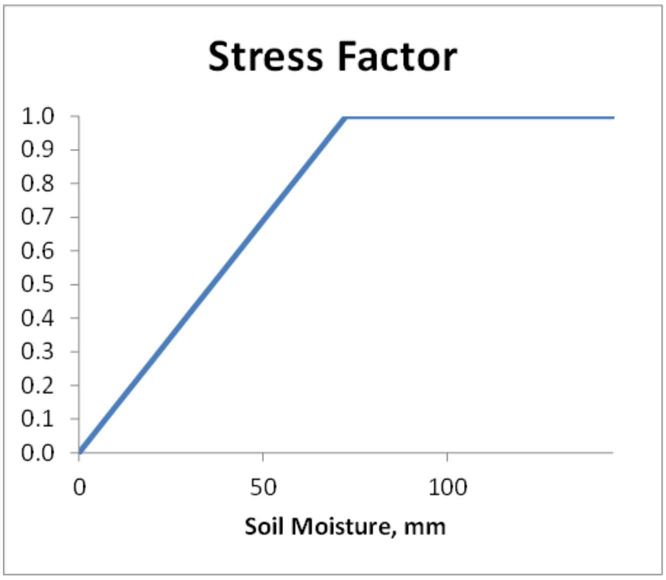
Within the data supplied there were 11 months (February 2004 to December 2004) of daily data missing. They were simply replaced by the same day and month data from 1986. This year was picked to fill the gap because its annual rain and PET averages were closest to 40 year averages.

4.3.2 Model Parameters

Within the GoldSim model there are routines that count for changes in evapotranspiration rate depending on soil moisture condition and also for flow within the unsaturated zone with water harvested for MAR.

PET is reduced to AET with the application of a stress factor. It is assumed that as the soil dries out the rate of evapotranspiration drops from PET to a lower AET. This reduction starts when the soil moisture reservoir is half full as shown in Figure 19.

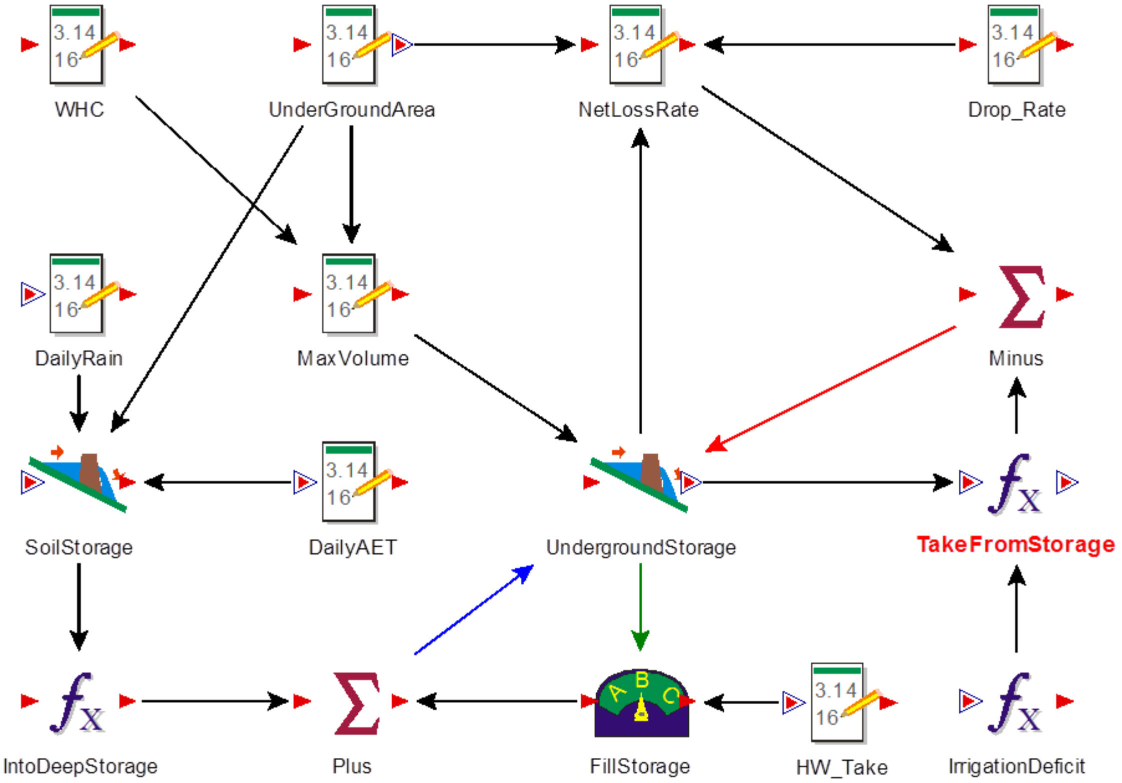
Figure 19 Stress factor as function of soil moisture value



The other factor in development of the irrigation demand model is the unsaturated zone storage of harvested water, which is MAR. In this case it is the volume of water going into and out of the unsaturated zone in addition to the take from the allocable groundwater volume. To achieve the volume assessment the full 8,500ha have been used to define area. The irrigation season is defined as eight months from 1September while the harvesting of water for MAR occurs all year.

It has been described in the model with the routine shown in Figure 20.

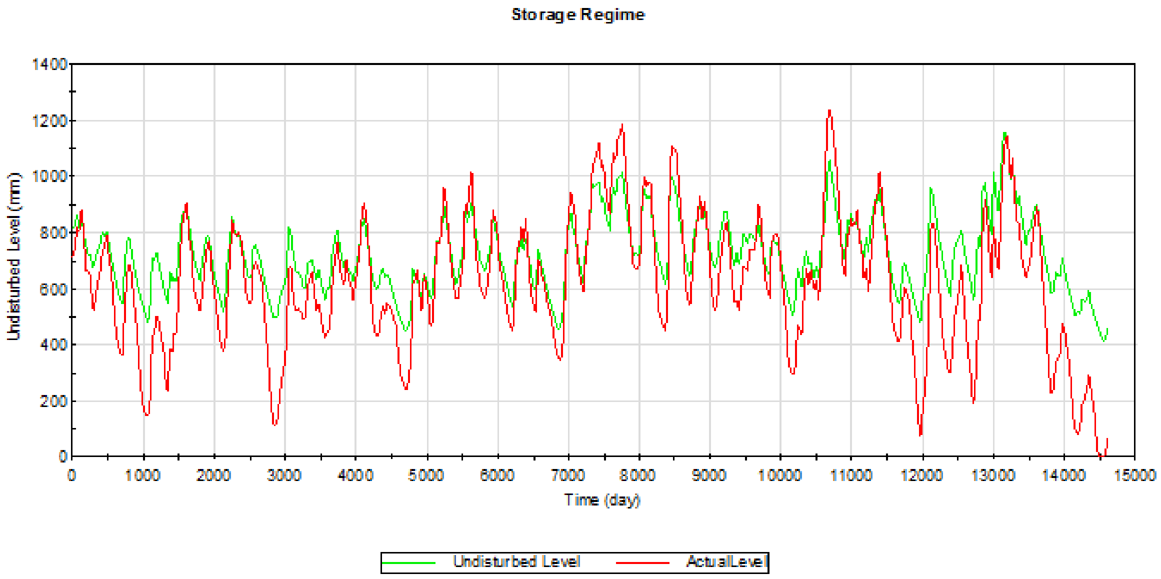
Figure 20 Components of the recharge and discharge from the unsaturated zone



In developing this routine it has been assumed that the entire command area recharges back to the usable reservoir during soil reservoir “spill” events. This might not be the case due to flow direction, and it is possible that this over estimates this part of inflow. Further, elevated groundwater levels may generate higher base flow in streams and rivers and so some of the water would be lost instead of being available for irrigation. Two other potential major inflow factors have been ignored; recharge from the hills/minor streams, and increase of soil overflow caused by irrigation itself.

The impact of irrigation withdrawals from the MAR is shown in Figure 21 where the established “natural” condition is compared with the effect from irrigation.

Figure 21 Effect of irrigation withdrawals from MAR



4.4 Irrigation Demand Model

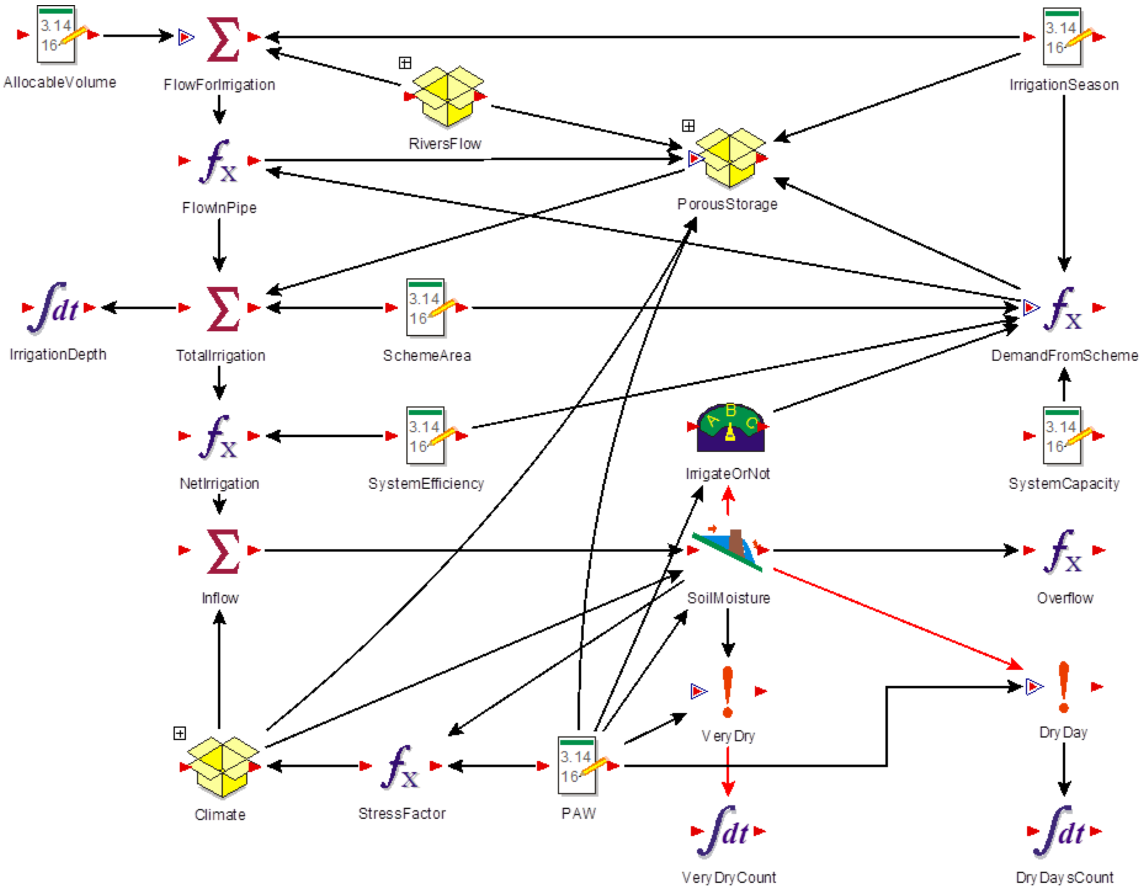
The main irrigation demand model integrates all the routines from climate data, river flow and the unsaturated zone MAR outputs. The structure of the model is shown in Figure 22.

Components/assumptions in the model are as follows:

Area	8,500ha
Irrigation efficiency	80%
System capacity	4mm/day is the peak demand that can be satisfied by the delivery infrastructure. Demand may change if the system capacity increases or decreases.
Peak Pond Pipe Outflow	5m^3/s maximum transfer to distributed infiltration basins
MAR basin infiltration	0.75m^3/s/ha
Allocable Groundwater	38,000m^3/day
Irrigation Threshold	PAW less than 70%
Dry day	PAW less than 50%
Very dry day	PAW less than 25%

Dry and very dry days are system performance criteria, where for 90% of the time PAW is greater than 50%, and 99% of the time PAW is greater than 25%.

Figure 22 Irrigation demand Model



4.5 Model Outputs

4.5.1 Irrigation demand

The irrigation demand model has been operated for 40 seasons and the summary of the seasonal total demand is provided in Table 3. The model is operated with two scenarios; 4mm per day which is a typical design value for the delivery network, and 20mm per day which is essential capacity great enough to meet all demand as no days have evaporation of 20mm.

Table 3 Seasonal Irrigation depth

Capacity (mm/day/ha)	Minimum (mm)	Mean (mm)	90th Percentile (mm)	Maximum (mm)
4	129	317	524	615
20	150	352	539	625

The results show that there is a significant temporal range in irrigation demand and this reflects the annual variability of rainfall and evaporation during the growing months.

4.5.2 Irrigation System performance

Three sources of water have been considered for irrigation:

1. Run of river take as a percentage of the Q5 low flow from the Rangitāiki and the Whirinaki Rivers,
2. Use of groundwater based on the allocable volume assuming existing irrigators who use groundwater would become part of any community scheme, and
3. MAR water that has been harvested during higher flows in the Whirinaki River.

An assessment has been undertaken considering three options for water take; river only, river and allocable groundwater, and water from all three sources. The results are provided in Table 4 and Table 5. Clearly there are significant reliability benefits if water is abstracted from all three sources. Being able to take 10% of Q_5 is also of significance especially if crops are being irrigated where the number of days and seasons when PAW is <50% are reduced by more than 50%.

Table 4 Irrigation Performance Indicators with 5% of Q5 abstracted

Water Source	Total days with PAW<50%	Maximum days in a season with PAW <50%	No. of Seasons when PAW <50%	Total Volume shortfall (mm)	Maximum Volume Shortfall in a Season(mm)
Run of River	2726	160	34	1650	60
Run of River + Allocable groundwater	2297	156	30	1418	56
Run of River + Allocable groundwater + MAR water	133	56	1	66	19

Table 5 Irrigation Performance Indicators with 10% of Q5 Abstracted

Water Source	Total days with PAW<50%	Maximum days in a season with PAW <50%	No. of Seasons when PAW <50%	Total Volume shortfall (mm)	Maximum Volume Shortfall in a Season(mm)
Run of River	1984	151	30	1231	52
Run of River + Allocable groundwater	1643	136	26	1014	47
Run of River + Allocable groundwater + MAR water	90	26	0	64	19

Considering the distribution of the dry days throughout the 40 years of record showed, in Figure 23:

- There were no very dry days when PAW was <25%.
- The criteria of 90% of the time PAW being >50% was met in all years except 2015. It was one day short of failing in 1979.
- There also appears to be a link between years as reflected in the unsaturated zone water levels. In 1978 there were nine dry days; however in 1979 it increased to 27 days, even though the irrigation demand was lower in 1979 compared to 1978.

Figure 23 System performance over the years

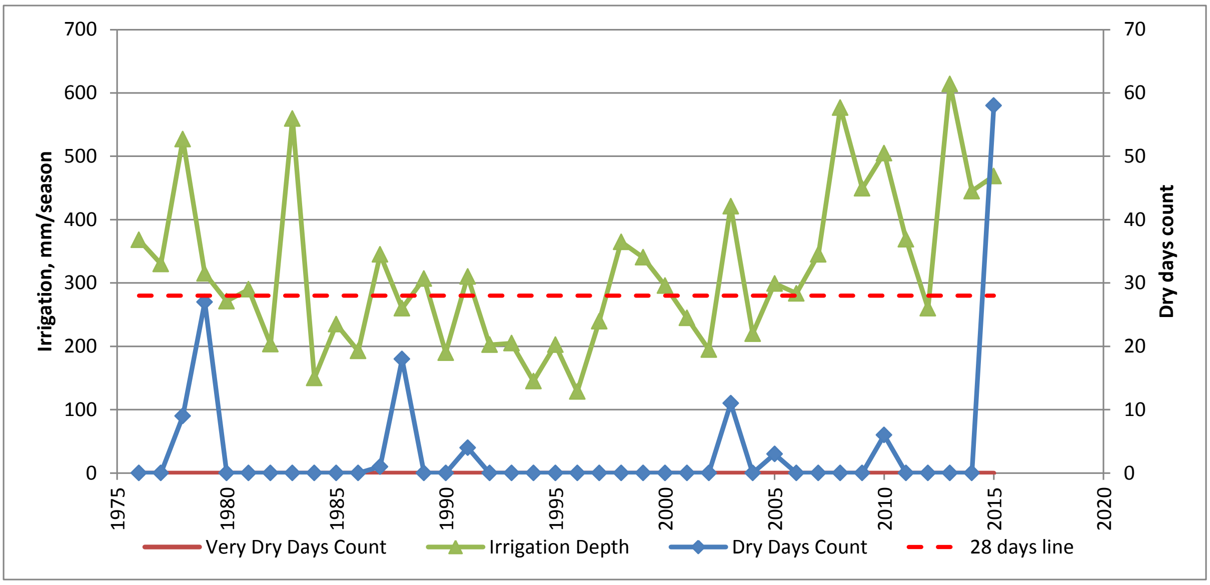
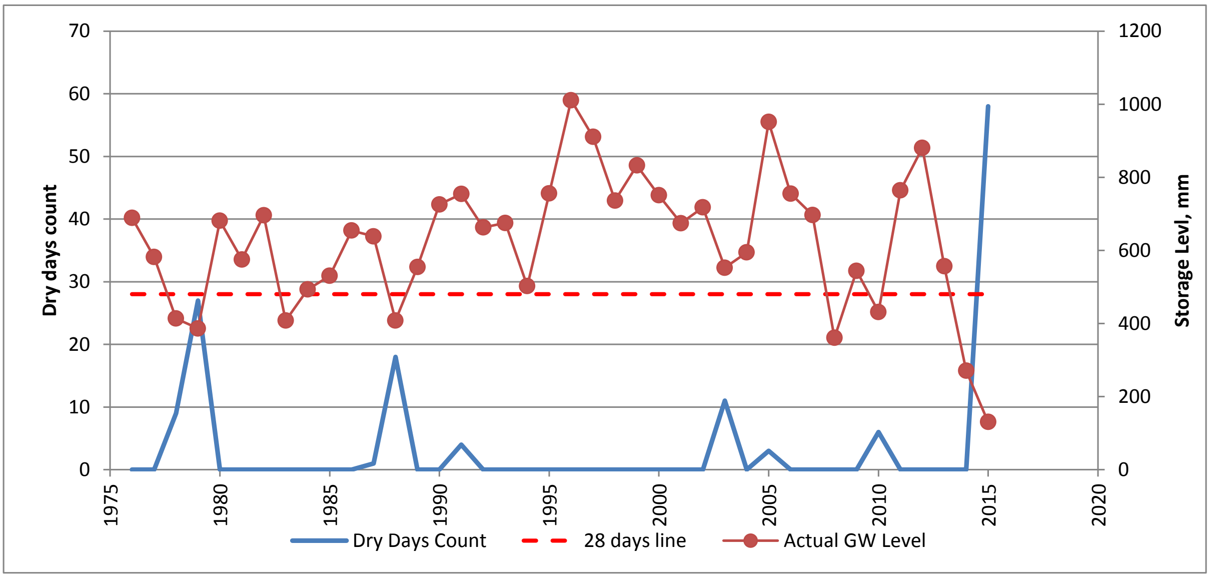


Figure 24 Impact of consecutive dry years on irrigation performance



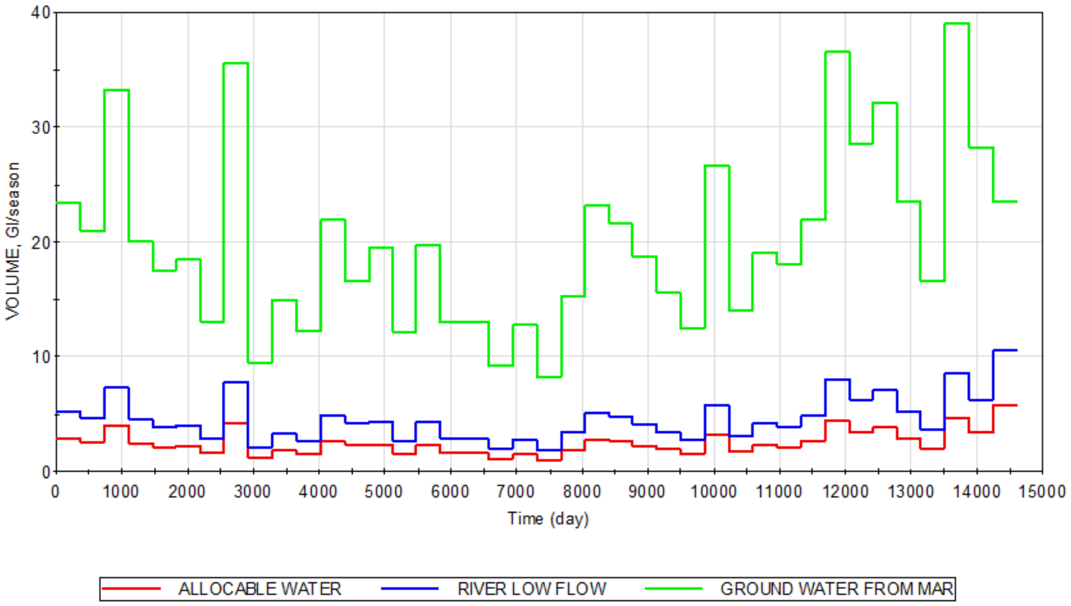
4.5.3 Sources of water for irrigation

The volume of water from each of the three sources is shown in Table 6 and Figure 25. Clearly the need to store water for irrigation is important and the reliability of any scheme is going to rely on this supplementary storage.

Table 6 Sources of water for irrigation

Source \ Volume (10^6m^3)	Min	Mean	90%	Max
Allocatable Natural Groundwater	0.977	2.47	4.26	5.78
River Low Flow	1.79	4.52	7.79	10.6
Groundwater from MAR	8.16	20.0	33.3	39.1

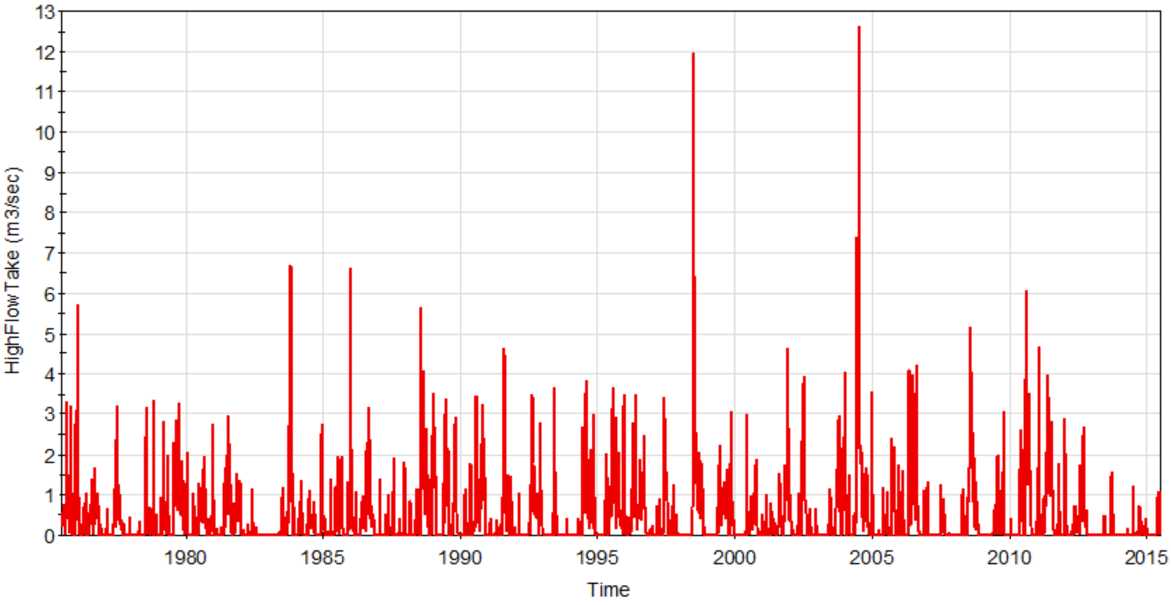
Figure 25 Sources of water for irrigation



4.5.4 Irrigation Water Harvesting Pond Size

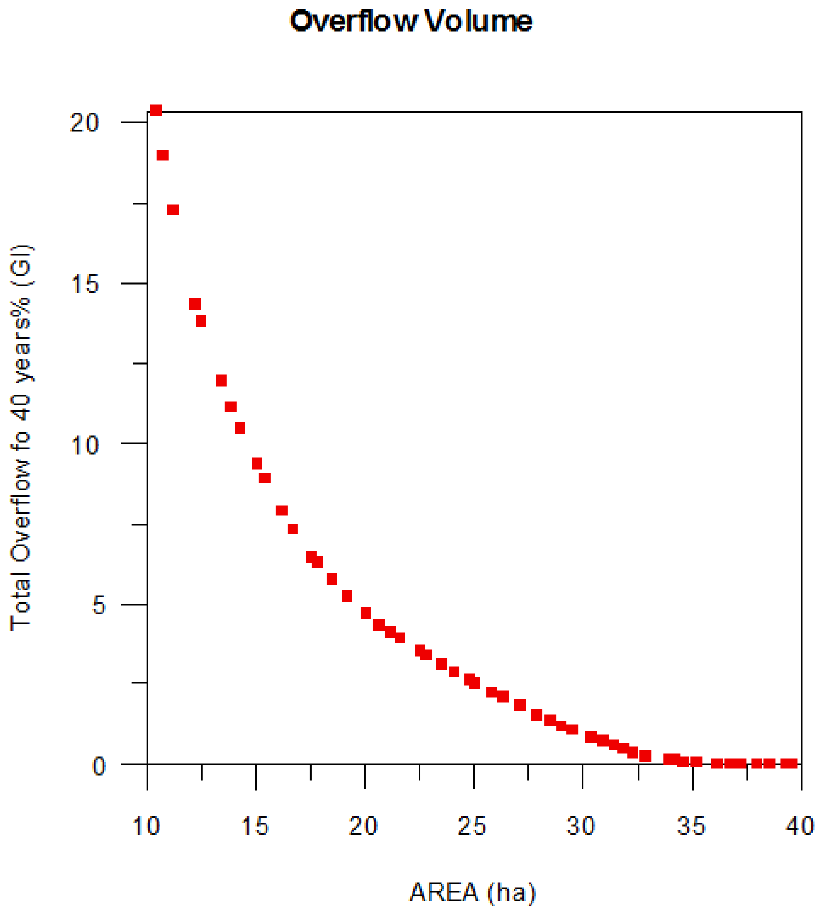
To meet the system performance water is harvested at high stage from the Whirinaki River and for this a harvesting storage pond is required. The intention is to utilise the same ponds for flood control and water harvesting for irrigation. However the flows are much less than the 100 year flow that is used for flood control design. A stochastic model was developed to optimise the irrigation water harvesting pond size based on the diverted flows from the Whirinaki River as shown in Figure 26.

Figure 26 High Flow Water Take from the Whirinaki River



As shown in Figure 27 the size of the 3m deep pond should be approximately 36.5ha in order to achieve no overflow from the pond.

Figure 27 Overflow Volume v Pond Size



5.0 Balancing Flood & Irrigation Storage

5.1 Concept

The objective of this assessment has been to establish if it is possible to combine flood control and irrigation infrastructure to provide multiple benefits. Various alternatives have been considered but the preferred option is off line water harvesting. The concept is for ponds on the right bank of the Whirinaki River between Troutbeck Road Bridge and the confluence with the Rangitāiki River.

At this initial stage there are uncertainties with respect to sizing and even location of these ponds. More detailed work on flood hydraulics to establish water levels and more detailed assessment of groundwater hydraulics is required.

However, the structure of the concept does allow flexibility. For flood control some ponds could be located on the left bank of the Whirinaki. Further, some of the ponds could be located on either bank of the Horomanga Stream. At this stage it is less certain as to the potential alternative locations for MAR harvesting ponds as more clarity and understanding is required on groundwater flow. The Horomanga could be considered although it is most likely that harvesting ponds need to be located at the east of the basin because of gradients.

5.2 Performance

It has been established that with off line water harvesting there are benefits for both irrigation and flood control.

The irrigation scheme would meet the target criteria with a pond area of 36.5ha.

The flood control in the 100 year event requires a pond area of 155.8ha to meet the goals of the flood study. This would still require the operation of Matahina Dam to assist in flood management. Increasing the pond area along either the Whirinaki or Horomanga Rivers would reduce the reliance on the flood control management of Matahina Dam.

6.0 Cost estimate

6.1 Harvesting Ponds

The cost estimate is high level with a 20% contingency and only considers components that are common to both irrigation and flood management. Three ponds with a fixed inlet control are required for flood control and for irrigation one pond with a variable inlet control because of the proportional take of the median flow needs control. Further the assumption that water depth is limited to 3m impacts cut and fill volumes so it has been assumed that there could be a need for imported fill and this is a significant proportion of the cost estimate. In reality detailed design would aim to minimise importing material. Infiltration basins to disperse water in a MAR scheme for irrigation have not been included, and neither has any estimate of bores and pumps for water extraction as these are viewed as being solely irrigation requirements and have no flood control benefit. For only flood control ponds it has been assumed that once completed these could be grazed and the land sold as they would be inundated infrequently. This could only be realised if pond integrity was assured.

The cost estimates are summarised below and detail provide in

Table 7and Table 8:

- Flood control only - $34.8M
- Irrigation only - $15.8M
- Combined flood and irrigation use $39M based on the irrigation pond and two flood control ponds.

Table 7 **Cost estimate - Flood Control Only**

Item	Description	Unit	Rate ($NZD)	Quantity	Rounded Amount
1.0	**Preparation of Foundation**				
1.1	Strip Topsoil - Entire pond	m^3	$4.00	469156	$1,880,000.00
1.2	Re-spread Topsoil and Re-grass	m^3	$5.00	469156	$2,350,000.00
1.3	Excavate to foundation- Entire pond	ls			$50,000.00
1.4	Treat Foundation	m^2	$5.00	227124	$1,140,000.00
2.0	**Embankment Earthworks**				
2.1	Cut to Fill	m^3	$8.00	279662	$2,240,000.00
2.2	Imported Fill	m^3	$20.00	535987	$10,720,000.00
2.4	Geofabric - For Flood Protection	m^2	$3.00	40000	$120,000.00
2.5	RipRap - River Facing For Flood Protection	m^3	$120.00	27500	$3,300,000.00
3.0	**Monitoring Equipment**				
3.1	Survey Points	ea	$500.00	12	$10,000.00
3.2	Water monitoring and alarm system	ls	$50,000.00	1	$50,000.00
4.0	**Site Fencing and Roads**				
4.1	Fencing	LM	$10.00	5000	$50,000.00
4.2	Temporary Access Roads	ls	$100,000.00	1	$100,000.00
4.3	Permanent Site Access Roads	ls	$100,000.00	1	$100,000.00
Construction Cost					**$22,110,000.00**
5.0	**Engineering**				
5.1	Design	10%			$2,220,000.00
5.2	Consents	8%			$1,770,000.00
5.3	Construction QA Supervision	4%			$890,000.00
5.4	Land Purchase	Ha	$30,000.00	200.00	$6,000,000.00
5.5	Land re-sale	Ha	-$20,000.00	200.00	$4,000,000.00
Total Construction Cost					**$28,990,000.00**
Total Construction Cost (20% contingency)					**$34,788,000.00**

Table 8 Cost estimate - Irrigation only

Item	Description	Unit	Rate ($NZD)	Quantity	Rounded Amount
1.0	**Preparation of Foundation**				
1.1	Strip Topsoil - Entire pond	m^3	$4.00	156385	$630,000.00
1.2	Re-spread Topsoil and Re-grass	m^3	$5.00	156385	$790,000.00
1.3	Excavate to foundation-Entire pond	ls			$50,000.00
1.4	Treat Foundation	m^2	$5.00	75708	$380,000.00
2.0	**Embankment Earthworks**				
2.1	Cut to Fill	m^3	$8.00	91177	$730,000.00
2.2	Imported Fill	m^3	$20.00	181710	$3,640,000.00
2.4	Geofabric - For Flood Protection	m^2	$3.00	14000	$50,000.00
2.5	RipRap - River Facing For Flood Protection	m^3	$120.00	9200	$1,110,000.00
3.0	**Secondary Embankment**				
3.1	Imported Fill	m^3	$20.00	10200	$210,000.00
3.2	Amouring	ls	$20,000.00	1	$20,000.00
4.0	**Monitoring Equipment**				
4.1	Survey Points	ea	$500.00	4	$2,000.00
4.2	Water monitoring	ls	$50,000.00	1	$50,000.00
5.0	**Intake Structure**				
5.1	Intake Channel	ls	$50,000.00	1	$50,000.00
5.2	Excavation, Dewatering & Backfill	ls	$50,000.00	1	$50,000.00
5.3	Foundation Preparation	ls	$10,000.00	1	$10,000.00
5.4	Structure	ls	$500,000.00	1	$500,000.00
5.5	Gate and controls	ls	$250,000.00	1	$250,000.00
5.6	Stop Logs	ls	$25,000.00	1	$30,000.00
5.7	Screen	ls	$20,000.00	1	$20,000.00
6.0	**Infiltration Gallery – Offtake**				
6.1	Infiltration gallery including excavation, reinstatement and culvert installation	ls	$500,000.00	1	$500,000.00
7.0	**Site Fencing and Roads**				
7.1	Fencing	LM	$10.00	5000	$50,000.00

Item	Description	Unit	Rate ($NZD)	Quantity	Rounded Amount
7.2	Temporary Access Roads	ls	$100,000.00	1	$100,000.00
7.3	Permanent Site Access Roads	ls	$100,000.00	1	$100,000.00
Construction Cost					**$9,322,000.00**
8.0	**Engineering**				
8.1	Design	10%			$940,000.00
8.2	Consents	8%			$750,000.00
8.3	Construction QA Supervision	4%			$380,000.00
8.4	Land Purchase	Ha	$30,000.00	60.00	$1,800,000.00
Total Construction Cost					**$13,192,000.00**
Total Construction Cost (20% contingency)					**$15,830,400.00**

7.0 Impact of Concept

The concept of providing off line water harvesting ponds has the potential to impact a number of aspects of the environment. However, as the ponds are off line and can be constructed largely in the dry where the major activity is excavation and movement of earth material the impacts are mostly constrained to the pond locations. Potential factors that could be impacted are discussed in the following subsections.

7.1 River Flow

The concept has been developed without consideration of the 160m^3/s threshold that limits water take because of hydroelectric generation. This will need to be considered further during more detailed feasibility assessment. One aspect that needs further modelling is the balance of water available for generation at the moment compared to the regime that could apply if MAR proceeds. At present there is some water lost to generation with spillway operation. If water is attenuated through groundwater and discharges slowly back to the rivers then the presently lost generation may benefit from more sustained base flow.

BOPRC is currently advancing the process whereby river and catchment values will be recognised with the setting of allocable water volumes and water quality standards. In this assessment two levels of abstraction from rivers have been considered. While more work on irrigation reliability is required it would appear that a reduced level of take from a river is not as significant as the ability to harvest flood water.

The harvesting of water into off line ponds means that any flood way is not impacted and water levels should remain very much as they do now. Further the sediment transport which is significant in the Whirinaki is unlikely to be significantly impacted and natural geomorphic processes should remain largely unchanged even though a proportion of higher flows will be diverted.

7.2 Groundwater

The establishment of a MAR scheme will likely maintain groundwater levels higher than those occurring at present although there is uncertainty on how much of the recharge will travel directly back to streams and rivers. The increased volume of water could potentially dilute any contaminants in the groundwater. Further an elevated groundwater level may result in discharge as springs and wetland. These groundwater issues cannot be resolved without a detailed groundwater model of the basin.

7.3 Flood Control

The provision of off line water harvesting ponds has been shown to provide the flood control opportunity that was identified in the previous flood study, but still relies on flood control by Matahina Dam. However, to ensure this objective is actually achieved a hydraulic model of the Whirinaki River is required to establish spill levels and performance into the water harvesting ponds. How this combines with the harvesting regime assumed for the MAR for irrigation may need some consideration and could result in modified pond design because of the flow capture regimes.

If more flood control is required through the use of fixed assets rather than relying on flood forecasting and operation at Matahina then more ponds would be required. The concept allows for these additional ponds and they could be located either on the Whirinaki or Horomanga Rivers.

7.4 Resilience and Climate Change

No detailed analysis has been undertaken with respect to climate change. However, the pond size and location could be adjusted to accommodate a modified flow regime for both irrigation and flood control. The flood control aspect is easy to address in that if floods are bigger then bigger ponds are required. However, for MAR and irrigation there is a dependence on continuous flow rather than the event flow for a major flood. If climate change alters the regime then the reliability and number of dry days for irrigation could change. Sensitivity testing or irrigation reliability under a modified flow regime would be required to establish any business case for infrastructure investment.

7.5 Construction

As the ponds are for water harvesting of higher flows they can be constructed in the dry and above normal river low flow levels. Noise, dust and sediment runoff control are likely to be the most significant environmental risks during construction.

7.6 Environmental Values and Risks

The off line ponds and their operation during higher flow events means that they do not act as a barrier to river fauna and flora and that habitat remains unchanged. River fauna crossing the weir during a flood event can be captured and returned to the river after the flood event. As there is no mechanised infrastructure anticipated there would be no effects on the fauna. Any river intakes for run of river flow are solely for irrigation supply and are not part of the combined irrigation / flood control infrastructure.

The run of river take for irrigation is a small part of the low flow and so would unlikely have a significant impact on water way depth and velocity but habitat modelling will be required to confirm this as part of the irrigation design.

8.0 Recommendation and Conclusions

AECOM recommends that as the harvesting of water to off line ponds assessments shows that both flood control and irrigation objectives can be achieved. More detailed investigations are required to substantiate assumptions made in this assessment and provide a basis for design. These assessments include:

- Recalibration of the Rangitāiki River model based on recent storm observations.
- Inclusion of hydraulic reach modelling in the Rangitāiki River model for the Whirinaki and Horomanga Rivers where they cross the Galatea Basin.
- Establishment of a calibrated groundwater model for the Galatea Basin such that MAR options can be assessed, including discharge to streams.
- Siting options for harvesting ponds and irrigation scheme infiltration basins be investigated, including preferred recharge areas and flow dispersion.
- Assessment of the impact of suspended sediment on pond design and operation.
- Updating of the base GoldSim model used in this assessment to include outputs for investigations.
- Expansion of the GoldSim model to consider changes in the flow regime on hydroelectric generation.
- A detailed assessment of water quality effects including impacts from increased agricultural activity and from any potential geochemical reaction with groundwater and aquifer materials.
- Engage with stakeholders on the merits of a MAR scheme for flood control and irrigation.
- Undertake a business case based on MAR for flood control and irrigation scheme development and operation.
- Development of a trial site for both data collection and testing of MAR in the basin.

Appendix A

MAR Memorandum

MEMORANDUM

BAY OF PLENTY
REGIONAL COUNCIL
TOI MOANA

To: Ian Morton
Water Programme Manager

From: Raoul Fernandes **Date:** 29 November 2016
Environmental Scientist

File Ref:

Subject: **Combined irrigation/Flood Storage in the Upper Rangitāiki.**

Following our meeting with John Male from AECOM on the 17th of November, you requested an evaluation of the report prepared by Pertziger et al., (2016)[1]. As indicated in the report at the meeting with J. Male there is a limited amount of information available in the Galatea basin and as the purpose of the report was mainly for flood control, it is therefore not feasible to review the entire report and any comments made in this memo are limited to Managed Aquifer Recharge (MAR).

In regards to MAR, there are three broad areas that need to be considered; the availability of a source for the recharge, the ability of the receiving aquifer to retain the "recharged water" and the overall effect of the activity on the aquifer. There are additional factors that may need to be considered should you decide to proceed further.

The availability of the recharge has been covered in the report in terms of quantity and the harvesting of flood flows is a technique that has been used in several areas. In this regard I do not find the suggestions of the report lacking in any respect. The report has however not assessed the quality of the water that may be recharged to the Galatea basin, given the purpose of the report this is understandable. Considering the predominant land use of the Whirinaki catchment area I do not anticipate any issues, nevertheless, this must be considered at more than just a cursory level.

The overall environmental effect of proposal on the aquifer must also be considered, while it may be perceived as beneficial, it is equally likely to cause unanticipated environmental issues. For example, Figure 10 in the report indicates that the water table in a significant amount of area in the Galatea basin is between 1-5m below land surface. An artificial increase of the water table may make the land saturated and unusable. Any further work into MAR will also need to address any water quality concerns in regards to the effect of the infiltrated water on the aquifer.

The ability of the aquifer to retain to retain the volume recharged is dependent on the geology and the hydraulic gradients that control the movement of groundwater. Pumping and other effects may need to be considered but these are outside the scope of the current review. In order to determine the geology of the basin bore logs form a random selection of wells were analysed. A complete analysis of all available bore logs is unable to be completed due to time constraints.

The logs indicate that the majority of the wells are in gravel material with some pumice and ignimbrites appearing in the logs. This is not surprising as the Galatea basin has been filled in by sedimentary deposits such as greywacke gravels, fans of greywacke alluvium, undifferentiated greywacke and alluvium all mantled with ash fall deposits[2]. Based on this information I have used the value of 375 m/d as the representative hydraulic conductivity value. This value is the mid-range value that has been used by AECOM and is within the range of hydraulic conductivity values for various unconsolidated materials[3], given the geological history of the basin and the current hydrological setting this is a reasonable value to use. To keep the discussion consistent I have also assumed that the saturated thickness is 40 m.

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[1] Pertziger, F.,Kirk, A.,Pattinson, Z., & Male, J. (2016) .Combined Irrigation / Flood Control Storage in the Upper Rangitāiki. Hamilton, New Zealand: AECOM.

[2] Pain, C.,F., & Pullar, W., A. (1968). Chronology of Fans and Terraces in the Galatea Basin. New Zealand: NZ Soil and Bureau Publication No. 446.

[3] Domenico, P.A. and Schwartz,F., W., (1990). *Physical and Chemical Hydrogeology*, New York : John Wiley & Sons

I have used the available static water level measurements to develop a potentiometric surface. This is not ideal but is similar to the method used by AECOM to determine the depth to the saturated zone. The values were converted to a height above the Moturiki Datum and were then used to create equipotential lines (Figure 1). Flow lines were then drawn perpendicular to the equipotential lines to approximate the flow direction. BOPRC monitor two well in the Galatea basin one at the southern end of the basin and the second in the north-eastern part of the basin. The developed potentiometric surface is within 2 metres of the mean of all measured water levels in the monitoring wells; this provides a practical amount of certainty and indicates the developed potentiometric surface is a reasonable estimate of the water table in the Galatea basin (Figure 2).

Data form the equipotential map, the hydraulic conductivity as described above and a porosity of 0.20 was used in a modified version of Darcy's law[4] to obtain the seepage velocity. This was then converted to residence time based on a selection of distances from the recharge basins to the Rangitāiki River. Based on these calculations a residence time of between 2.1 to 2.5 years has been estimated. Using an extreme case the longest residence time that can be calculated is ~ 6 years. This is an extreme case that ignores the hydrology and interaction of the groundwater with the surface water that assumes that the only direction that the water that is infiltrated will flow is directly towards the Rangitāiki River. This is a highly unlikely case.

The location of the recharge basins (Figure 3) raises some additional questions to the feasibility of the MAR. If as proposed the flood water is held in the storage basin (Figure 4 , ~1700m in the profile) to be released at some point later this would mean that the majority of the recharged subsurface water from the recharge basin would drain back into the Whirinaki River with some flowing to the Mangamate stream and eventually into the Rangitāiki River. If there were sufficient volumes to allow hyporheic flow the additional recharge water would be intercepted by the Ruareouae stream or the Mangamutu stream as they would create preferential flow paths for any groundwater that is close to the surface.

Given the potentiometric surface, the geological history, the preliminary analysis of the available data, the groundwater flow paths, the short residence times and the proposed recharge location, in my opinion I do not believe that managed aquifer recharge is a viable solution for the Galatea Basin as it is unlikely to bring any potential benefit to the entire Galatea Basin. The maximum amount of time that water may be retained in the basin is ~ 2.5 years, ignoring the above concerns this implies that any recharged water will exit the system in less than 30 months

Should you wish to pursue this any further I would recommend the following options be considered before any further investment is made in the pursuit of MAR for the Galatea basin.

- Exploratory bore(s) should be drilled to depth to assess the true depth of the aquifer, this will result in an accurate bore log(s) that will be able to reduce the uncertainty and supplement the bore log information currently available.
- Pumping tests should be completed to determine the aquifer properties and the extent of the interaction between the ground and surface water.
- Analysis of the residence time of the aquifer by using isotope analysis.
- Water level survey to determine a piezometric surface for the Galatea Basin.
- Review of all consent files for wells in the Galatea basin and use the pump tests available to determine an appropriate range of transmissivities for the basin.

Best Regards,

Raoul

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[4] Fetter, C., W. (2001). Applied Hydrogeology (4th Eds.). New Jersey : Prentice Hall.

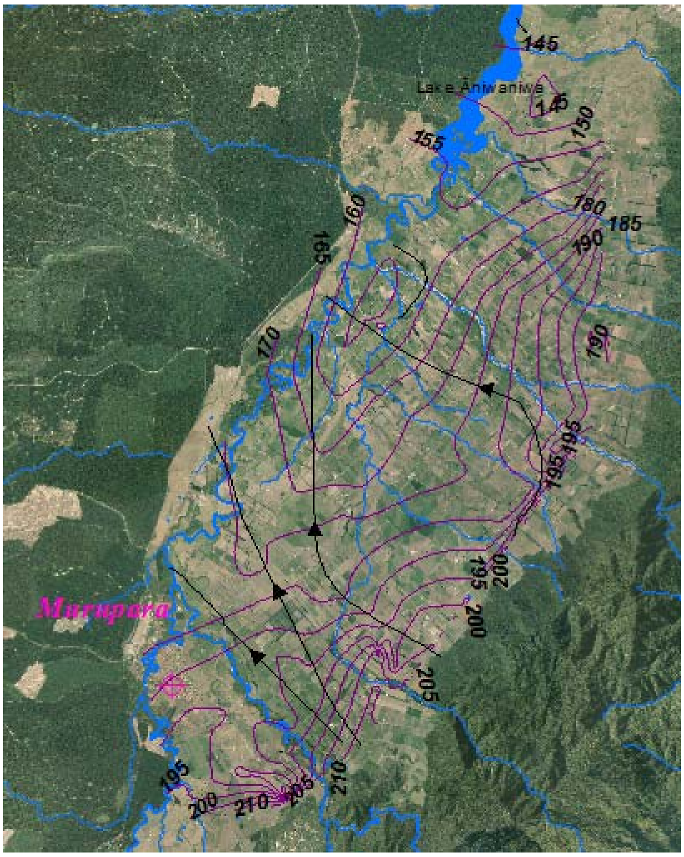

Figure 1: Potentiometric surface of the Galatea Basin (Black arrows are generated flow direction lines).

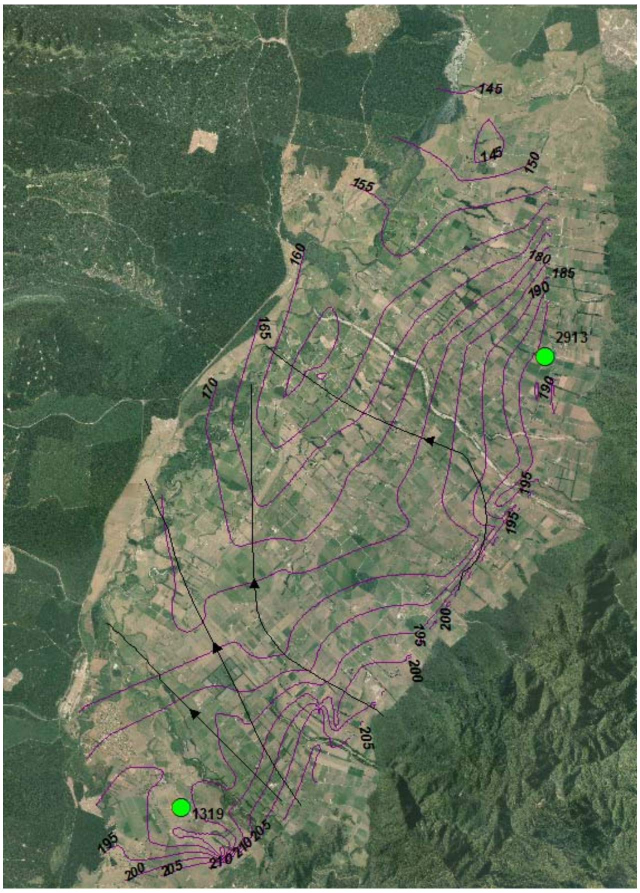

Figure 2 : Potentiometric surface and monitoring wells.

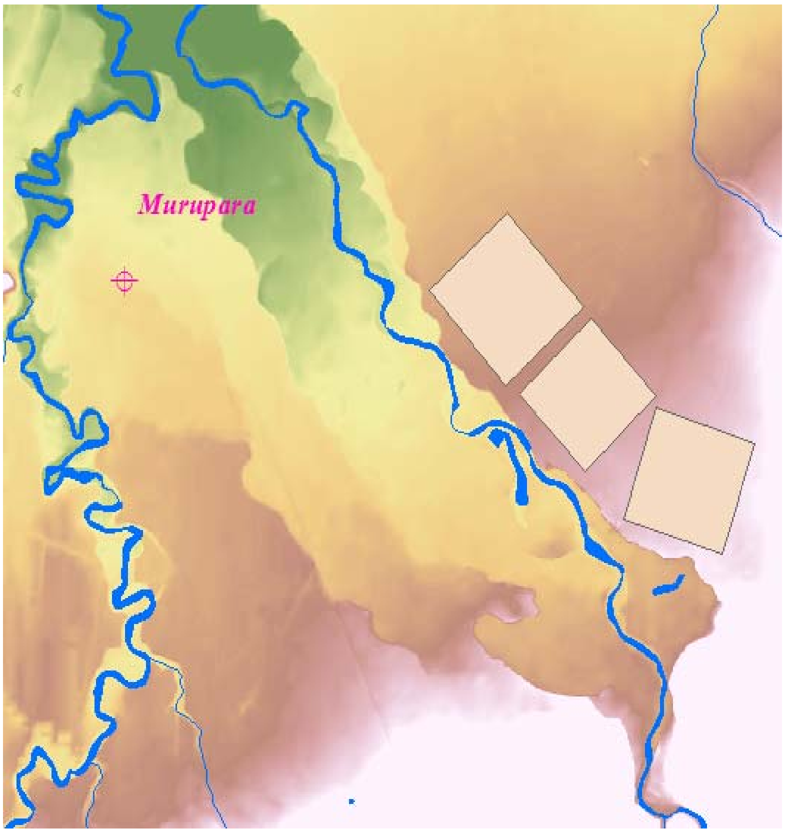

Figure 3 : Recharge Basins (White is higher elevation and green is lower).

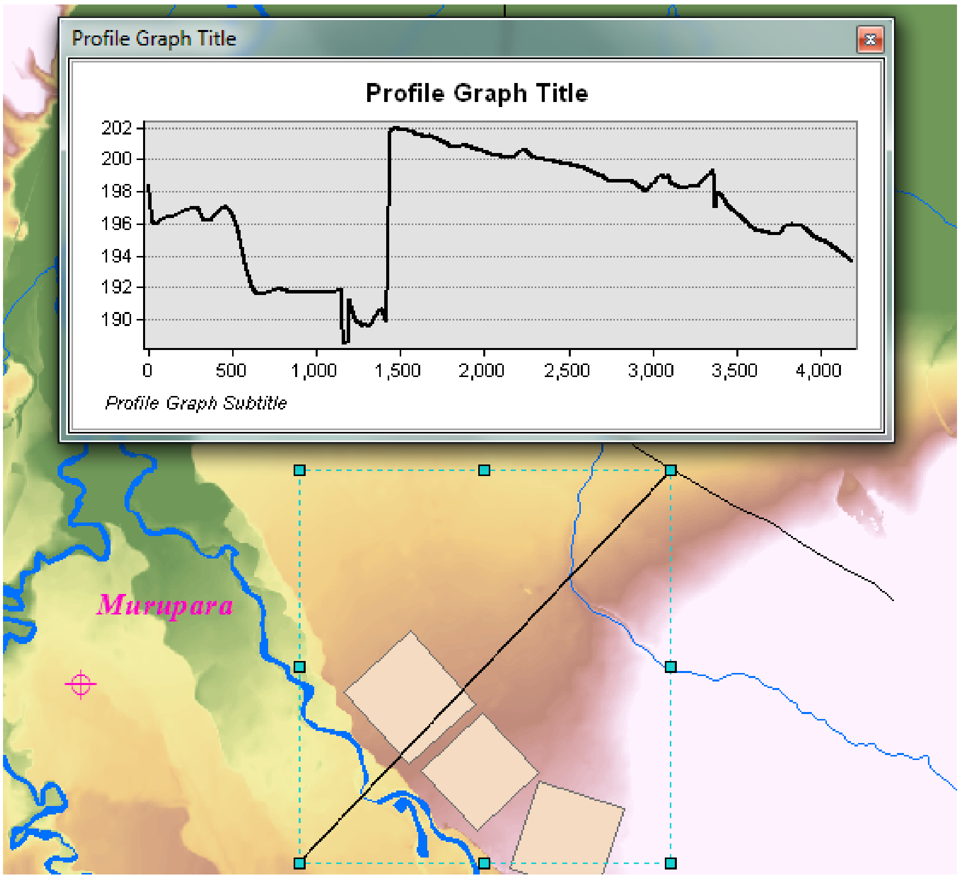

Figure 4 : Recharge Basins and Elevation Profile

Appendix B

Combined Irrigation Memorandum

AECOM

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Memorandum

To	Ian Morton - Water Programme Manager	Page	1
CC			
Subject	Combined Irrigation/Flood Control Storage in the Upper Rangitaiki - response to request for additional information		
From	John Male		
File/Ref No.	60529748	Date	11-Jan-2017

Following my meeting with yourself and Raoul Fernandes on the 17th November 2016, you requested that AECOM consider additional aspects outside of our initial scope of work. This memo specifically addresses the additional aspects required from AECOM, provides comments on the additional information provided by Raoul Fernandes to you (as discussed in our teleconference of 9th January 2017), and provides an updated and more specific conclusion targeted at an irrigation only water management scheme in the Galatea basin.

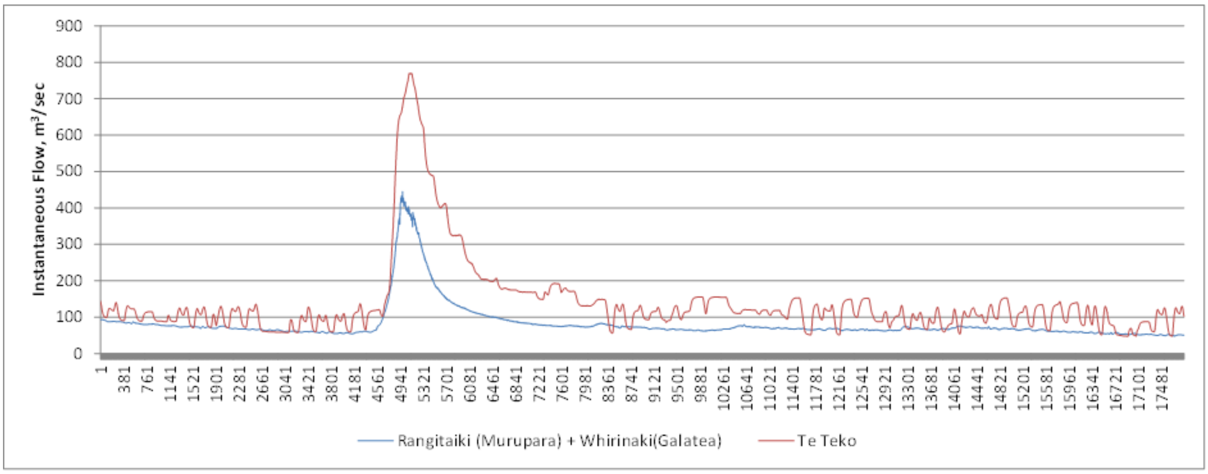
The additional aspect that you have asked AECOM to consider is *what is the impact of the consent condition for the operation of the Matahina Dam that limits any new water takes to flows greater than 160m^3/s at Matahina dam*.

1.0 Impact of the consent condition

1.1 Approach

The approach that has been adopted to assessing the impact has been to develop a relationship using existing flow records that provides an approximation of flow at the two proposed intake points on the Rangitaiki and Whirinaki Rivers in relation to flows at Matahina. Flows at Te Teko have been used because of data availability and it should be noted that these will incorporate an impact from some flow attenuation in upstream reservoirs which may lead to a conservative result. The hydrographs plotted below from a previous flood study for Council show the relationship for instantaneous flows for July and August 2004 (Figure 1).

Figure 1 Flow Relationship between Matahina and Te Teko



The second stage of the work was to apply the revised water abstract rules to the Goldsim model and determine what impact the consent condition would have on availability of water for irrigation.

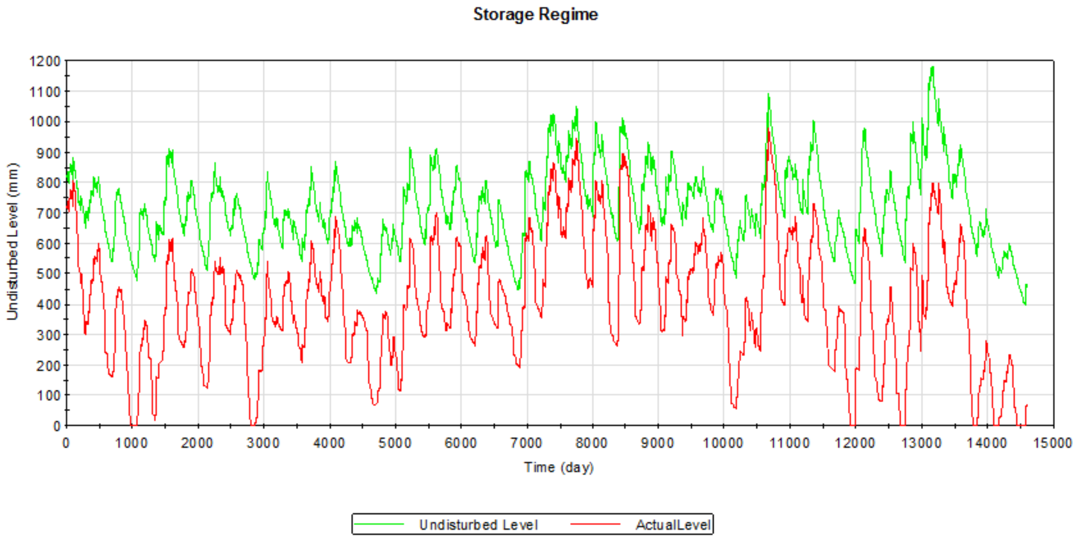
1.2 Results

The flow relationship that was developed using instantaneous flows indicates that a flow of 160m^3/s at Te Teko equates to a combined Rangitaiki and Whirinaki flow of 87.4m^3/s at the intake locations.

This flow threshold was then used to determine water availability for extraction for irrigation. There is a minor effect depending on the proportion of the total available flow that can be diverted to water harvesting and MAR. A 25% capture of flow has been adopted. Out of the 40 years of modelled data flow can be harvested for 67 days.

The impact on the available water for irrigation from a MAR scheme is shown in Figure 2 where the red line shows that all available water is depleted in 7 years of the 40 years of modelled data.

Figure 2 Impact of consent condition on MAR storage



The total dry day (based on irrigation criteria outlined in the main report) count for the 40 years is 513 days. If the proportion of harvested flow drops from 25% to 10% of river flow the dry count increases by 3 days. Hypothetically, if the consent condition was to be modified and the flow threshold reduced to 80m^3/s the dry day count drops to 429 days but the MAR storage would still be depleted in 6 years with 25% of the flow diverted. With only 10% of the flow diverted the failure year's increases to 7 years and the total dry days to 470 days.

1.3 Assessment

The impact of the Matahina dam consent condition is that there would be a shortfall in available water in 7 years out of 40 years or 1 year in every 5.7 years on average compared to 1 year in 40 years with no Matahina dam flow threshold. The total number of dry days I 40 years would increase from 90 days to 513 days.

Given that reliable irrigation water is required (usually 9 years out of 10 years) the impact of the Matahina dam consent condition is likely to make an irrigation scheme uneconomic. However detailed assessment of farm economics is required to confirm such an assumption.

2.0 Response to comments on Groundwater Review

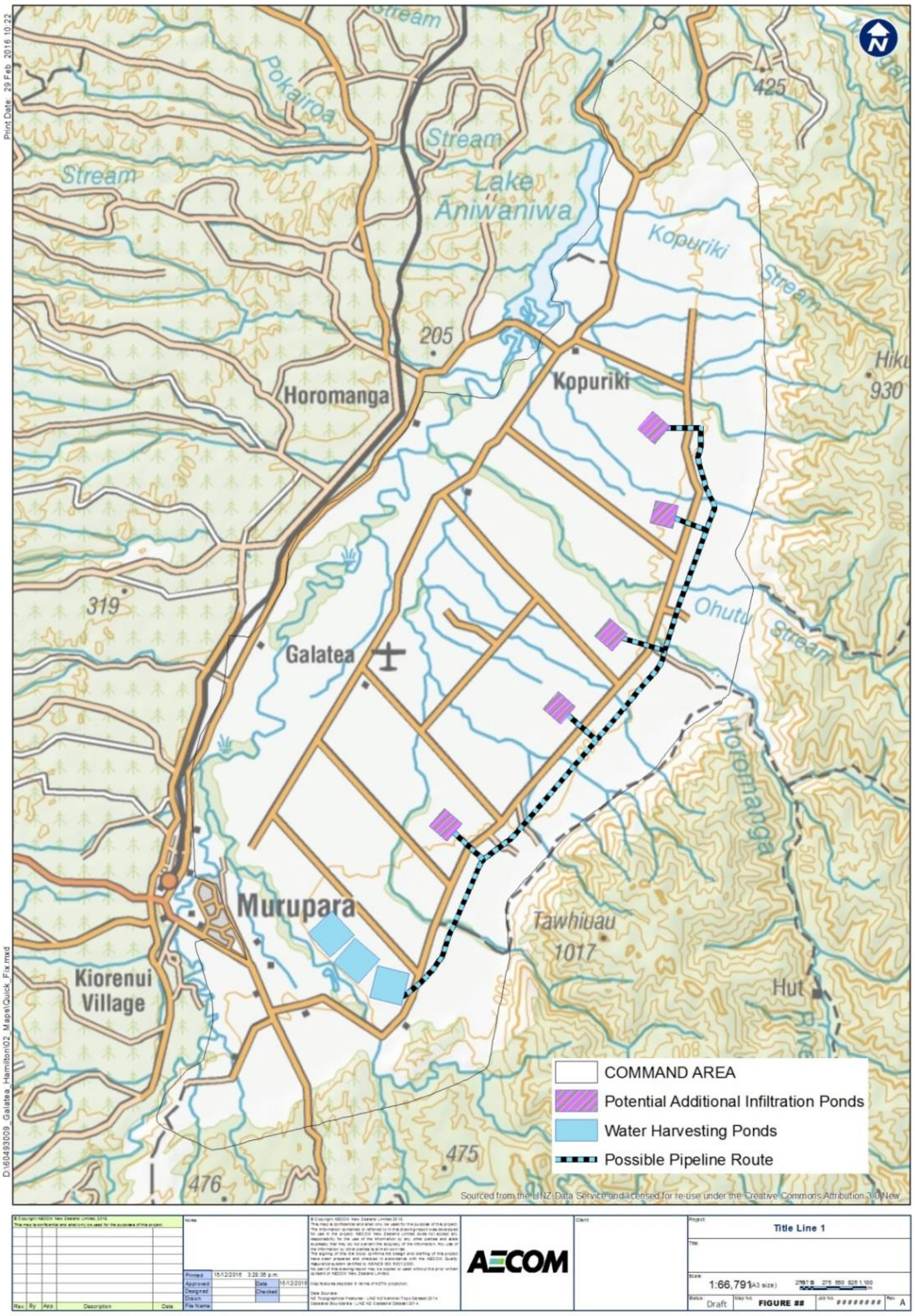
The review of groundwater aspects by Raoul Fernandes for the most part confirms the position that AECOM has presented. However, it raises some issues that require clarification in relation to the main report.

2.1 Spatial extent of infiltration

The MAR concept proposed relies on infiltration water being widely spread across the Galatea basin. Without distributing the water from the harvesting pond a mound of groundwater would be created and this would quickly flow back to the rivers. In section 3.3.2 of the original report it is stated… *For MAR* *to be effective water needs to recharge across the Galatea Basin. An irrigation scheme would use a piped network with an intake capacity of approximately 5m^3/s. This pipe would be used to shift the harvested water to smaller infiltration basins placed strategically across the Galatea Basin.*

As it is primarily flood water that is being harvested that water cannot be immediately transferred across the basin because of the higher flow rate so needs to be stored in ponds along the river banks and then routed through pipes to infiltration basins. The harvesting basins for an irrigation only scheme could be located on streams and rivers other than the Whirinaki e.g. Horomanga. The infiltration basins would be located based on detailed groundwater modelling. Conceptually the configuration could be as shown in Figure 3.

Figure 3 Potential infiltration pond locations



Such an approach will minimise groundwater mounding and optimise the storage volume available for MAR and irrigation.

2.2 Groundwater storage and irrigation

The groundwater review indicates that an average of approximately 2.5 years residence time could be expected. This equates to 2 or 3 irrigation seasons, suggesting that storage under a MAR scheme should be sufficient. The original work indicates the annual fluctuations in the MAR storage based on a water balance that includes;

- Inflows, natural groundwater, rainfall and MAR water.
- Outflows
    - Irrigation takes
    - Losses due to groundwater flow back to rivers and streams at an average rate of 2mm equivalent per day. This is consistent with the assessment of the potentiometric surface by Raoul Fernandes that shows groundwater flows to the streams.

Using the water balance approach figure 21 of the original report shows that for all but 2015 season there would be sufficient water stored using MAR.

3.0 Conclusions

Given the aspects being addressed in this memo arise because of the potential for an irrigation only scheme and the subsequent review by Raoul Fernandes the conclusions of the original report have been reviewed and restated here. Essentially the recommendations still apply along with the more detailed recommendations on groundwater aspects from Raoul Fernandes.

What is now important though given the stand alone irrigation scheme consideration is the need to prioritise future investigations and assessments and coordinate any work in conjunction with other issues that need to be addressed for irrigation scheme development. This means that water supply and demand, engineering, social, environmental and economic considerations all need to be collectively addressed in a logical manner. The recommendations of MAR which is the focus of the AECOM reporting need to be addressed within the wider context of an irrigation scheme.

A staged approach is required to ensure that an investment is warranted and that an irrigation scheme is supported by the wider community. It is recommended that to progress an irrigation scheme with storage based on a MAR concept the following needs to be addressed;

- Scheme support – it needs to be established the extent of the farming community support for an irrigation scheme. If there is support then appropriate governance structures need to be established and the wider community engaged. Stakeholder working groups could be established to collaboratively work through the various aspects of irrigation scheme development.
- Potential fatal flaws – two potential flaws have been identified and need to be addressed early on.
    - For MAR to be sustainable water needs to be stored for sufficient time. Isotope analysis of groundwater will indicate residence time.
    - Initial negotiations need to be undertaken with TrustPower to assess the willingness for modifications of consent conditions to deliver a win-win outcome.
- Economics – The potential benefits at farm level need to be established so that affordability and the maximum capital and operating expenditure on an irrigation scheme can be determined. The financial considerations would determine whether further investigations are warranted.
- Groundwater resource – A detailed understanding of the dynamics of the groundwater system needs to be established; including groundwater – surface water connectivity. This will involve drilling to determine aquifer depth. Aquifer properties need to be determined from pumping tests. A groundwater model should be developed to optimise location and design of infiltration locations and abstract points.
- Water demand – Establishing how much water is required for irrigation needs to be refined. Existing work is based on single point estimates but rainfall, evapotranspiration and soil water

holding capacity vary across the basin. A spatially varying estimation tool needs to be applied to refine water demand and include specific farm crop water demand profiles.

- Engineering – an irrigation scheme concept based on MAR should be developed and initial costs estimated. From here investigations on abstraction locations, inlet weir levels, pipe layout etc would follow. Development of a trial site is recommended.
- Environmental – for all irrigation schemes there are common environmental factors that need to be addressed. These should be listed and any required work programmes established. Galatea specific issues may be obvious or may become apparent as investigations proceed. Any factor that requires time dependent sampling should be addressed early on with water quality and potential geochemical changes along with nutrient aspects being an item that both AECOM and the groundwater reviewer have identified.

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