Surface water quantity scenario modelling in the Tūtaekurī, Ngaruroro and Karamū catchments

Greater Heretaunga and Ahuriri Plan Change (PC9)

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Environmental Science – Hydrology

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Executive summary

Hawke's Bay Regional Council is currently undertaking a change to the Regional Resource Management Plan with respect to managing water resources in the Greater Heretaunga and Ahuriri area in Hawke's Bay. The Tūtaekurī, Ahuriri, Ngaruroro and Karamū river catchments (referred to as 'TANK') make up the Greater Heretaunga and Ahuriri area. The Greater Heretaunga and Ahuriri Plan Change (PC9) seeks to implement the Hawke's Bay Land and Water Management Strategy and the National Policy Statement for Freshwater Management. It will address specific water quantity and quality issues within the TANK catchments.

The plan change process has been run as a collaborative process whereby HBRC has been working with a group of community members that form the TANK Stakeholder Group. The TANK Stakeholder Group is comprised of approximately 30 Hawke's Bay representatives from agricultural and horticultural sectors, tangata whenua, environmental and community interest groups, and government agencies. The TANK catchments cover a large and diverse area with complex water related issues. Throughout the plan change process, the TANK Stakeholder Group has provided feedback and recommendations on how water resources within the TANK catchments should be managed.

One of the key issues being addressed in the plan change is how water allocation and abstraction from surface water and groundwater are managed, including how much water is allocated for abstraction and when/what restrictions may apply to abstractions.

This report documents the surface water quantity modelling scenarios that have been designed and simulated to explore the potential effects of different management options and to subsequently inform the TANK Stakeholder Group and plan change process.

Modelling requirements and objectives

The requirements for modelling surface water quantity in the TANK catchments were defined throughout the course of the plan change process. Specific scenarios were developed and modelled in response to management issues identified during the plan change process. The results of these scenarios have been used to inform the TANK Stakeholder Group to help with decision making and subsequent drafting of the proposed plan change.

Surface water modelling was undertaken in combination with groundwater modelling. Due to complex interactions between surface water and groundwater within the TANK catchments, the surface water and groundwater models are linked and also interact with each other. Although the requirements for groundwater modelling differ to that of surface water, the linked nature of the models means that all modelled surface water scenarios incorporate both surface water related settings and groundwater settings.

The Ahuriri catchment (one of the TANK catchments) and the Poukawa sub-catchment (located within the Karamū catchment) are excluded from the surface quantity modelling presented in this report. The modelling of water resources in these catchments may be addressed via separate studies.

The following categories of scenario modelling are presented in this report:

1. Cease-take trigger flow scenarios
2. Groundwater augmentation to surface water scenarios
3. 10% emergency water allocation scenarios
4. High flow allocation scenario modelling

SOURCE model

Hawke's Bay Regional Council commissioned Williamson Water Advisory in April 2016 to develop a hydrological model using the SOURCE modelling platform, to simulate flow and water quality in the rivers and streams of the Tūtaekurī, Ngaruroro and Karamū catchments. This model was developed and calibrated to simulate river flows between 1979 and 2015, incorporating the effects of past abstractions from both surface water and groundwater.

The calibrated model was used to develop the predictive scenarios that simulate the hydrological system into the future for the years 2015 to 2032.

Cease-take trigger flow scenario modelling

A range of cease-take trigger flow scenarios was simulated across all SOURCE modelled catchments to understand the effects of current flow management rules and to explore potential future alternatives. Analyses were undertaken to identify the positive and negative effects on river flows and the reliability of supply for existing water abstractors, which are predicted as a consequence of implementing different flow management options.

Base Case compared to Naturalised scenario:

- Under the Base Case scenario, low flow statistics (Mean Annual Low Flow and Q95 – i.e. the flow exceeded 95% of the time) for all rivers and streams was predicted to be lower, as expected, than flows under naturalised conditions.
- Low flows in the Tūtaekurī River were predicted to be approximately 7% lower than flows under naturalised conditions, compared to around 24% lower in the Ngaruroro River. The impact on the low flow regime was greater in the Ngaruroro River than in the Tūtaekurī, due to higher stream depletion effects of groundwater abstractions from the Heretaunga Plains aquifer combined with the larger total surface water abstraction in the Ngaruroro catchment.
- For most streams within the Karamū catchment (excluding the Louisa Stream), the large predicted effects on flow are predominantly caused by the stream depleting effects of groundwater abstractions from the Heretaunga Plains aquifer.
- The smallest impacts on low flow statistics were predicted in the Louisa and Maraekakaho streams. In these two streams, it is most likely that modelled surface water abstractions are the main source of effects on flow.

Abstraction of maximum allocation compared to Base Case scenario:

- The Base Case_Max Allocation scenario simulated the effects of increasing surface water abstractions up to the maximum current consented allocation, whereas the Base Case scenario (and all other abstraction scenarios) simulated abstraction based on estimated future demand. Modelled cease-take trigger flows (which are based on current trigger flows) were the same in both scenarios.
- Increasing surface water abstractions up to the maximum allocation predicted small adverse impacts on flow regimes and reliability of supply at all modelled flow management sites.
- For the Tūtaekurī River, a small negative impact on low flows was predicted. A greater impact on the low flow regime was predicted in the Ngaruroro River, where MALF and Q95 decreased more than 10%.
- No restriction was predicted in the Tūtaekurī River with the current cease-take trigger flow set at 2000 l/s under the Base Case scenario. Simulating the increase to surface water abstractions in the Tūtaekurī catchment was not predicted to cause any new restriction, so reliability of supply for existing water abstractors would be unaffected.
- In the Ngaruroro River, small increases in restriction were predicted as a consequence of abstracting the maximum surface water allocation. However, there were no predicted changes to periods of consecutive days of restriction.
- The largest effect on flow in the Karamū catchment streams and Ngaruroro tributaries was predicted in the Tūtaekurī Waimate Stream, which is most likely due to the maximum allocation modelled in the Tūtaekurī Waimate, being the largest out of all streams in the Karamu catchment and Ngaruroro tributaries.
- The impact on reliability of supply from abstracting the maximum surface water allocation, was predicted to be very small across all streams within the Karamū catchment.
- In the Ngaruroro tributaries, the impact on reliability of supply due to increasing surface water abstractions, was predicted to be very small in the Maraekakaho Stream, while in the Tūtaekurī Waimate Stream, no impact was predicted.

Restricting groundwater abstractions within Stream Depletion Zone 1 combined with rationalised flow management sites:

- The Modified Base Case scenario simulated the restriction of groundwater abstractions located within the proposed 'Stream Depletion Zone 1', which contrasts with the groundwater abstractions currently classed as stream depleting and subject to restrictions in the Base Case. It also simulated 11 selected scenario flow management sites which were rationalised from the current flow management sites. The Modified Base Case was compared to the Base Case scenario to identify the predicted effects on flow and reliability of supply.
- Very small effects on flow were predicted in both the Tūtaekurī and Ngaruroro rivers when comparing the Modified Base Case scenario to the Base Case. Changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1, is the single cause of reduced flows in the Ngaruroro River. However, flow reductions in the Tūtaekurī River (which were slightly larger than in the Ngaruroro) are also affected by the transfer of abstractions linked to the Tūtaekurī River at Ngaroto flow management site, to the downstream site at Puketapu. Irrespective of the causes, the predicted negative impacts on Tūtaekurī and Ngaruroro river flows are very small.

- No restriction was predicted in the Tūtaekurī River with the current cease-take trigger flow set at 2000 l/s under the Base Case scenario. Changing the restriction of groundwater abstractions to those only located in Stream Depletion Zone 1 was predicted to have no effect on restriction in the Tūtaekurī River. By contrast, very small increases to restriction were predicted in the Ngaruroro River.
- Changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1 predicted very small impacts on low flows and reliability of supply in all streams in the Karamū Catchment.
- There were no predicted effects on flow or restriction in the Maraekakaho Stream (a tributary of the Ngaruroro River). The Maraekakaho Stream D/S Tait Rd flow management site is located outside the boundary of the Heretaunga Plains aquifer and groundwater model domain, so simulated changes to groundwater abstractions within the groundwater model do not affect this site.
- The Tūtaekurī-Waimate Stream is the other simulated tributary of the Ngaruroro River. There were no predicted changes to restriction in this stream and only very small predicted effects on flow.

Increasing primary cease-take trigger flows:

- Scenarios incorporating increasing primary cease-take trigger flows were only simulated on the Tūtaekurī and Ngaruroro rivers.
- The Tūtaekurī scenario restriction statistics show that no restriction was predicted with cease-take trigger flows ranging from 2000 l/s to 2500 l/s. No restriction means no predicted impact on the reliability of supply for existing water users under these scenarios.
- Increasing the cease-take trigger flow beyond 2500 l/s predicted that restriction would begin to occur. Simulating a trigger flow of 2800 l/s (Tūtaekurī 7) predicted a very small proportion of restriction (0.3%), with no more than 5 days of restriction in one of the driest simulated years, when the climate is equivalent to 2008-2009. The predicted impact on reliability of supply continued to increase under scenarios with higher cease-take trigger flows.
- For the Ngaruroro River, increasing the primary cease-take trigger flow predicted progressively larger effects on restriction, thus progressively reducing the reliability of supply for existing water abstractors.
- Tūtaekurī river flows were only predicted to increase when the primary cease-take trigger flow was raised to 3300 l/s (Tūtaekurī 8), at which point restrictions are imposed on water abstractions to limit the effects on flow. However, the predicted benefits to the Tūtaekurī River flow were still relatively small, with up to a 1.4% increase in low flow statistics.
- Increasing the cease-take trigger flow under the Ngaruroro scenarios predicted small improvements to low flows.

Groundwater augmentation to surface water scenario modelling

A range of groundwater augmentation to surface water scenarios was simulated to explore the effects of abstracting groundwater to augment and enhance flows in lowland streams within the Heretaunga Plains. Analyses were undertaken to identify the positive and negative effects on river flows and the reliability of supply for existing water abstractors, as a consequence of groundwater abstraction for lowland stream flow augmentation and enhancement. To achieve this, augmentation scenarios were compared to the equivalent cease-take trigger flow scenarios in which groundwater augmentation is not activated.

Karamū Catchment:

- Groundwater augmentation for stream flow enhancement was simulated for streams within the Karamū Catchment, which revealed that low flow statistics in these streams are likely to increase. The scenarios were designed to trigger augmentation when stream flows were at or below the cease-take trigger flow (at the associated flow management site) and to maintain flows at cease-take trigger flows.
- The stream network downstream of any augmentation point would benefit from augmentation, providing there are no losing reaches in the downstream network.
- The following summarises the key findings for each stream considered:
  - *Awanui Stream* – Low flows in the Awanui Stream were predicted to increase as a consequence of the augmentation and enhancement of flows upstream in the Karewarewa Stream.
  - *Karamū Stream* – The Karamū Stream would also benefit from the augmentation of upstream tributary flows. The upstream augmentation increased flows in the lower Karamū reaches, thus reducing the additional augmentation required to maintain the Karamū flow at the 1100 l/s cease-take trigger flow. Most streams within the Karamū Catchment were predicted to benefit from the augmentation from groundwater.
  - *Karewarewa and Mangateretere Streams* – The greatest increase in flow was predicted for the Karewarewa and Mangateretere streams, where both MALF and Q95 increased by more than 200% from the Base Case scenario.
  - *Louisa Stream* – There were no predicted changes to flow in the Louisa Stream, because augmentation was not simulated upstream of the Louisa Stream flow management site.
  - *Raupare Stream* – Low flows were predicted to decrease in the Raupare Stream by up to 2.3%. This small decrease is likely to be caused by additional stream depletion resulting from the abstraction of groundwater to augment the lowland streams across the plains.
- It was anticipated that abstracting groundwater for augmentation purposes may cause slightly increased stream depletion from rivers and streams across the Heretaunga Plains. However, in a ‘real life’ situation with an established augmentation scheme, operation of the scheme could be adjusted in response to real time monitoring data, to ensure augmentation also compensates for this additional stream depletion.
- For all flow management sites within the Karamū Catchment, no changes to restriction were predicted as a consequence of abstracting groundwater to augment and enhance lowland streams. Therefore, the reliability of supply for existing water abstractors was not compromised under the augmentation scenarios. At some sites, the simulated groundwater augmentation was predicted to increase flow above the cease-take trigger flow, however the intent of the modelled augmentation scheme was only to increase/improve flow and not to provide water for additional abstraction for out of stream uses.

Ngaruroro tributaries:

- The simulation of the augmentation scenario predicted no impact on flow or restriction at the Maraekakaho Stream D/S Tait Rd flow management site. This site is located in a reach outside the Heretaunga Plains aquifer boundary and groundwater model domain, which indicates it is unlikely to be hydraulically connected to the main Heretaunga Plains aquifer system. Consequently, simulated changes to groundwater abstractions within the groundwater model do not affect this site.

- For the Tūtaekurī-Waimate Stream, there were no predicted impacts on restriction, whereas very small reductions were predicted to the MALF and Q95. These very small reductions are attributed to the increased stream depletion resulting from groundwater abstraction for augmentation purposes in the lowland streams.

Tūtaekurī River:

- For the Tūtaekurī River, no impacts were predicted on flow or on the reliability of supply for existing water abstractors, as a result of abstracting groundwater to augment and enhance lowland streams.

Ngaruroro River:

- In the Ngaruroro River, the abstraction of groundwater to augment lowland streams was not predicted to affect restriction when the cease-take trigger flow is 2400 l/s. Effects on restriction were predicted when higher trigger flows of 3600 l/s and 4000 l/s are simulated, however the potential adverse effects are very small with less than one extra day of restriction predicted.
- Ngaruroro augmentation scenarios predicted very small adverse impacts on the low flow regime. The predicted impacts on flow and water take restrictions, are likely to be caused by additional stream depletion resulting from the abstraction of groundwater to augment and enhance lowland streams across the Heretaunga Plains.

Emergency water allocation scenario modelling

A range of scenarios that incorporate a 10% emergency water allocation was modelled to identify the potential impact on river flow in the Ngaruroro and Tūtaekurī rivers.

When simulating the abstraction of a 10% emergency water allocation under each scenario, the abstraction would only occur when the river flow was at or below the trigger flow. Consequently, only flow at or below the trigger flow was modified.

For the Ngaruroro River, the predicted impact on flow resulting from the abstraction of a 10% emergency water allocation ranged between a 4% and 13% reduction in river flow.

Simulated flows in the Tūtaekurī River never go below the 2000 l/s or 2500 l/s trigger flows, meaning a 10% emergency water allocation was never required under scenarios with these trigger flows. Flows in the Tūtaekurī River were predicted to drop below the highest trigger flow of 3300 l/s (although infrequently) and, with this trigger flow, the abstraction of a 10% emergency water allocation was predicted to reduce river flow by no more than 3%.

High flow allocation scenario modelling

A range of high flow allocation scenarios for the Ngaruroro River was modelled to identify the potential impact of each scenario on flushing flows and to assess the capacity of the modelled high flow allocation to meet potential new demand.

High flow allocation enables water to be abstracted/harvested from a river during periods of higher flow and stored for later use, for example during periods of restricted low flow abstraction or for river flow enhancement. Abstracting water at higher flows outside of typical low flow conditions helps to minimise any impact of the abstraction on instream values and protects the reliability of low flow abstractions relating to primary allocation.

A high flow allocation will typically have a relatively high cease-take trigger flow, to ensure that low flows in a river are not affected.

It is important to ensure that high flow allocation does not compromise in-stream values that are dependent on flushing flows to remove periphyton biomass and maintain macroinvertebrate structure. The FRE_3 is a measure of flow variability that represents the frequency of flood events with flows greater than three times the median flow. These three times median flow events are considered to provide a flushing function.

Impact of high flow allocation on flushing flows

In this study, high flow allocation scenarios that reduced the FRE_3 by less than 10% are considered to be low risk in terms of their potential impact on ecological instream values.

Scenarios were modelled on the Ngaruroro River at Fernhill, combining an allocation with a cease-take trigger flow. All of the scenarios predicted less than a 10% reduction to FRE_3. Therefore, in terms of the potential impact on flushing flows and associated ecological instream values, all high flow allocation scenarios (with total allocation ranging from 2000 l/s to 8000 l/s) are considered to have a low risk of adverse impacts.

Capacity of high flow allocation to meet demand

The second part of the high flow allocation scenario assessment was to identify a high flow allocation that may be sufficient to meet the irrigation demand for 3500 ha with 17.5 Mm^3 storage.

The assessment identified that a total high flow allocation of 6000 l/s may be sufficient to provide water for potential new irrigation to 3500 ha in most years. However, there is greater certainty of a total high flow allocation of 8000 l/s providing for potential future demand to irrigate 3500 ha. Furthermore, a total high flow allocation of 8000 l/s is the most likely scenario to provide additional volume to store water for environmental purposes, such as augmentation of surface water bodies during low flow periods.

It is important to note that one of the primary reasons for considering a high flow allocation in the draft Greater Heretaunga and Ahuriri plan, is to provide for water harvesting in the future, if storage is considered for meeting additional demand and improving reliability of supply. If the plan fails to make this provision, it will be far more onerous to implement a storage scheme in future.

Along with demand for irrigation, there may be environmental benefits from harvesting high flows for storage. For example, offline (i.e. non-mainstem) storage may be considered for augmenting the Ngaruroro River during periods of low flow. This augmentation may be valuable for environmental benefits or to offset the effects of run-of-river abstractions during low flow periods. In addition, harvesting high flows from the Ngaruroro River for storage may be required in the future for lowland stream augmentation, particularly for streams with technical challenges to augmentation from groundwater such as the Paritua and Karewarewa.

1 Introduction

Hawke’s Bay Regional Council (HBRC) is currently undertaking a change to the Regional Resource Management Plan (RRMP) with respect to managing water resources in the Greater Heretaunga and Ahuriri area in Hawke’s Bay. The Tūtaekurī, Ahuriri, Ngaruroro and Karamū river catchments (referred to as ‘TANK’) make up the Greater Heretaunga and Ahuriri area (the TANK catchments are shown in Figure 1-1). The Greater Heretaunga and Ahuriri Plan Change (PC9) seeks to implement the Hawke’s Bay Land and Water Management Strategy and the National Policy Statement for Freshwater Management (MfE 2014). It will address specific water quantity and quality issues within the TANK catchments.

The plan change process has been run as a collaborative process whereby HBRC has been working with a group of community members that form the TANK Stakeholder Group. The TANK Stakeholder Group is comprised of approximately 30 Hawke’s Bay representatives from agricultural and horticultural sectors, tangata whenua, environmental and community interest groups, and government agencies. The TANK catchments cover a large and diverse area with complex water related issues. Throughout the plan change process, the TANK Stakeholder Group has provided feedback and recommendations on how water resources within the TANK catchments should be managed.

One of the key issues being addressed in the plan change is how water allocation and abstraction from surface water and groundwater are managed, including how much water is allocated for abstraction and when/what restrictions may apply to abstractions.

This report documents the surface water quantity modelling scenarios that have been designed and simulated to explore the potential effects of different management options and to subsequently inform the TANK Stakeholder Group and plan change process.

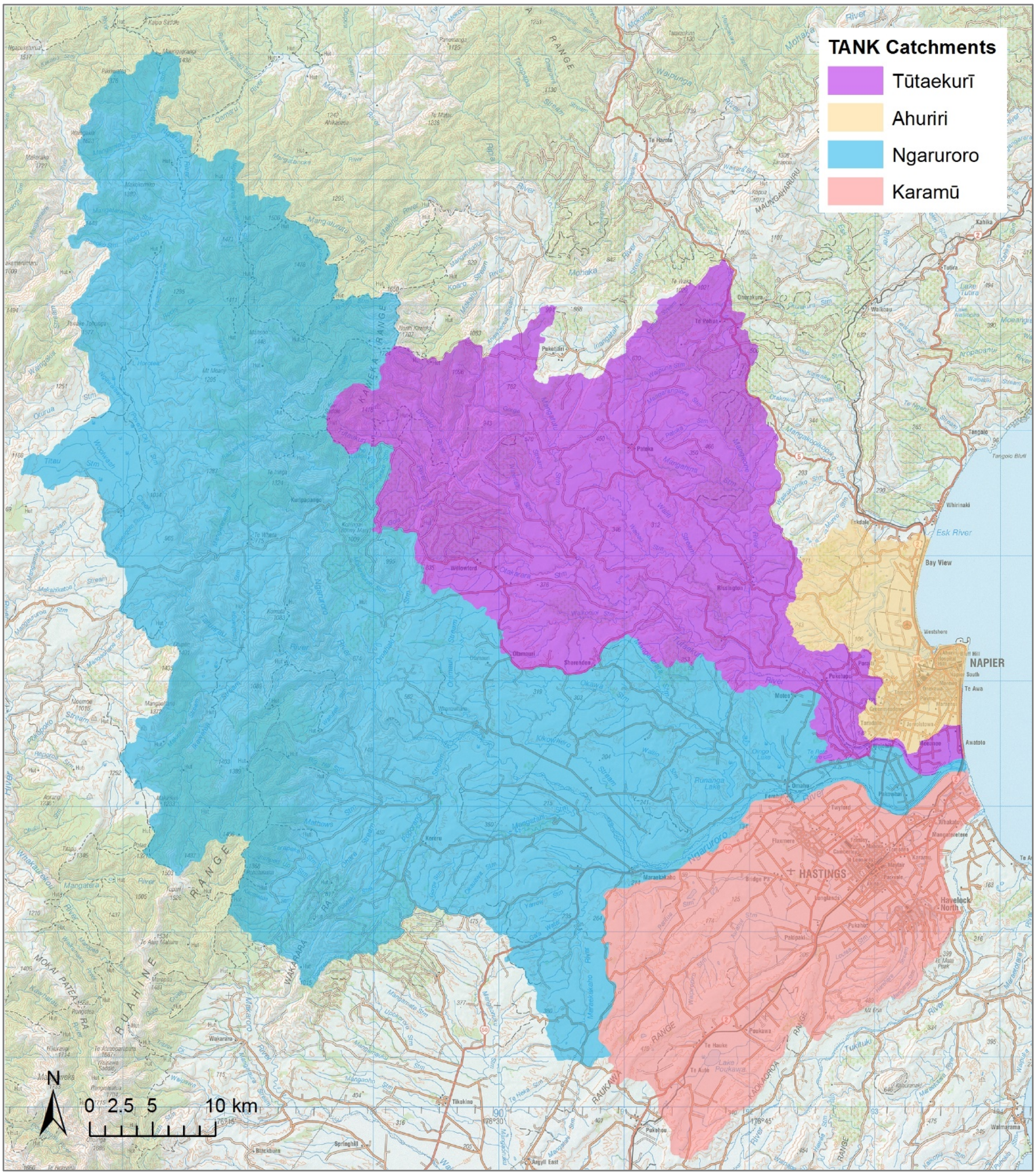

Figure 1-1: The TANK (Tūtaekurī, Ahuriri, Ngaruroro and Karamū) river catchments. Location of the TANK catchments within Hawke's Bay.

2 Surface water quantity modelling requirements

The requirements for modelling surface water quantity in the TANK catchments were defined throughout the course of the plan change process, with specific scenarios developed and modelled in response to identified management issues. The results of these scenarios have been used to inform the TANK Stakeholder Group to help with decision making and subsequent drafting of the proposed plan change.

Surface water modelling was undertaken in combination with groundwater modelling. Due to the complex interaction between surface water and groundwater within the TANK catchments, the surface water and groundwater models (that have been developed to model scenarios) are linked and interact with each other. Although the requirements for groundwater modelling differ to that of surface water, the linked nature of the models means that all modelled surface water scenarios incorporate both surface water related settings and groundwater settings.

The Ahuriri catchment (one of the TANK catchments) and the Poukawa sub-catchment (located within the Karamū catchment) are excluded from the surface quantity modelling presented in this report. The modelling of water resources in these catchments may be addressed via separate studies.

2.1 River flow management issues

1. Managing the effects of water abstractions in the TANK catchments

River and stream flows in the Tūtaekurī, Ngaruroro and Karamū catchments are affected by the cumulative impact of groundwater and surface water abstractions. Abstractions reduce river flows, which in turn affects available instream habitat. To minimise the effects on flow and instream habitat, abstractions may be restricted if an abstraction is linked to a "minimum flow" (referred to as a "cease-take trigger flow"[1] throughout the remainder of this report), however these restrictions also affect the reliability of supply for water abstractors.

River flow management rules that result in abstraction restrictions (i.e. cease-take trigger flows) apply to surface water abstractions and groundwater abstractions classed as stream depleting. Groundwater stream depletion modelling has also been undertaken to inform the plan change process (Rakowski & Knowling 2018) and identified an area referred to as 'Stream Depletion Zone 1'. Groundwater abstractions in Zone 1 (Figure 2-1) are estimated to have a high stream depleting effect, with abstraction manifesting as reduction of river flow, equal to at least 90% of the groundwater abstraction rate, within seven days of pumping.

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[1] In this report, a "cease-take trigger flow" is an alternative name used for a traditional "minimum flow". In the past, the term "minimum flow" refers to a flow threshold at which abstractions must cease. The use of the term "minimum flow" can be problematic and this is discussed by Wilding (2018). A flow threshold that is used to trigger a management response (e.g. restriction of abstractions or surface water augmentation) can be referred to as a "trigger flow". In this report, various modelled scenarios incorporate a "cease-take trigger flow", which is a "trigger flow" that prompts restriction of abstractions. Other modelled scenarios may incorporate trigger flows that initiate alternative management responses such as: groundwater augmentation to surface water, or a reduction of abstractions (as opposed to complete cessation).

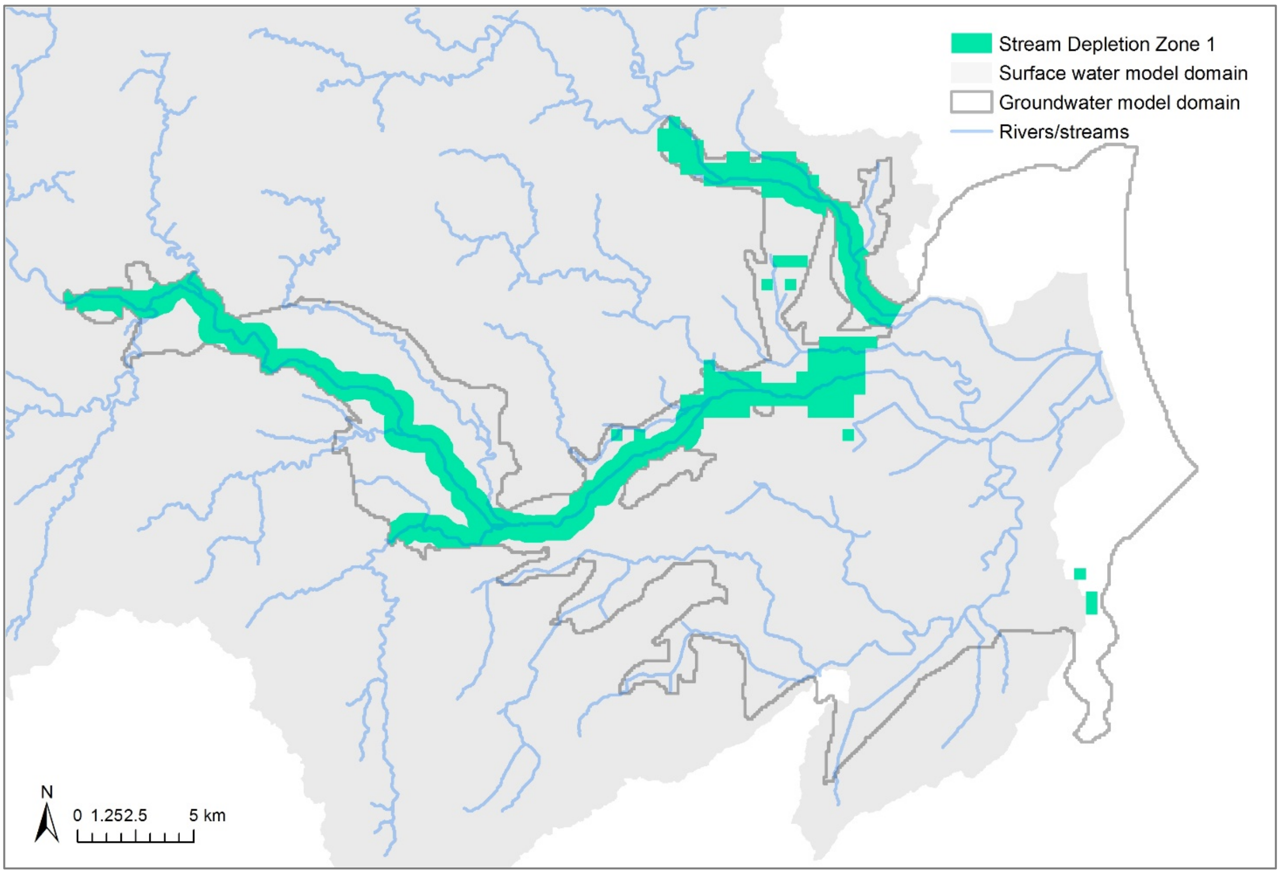

Figure 2-1: Groundwater Stream Depletion Zone 1.

Flow management scenarios were developed in consultation with the TANK Stakeholder Group, to model and understand the effects of current flow management rules and to explore potential future alternatives. The TANK Stakeholder Group agreed that scenarios representing potential future flow management rules should specify that only groundwater abstractions located within Stream Depletion Zone 1, are subject to river flow management rules (including restrictions based on cease-take trigger flows).

The scenarios were therefore designed to not only simulate potential new flow management rules, but to also simulate the effects of restricting groundwater abstractions currently classified as stream depleting and compare those with the effects of restricting only groundwater abstractions located within Stream Depletion Zone 1. The differences between the number of groundwater abstractions currently classified as stream depleting and the number located within Stream Depletion Zone 1 are shown in Table 2-1. There are 67 groundwater abstractions located within Stream Depletion Zone 1, which is 45% less than the 151 Heretaunga groundwater abstractions that are currently classified as stream depleting in the HBRC consents database.

Table 2-1: Stream depleting groundwater abstractions - currently classified vs Stream Depletion Zone 1. For each flow management site, the number of managed groundwater abstractions currently classified as stream depleting are compared to the number located within Stream Depletion Zone 1.

Flow management site	Number of managed GW abstractions	
	Currently classified as stream depleting	Located within Stream Depletion Zone 1
Maraekakaho Stream D/S Tait Rd	1	-
Ngaruroro River at Fernhill	45	21
Raupare Drain at Ormond Road	46	15
Tūtaekurī River at Puketapu HBRC Site	37	22
Tūtaekurī Waimate Stm at Goods Bridge	22	9
Total	***151***	***67***

Modelled scenarios in this suite are referred to as *cease-take trigger flow scenarios* throughout the remainder of this report.

2. *Stream flow enhancement via groundwater augmentation*

During the TANK stakeholder engagement process, the augmentation of lowland streams in the Heretaunga Plains using abstracted groundwater was proposed as a potential new flow enhancement option that could be used in combination with more traditional flow management rules (such as cease-take trigger flows and allocation limits).

A range of scenarios was developed in consultation with the TANK Stakeholder Group, to explore the potential benefits or adverse effects from using groundwater to augment flows of lowland streams in the Heretaunga Plains.

Modelled scenarios in this suite are referred to as *groundwater augmentation to surface water scenarios* throughout the remainder of this report.

3. *Potential emergency water allocation from the Ngaruroro and Tūtaekurī rivers*

During low flow periods, an emergency water allocation is highly valuable to help ensure the survival of rootstock crops such as trees and vines, and for salvaging revenue from high value crops. An emergency water provision could apply to abstractions that are subject to cease-take management rules such as surface water abstractions and stream depleting groundwater abstractions.

An emergency allocation was proposed by the TANK Stakeholder Group, based on 10% of consented primary allocation. A range of scenarios was developed to model and estimate the effects of a potential 10% emergency water allocation from the Ngaruroro and Tūtaekurī Rivers.

Modelled scenarios in this suite are referred to as *emergency water allocation scenarios* throughout the remainder of this report.

4. Proposed high flow allocation management framework

High flow allocation enables water to be harvested from a river during periods when flow is much greater than typical low flow conditions. The high flow allocation is intended for storage and subsequent use at a later time, as required (e.g. out of stream use during periods of restricted low flow abstraction, or for river flow augmentation).

The Ngaruroro River currently has a high flow allocation of 2000 l/s. However, stakeholders indicated that there may be potential new demand for additional high flow allocation from the Ngaruroro River.

A range of scenarios was developed in consultation with the TANK Stakeholder Group, to model the effects of the current and potential additional high flow allocations from the Ngaruroro River, and to assess the capacity of the modelled high flow allocations to meet potential demand.

Modelled scenarios in this suite are referred to as *high flow allocation scenarios* throughout the remainder of this report.

2.2 Key modelling objectives

Requirements and objectives for scenario modelling simulations (including background and context) are listed below.

1. Cease-take trigger flow scenarios

Model a range of scenarios for managing river flows in the Tūtaekurī, Ngaruroro and Karamū catchments, to identify the potential positive and negative effects on river flow and the reliability of supply for water abstractors. Scenarios include:

- Naturalised scenario to simulate river flows without the effects of any abstraction. The primary purpose of this scenario is to allow comparison with the base case scenario, in order to estimate relative changes from a naturalised system to one that is managed using current flow management rules.
- Base case scenario that simulates current flow management rules (i.e. cease-take trigger flows that are currently applied at flow management sites) to simulate the effects of estimated future water use on river flows and abstraction restrictions.
- Base case with maximum allocation abstracted. The purpose of this scenario is to predict the effects of simulating the potential abstraction of all available surface water allocation, with the application of all current flow management sites and rules.
- The modified base case scenario applies current flow management rules, but the number of flow management sites is reduced to 11 selected scenario sites (Section 2.3). In addition, groundwater abstractions located within the proposed 'Stream Depletion Zone 1' are classed as stream depleting and are subject to restrictions based on cease-take trigger flows.
- Alternative scenarios based on potential new flow management rules to explore the effects of increasing cease-take trigger flows and the restriction of stream depleting groundwater abstractions within the proposed 'Stream Depletion Zone 1'.

2. Groundwater augmentation to surface water scenarios

Model a range of scenarios that combine flow management rules with the groundwater augmentation of lowland streams in the Heretaunga Plains, to identify the potential positive and negative effects on river flow and the reliability of supply for water abstractors. Scenarios include:

- Modified base case scenario that incorporates groundwater augmentation.
- Alternative scenarios incorporating potential new flow management rules and groundwater augmentation.

3. *Emergency water allocation scenarios*

Model a range of scenarios that incorporate a 10% emergency water allocation to identify the potential impact on flow in the Ngaruroro and Tūtaekurī rivers. Scenarios include:

- Modified base case scenario that incorporates a 10% emergency water allocation.
- Alternative scenarios based on potential new flow management rules that incorporate a 10% emergency water allocation.

4. *High flow allocation scenarios*

Model a range of high flow allocation scenarios for the Ngaruroro River to assess the potential impact of each scenario on flushing flows and assess the capacity of the modelled high flow allocation to meet potential new demand. Scenarios include:

- A scenario based on the current high flow allocation of 2 m^3/s
- A range of scenarios with increased high flow allocation

2.3 Current flow management sites

There are 14 currently active flow management sites in the surface water model domain (Table 2-2, Figure 2-2).

The currently active flow management sites and their current flow management rules were simulated under a base case scenario for each river and stream, along with a scenario that considers the base case, but with abstraction of all currently available surface water allocation. All other scenarios (excluding naturalised) simulated abstractions managed by the selected scenario flow management sites discussed in Section 2.3.

Table 2-2: Currently active flow management sites. Fourteen currently active flow management sites located within the surface water model domain.

Catchment	Flow management site
Tūtaekurī	Tūtaekurī River at Ngaroto
	Tūtaekurī River at Puketapu HBRC Site
Ngaruroro	Maraekakaho Stream D/S Tait Rd
	Ngaruroro River at Fernhill
	Ngaruroro River at Whanawhana
	Tūtaekurī Waimate Stm at Goods Bridge
Karamū	Karamū Stream at Floodgates
	Karewarewa Stream at Paki Paki
	Louisa Stream at Te Aute Road
	Mangateretere Stream at Napier Road
	Ongaru Drain at Wenley Road
	Paritua Stream at Water Wheel
	Raupare Drain at Ormond Road
	Te Waikaha at Mutiny Road

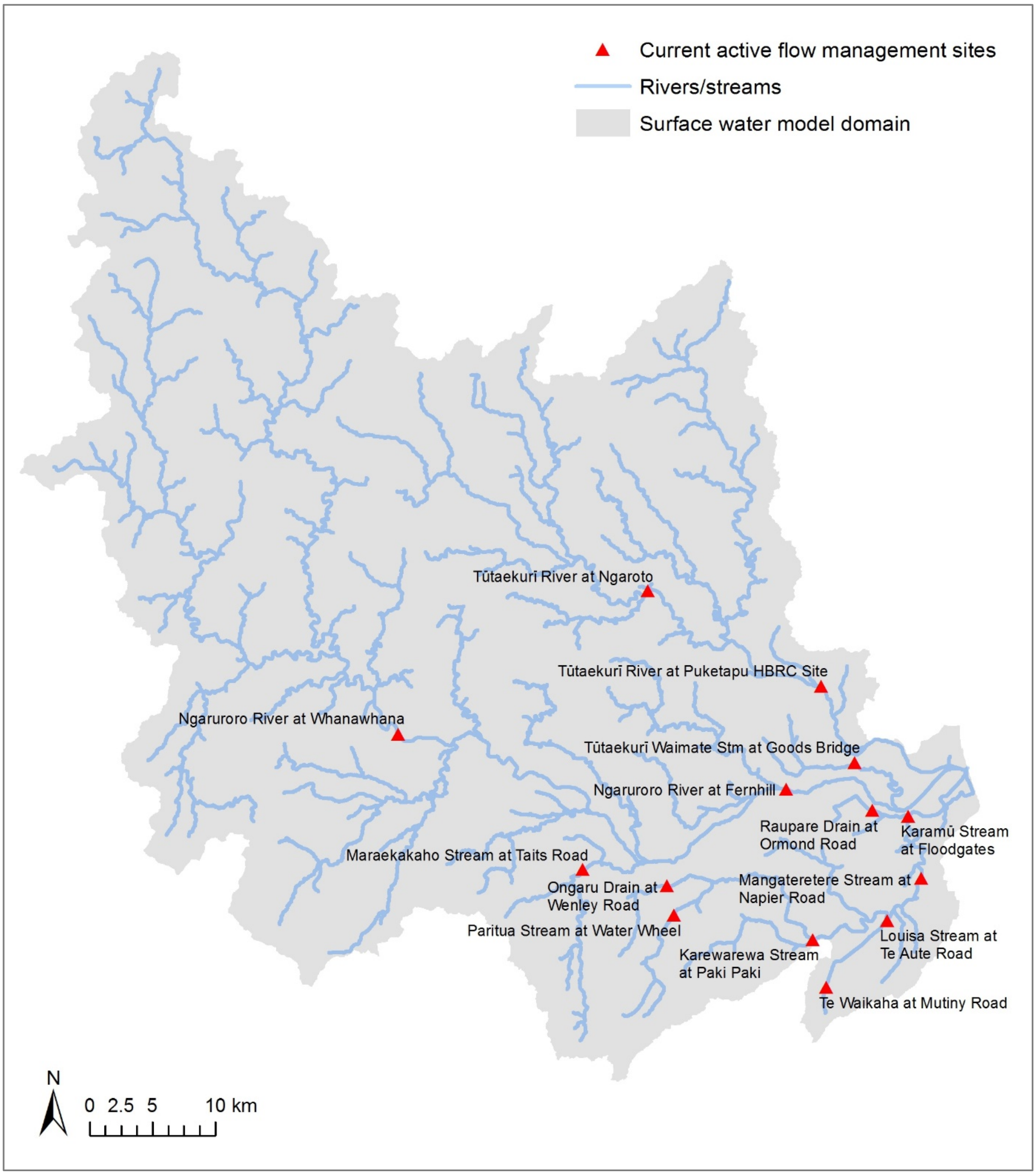

Figure 2-2: Current active flow management sites. Locations of the fourteen currently active flow management sites within the surface water model domain.

2.4 Selected scenario flow management sites

Flow management sites can be used to trigger regulatory responses during low flows, including cease-take restrictions, flow enhancement via augmentation, or reduced abstractions. During the TANK stakeholder engagement process it was proposed that the number of flow management sites used for modelling could be rationalised.

Eleven sites were selected, based on the potential for each site to provide effective management of instream habitat and oxygen requirements in the rivers and streams. The 11 selected sites included current active flow management sites and one inactive site – the Awanui Stream at Flume, which is deemed inactive because currently there are no consented abstractions linked to it. Due to the Awanui site being inactive, the nearest currently active upstream flow management site located on the Karewarewa Stream was included in the selection of sites to be modelled.

The 11 flow management sites used for scenario modelling in this report are listed in Table 2-3 and the locations of these are shown in Figure 2-3.

Table 2-3: Selected scenario flow management sites. Eleven sites selected to use for modelling various scenarios within the surface water model domain.

Catchment	Flow management site
Tūtaekurī	Tūtaekurī River at Puketapu HBRC Site
Ngaruroro	Maraekakaho Stream D/S Tait Rd
	Ngaruroro River at Fernhill
	Tūtaekurī Waimate Stm at Goods Bridge
Karamū	*Awanui Stream at Flume
	Irongate Stream at Clarkes Weir
	Karamū Stream at Floodgates
	Karewarewa Stream at Paki Paki
	Louisa Stream at Te Aute Road
	Mangateretere Stream at Napier Road
	Raupare Drain at Ormond Road

*Currently inactive site

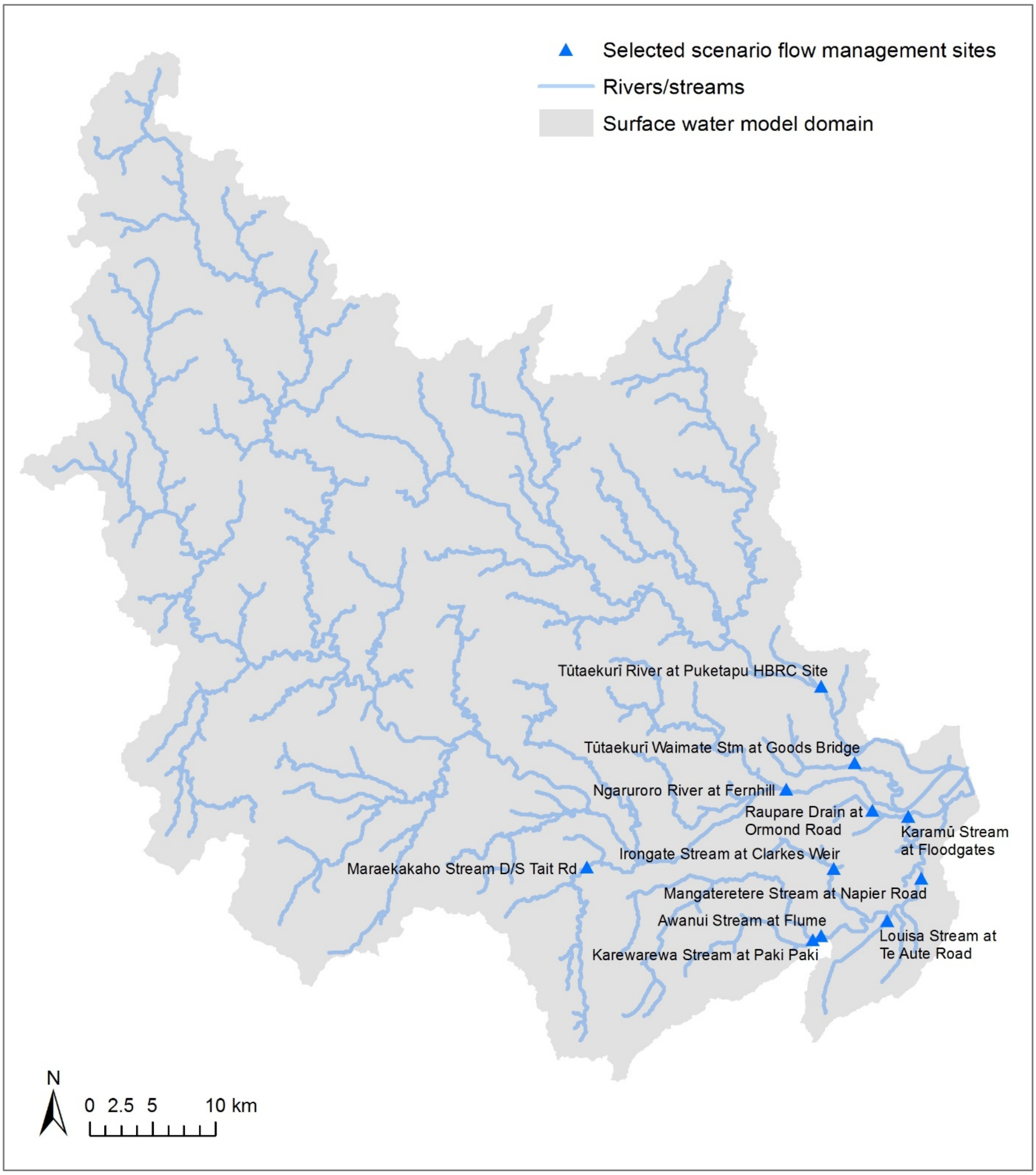

Figure 2-3: Selected scenario flow management sites. Map showing the locations of the 11 selected scenario flow management sites within the surface water model domain.

To ensure consistency with comparisons between scenarios, statistics were generated and analysed for the 11 selected scenario flow management sites.

3 SOURCE hydrological model

3.1 Modelling platform

SOURCE is a hydrological modelling platform developed by eWater (2018), which is owned by a collection of Australian government agencies. SOURCE is a tool that can simulate river systems and catchments to support the planning and management of freshwater resources. Models developed in SOURCE can simulate both water quantity and quality processes. SOURCE can be run on a daily time step and is capable of simulating a range of flow management rules including those relating to abstractions for out of river use. Scenarios can be created, run and analysed to assess and compare the simulated impacts of each scenario.

3.2 Model development

HBRC commissioned Williamson Water Advisory (WWA) in April 2016 to develop a hydrological model using the SOURCE modelling platform to simulate flow and water quality in the rivers and streams of the TANK catchments. This model was developed and calibrated to simulate river flows between 1979 and 2015, incorporating the effects of past abstractions from both surface water and groundwater. Development and construction of the TANK SOURCE model was fully reported by Williamson and Diack (2018) and is briefly summarised here.

Within the SOURCE model, the Ngaruroro, Tūtaekurī and Karamū catchments were divided into 137 sub-catchments. The Soil Moisture Water Balance Model (SMWBM) developed by WWA, is a daily model that functions as a plugin to SOURCE. The SMWBM generates a daily time series flow record for each sub-catchment, based on climate data (rainfall and potential evapotranspiration) and sub-catchment characteristics. The SOURCE model routes the sub-catchment flow downstream through the sub-catchment network, while simulating water abstractions or other processes (e.g. gains from/losses to groundwater) that affect flow throughout the catchment. The SOURCE model sub-catchments and the locations of simulated surface water abstractions are shown in Figure 3-1.

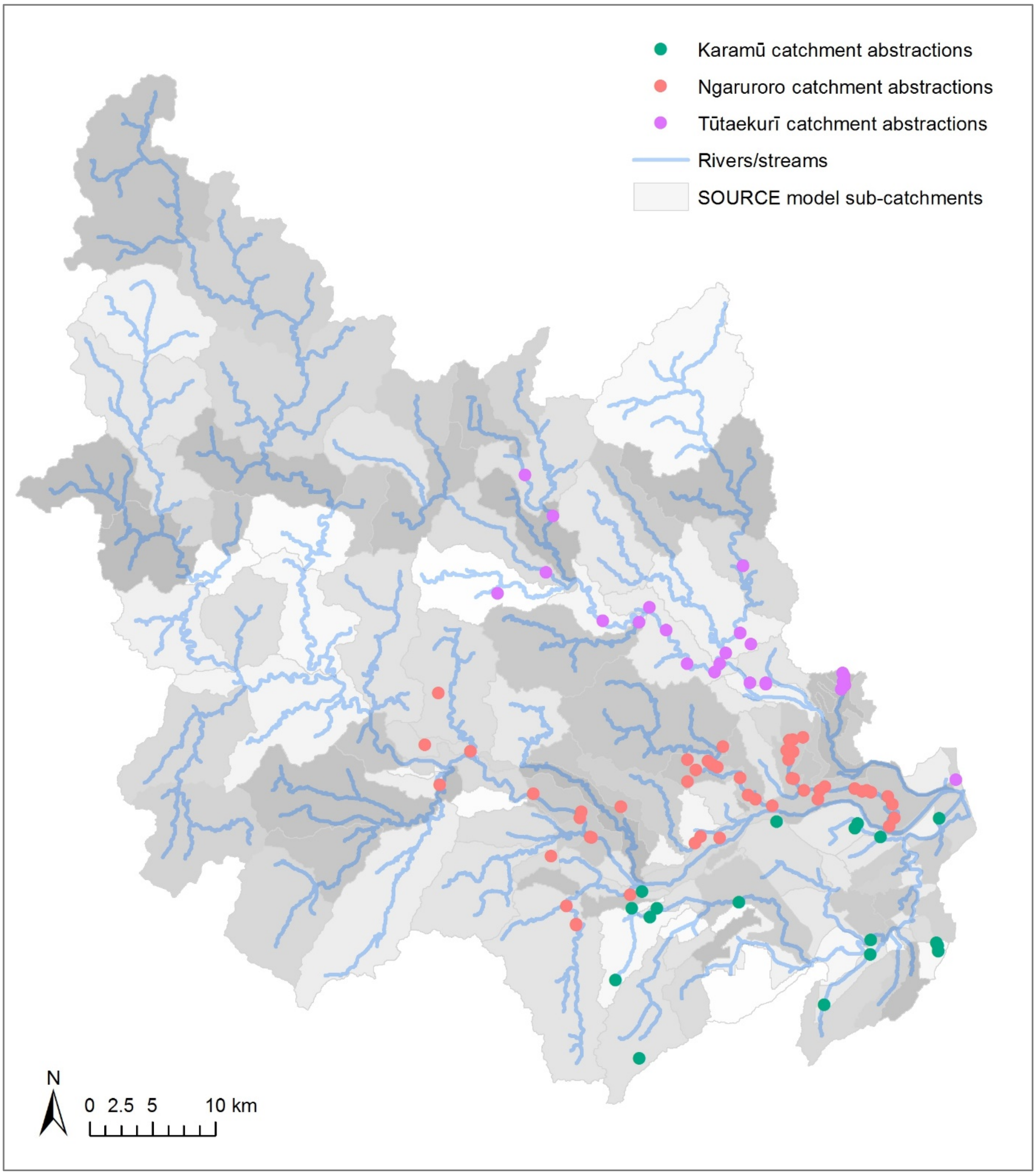

Figure 3-1: SOURCE model sub-catchments and locations of surface water abstraction. Map showing the locations of the modelled abstractions within the Karamū, Ngaruroro and Tūtaekurī catchments.

3.2.1 Linking SOURCE and MODFLOW

The SOURCE model was linked with the HBRC Heretaunga aquifer groundwater model that was developed with MODFLOW by Rakowski and Knowling (2018). The linkage between the surface water and groundwater models was required to represent the complex interaction between surface water and the underlying aquifer system. Linking the two models enabled the impact of groundwater abstractions on surface water bodies to be incorporated into the simulated surface water flow regimes. The surface water (SOURCE) and groundwater (MODFLOW) model domains are shown in Figure 3-2.

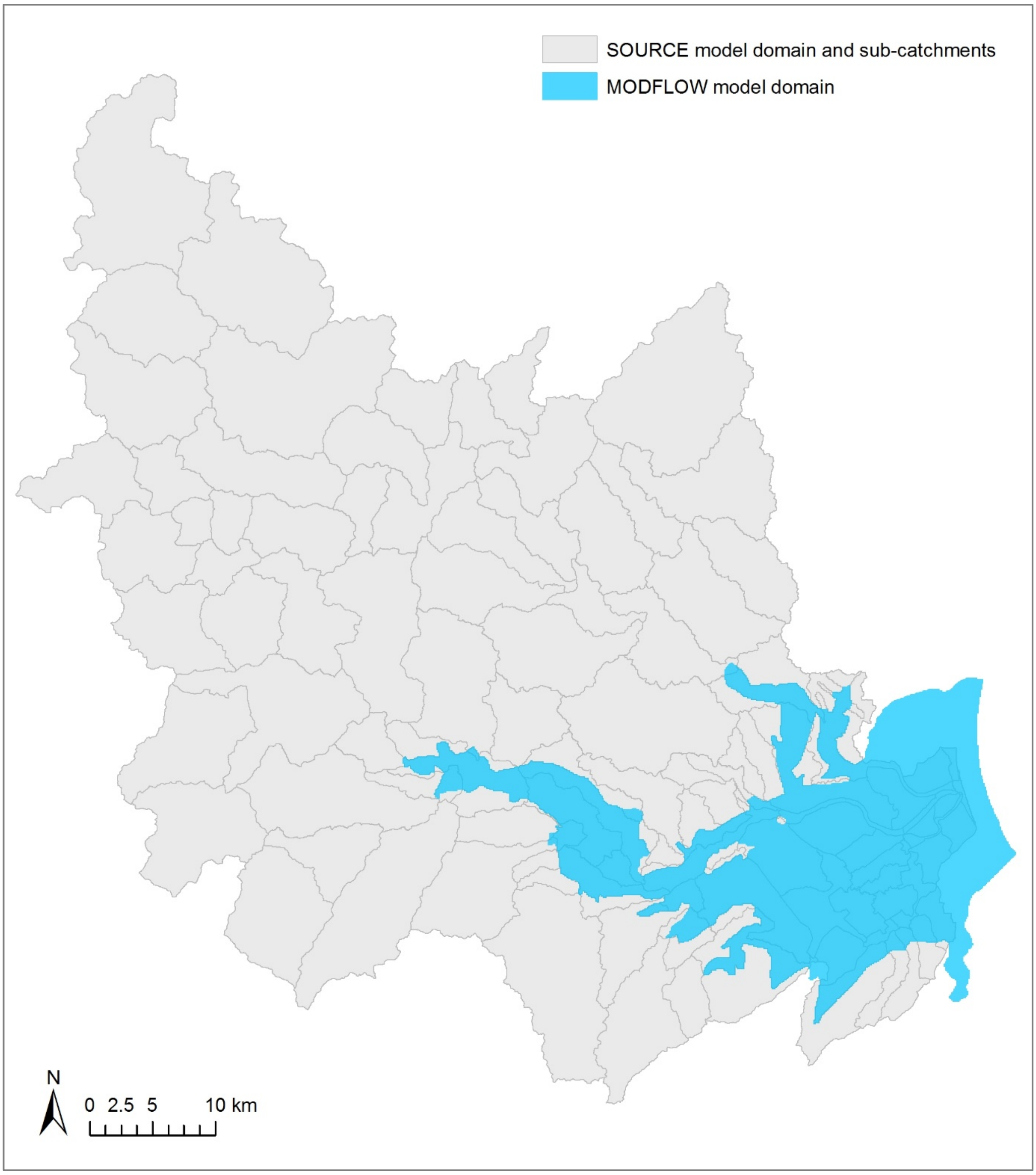

Figure 3-2: SOURCE (surface water) and MODFLOW (Groundwater) model domains. Map showing the SOURCE and MODFLOW model domains together with the SOURCE model sub-catchments.

The link between the SOURCE and MODFLOW models only occurs where the modelling domains overlap. The MODFLOW groundwater model captures the Heretaunga Plains gravel aquifer system and the exchanges of water between groundwater and surface water bodies. The SOURCE model sub-catchments, within which rivers and streams ‘gain from’ or ‘lose to’ groundwater (refer to the map provided in Appendix C), were configured to integrate groundwater datasets generated by the MODFLOW model, which account for the groundwater-surface water interaction.

3.2.2 Model calibration

The report by Williamson and Diack (2018) also provides full details of the SOURCE model calibration to observed historical data. A brief summary is provided here.

The model was calibrated for flow at 16 continuous monitoring sites and 24 spot gauging locations, with the calibration process carried out systematically downstream through the sub-catchments. Model parameters were repeatedly adjusted until either a satisfactory or best possible match between simulated and observed data was achieved.

The calibration process used a range of model evaluation criteria to assess the ability of the model to accurately predict flow. The Ngaruroro River at Fernhill is a key flow management site within the Ngaruroro river catchment. An assessment, based on the evaluation criteria and general visual comparisons between modelled and observed flows, indicated that the model over simulates flow at the Fernhill site. This over-simulation of flow was thoroughly investigated, making use of all available data and knowledge, in an attempt to improve the model calibration at this site. However, after numerous improvements, the final calibration still resulted in over-simulation of flow at the site. The over simulation of flow may potentially be attributed to:

1. Potential error and uncertainty in climate input data (rainfall and evapotranspiration data from the NIWA Virtual Climate Station Network).
    - Cichota et al. (2008) evaluated the performance of Virtual Climate Station (VCS) rainfall data and found that:
        - VCS data can deviate considerably from observed rainfall at some locations, particularly locations with large local rainfall variability or sparse input data for the VCS model. The upper Ngaruroro catchment is likely affected by both of these phenomena;
        - model outputs that are closely related to rainfall events (e.g. drainage or the SMWBM) are most sensitive to deviations in VCS data and that care should be exercised when using VCS rainfall for short term simulations (i.e. daily time steps); and
        - where long-term measurements are not available, the VCS rainfall data is a viable substitute, although preference is given to correcting the VCS data for any bias using locally measured observations.
2. The potential for observed flow data not capturing possible sub-surface flow within the river gravels of the Ngaruroro River.
    - Field based river flow measurements provide observations of water flowing above the river bed. However, sub-surface flow within the river gravels is unable to be captured during flow measurements. This could result in flow measurements that under-estimate the total volume of water moving through a catchment at a specific measuring location, such as the Fernhill site.

Based on the data currently available, the final calibration of the model is considered to provide the best possible simulation of flow throughout all catchments. The over-simulation of flow at Ngaruroro River at Fernhill is considered to be one limitation of the model, however, the model still simulates the same seasonal peaks and troughs as those observed in the measured flow record, and can be used to indicate relative changes to flow at the site. Predictive scenario modelling, simulated various trigger flow options for the Ngaruroro River at Fernhill, each modelled trigger flow was adjusted, to provide equivalency with the over simulated flow record. This is discussed further in Section 3.2.4.

WWA provided HBRC with a finalised calibrated SOURCE flow model in May 2017 (model version file name – *Base Case_All Losses (6.1) 20170927 GW Data.rsproj*).

The calibrated model is configured for simulation between 1979 and 2015, which is referred to as the *historical base case scenario*. The calibrated model was also used in this report for developing predictive scenarios that simulate the hydrological system into the future for the years 2015 to 2032.

3.2.3 Model development for predictive scenarios

The first stage in developing the SOURCE model for predictive scenario forecasting, was to extend the model to simulate the hydrological system out to 2032. This required additional input data for the period 2015-2032, including climate, groundwater (from MODFLOW) and estimated abstraction demand data.

The historical base case scenario was developed to incorporate estimated past abstractions that have been affected by different management rules over time (e.g. revised trigger flow limits). In contrast to this, the predictive scenario forecasts use an estimated future abstraction demand dataset, based on the management options proposed for the different scenarios. The SOURCE model was adapted to accurately simulate the range of management options (e.g. restriction rules, augmentation, etc.) for the different scenarios.

The details of all modelled future predictive scenarios are included within each section of this report (from sections 4 to 7). A SOURCE model log is also included for reference in Appendix A. This log tracks the development of the model from the historical base case scenario to the different future predictive scenarios that were simulated and presented in sections 4 to 7. It details the different input data that was required for each modelled scenario and also includes a brief description of the key modifications that were made in SOURCE to configure the model for each scenario.

3.2.4 Ngaruroro trigger flows

Scenario modelling presented in sections 4 to 7 explores the potential effects of different trigger flow options on rivers and streams within the TANK catchments. Effects that were considered include relative changes to abstraction restrictions and changes to river flows. To estimate the relative changes resulting from various trigger flow options for the Ngaruroro River at Fernhill, each modelled trigger flow was adjusted, to be applicable with the over-simulated flow record generated by the SOURCE model.

To achieve this, a rating was constructed based on flow duration curves from the measured (observed) and simulated Fernhill flow records. The resulting ‘measured-to-simulated’ flow rating curve (Figure 3-3) was used to convert each trigger flow into an offset trigger flow for each scenario modelled.

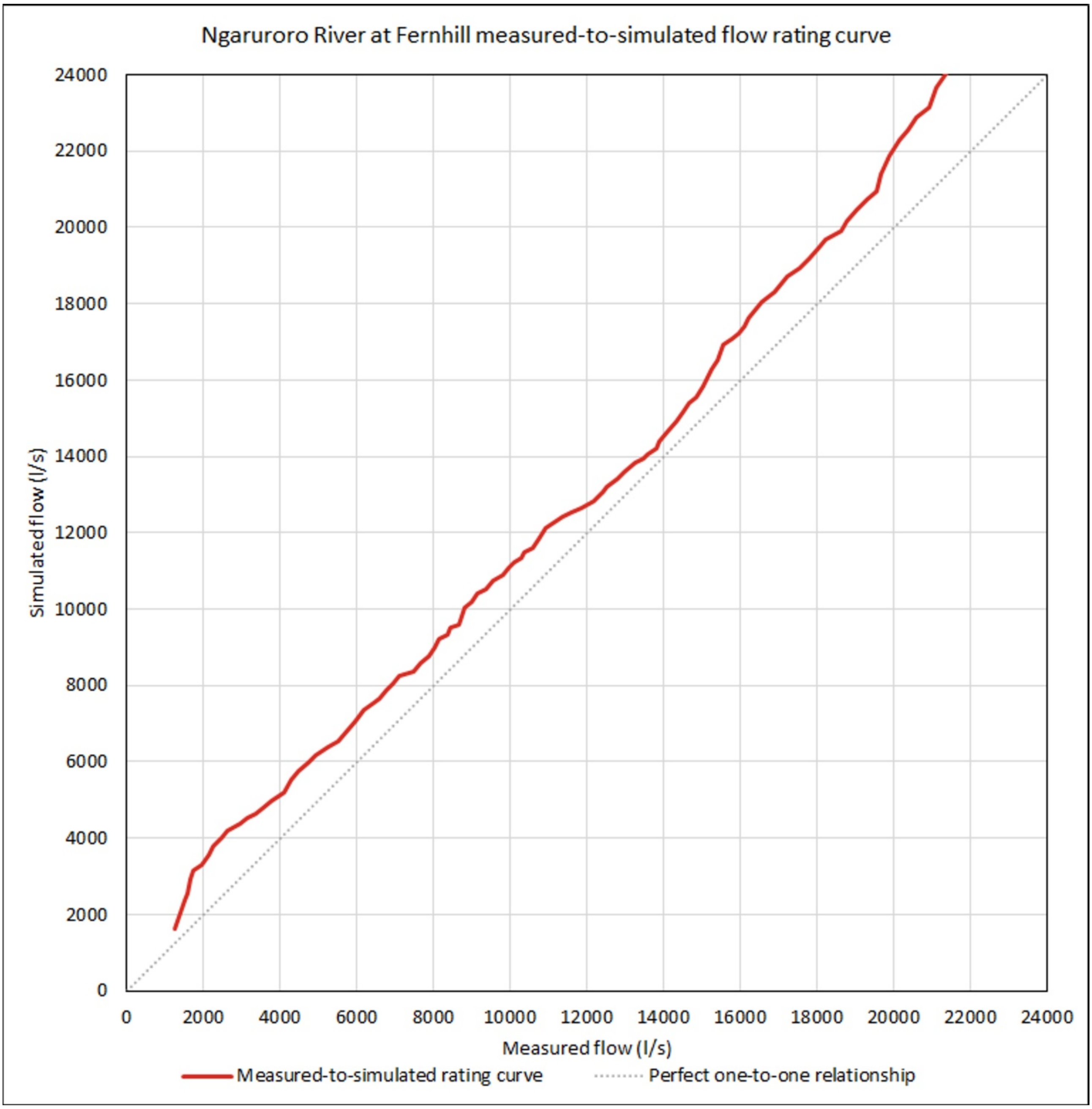

Figure 3-3: Ngaruroro River at Fernhill measured-to-simulated flow rating curve. Rating curve constructed to convert trigger flows to offset trigger flows for each modelled scenario.

The offset trigger flows represent thresholds used for application to the over-simulated flow data, which are equivalent to trigger flows related to observed flow data. Examples of calculated offset trigger flows are shown in Table 3-1.

Table 3-1: Ngaruroro River at Fernhill example offset trigger flows. Example offset trigger flows calculated using the measured-to-simulated flow rating curve. The offset trigger flows have been adjusted using the rating curve in Figure 3-3 and represent equivalent flows applied to the modelled flow data.

Ngaruroro River at Fernhill	
Trigger flow (l/s)	**Offset trigger flow (l/s)**
2400	3970
3600	4840
4000	5120

A trigger flow of 2400 l/s that relates to the measured Fernhill flow record is plotted in Figure 3-4, together with the offset trigger flow of 3970 l/s used with the simulated flow record. The figure shows that the period of time when the measured flow record is less than the trigger flow is equal to the period of time the over-simulated flow is less than the offset trigger flow.

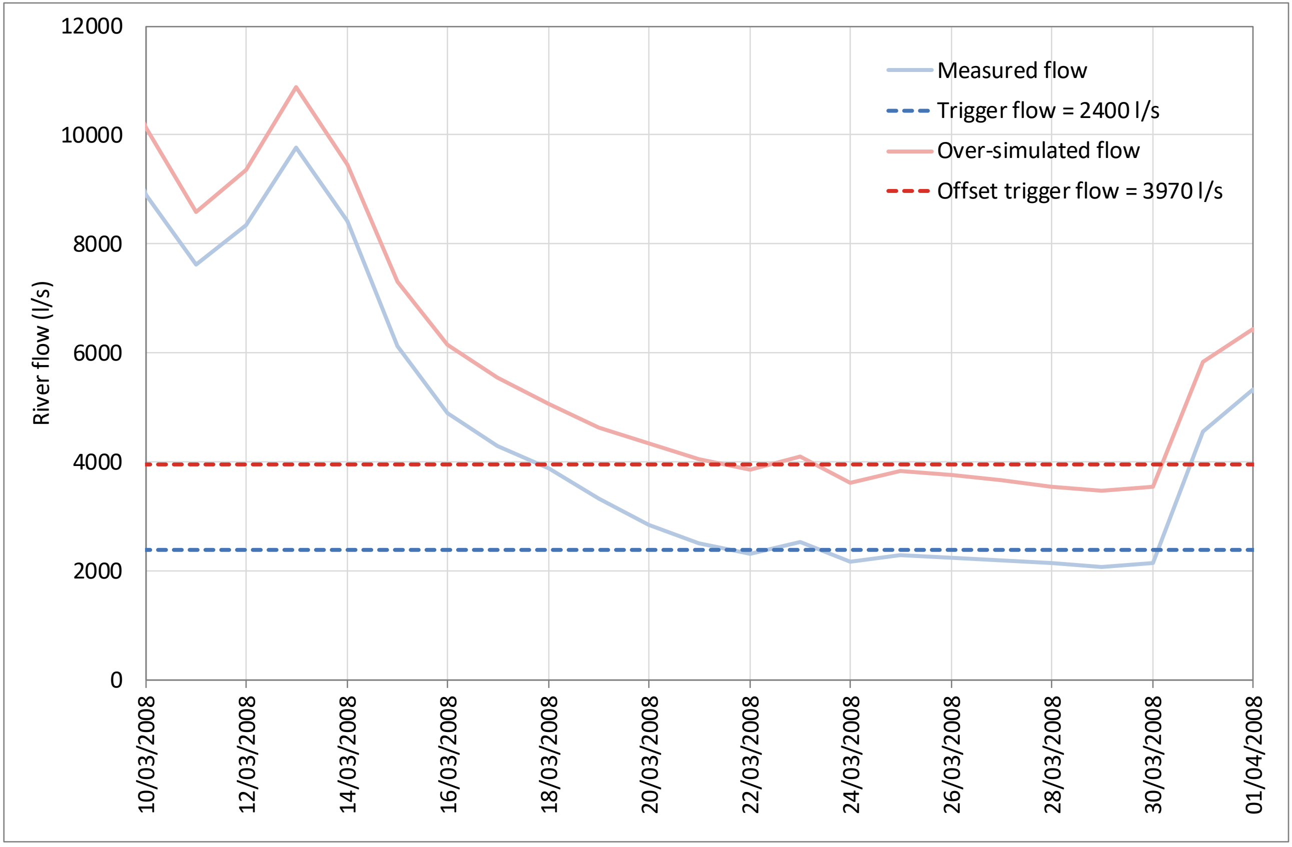

Figure 3-4: Ngaruroro trigger flow with and without offset.

Modelling the offset trigger flows with the simulated flows meant that the Ngaruroro restriction data exported from SOURCE could be analysed without the need for any further adjustment. The effect of applying an offset to a 2400 l/s trigger flow is shown in Table 3-2. For the three example years, the table presents the number of restriction days modelled using the Fernhill measured flow record and the SOURCE simulated flow record, with and without an offset applied to the trigger flow. The table indicates that simulating flows in SOURCE with the offset trigger flow, predicts restriction days with a reasonable match to those modelled using the measured flow record. If an offset is not applied to the trigger flow in SOURCE, the number of restriction days are significantly underestimated.

Table 3-2: Example of applying an offset to a Ngaruroro trigger flow. Based on a 2400 l/s trigger flow, the number of restriction days modelled using the measured Ngaruroro flow record (for three example years) is compared to SOURCE simulated flows with and without the offset applied to the trigger flow.

	Ngaruroro River at Fernhill - No. of restriction days based on a 2400 l/s trigger flow		
Year	**Measured flow record**	**SOURCE simulated flow record***	
		With offset applied to trigger flow	**Without offset applied to trigger flow**
2007-2008	9	11	0
2012-2013	64	52	6
2014-2015	13	17	0

*Simulated flow record for equivalent climate year

3.2.5 Ngaruroro simulated flows

Further to the adjustments made in SOURCE for the purposes of simulating restrictions, the simulated flow exported from the model was adjusted downwards using the ‘measured-to-simulated’ rating curve (Figure 3-3) in reverse. This process removed the over-simulated component from the exported flow data, resulting in flow records that were considered more suitable for identifying relative changes to flow regimes, and would be more comparable to the measured historical flow record.

4 Cease-take trigger flow scenario modelling

The purpose of modelling the cease-take trigger flow scenarios was to understand the impacts of current flow management rules in the Tūtaekurī, Ngaruroro, and Karamū catchments, explore potential future alternatives and to identify:

1. Potential adverse effects on the reliability of supply for existing water abstractors resulting from current and alternative flow management options for rivers and streams in the modelled catchments.

2. Effects of current flow management rules on river flow compared to flows in a naturalised system (unaffected by abstractions).

3. Potential benefits or adverse effects on river flow resulting from alternative flow management options for rivers and streams in the modelled catchments.

4.1 Scenario configuration

The cease-take trigger flow scenarios modelled for the Tūtaekurī River, Ngaruroro River, Karamū Catchment and tributaries of the Ngaruroro River were configured with several different settings, including modelled abstraction demand, restriction regime and cease-take trigger flow. These settings were not required for modelling naturalised scenarios, which simulate river flows that would occur in the absence of any abstractions.

Modelled abstraction

Abstraction was modelled either as estimated future demand or maximum allocation. Estimated future demand for irrigation was modelled by Aqualinc (Rajanayaka & Fisk 2018a, 2018b) using climate data, land use data, crop water requirements and available metered water use data. Maximum allocation was based on increasing surface water abstractions up to the maximum current consented allocation.

Restriction regime

The restriction regime specifies the restriction rule, meaning the type of restriction that is initiated by the trigger flow. All scenarios that simulate abstraction have a restriction rule that triggers cessation of abstraction when flow is less than or equal to the cease-take trigger flow. The restriction regime also specifies the type of surface water and groundwater abstractions that are subject to the restriction rule (e.g. groundwater abstractions located within Stream Depletion Zone 1).

Primary cease-take trigger flow

Some flow management sites have more than one cease-take trigger flow. A 'primary' cease-take trigger flow refers to the lowest trigger flow at all sites.

Various primary cease-take trigger flows were modelled for different scenarios. However, 31 surface water abstractions are currently managed with additional higher trigger flows and these were retained throughout all scenarios. Therefore, the relative changes to modelled effects between scenarios (identified in analyses described in Section 0) will be attributed to the different primary cease-take trigger flows, and not any other existing higher trigger flows.

Alternative scenarios developed for the Ngaruroro and Tūtaekurī rivers, incorporated potential new cease-take trigger flows based on instream habitat modelling undertaken by Wilding (2018).

The configuration of cease-take trigger flow scenarios modelled for the Tūtaekurī River, Ngaruroro River, Karamū Catchment and tributaries of the Ngaruroro River are presented in sections 4.3.1 and 4.4.1.

4.2 Analysis description

Two different analyses have been undertaken for each cease-take trigger flow scenario to identify the predicted effects on the reliability of supply for water abstractors and effects on river flow. Statistics from each analysis are reported for the 11 flow management sites (Section 2.3). The following two analyses are provided in sections 4.3 to 4.4:

- **Restriction analysis**

  When simulating different scenarios, a restriction index was generated by the SOURCE model for each flow management site. The restriction index is a time series that indicates the numbers of days with and without modelled restriction of abstraction. A range of restriction statistics for each flow management site were calculated from the restriction index generated under each scenario. Restriction statistics identify total and average restrictions, plus periods of 3 and 10 consecutive days on restriction.

  The restriction statistics calculated for the Base Case scenario are compared to all other cease-take trigger flow scenarios to identify predicted changes to restriction between scenarios. The predicted changes indicate the potential impacts on reliability of supply for water abstractors that are a consequence of the different simulated flow management options (particularly different cease-take trigger flows).

  All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.

- **Flow regime analysis**

  A range of summary river flow statistics have been calculated from the scenario modelled flow records for each flow management site. The mean annual low flow (MALF) and Q95 are reported for each scenario, and are defined as:

  - **Mean annual low flow (MALF)** - This is the average of annual low flows (ALF) in a flow record. In this report, ALFs are calculated for each hydrological year (Jul-Jun) from a 7-day moving average of daily mean flows. ALFs are excluded from years with gaps in the flow record at times when the annual minimum may have occurred.

  - **Q95** - The daily mean flow that is equalled or exceeded for 95% of the time over the period of record. The Q95 is used as a descriptor of the low flow of a river.

  The MALF and Q95 are low flow statistics which help to describe and understand simulated changes to the low flow regime under different scenarios. The relative percentage change to these statistics is used to evaluate the predicted effects to the low flow regime between the Naturalised and Base Case scenarios, and between the Base Case scenario and all other cease-take trigger flow scenarios. The predicted effects on flow are summarised and discussed in sections 4.3 to 4.5 of this report. Full suites of summary flow statistics are also included for reference in Appendix F[2]. Definitions of other river flow statistics are provided in Appendix E.

  Unless stated otherwise, flow statistics are based on analyses of full hydrological years (Jul-Jun) for the modelled record between 2015 and 2032.

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[2] In this report, 'Q5' is a high flow statistic defined as the daily mean flow that is equalled or exceeded for 5% of the time over the period of record. It is acknowledged that in other regions a 'Q5' flow often refers to a 'one in five year 7-day low flow', which is a flow that has a 20 percent chance of occurring in any one year (or a likelihood of occurrence of once in every five years, also termed a '5-year return period').

4.3 Tūtaekurī and Ngaruroro

4.3.1 Scenario overview

The configuration of the cease-take trigger flow scenarios modelled for the Tūtaekurī and Ngaruroro rivers are provided in Table 4-1 and Table 4-2 respectively. These tables also identify the types of analysis (described in Section 0) and comparisons undertaken, and the SOURCE model ID is included as a reference for future modelling applications.

The restriction analysis (Section 4.3.2) was undertaken for all scenarios that simulate abstraction, however, only some scenarios were selected for further modelling and analysis:

- Four default scenarios:
    1. **Naturalised** (**Tūtaekurī 1 and Ngaruroro 1**) – modelled and analysed for comparison with the Base Case scenario.
    2. **Base Case** (**Tūtaekurī 2 and Ngaruroro 2**) – modelled and analysed because it represents current flow management rules that could potentially be retained into the future if nothing was changed. For this scenario, estimated future water demand is modelled, rather than the full allocation that may be available.
    3. **Base Case_Max Allocation** (**Tūtaekurī 3 and Ngaruroro 3**) – modelled and analysed to estimate future effects if the maximum surface water allocation was abstracted and managed by current flow management rules.
    4. **Modified Base Case** (**Tūtaekurī 4 and Ngaruroro 4**) – modelled and analysed to estimate the effects of retaining current flow management rules for the Tūtaekurī River at Puketapu HBRC Site and Ngaruroro River at Fernhill, with the exception of restricting groundwater abstractions located within the proposed 'Stream Depletion Zone 1' instead of groundwater abstractions that are currently classed as stream depleting and subject to restrictions. In this scenario, abstractions currently linked to the Tūtaekurī River at Ngaroto flow management site, are transferred to the downstream site at Puketapu.
- Two additional scenarios were also requested for each river by the TANK Stakeholder Group.

    Tūtaekurī:

    1. **Tūtaekurī 6** – this scenario has a cease-take trigger flow at Tūtaekurī River at Puketapu HBRC Site that is based on a flow that provides 75% of habitat available at the MALF (Wilding 2018).
    2. **Tūtaekurī 8** – this scenario has a cease-take trigger flow at Tūtaekurī River at Puketapu HBRC Site that is based on a flow that provides 90% of habitat available at the MALF (Wilding 2018).

    Ngaruroro:

    1. **Ngaruroro 5** – this scenario has a cease-take trigger flow for the Ngaruroro River at Fernhill that is based on a flow that provides 70% of habitat available at the MALF (Wilding 2018).
    2. **Ngaruroro 6** – this scenario has a cease-take trigger flow at Fernhill that is based on a flow that provides 80% of habitat available at the MALF (Wilding 2018).

The flow regime analysis was only undertaken for the selected scenarios and this analysis is presented in Section 4.3.3.

Table 4-1: Tūtaekurī cease-take trigger flow scenarios. This table shows the configuration of the cease-take trigger flow scenarios and the analyses undertaken.

Scenario ID	Scenario name	Flow management site	Modelled SW abstraction	Abstraction restriction regime			Primary cease-take trigger flow		Scenario analysis undertaken		Scenario compared with	SOURCE model ID reference
				Restriction rule	Restricted SW abstractions	Restricted GW abstractions	Basis	Flow (l/s)	Restriction	Flow regime		
Tūtaekurī 1	Naturalised	Tūtaekurī River at Puketapu HBRC Site	-	-	-	-	-	-	-	Yes	Tūtaekurī 2 - Base Case	7.1
Tūtaekurī 2	Base Case	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Current classified stream depleting GW	Current	2000	Yes	Yes	Tūtaekurī 1 - Naturalised	8.1_SDC
Tūtaekurī 3	Base Case_Max Allocation	Tūtaekurī River at Puketapu HBRC Site	Maximum allocation	Cease-take (flow ≤ trigger flow)	All	Current classified stream depleting GW	Current	2000	Yes	Yes	Tūtaekurī 2 - Base Case	9.2_SDC
Tūtaekurī 4	Modified Base Case	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	Current	2000	Yes	Yes	Tūtaekurī 2 - Base Case	8.1_SDZ1
Tūtaekurī 5	Tūtaekurī 70% Habitat Trigger Flow	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	70% habitat at MALF	2300	Yes	-	Tūtaekurī 4 - Modified Base Case	11.0_SDZ1
Tūtaekurī 6	Tūtaekurī 75% Habitat Trigger Flow	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	75% habitat at MALF	2500	Yes	Yes	Tūtaekurī 4 - Modified Base Case	16.0_SDZ1
Tūtaekurī 7	Tūtaekurī 80% Habitat Trigger Flow	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	80% habitat at MALF	2800	Yes	-	Tūtaekurī 4 - Modified Base Case	12.0_SDZ1
Tūtaekurī 8	Tūtaekurī 90% Habitat Trigger Flow	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	90% habitat at MALF	3300	Yes	Yes	Tūtaekurī 4 - Modified Base Case	13.0_SDZ1
Tūtaekurī 9	Tūtaekurī MALF Trigger Flow	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	MALF	3900	Yes	-	Tūtaekurī 4 - Modified Base Case	14.0_SDZ1

Table 4-2: Ngaruroro cease-take trigger flow scenarios. This table shows the configuration of the cease-take trigger flow scenarios and the analyses undertaken.

Scenario ID	Scenario name	Flow management site	Modelled SW abstraction	Abstraction restriction regime			Primary cease-take trigger flow		Scenario analysis undertaken		Scenario compared with	SOURCE model ID reference
				Restriction rule	Restricted SW abstractions	Restricted GW abstractions	Basis	Flow (l/s)	Restriction	Flow regime		
Ngaruroro 1	Naturalised	Ngaruroro River at Fernhill	-	-	-	-	-	-	-	Yes	Ngaruroro 2 - Base Case	7.1
Ngaruroro 2	Base Case	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Current classified stream depleting GW	Current	2400	Yes	Yes	Ngaruroro 1 - Naturalised	8.1_SDC
Ngaruroro 3	Base Case_Max Allocation	Ngaruroro River at Fernhill	Maximum allocation	Cease-take (flow ≤ trigger flow)	All	Current classified stream depleting GW	Current	2400	Yes	Yes	Ngaruroro 2 - Base Case	9.2_SDC
Ngaruroro 4	Modified Base Case	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	Current	2400	Yes	Yes	Ngaruroro 2 - Base Case	8.1_SDZ1
Ngaruroro 5	Ngaruroro 70% Habitat Trigger Flow	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	70% habitat at MALF	3600	Yes	Yes	Ngaruroro 3 - Modified Base Case	11.0_SDZ1
Ngaruroro 6	Ngaruroro 80% Habitat Trigger Flow	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	80% habitat at MALF	4000	Yes	Yes	Ngaruroro 3 - Modified Base Case	12.0_SDZ1
Ngaruroro 7	Ngaruroro 90% Habitat Trigger Flow	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	90% habitat at MALF	4400	Yes	-	Ngaruroro 3 - Modified Base Case	13.0_SDZ1
Ngaruroro 8	Ngaruroro MALF Trigger Flow	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	MALF	4700	Yes	-	Ngaruroro 3 - Modified Base Case	14.0_SDZ1

4.3.2 Restriction analysis

The restriction statistics calculated for the Tūtaekurī River at Puketapu HBRC Site under each modelled scenario are presented in Table 4-3, while the restriction statistics for the Ngaruroro River at Fernhill are presented in Table 4-4. For both rivers, the restriction statistics under the Base Case scenario are compared to all other scenarios to indicate the relative changes to restriction. Select restriction statistics for both rivers are also presented in graphical form in Appendix D.

Table 4-3: Tūtaekurī River at Puketapu HBRC Site cease-take trigger flow scenario restriction statistics. A range of restriction statistics including the calculated change from the Base Case scenario to all other alternative scenarios. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.

Tūtaekurī River at Puketapu HBRC Site	Scenario															
	Tūtaekurī 2	Tūtaekurī 3		Tūtaekurī 4		Tūtaekurī 5		Tūtaekurī 6		Tūtaekurī 7		Tūtaekurī 8		Tūtaekurī 9	
	Base Case	Base Case_Max Allocation		Modified Base Case		Tūtaekurī 70% Habitat Trigger Flow		Tūtaekurī 75% Habitat Trigger Flow		Tūtaekurī 80% Habitat Trigger Flow		Tūtaekurī 90% Habitat Trigger Flow		Tūtaekurī MALF Trigger Flow	
	Primary cease-take trigger flow (l/s)															
	2000	2000		2000		2300		2500		2800		3300		3900	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics																
Record length (Years)	15	15	-	15	-	15	-	15	-	15	-	15	-	15	-
Total % restriction	0%	0%	-	0%	-	0%	-	0%	-	0.3%	0.3%	3.2%	3.2%	9.1%	9.1%
Average no. days restriction per year	0	0	-	0	-	0	-	0	-	0.7	0.7	8.7	8.7	24.8	24.8
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	0	0	-	0	-	0	-	0	-	0	-	3.8	3.8	1.9	1.9
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	0	0	-	0	-	0	-	0	-	0	-	7.5	7.5	2.5	2.5
Example dry year statistics - Climate equivalent to 2008-2009																
No. days restriction	0	0	-	0	-	0	-	0	-	5	5	35	35	65	65
No. periods of ≥3 consec. days restriction	0	0	-	0	-	0	-	0	-	0	-	1	1	4	4
No. periods of ≥10 consec. days restriction	0	0	-	0	-	0	-	0	-	0	-	1	1	2	2

Table 4-4: Ngaruroro River at Fernhill cease-take trigger flow scenario restriction statistics. A range of restriction statistics including the calculated change from the Base Case scenario to all other alternative scenarios. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.

Ngaruroro River at Fernhill	Scenario												
	Ngaruroro 2	Ngaruroro 3		Ngaruroro 4		Ngaruroro 5		Ngaruroro 6		Ngaruroro 7		Ngaruroro 8	
	Base Case	Base Case_Max Allocation		Modified Base Case		Ngaruroro 70% Habitat Trigger Flow		Ngaruroro 80% Habitat Trigger Flow		Ngaruroro 90% Habitat Trigger Flow		Ngaruroro MALF Trigger Flow	
	Primary cease-take trigger flow (l/s)												
	2400	2400		2400		3600		4000		4400		4700	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics													
Record length (Years)	17	17	-	17	-	17	-	17	-	17	-	17	-
Total % restriction	2.2%	3.4%	1.2%	2.2%	0.02%	4.7%	2.6%	5.6%	3.5%	7.1%	5.0%	8.0%	5.8%
Average no. days restriction per year	5.9	9.2	3.3	5.9	0.06	12.9	7.0	15.4	9.5	19.5	13.6	21.8	15.9
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	3.4	3.4	-	3.4	-	1.9	-1.5	1.7	-1.7	1.5	-1.9	1.4	-2.0
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	17	17	-	17	-	5.7	-11.3	4.3	-12.8	2.4	-14.6	2.1	-14.9
Example dry year statistics - Climate equivalent to 2012-2013													
No. days restriction	52	58	6	52	-	63	11	66	14	73	21	78	26
No. periods of ≥3 consec. days restriction	3	3	-	3	-	4	1	5	2	5	2	5	2
No. periods of ≥10 consec. days restriction	2	2	-	2	-	2	-	2	-	2	-	2	-

The Tūtaekurī scenario restriction statistics show that no restriction was predicted with cease-take trigger flows ranging from 2000 l/s to 2500 l/s. No restriction means no predicted impact on the reliability of supply for existing water users under these scenarios.

Increasing the cease-take trigger flow beyond 2500 l/s predicted that restriction will begin to occur. Simulating a trigger flow of 2800 l/s (Tūtaekurī 7) predicted a very small percentage of restriction (0.3%) with zero periods of 3 or more consecutive days of restriction, and no more than 5 days of restriction in one the driest simulated years (climate equivalent to 2008-2009).

The impact on reliability of supply was predicted to increase (i.e. more restrictive) under scenarios with higher cease-take trigger flows. For a trigger flow of 3300 l/s (Tūtaekurī 8), a year with a period of 3 or more consecutive days of restriction was predicted to occur approximately every 4 years (recurrence interval = 3.8 years).

For the Ngaruroro River, simulating the abstraction of the current maximum surface water allocation (Base Case_Max Allocation scenario) predicted small increases in restriction from the Base Case scenario, but no change to periods of consecutive days of restriction.

Changing the restriction of groundwater abstractions to those only located in Stream Depletion Zone 1 (Ngaruroro 4 - Modified Base Case scenario) predicted only very small increases to restriction from the Base Case scenario. Whereas, increasing the primary cease-take trigger flow throughout the remaining scenarios, predicted progressively larger effects on restriction, thus progressively reducing the reliability of supply for existing water abstractors. For example, increasing the trigger flow from 2400 l/s to 3600 l/s predicted there would be on average 7 more days of restriction each year. When the trigger flow is increased to 4000 l/s, a further 1.5 restricted days were predicted.

4.3.3 Flow regime analysis

Base Case vs Naturalised scenario

The MALF and Q95 low flow statistics have been calculated for the Tūtaekurī and Ngaruroro rivers under the Naturalised and Base Case scenarios. These statistics are provided in Table 4-5 (Tūtaekurī) and Table 4-6 (Ngaruroro), together with the percentage change from the Naturalised scenario. All flow statistics are based on the analysis of a full hydrological year (Jul-Jun) for the modelled record 2015-2032.

Table 4-5: Tūtaekurī cease-take trigger flow scenarios – MALF and Q95 for Base Case vs Naturalised scenarios. The MALF and Q95 have been calculated from the scenario modelled flow records at Tūtaekurī River at Puketapu HBRC Site.

	Scenario		
	Tūtaekurī 1	Tūtaekurī 2	
	Naturalised	Base Case	
Tūtaekurī River at Puketapu HBRC Site	River Flow (l/s)	River Flow (l/s)	% change from Naturalised
MALF	3965	3676	-7.3%
Q95	3843	3566	-7.2%

Table 4-6: Ngaruroro cease-take trigger flow scenarios – MALF and Q95 for Base Case vs Naturalised scenarios. The MALF and Q95 have been calculated from the scenario modelled flow records at Ngaruroro River at Fernhill.

	Scenario		
	Ngaruroro 1	Ngaruroro 2	
	Naturalised	Base Case	
Ngaruroro River at Fernhill	River Flow (l/s)	River Flow (l/s)	% change from Naturalised
MALF	5035	3842	-23.7%
Q95	5576	4221	-24.3%

Under the Base Case scenario, low flow statistics (MALF and Q95) were predicted to be approximately 7% lower than flows under naturalised conditions in the Tūtaekurī River, and around 24% lower in the Ngaruroro River. The differences between flows simulated under the Base Case and Naturalised scenarios, highlight the range of impact that water abstractions have on river flow. The impact on the low flow regime was greater in the Ngaruroro River than in the Tūtaekurī, which is due to the higher stream depletion effects of groundwater abstractions from the Heretaunga Plains aquifer (Rakowski 2018 simulated stream depletion effects under a range of scenarios), combined with the larger total surface water abstraction in the Ngaruroro catchment (Appendix B).

Alternative scenarios vs Base Case scenario

The MALF and Q95 low flow statistics have been calculated for the Tūtaekurī and Ngaruroro rivers under the Base Case scenario and alternative scenarios. These statistics are compared in Table 4-7 (Tūtaekurī) and Table 4-8 (Ngaruroro) and the proportional changes to both statistics are also provided. All flow statistics are based on the analysis of a full hydrological year (Jul-Jun) for the modelled record 2015-2032.

Table 4-7: Tūtaekurī cease-take trigger flow scenarios – MALF and Q95 for Base Case vs alternative scenarios. The MALF and Q95 have been calculated from the scenario modelled flow records at Tūtaekurī River at Puketapu HBRC Site.

	Scenario								
	Tūtaekurī 2	**Tūtaekurī 3**		**Tūtaekurī 4**		**Tūtaekurī 6**		**Tūtaekurī 8**	
	Base Case	**Base Case_Max Allocation**		**Modified Base Case**		**Tūtaekurī 75% Habitat Trigger Flow**		**Tūtaekurī 90% Habitat Trigger Flow**	
Tūtaekurī River at Puketapu HBRC Site	**River Flow (l/s)**	**River Flow (l/s)**	**% change from Base Case**	**River Flow (l/s)**	**% change from Base Case**	**River Flow (l/s)**	**% change from Base Case**	**River Flow (l/s)**	**% change from Base Case**
MALF	3676	3595	-2.2%	3658	-0.5%	3658	-0.5%	3728	1.4%
Q95	3566	3503	-1.8%	3563	-0.1%	3563	-0.1%	3575	0.2%

Table 4-8: Ngaruroro cease-take trigger flow scenarios – MALF and Q95 for Base Case vs alternative scenarios. The MALF and Q95 have been calculated from the scenario modelled flow records at Ngaruroro River at Fernhill.

	Scenario								
	Ngaruroro 2	**Ngaruroro 3**		**Ngaruroro 4**		**Ngaruroro 5**		**Ngaruroro 6**	
	Base Case	**Base Case_Max Allocation**		**Modified Base Case**		**Ngaruroro 70% Habitat Trigger Flow**		**Ngaruroro 80% Habitat Trigger Flow**	
Ngaruroro River at Fernhill	**River Flow (l/s)**	**River Flow (l/s)**	**% change from Base Case**	**River Flow (l/s)**	**% change from Base Case**	**River Flow (l/s)**	**% change from Base Case**	**River Flow (l/s)**	**% change from Base Case**
MALF	3842	3419	-11.0%	3837	-0.1%	3935	2.4%	3967	3.3%
Q95	4221	3534	-16.3%	4220	-0.04%	4231	0.2%	4243	0.5%

For the Tūtaekurī River, increasing surface water abstractions up to the maximum allocation (Base Case_Max Allocation scenario), predicted a small negative impact (approximately a 2% reduction) on low flow statistics when compared to the Base Case scenario. The equivalent scenarios on the Ngaruroro River, predicted a greater impact on low flow statistics, whereby MALF and Q95 decreased more than 10%. The modelled maximum allocation was much higher in the Ngaruroro catchment than in the Tūtaekurī catchment (1610 l/s vs 826 l/s – Appendix B), which is likely why the impact of abstracting the maximum allocation was greater on the Ngaruroro River.

The Modified Base Case scenarios (Tūtaekurī 4 and Ngaruroro 4) predicted very small reductions to low flow statistics (≤ 0.5%) from the Base Case scenario in both rivers. Changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1 (around 45% less restricted abstractions – Table 2-1), is the single cause of reduced flows in the Ngaruroro River. However, flow reductions in the Tūtaekurī River (which are slightly larger than in the Ngaruroro) are also affected by the transfer of abstractions linked to the Tūtaekurī River at Ngaroto flow management site, to the downstream site at Puketapu. Irrespective of the causes, the predicted negative impacts on Tūtaekurī and Ngaruroro river flows are very small.

Tūtaekurī river flows were predicted to increase when the primary cease-take trigger flow is raised to 3300 l/s (Tūtaekurī 8), at which point the predicted benefits to flow are still relatively small (0.2% and 1.4% increase in low flow statistics).

Increasing the cease-take trigger flow under the Ngaruroro scenarios predicted small improvements to low flows, up to a 3.3% increase in MALF when simulating a 4000 l/s cease-take trigger flow (Ngaruroro 6 scenario).

4.4 Karamū and tributaries

4.4.1 Scenario overview

The configuration of the cease-take trigger flow scenarios modelled for the Karamū Catchment and tributaries of the Ngaruroro River are provided in Table 4-9. This table also identifies the types of analysis (described in Section 0) and comparisons undertaken, and the SOURCE model ID is included as a reference for future modelling applications. The cease-take trigger flows modelled for each flow management site are provided in Table 4-10.

The restriction analysis (Section 4.4.2) and flow regime analysis (Section 4.4.3) were undertaken for all scenarios.

Four scenarios were modelled:

1. **Naturalised (Karamū+Tributaries 1)** – modelled and analysed for comparison with the Base Case scenario.
2. **Base Case (Karamū+Tributaries 2)** – modelled and analysed because it represents current flow management rules that could potentially be retained into the future if nothing was changed. For this scenario, estimated future water demand is modelled, rather than the full allocation that may be available.
3. **Base Case_Max Allocation (Karamū+Tributaries 3)** – modelled and analysed to estimate future effects if the maximum surface water allocation was abstracted and managed by current flow management rules.
4. **Modified Base Case (Karamū+Tributaries 4)** – modelled and analysed to estimate the effects of retaining current flow management rules for nine selected scenario flow management sites (Table 4-10), with the exception of restricting groundwater abstractions located within the proposed 'Stream Depletion Zone 1' instead of groundwater abstractions that are currently classed as stream depleting and subject to restrictions. In this scenario, abstractions currently linked to the Te Waikaha at Mutiny Road flow management site, are transferred downstream to the Louisa Stream at Te Aute Road site. Abstractions currently linked to the Ongaru Drain at Wenley Road flow management site, are transferred downstream to the Karewarewa Stream at Paki Paki site.

Table 4-9: Karamū and Tributaries cease-take trigger flow scenarios. This table shows the configuration of the cease-take trigger flow scenarios and the analyses undertaken.

Scenario ID	Scenario name	Flow management site	Modelled SW abstraction	Abstraction restriction regime			Primary cease-take trigger flows		Scenario analysis undertaken		Scenario compared with	SOURCE model ID reference
				Restriction rule	Restricted SW abstractions	Restricted GW abstractions	Basis	Flow (l/s)	Restriction	Flow regime		
Karamū+ Tributaries 1	Naturalised	Various - 9 sites*	-	-	-	-	-	-	-	Yes	Karamū+ Tributaries 2 - Base Case	7.1
Karamū+ Tributaries 2	Base Case	Various - 9 sites*	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Current classified stream depleting GW	Current	Various - 9 sites*	Yes	Yes	Karamū+ Tributaries 1 - Naturalised	8.1_SDC
Karamū+ Tributaries 3	Base Case_Max Allocation	Various - 9 sites*	Maximum allocation	Cease-take (flow ≤ trigger flow)	All	Current classified stream depleting GW	Current	Various - 9 sites*	Yes	Yes	Karamū+ Tributaries 2 - Base Case	9.2_SDC
Karamū+ Tributaries 4	Modified Base Case	Various - 9 sites*	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	Current	Various - 9 sites*	Yes	Yes	Karamū+ Tributaries 2 - Base Case	8.1_SDZ1

*See trigger flows listed in Table 4-10.

Table 4-10: Karamū and Tributaries flow management sites and cease-take trigger flows.

Flow management site	Catchment	Cease-take trigger flow (l/s)
Awanui Stream at Flume	Karamū	120
Irongate Stream at Clarkes Weir	Karamū	100
Karamū Stream at Floodgates	Karamū	1100
Karewarewa Stream at Paki Paki	Karamū	75
Louisa Stream at Te Aute Road	Karamū	30
Mangateretere Stream at Napier Road	Karamū	100
Raupare Drain at Ormond Road	Karamū	300
Maraekakaho Stream D/S Tait Rd	Ngaruroro	109
Tūtaekurī Waimate Stm at Goods Bridge	Ngaruroro	1200

4.4.2 Restriction analysis

The restriction statistics calculated for each modelled scenario sites are presented for each flow management from Table 4-12 to Table 4-19. The relative changes to restriction from the Base Case scenario to all other scenarios are provided in the tables for each site. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.

Karamū catchment

Table 4-11: Awanui Stream at Flume cease-take trigger flow scenario restriction statistics.

	Scenario				
	Karamū+ Tributaries 2	Karamū+Tributaries 3		Karamū+Tributaries 4	
Awanui Stream at Flume	Base Case	Base Case_Max Allocation		Modified Base Case	
	Primary cease-take trigger flow (l/s)				
	120	120		120	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	21.1%	21.5%	0.39%	21.3%	0.2%
Average no. days restriction per year	57.8	58.8	1.1	58.2	0.4
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	1.1	1.1	-	1.1	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	1.3	1.3	-	1.3	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	143	145	2	143	-
No. periods of ≥3 consec. days restriction	9	9	-	9	-
No. periods of ≥10 consec. days restriction	5	5	-	5	-

Table 4-12: Irongate Stream at Clarkes Weir cease-take trigger flow scenario restriction statistics.

	Scenario				
	Karamū+ Tributaries 2	Karamū+Tributaries 3		Karamū+Tributaries 4	
Irongate Stream at Clarkes Weir	Base Case	Base Case_Max Allocation		Modified Base Case	
	Primary cease-take trigger flow (l/s)				
	100	100		100	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	16.4%	16.8%	0.4%	16.6%	0.2%
Average no. days restriction per year	44.9	45.9	1.0	45.4	0.5
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	1.4	1.4	-	1.3	-0.1
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	1.4	1.4	-	1.4	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	88	91	3	91	3
No. periods of ≥3 consec. days restriction	3	3	-	3	-
No. periods of ≥10 consec. days restriction	3	3	-	3	-

Table 4-13: Karamū Stream at Floodgates cease-take trigger flow scenario restriction statistics.

Karamū Stream at Floodgates	Scenario				
	Karamū+ Tributaries 2	Karamū+Tributaries 3		Karamū+Tributaries 4	
	Base Case	Base Case_Max Allocation		Modified Base Case	
	Primary cease-take trigger flow (l/s)				
	100	100		100	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	16.6%	16.7%	0.2%	16.6%	0.04%
Average no. days restriction per year	45.2	45.7	0.47	45.4	0.12
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	1.1	1.1	-	1.1	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	1.3	1.3	-	1.3	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	91	91	-	91	-
No. periods of ≥3 consec. days restriction	5	5	-	5	-
No. periods of ≥10 consec. days restriction	3	3	-	3	-

Table 4-14: Karewarewa Stream at Paki Paki cease-take trigger flow scenario restriction statistics.

Karewarewa Stream at Paki Paki	Scenario				
	Karamū+ Tributaries 2	Karamū+Tributaries 3		Karamū+Tributaries 4	
	Base Case	Base Case_Max Allocation		Modified Base Case	
	Primary cease-take trigger flow (l/s)				
	100	100		100	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	28.6%	29.2%	0.7%	28.6%	0.06%
Average no. days restriction per year	78.1	79.9	1.82	78.2	0.18
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	1.1	1.0	-0.1	1.1	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	1.2	1.2	-	1.2	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	172	171	-1	172	-
No. periods of ≥3 consec. days restriction	7	7	-	7	-
No. periods of ≥10 consec. days restriction	5	5	-	5	-

Table 4-15: Louisa Stream at Te Aute Road cease-take trigger flow scenario restriction statistics.

Louisa Stream at Te Aute Road	**Scenario**				
	Karamū+ Tributaries 2	**Karamū+Tributaries 3**		**Karamū+Tributaries 4**	
	Base Case	**Base Case_Max Allocation**		**Modified Base Case**	
	Primary cease-take trigger flow (l/s)				
	100	**100**		**100**	
	Statistic value	**Statistic value**	Change from Base Case	**Statistic value**	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	2.1%	3.1%	1.0%	1.9%	-0.2%
Average no. days restriction per year	5.8	8.5	2.76	5.1	-0.65
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	5.7	8.5	2.8	17.0	11.3
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	17	17	-	17	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	73	62	-11	65	-8
No. periods of ≥3 consec. days restriction	9	6	-3	6	-3
No. periods of ≥10 consec. days restriction	4	3	-1	3	-1

Table 4-16: Mangateretere Stream at Napier Road cease-take trigger flow scenario restriction statistics.

Mangateretere Stream at Napier Road	**Scenario**				
	Karamū+ Tributaries 2	**Karamū+Tributaries 3**		**Karamū+Tributaries 4**	
	Base Case	**Base Case_Max Allocation**		**Modified Base Case**	
	Primary cease-take trigger flow (l/s)				
	100	**100**		**100**	
	Statistic value	**Statistic value**	Change from Base Case	**Statistic value**	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	42.4%	42.5%	0.04%	42.7%	0.3%
Average no. days restriction per year	116.0	116.1	0.1	116.7	0.7
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	1.0	1.0	-	1.0	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	1.0	1.0	-	1.0	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	151	151	-	151	-
No. periods of ≥3 consec. days restriction	1	1	-	1	-
No. periods of ≥10 consec. days restriction	1	1	-	1	-

Table 4-17: Raupare Drain at Ormond Road cease-take trigger flow scenario restriction statistics.

Raupare Drain at Ormond Road	**Scenario**				
	Karamū+ Tributaries 2	**Karamū+Tributaries 3**		**Karamū+Tributaries 4**	
	Base Case	**Base Case_Max Allocation**		**Modified Base Case**	
	Primary cease-take trigger flow (l/s)				
	100	**100**		**100**	
	Statistic value	**Statistic value**	Change from Base Case	**Statistic value**	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	0.5%	0.9%	0.5%	1.0%	0.6%
Average no. days restriction per year	1.2	2.5	1.29	2.8	1.53
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	0	0	-	0	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	0	0	-	0	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	15	20	5	39	24
No. periods of ≥3 consec. days restriction	0	0	-	0	-
No. periods of ≥10 consec. days restriction	0	0	-	0	-

The impact on reliability of supply due to increasing surface water abstractions up to the maximum allocation (Base Case_Max Allocation scenario), was predicted to be very small across all streams within the Karamū catchment. The largest change to restriction was predicted in the Louisa Stream, where total restriction was predicted to rise by 1% and the average number of restriction days per were predicted to increase by nearly 3 days.

The Modified Base Case scenario simulates changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1. For all streams within the Karamū catchment, the impact on reliability of supply under this scenario was predicted to be very small. The greatest impact was predicted in the Raupare Stream, where total restriction was predicted to rise by 0.6%. In the Louisa Steam however, a decrease in restriction was predicted, where total restriction fell by 0.2%.

Ngaruroro tributaries

Table 4-18: Maraekakaho Stream D/S Tait Rd cease-take trigger flow scenario restriction statistics.

Maraekakaho Stream D/S Tait Rd	Scenario				
	Karamū+ Tributaries 2	Karamū+Tributaries 3		Karamū+Tributaries 4	
	Base Case	Base Case_Max Allocation		Modified Base Case	
	Primary cease-take trigger flow (l/s)				
	100	100		100	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	0.02%	0.62%	0.6%	0.02%	-
Average no. days restriction per year	0.1	1.7	1.6	0.1	-
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	0	0	-	0	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	0	0	-	0	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	1	14	13	1	-
No. periods of ≥3 consec. days restriction	0	0	-	0	-
No. periods of ≥10 consec. days restriction	0	0	-	0	-

Table 4-19: Tūtaekurī Waimate Stm at Goods Bridge cease-take trigger flow scenario restriction statistics.

Tūtaekurī Waimate Stm at Goods Bridge	Scenario				
	Karamū+ Tributaries 2	Karamū+Tributaries 3		Karamū+Tributaries 4	
	Base Case	Base Case_Max Allocation		Modified Base Case	
	Primary cease-take trigger flow (l/s)				
	100	100		100	
	Statistic value	Statistic value	Change from Base Case	Statistic value	Change from Base Case
Full record statistics					
Record length (Years)	17	17	-	17	-
Total % restriction	0.02%	0.02%	-	0.02%	-
Average no. days restriction per year	0.1	0.1	-	0.1	-
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	0	0	-	0	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	0	0	-	0	-
Example dry year statistics - Climate equivalent to 2012-2013					
No. days restriction	0	0	-	0	-
No. periods of ≥3 consec. days restriction	0	0	-	0	-
No. periods of ≥10 consec. days restriction	0	0	-	0	-

In the Ngaruroro tributaries, the impact on reliability of supply due to increasing surface water abstractions up to the maximum allocation (Base Case_Max Allocation scenario) was predicted to be very small in the Maraekakaho Stream (0.6% increase in total restriction). Whereas in the Tūtaekurī Waimate Stream, there was no impact predicted.

Changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1 (Modified Base Case scenario), was not predicted to effect the Maraekakaho or Tūtaekurī Waimate streams.

4.4.3 Flow regime analysis

Base Case vs Naturalised scenario

The MALF and Q95 flow statistics calculated for each flow management site under the Naturalised and Base Case scenarios are provided in Table 4-20 and Table 4-21 respectively. The change to flow statistics and modelled surface water abstraction rates are also presented. All flow statistics are based on the analysis of a full hydrological year (Jul-Jun) for the modelled record 2015-2032.

Table 4-20: Karamū and Tributaries cease-take trigger flow scenarios – MALF for Base Case vs Naturalised scenarios. The surface water abstraction modelled in the Base Case scenario is also presented for reference.

	Scenario				
	Karamū+ Tributaries 1	Karamū+Tributaries 2			
	Naturalised	Base Case			
Flow management site	**MALF (l/s)**	**MALF (l/s)**	**% change from Naturalised**	**Change from Naturalised (l/s)**	**Modelled surface water abstraction - Highest total daily rate (l/s)**
Awanui Stream at Flume	330	57	-82.9%	-273	59.8
Irongate Stream at Clarkes Weir	208	76	-63.2%	-131	1.1
Karamū Stream at Floodgates	1733	872	-49.7%	-861	85.8
Karewarewa Stream at Paki Paki	293	22	-92.4%	-270	59.8
Louisa Stream at Te Aute Road	48	43	-10.5%	-5	14.4
Mangateretere Stream at Napier Road	87	15	-82.6%	-72	1.5
Raupare Drain at Ormond Road	589	349	-40.6%	-239	39.6
Maraekakaho Stream D/S Tait Rd	172	165	-4.3%	-7	16.9
Tūtaekurī Waimate Stm at Goods Bridge	2426	2013	-17.0%	-413	106.9

Table 4-21: Karamū and Tributaries cease-take trigger flow scenarios – Q95 for Base Case vs Naturalised scenarios. The surface water abstraction modelled in the Base Case scenario is also presented for reference.

	Scenario				
	Karamū+ Tributaries 1	Karamū+Tributaries 2			
	Naturalised	Base Case			
Flow management site	**Q95 (l/s)**	**Q95 (l/s)**	**% change from Naturalised**	**Change from Naturalised (l/s)**	**Modelled surface water abstraction - Highest total daily rate (l/s)**
Awanui Stream at Flume	350	57	-83.7%	-293	59.8
Irongate Stream at Clarkes Weir	200	67	-66.5%	-133	1.1
Karamū Stream at Floodgates	1696	816	-51.9%	-880	85.8
Karewarewa Stream at Paki Paki	295	4	-98.5%	-291	59.8
Louisa Stream at Te Aute Road	43	37	-13.4%	-6	14.4
Mangateretere Stream at Napier Road	114	27	-76.2%	-87	1.5
Raupare Drain at Ormond Road	575	333	-42.1%	-242	39.6
Maraekakaho Stream D/S Tait Rd	168	161	-4.5%	-8	16.9
Tūtaekurī Waimate Stm at Goods Bridge	2427	1970	-18.8%	-458	106.9

Under the Base Case scenario, low flow statistics (MALF and Q95) for all streams were predicted to be lower than flows under naturalised conditions, which was to be expected.

The greatest percentage change in low flow statistics was predicted in the Karewarewa Stream, where MALF and Q95 both decrease by more than 90%. Whereas, the smallest changes to MALF and Q95 (in terms of % and l/s) were predicted in the Louisa and Maraekakaho streams.

With the exception of the Louisa and Maraekakaho streams, the predicted changes to flow from naturalised conditions in all other streams, were much greater than the surface water abstractions modelled under the Base Case scenario. This indicates that the large predicted changes to flow in these streams is not caused by surface water abstraction but is the caused by the stream depleting effects of groundwater abstractions from the Heretaunga Plains aquifer.

The differences between flows simulated under the Base Case and Naturalised scenarios, highlight the range of impact that water abstractions have on streamflow.

Alternative scenarios vs Base Case scenario

The MALF and Q95 flow statistics calculated for each flow management site under the Base Case scenario are compared to all other alternative scenarios in Table 4-22 and Table 4-23 respectively. All flow statistics are based on the analysis of a full hydrological year (Jul-Jun) for the modelled record 2015-2032.

Table 4-22: Karamū and Tributaries cease-take trigger flow scenarios – MALF for Base Case vs alternative scenarios..

	Scenario				
	Karamū+ Tributaries 2	Karamū+ Tributaries 3		Karamū+ Tributaries 4	
	Base Case	Base Case_Max Allocation		Modified Base Case	
Flow management site	MALF (l/s)	MALF (l/s)	% change from Base Case	MALF (l/s)	% change from Base Case
Awanui Stream at Flume	56.5	54.1	-4.4%	56.3	-0.4%
Irongate Stream at Clarkes Weir	76.5	75.2	-1.7%	75.6	-1.1%
Karamū Stream at Floodgates	872.2	868.4	-0.4%	869.8	-0.3%
Karewarewa Stream at Paki Paki	22.3	20.7	-7.2%	22.1	-0.8%
Louisa Stream at Te Aute Road	42.7	42.1	-1.4%	42.9	0.4%
Mangateretere Stream at Napier Road	15.1	15.1	0.6%	14.9	-1.0%
Raupare Drain at Ormond Road	349.5	341.1	-2.4%	346.4	-0.9%
Maraekakaho Stream D/S Tait Rd	164.7	151.9	-7.8%	164.7	0.0%
Tūtaekurī Waimate Stm at Goods Bridge	2013.0	1950.8	-3.1%	2010.7	-0.1%

Table 4-23: Karamū and Tributaries cease-take trigger flow scenarios – Q95 for Base Case vs alternative scenarios.

	Scenario				
	Karamū+ Tributaries 2	Karamū+ Tributaries 3		Karamū+ Tributaries 4	
	Base Case	Base Case_Max Allocation		Modified Base Case	
Flow management site	Q95 (l/s)	Q95 (l/s)	% change from Base Case	Q95 (l/s)	% change from Base Case
Awanui Stream at Flume	57.2	56.6	-1.1%	57.0	-0.3%
Irongate Stream at Clarkes Weir	67.0	65.8	-1.8%	66.3	-1.0%
Karamū Stream at Floodgates	816.0	814.4	-0.2%	814.3	-0.2%
Karewarewa Stream at Paki Paki	4.3	4.1	-5.2%	4.3	0.5%
Louisa Stream at Te Aute Road	37.2	36.3	-2.5%	37.5	0.8%
Mangateretere Stream at Napier Road	27.1	27.2	0.4%	26.9	-0.8%
Raupare Drain at Ormond Road	332.8	331.4	-0.4%	330.3	-0.8%
Maraekakaho Stream D/S Tait Rd	160.6	149.6	-6.8%	160.6	0.0%
Tūtaekurī Waimate Stm at Goods Bridge	1969.8	1895.4	-3.8%	1967.5	-0.1%

Increasing surface water abstractions up to the maximum available allocation (Base Case_Max Allocation scenario), predicted relatively small negative impacts across all streams.

The largest percentage reduction in low flow statistics was predicted in the Maraekakaho Stream (≤ 7.8%), whereas the largest change in flow was predicted in the Tūtaekurī Waimate Stream (most likely due to the maximum allocation modelled on the Tūtaekurī Waimate, being the largest out of all streams in the Karamu catchment and Ngaruroro tributaries – Appendix B).
Changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1 (Modified Base Case scenario) predicted very small impacts on the low flow regime for all streams.

4.5 Cease-take trigger flow scenario modelling: Discussion and summary

A range of cease-take trigger flow scenarios was simulated across all SOURCE modelled catchments to understand the effects of current flow management rules and to explore the potential future alternatives. Analyses were undertaken to identify the positive and negative effects on river flows and the reliability of supply for existing water abstractors, which are predicted as a consequence of implementing different flow management options.

Base Case compared to Naturalised scenario

Under the Base Case scenario, low flow statistics (MALF and Q95) for all rivers and streams were predicted to be lower, as expected, than flows under naturalised conditions.

Low flows in the Tūtaekurī River were predicted to be approximately 7% lower than flows under naturalised conditions, compared to around 24% lower in the Ngaruroro River. The impact on the low flow regime was greater in the Ngaruroro River than in the Tūtaekurī, due to higher stream depletion effects of groundwater abstractions from the Heretaunga Plains aquifer (Rakowski 2018) combined with the larger total surface water abstraction in the Ngaruroro catchment (Appendix B).

For most streams within the Karamū catchment (excluding the Louisa Stream), the large predicted effects on flow are predominantly caused by the stream depleting effects of groundwater abstractions from the Heretaunga Plains aquifer.

The smallest impacts on low flow statistics were predicted in the Louisa and Maraekakaho streams. In these two streams, it is most likely that modelled surface water abstractions are the main source of the effects on flow.

Abstraction of maximum allocation compared to Base Case scenario

The Base Case_Max Allocation scenario simulated the effects of increasing surface water abstractions up to the maximum current consented allocation, whereas the Base Case scenario (and all other abstraction scenarios) simulates abstraction based on estimated future demand. Modelled cease-take trigger flows (which are based on current trigger flows) were the same in both scenarios.

Increasing surface water abstractions up to the maximum allocation predicted small adverse impacts on flow regimes and reliability of supply at all modelled flow management sites.

For the Tūtaekurī River, a small negative impact on low flows was predicted, as indicated by an approximate 2% reduction in low flow statistics. A greater impact on the low flow regime was predicted in the Ngaruroro River, where MALF and Q95 decrease more than 10%. The modelled maximum allocation is much higher in the Ngaruroro catchment than in the Tūtaekurī catchment (1610 l/s vs 826 l/s – Appendix B), which is likely why the predicted impact of abstracting the maximum allocation is greater on the Ngaruroro River.

No restriction was predicted in the Tūtaekurī River with the current cease-take trigger flow set at 2000 l/s under the Base Case scenario. Simulating the increase to surface water abstractions in the Tūtaekurī catchment was not predicted to cause any new restriction, so reliability of supply for existing water abstractors would be unaffected.

In the Ngaruroro River, small increases in restriction were predicted as a consequence of abstracting the maximum surface water allocation. However, there were no predicted changes to periods of consecutive days of restriction.

The largest effect on flow (l/s change) in the Karamū catchment streams and Ngaruroro tributaries was predicted in the Tūtaekurī Waimate Stream, which is most likely due to the maximum allocation modelled in the Tūtaekurī Waimate, being the largest out of all streams in the Karamu catchment and Ngaruroro tributaries (Appendix B).

The impact on reliability of supply due to the abstracting the maximum surface water allocation, was predicted to be very small across all streams within the Karamū catchment. The largest increase in restriction was predicted in the Louisa Stream, where a 1% rise equates to nearly 3 days additional days of restriction on average per year.

In the Ngaruroro tributaries, the impact on reliability of supply due to increasing surface water abstractions, was predicted to be very small in the Maraekakaho Stream, while in the Tūtaekurī Waimate Stream, no impact was predicted.

Restricting groundwater abstractions within Stream Depletion Zone 1 combined with rationalised flow management sites

The Modified Base Case scenario simulated the restriction of groundwater abstractions located within the proposed 'Stream Depletion Zone 1' (as opposed to the groundwater abstractions currently classed as stream depleting and subject to restrictions in the Base Case). It also simulated 11 selected scenario flow management sites which were rationalised from the current flow management sites (Section 2.3). The Modified Base Case was compared to the Base Case scenario to identify the predicted effects on flow and reliability of supply.

Very small effects on flow were predicted in both the Tūtaekurī and Ngaruroro rivers (≤ 0.5% reductions to low flow statistics) when comparing the Modified Base Case scenario to the Base Case. Changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1 (around 45% less restricted abstractions – Table 2-1), is the single cause of reduced flows in the Ngaruroro River. However, flow reductions in the Tūtaekurī River (which are slightly larger than in the Ngaruroro) are also affected by the transfer of abstractions linked to the Tūtaekurī River at Ngaroto flow management site, to the downstream site at Puketapu. Irrespective of the causes, the predicted negative impacts on Tūtaekurī and Ngaruroro river flows are very small.

As indicated previously in this section, no restriction was predicted in the Tūtaekurī River with the current cease-take trigger flow set at 2000 l/s under the Base Case scenario. Changing the restriction of groundwater abstractions to those only located in Stream Depletion Zone 1 was predicted to have no effect on restriction in the Tūtaekurī River. Whereas, very small increases to restriction were predicted in the Ngaruroro River.

Changing the restriction of groundwater abstractions to only those located within Stream Depletion Zone 1 predicted very small impacts on low flows and reliability of supply in all streams in the Karamū Catchment.

There were no predicted effects on flow or restriction in the Maraekakaho Stream (a tributary of the Ngaruroro River). The Maraekakaho Stream D/S Tait Rd flow management site is located outside the boundary of the Heretaunga Plains aquifer and groundwater model domain, so simulated changes to groundwater abstractions within the groundwater model do not affect this site.

The Tūtaekurī-Waimate Stream is the other simulated tributary of the Ngaruroro River. There were no predicted changes to restriction in this stream and only very small predicted effects on flow (MALF and Q95 reduce by 0.1%).

Increasing primary cease-take trigger flows

Scenarios incorporating increasing primary cease-take trigger flows were only simulated on the Tūtaekurī and Ngaruroro rivers.

The Tūtaekurī scenario restriction statistics show that no restriction was predicted with cease-take trigger flows ranging from 2000 l/s to 2500 l/s. No restriction means no predicted impact on the reliability of supply for existing water users under these scenarios.

Increasing the cease-take trigger flow beyond 2500 l/s predicted that restriction would begin to occur. Simulating a trigger flow of 2800 l/s (Tūtaekurī 7) predicted a very small percentage of restriction (0.3%), with no more than 5 days of restriction in one of the driest simulated years (when the climate is equivalent to 2008-2009). The predicted impact on reliability of supply continued to increase under scenarios with higher cease-take trigger flows. For a trigger flow of 3300 l/s (Tūtaekurī 8), a year with a period of 3 or more consecutive days restriction was predicted to occur approximately every 4 years (recurrence interval = 3.8 years).

For the Ngaruroro River, increasing the primary cease-take trigger flow predicted progressively larger effects on restriction, thus progressively reducing the reliability of supply for existing water abstractors. For example, increasing the trigger flow from 2400 l/s to 3600 l/s predicted that the average number of restriction days per year would increase by 7 days. When the trigger flow is increased to 4000 l/s, the predicted number days increased by a further 1.5 days.

Tūtaekurī river flows were only predicted to increase when the primary cease-take trigger flow was raised to 3300 l/s (Tūtaekurī 8), at which point restrictions are imposed on water abstractions to limit the effects on flow. However, the predicted benefits to the Tūtaekurī River flow were still relatively small (up to a 1.4% increase in low flow statistics).

Increasing the cease-take trigger flow under the Ngaruroro scenarios predicted small improvements to low flows, up to a 3.3% increase in MALF when simulating a 4000 l/s cease-take trigger flow (Ngaruroro 6 scenario).

5 Groundwater augmentation to surface water scenario modelling

The purpose of modelling the groundwater augmentation to surface water scenarios (hereafter referred to as *augmentation scenarios*) was to explore the effects of abstracting groundwater to augment and enhance flows in lowland streams within the Heretaunga Plains. Modelling of these scenarios was performed to identify:

1. Benefits to lowland streams in the Karamū catchment, along with potential adverse effects on these streams as a consequence of groundwater abstraction for lowland stream flow enhancement.
2. Potential adverse effects on other hydraulically connected surface water bodies as a consequence of groundwater abstraction for lowland stream flow enhancement. These water bodies include the Ngaruroro River, Tūtaekurī River and tributaries of the Ngaruroro River.
3. Potential adverse effects on the reliability of supply for existing water abstractors in the Karamu, Tūtaekurī and Ngaruroro catchments, as a consequence of groundwater abstraction for lowland stream flow enhancement.

5.1 Scenario configuration

The scenarios were based on a subset of the cease-take trigger flow scenarios reported in Section 4. The cease-take trigger flow scenarios incorporated several settings including modelled abstraction, restriction regimes and cease-take trigger flows (all of which are explained in Section 4). The only change made to these scenarios was the inclusion of the groundwater augmentation to surface water. This enabled the scenarios with and without groundwater augmentation to be analysed and compared, to identify relative changes that could be attributed solely to the impact of abstracting groundwater to augment flows in lowland streams.

Seven streams within the Karamū Catchment were proposed for the simulation of groundwater augmentation to surface water. Based on a pre-modelling assessment, hypothetical augmentation bore locations were identified for five of the seven proposed streams. The process undertaken to select these bores is explained by Rakowski (2018).

Details of the augmentation bore locations, bore names and augmentation trigger flows are provided in Table 5-1. The locations of modelled hypothetical augmentation bores are shown in Figure 5-1.

Table 5-1: Groundwater augmentation bore selection. This table indicates the streams proposed for simulating flow enhancement and identifies the hypothetical augmentation bores that were selected for scenario modelling.

Stream proposed for augmentation	Groundwater augmentation bore selection		Groundwater augmentation bore names	Flow management site	Augmentation trigger flow (l/s)
	Stream catchment location	Comment			
Awanui Stream	-	*No suitable bore location identified based on pre-modelling assessment*	-	-	-
Irongate Stream	Irongate	1 x bore location selected	Irongate Stream	Irongate Stream at Clarkes Weir	100
Karamū Stream	Karamū	3 x bore locations selected (multiple bores required to provide sufficient abstraction capacity for augmenting the Karamū Stream)	Karamū Stream 1 Karamū Stream 2 Karamū Stream 3	Karamū Stream at Floodgates	1100
Karewarewa Stream	Karewarewa	1 x bore location selected	Karewarewa Stream	Karewarewa Stream at Paki Paki	75
Louisa Stream	-	*No suitable bore location identified based on pre-modelling assessment*	-	-	-
Mangateretere Stream	Mangateretere	1 x bore location selected	Mangateretere Stream	Mangateretere Stream at Napier Road	100
Raupare Stream	Raupare	1 x bore location selected	Raupare Stream	Raupare Drain at Ormond Road	300

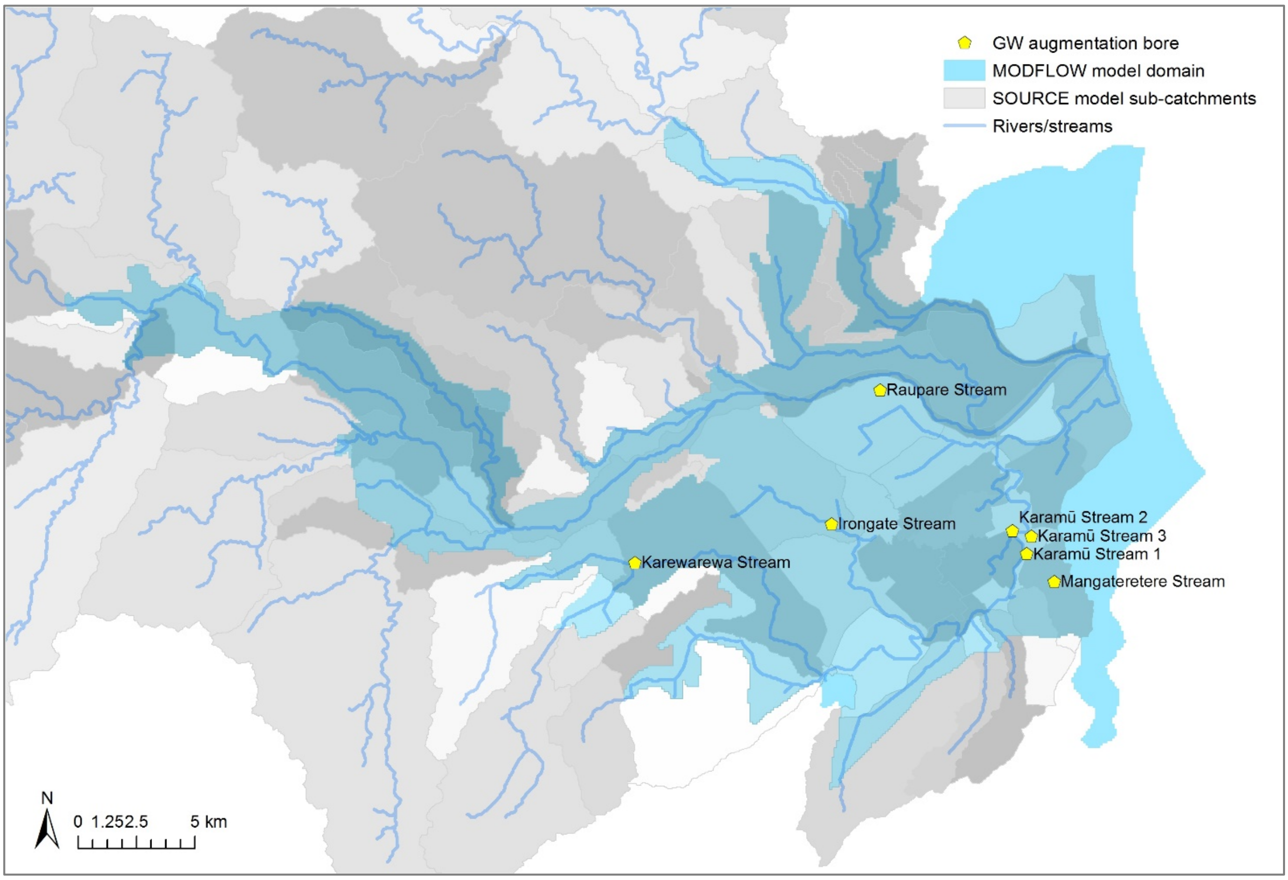

Figure 5-1: Locations of modelled groundwater augmentation bores. These hypothetical bore locations were used for simulating groundwater abstraction for the purpose of augmentation to enhance lowland stream flows within the Heretaunga Plains.

For each modelled scenario, the abstraction of groundwater to augment stream flows was triggered when flows were less than or equal to the augmentation trigger flows for the relevant flow management sites (Table 5-1). The simulated groundwater augmentation was intended to maintain flows at the trigger flow for each flow management site.

The SOURCE model was configured to generate flow data used to calculate the duration and magnitude of abstraction from augmentation bores in the MODFLOW groundwater model. MODFLOW was then configured to simulate the abstraction from the groundwater augmentation bores and generate a time series dataset of augmentation flow for input to relevant catchments in the SOURCE model.

The quantity of groundwater required for maintaining stream flows at the trigger flow thresholds was calculated as the difference between simulated 'pre-augmentation' flows and the specified trigger flows. For example, if the trigger flow at a site was 100 l/s, and the pre-augmentation flow was 80 l/s, then 20 l/s augmentation would be required to maintain flow at the 100 l/s trigger threshold.

It was anticipated that abstracting groundwater for augmentation purposes may increase stream depletion from rivers and streams across the Heretaunga Plains, thus further reducing flows and requiring additional augmentation to maintain flows at the trigger flows. This type of dynamic could potentially be simulated indefinitely, through running consecutive iterations of the SOURCE and MODFLOW models to compensate for the stream depletion effects of groundwater abstraction for augmentation. However, an alternative modelling approach was developed to account for increased stream depletion (while still augmenting stream flows at or close to the trigger flow), whereby MODFLOW was configured to simulate the groundwater abstraction required to maintain flows that were 10% greater than trigger flows. In a ‘real life’ situation with an established augmentation scheme, the operation of an augmentation scheme could be refined to adjust abstraction and augmentation in response to real time monitoring data.

The configuration of augmentation scenarios modelled for the Tūtaekurī River, Ngaruroro River, Karamū Catchment and tributaries of the Ngaruroro River are presented in sections 5.4.1 and 5.3.1.

5.2 Analysis description

Two different analyses have been undertaken for each augmentation scenario to estimate the potential effects on the reliability of supply for water abstractors and effects on river flow. Statistics from each analysis are reported for the 11 selected scenario flow management sites (Section 2.3). The following two analyses are provided within sections 5.3 to 5.3:

- **Restriction analysis**

  The restriction analysis undertaken is similar to that described earlier (Section 0).

  Restriction statistics have been calculated for each augmentation scenario and compared to statistics from the equivalent cease-take trigger flow scenario in which groundwater augmentation is not activated. This comparison enables the identification of relative changes to restriction between scenarios resulting solely from the effects of groundwater augmentation. The identified changes indicate the potential impacts on reliability of supply for water abstractors that are a direct consequence of abstracting groundwater for augmentation.

  All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.

- **Flow regime analysis**

  The flow regime analysis undertaken is similar to that described in Section 0.

  Low flow statistics (MALF and Q95) are presented for each augmentation scenario in sections 5.3 to 5.4. The low flow statistics calculated for each augmentation scenario are compared to the statistics from the equivalent cease-take trigger flow scenario in which groundwater augmentation is not activated. This comparison helps identify the predicted effects on flow resulting from groundwater augmentation, in terms of both benefits and negative impacts.

  A full suite of summary flow statistics for each scenario and flow management site are provided for reference in Appendix H and definitions of all river flow statistics are provided in Appendix E.

  Unless stated otherwise, flow statistics are based on the analysis of hydrological years (Jul-Jun) for the simulation period between 2015 and 2032.

5.3 Karamū and tributaries

5.3.1 Scenario overview

The configuration of the augmentation scenario modelled for the Karamū Catchment and tributaries of the Ngaruroro River is provided in Table 5-2. This table also identifies the types of analysis undertaken (described in Section 5.2) and the scenario used for comparison to evaluate the impact of groundwater abstraction for lowland stream enhancement. The SOURCE model ID is also included as a reference for future modelling applications. The cease-take trigger flows modelled for each flow management site are provided in Table 5-3.

Table 5-2: Karamū and tributaries groundwater augmentation to surface water scenario. This table shows the configuration of the augmentation scenario and the analyses undertaken.

Scenario ID	Scenario name	Flow management site	Modelled SW abstraction	Abstraction restriction regime			Primary cease-take trigger flows		GW augmentation to SW	Scenario analysis undertaken		Scenario compared with	SOURCE model ID reference
				Restriction rule	Restricted SW abstractions	Restricted GW abstractions	Basis	Flow (l/s)		Restriction	Flow regime		
Karamū+ Tributaries 5	Modified Base Case_GW Augmentation	Various - 9 sites*	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	Current	Various - 9 sites*	Yes - Trigger flows = cease-take trigger flows	Yes	Yes	Karamū+ Tributaries 4 - Modified Base Case	8.3_SDZ1

*See trigger flows listed in Table 5-3.

Table 5-3: Karamū and tributaries groundwater augmentation to surface water scenario flow management sites and cease-take trigger flows.

Flow management site	Catchment	Cease-take trigger flow (l/s)
Awanui Stream at Flume	Karamū	120
Irongate Stream at Clarkes Weir	Karamū	100
Karamū Stream at Floodgates	Karamū	1100
Karewarewa Stream at Paki Paki	Karamū	75
Louisa Stream at Te Aute Road	Karamū	30
Mangateretere Stream at Napier Road	Karamū	100
Raupare Drain at Ormond Road	Karamū	300
Maraekakaho Stream D/S Tait Rd	Ngaruroro	109
Tūtaekurī Waimate Stm at Goods Bridge	Ngaruroro	1200

5.3.2 Restriction analysis

Restriction statistics are presented for both the augmentation scenario (Karamū+Tributaries 5) and the equivalent cease-take trigger flow scenario without augmentation (Karamū+Tributaries 4) for all flow management sites in Table 5-4. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032

Table 5-4: Karamū and tributaries groundwater augmentation to surface water scenario restriction statistics. Restriction statistics for scenarios with and without groundwater augmentation.

	Awanui Stream at Flume		Irongate Stream at Clarkes Weir		Karamū Stream at Floodgates		Karewarewa Stream at Paki Paki		Louisa Stream at Te Aute Road		Mangateretere Stream at Napier Road		Raupare Drain at Ormond Road	
	Scenario		Scenario		Scenario		Scenario		Scenario		Scenario		Scenario	
	Karamū+ Tributaries 4	Karamū+ Tributaries 5	Karamū+ Tributaries 4	Karamū+ Tributaries 5	Karamū+ Tributaries 4	Karamū+ Tributaries 5	Karamū+ Tributaries 4	Karamū+ Tributaries 5	Karamū+ Tributaries 4	Karamū+ Tributaries 5	Karamū+ Tributaries 4	Karamū+ Tributaries 5	Karamū+ Tributaries 4	Karamū+ Tributaries 5
	Modified Base Case	Modified Base Case_GW Augmentation	Modified Base Case	Modified Base Case_GW Augmentation	Modified Base Case	Modified Base Case_GW Augmentation	Modified Base Case	Modified Base Case_GW Augmentation	Modified Base Case	Modified Base Case_GW Augmentation	Modified Base Case	Modified Base Case_GW Augmentation	Modified Base Case	Modified Base Case_GW Augmentation
	Primary cease-take trigger flow (l/s)		Primary cease-take trigger flow (l/s)		Primary cease-take trigger flow (l/s)		Primary cease-take trigger flow (l/s)		Primary cease-take trigger flow (l/s)		Primary cease-take trigger flow (l/s)		Primary cease-take trigger flow (l/s)	
	120	120	100	100	1100	1100	75	75	30	30	100	100	300	300
Full record statistics														
Record length (Years)	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Total % restriction	21.3%	21.3%	16.6%	16.6%	16.6%	16.6%	28.6%	28.6%	2.1%	2.1%	42.7%	42.7%	1.0%	1.0%
Average no. days restriction per year	58.2	58.2	45.4	45.4	45.4	45.4	78.2	78.2	5.8	5.8	116.7	116.7	2.8	2.8
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	1.1	1.1	1.3	1.3	1.1	1.1	1.1	1.1	5.7	5.7	1	1	0	0
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	1.3	1.3	1.4	1.4	1.3	1.3	1	1	17	17	1	1	0	0
Example dry year statistics - Climate equivalent to 2012-2013														
No. days restriction	143	143	91	91	91	91	172	172	73	73	151	151	39	39
No. periods of ≥3 consec. days restriction	9	9	3	3	5	5	7	7	9	9	1	1	0	0
No. periods of ≥10 consec. days restriction	5	5	3	3	3	3	5	5	4	4	1	1	0	0

	Maraekakaho Stream D/S Tait Rd		Tūtaekurī Waimate Stm at Goods Bridge	
	Scenario		Scenario	
	Karamū+ Tributaries 4	Karamū+ Tributaries 5	Karamū+ Tributaries 4	Karamū+ Tributaries 5
	Modified Base Case	Modified Base Case_GW Augmentation	Modified Base Case	Modified Base Case_GW Augmentation
	Primary cease-take trigger flow (l/s)		Primary cease-take trigger flow (l/s)	
	109	109	1200	1200
Full record statistics				
Record length (Years)	17	17	17	17
Total % restriction	0.02%	0.02%	0.02%	0.02%
Average no. days restriction per year	0.1	0.1	0.1	0.1
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	0	0	0	0
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	0	0	0	0
Example dry year statistics - Climate equivalent to 2012-2013				
No. days restriction	1	1	0	0
No. periods of ≥3 consec. days restriction	0	0	0	0
No. periods of ≥10 consec. days restriction	0	0	0	0

For all flow management sites, no changes to restriction were predicted as a consequence of abstracting groundwater to augment and enhance lowland streams. Therefore, the reliability of supply for existing water abstractors was not compromised under the augmentation scenarios.

5.3.3 Flow regime analysis

The MALF and Q95 low flow statistics are provided below for both the augmentation scenario (Karamū+Tributaries 5) and the equivalent cease-take trigger flow scenario without augmentation (Karamū+Tributaries 4) for all flow management sites. The MALF for each site is presented in Table 5-5 and the Q95 is presented in Table 5-6. The percentage change to MALF and Q95 between scenarios is also provided in the respective tables. All flow statistics are based on the analysis of hydrological years (Jul-Jun) for the simulation period 2015 to 2032.

Table 5-5: Karamū and Tributaries groundwater augmentation to surface water scenarios – MALF comparison.

	Scenario		
	Karamū+ Tributaries 4	Karamū+Tributaries 5	
	Modified Base Case	Modified Base Case_GW Augmentation	
Flow management site	MALF (l/s)	MALF (l/s)	% change from Karamū+ Tributaries 4
Awanui Stream at Flume	56	92	62.9%
Irongate Stream at Clarkes Weir	76	106	39.9%
Karamū Stream at Floodgates	870	1177	35.3%
Karewarewa Stream at Paki Paki	22	67	203.5%
Louisa Stream at Te Aute Road	43	43	0.0%
Mangateretere Stream at Napier Road	15	91	511.9%
Raupare Drain at Ormond Road	346	344	-0.7%
Maraekakaho Stream D/S Tait Rd	165	165	0.0%
Tūtaekurī Waimate Stm at Goods Bridge	2011	1998	-0.6%

Table 5-6: Karamū and Tributaries groundwater augmentation to surface water scenarios – Q95 comparison.

	Scenario		
	Karamū+ Tributaries 4	Karamū+Tributaries 5	
	Modified Base Case	Modified Base Case_GW Augmentation	
Flow management site	Q95 (l/s)	Q95 (l/s)	% change from Karamū+ Tributaries 4
Awanui Stream at Flume	57	112	96.4%
Irongate Stream at Clarkes Weir	66	103	55.9%
Karamū Stream at Floodgates	814	1148	41.0%
Karewarewa Stream at Paki Paki	4	66	1427.8%
Louisa Stream at Te Aute Road	37	37	0.0%
Mangateretere Stream at Napier Road	27	94	249.4%
Raupare Drain at Ormond Road	330	323	-2.3%
Maraekakaho Stream D/S Tait Rd	161	161	0.0%
Tūtaekurī Waimate Stm at Goods Bridge	1967	1954	-0.7%

Simulating the abstraction of groundwater to augment and enhance lowland streams predicted a range of changes to MALF and Q95 across all sites. Most streams within the Karamū Catchment were predicted to benefit from the augmentation from groundwater. The greatest increase in flow was predicted for the Karewarewa and Mangateretere streams, where both MALF and Q95 increased by more than 200% from the Base Case scenario (equating to increases in flow of more than 60 l/s). The Q95 in the Karewarewa Stream predicted the most dramatic increase of over 1400%, which related to an increase from 4 l/s to 66 l/s.

Low flows in the Awanui stream were predicted to increase as a consequence of the augmentation and enhancement of flows upstream in the Karewarewa Stream.

There were no predicted changes to flow in the Louisa Stream, because augmentation was not simulated upstream of the Louisa Stream flow management site.

Low flow statistics were predicted to decrease in the Raupare Stream by up to 2.3%. This small decrease is likely to be caused by additional stream depletion resulting from the abstraction of groundwater to augment the lowland streams across the plains.

There were no predicted changes to flow in the Maraekakaho Stream resulting from the simulation of the augmentation scenario, whereas very small reductions were predicted for the Tūtaekurī Waimate Stream.

5.4 Tūtaekurī and Ngaruroro

5.4.1 Scenario overview

The configuration of the augmentation scenarios modelled for the Tūtaekurī and Ngaruroro rivers are presented in Table 5-7 and Table 5-8 respectively. These tables also identify the types of analysis (described in Section 5.2) and comparisons undertaken, and the SOURCE model ID is included as a reference for future modelling applications.

Table 5-7: Tūtaekurī groundwater augmentation to surface water scenarios. This table shows the configuration of the augmentation scenarios and the analyses undertaken.

Scenario ID	Scenario name	Flow management site	Modelled SW abstraction	Abstraction restriction regime			Primary cease-take trigger flow		GW augmentation to SW	Scenario analysis undertaken		Scenario compared with	SOURCE model ID reference
				Restriction rule	Restricted SW abstractions	Restricted GW abstractions	Basis	Flow (l/s)		Restriction	Flow regime		
Tūtaekurī 10	Modified Base Case_GW Augmentation	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	Current	2000	Yes - Trigger flows = cease-take trigger flow	Yes	Yes	Tūtaekurī 4 - Modified Base Case	8.3_SDZ1
Tūtaekurī 11	Tūtaekurī 75% Habitat Trigger Flow_GW Augmentation	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	75% habitat at MALF	2500	Yes - Trigger flows = cease-take trigger flow	Yes	Yes	Tūtaekurī 6 - Tūtaekurī 75% Habitat Trigger Flow	16.1_SDZ1
Tūtaekurī 12	Tūtaekurī 90% Habitat Trigger Flow_GW Augmentation	Tūtaekurī River at Puketapu HBRC Site	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	90% habitat at MALF	3300	Yes - Trigger flows = cease-take trigger flow	Yes	Yes	Tūtaekurī 8 - Tūtaekurī 90% Habitat Trigger Flow	18.0_SDZ1

Table 5-8: Ngaruroro groundwater augmentation to surface water scenarios. This table shows the configuration of the augmentation scenarios and the analyses undertaken.

Scenario ID	Scenario name	Flow management site	Modelled SW abstraction	Abstraction restriction regime			Primary cease-take trigger flow		GW augmentation to SW	Scenario analysis undertaken		Scenario compared with	SOURCE model ID reference
				Restriction rule	Restricted SW abstractions	Restricted GW abstractions	Basis	Flow (l/s)		Restriction	Flow regime		
Ngaruroro 9	Modified Base Case_GW Augmentation	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	Current	2400	Yes - Trigger flows = cease-take trigger flow	Yes	Yes	Ngaruroro 4 - Modified Base Case	8.3_SDZ1
Ngaruroro 10	Ngaruroro 70% Habitat Trigger Flow_GW Augmentation	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	70% habitat at MALF	3600	Yes - Trigger flows = cease-take trigger flow	Yes	Yes	Ngaruroro 5 - Ngaruroro 70% Habitat Trigger Flow	16.1_SDZ1
Ngaruroro 11	Ngaruroro 80% Habitat Trigger Flow_GW Augmentation	Ngaruroro River at Fernhill	Estimated future demand	Cease-take (flow ≤ trigger flow)	All	Located in GW Stream Depletion Zone 1	80% habitat at MALF	4000	Yes - Trigger flows = cease-take trigger flow	Yes	Yes	Ngaruroro 6 - Ngaruroro 80% Habitat Trigger Flow	18.0_SDZ1

5.4.2 Restriction analysis

In the following tables, restriction statistics are presented for both augmentation scenarios and the equivalent cease-take trigger flow scenarios (without augmentation) for the Tūtaekurī River at Puketapu HBRC Site (Table 5-9) and the Ngaruroro river at Fernhill (Table 5-10). The relative change to restriction between scenarios is also provided in the tables for each site. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032. Selected restriction statistics are also presented in graphical form in Appendix G.

Table 5-9: Tūtaekurī groundwater augmentation to surface water scenario restriction statistics. Restriction statistics for scenarios with and without groundwater augmentation.

Tūtaekurī River at Puketapu HBRC Site	**Scenario**								
	Tūtaekurī 4	Tūtaekurī 10		**Tūtaekurī 6**	Tūtaekurī 11		**Tūtaekurī 8**	Tūtaekurī 12	
	Modified Base Case	Modified Base Case_GW Augmentation		**Tūtaekurī 75% Habitat Trigger Flow**	Tūtaekurī 75% Habitat Trigger Flow_GW Augmentation		**Tūtaekurī 90% Habitat Trigger Flow**	Tūtaekurī 90% Habitat Trigger Flow_GW Augmentation	
	Primary cease-take trigger flow (l/s)								
	2000	2000		**2500**	2500		**3300**	3300	
	Statistic value	Statistic value	Change from Tūtaekurī 4	**Statistic value**	Statistic value	Change from Tūtaekurī 6	**Statistic value**	Statistic value	Change from Tūtaekurī 8
Full record statistics									
Record length (Years)	15	15	-	15	15	-	15	15	-
Total % restriction	0%	0%	-	0%	0%	-	3.2%	3.2%	-
Average no. days restriction per year	0	0	-	0	0	-	8.7	8.7	-
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	0	0	-	0	0	-	3.8	3.8	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	0	0	-	0	0	-	7.5	7.5	-
Example dry year statistics - Climate equivalent to 2008-2009									
No. days restriction	0	0	-	0	0	-	35	35	-
No. periods of ≥3 consec. days restriction	0	0	-	0	0	-	1	1	-
No. periods of ≥10 consec. days restriction	0	0	-	0	0	-	1	1	-

Table 5-10: Ngaruroro groundwater augmentation to surface water scenario restriction statistics. Restriction statistics for scenarios with and without groundwater augmentation.

Ngaruroro River at Fernhill	**Scenario**								
	Ngaruroro 4	Ngaruroro 9		**Ngaruroro 5**	Ngaruroro 10		**Ngaruroro 6**	Ngaruroro 11	
	Modified Base Case	Modified Base Case_GW Augmentation		**Ngaruroro 70% Habitat Trigger Flow**	Ngaruroro 70% Habitat Trigger Flow_GW Augmentation		**Ngaruroro 80% Habitat Trigger Flow**	Ngaruroro 80% Habitat Trigger Flow_GW Augmentation	
	Primary cease-take trigger flow (l/s)								
	2400	2400		**3600**	3600		**4000**	4000	
	Statistic value	Statistic value	Change from Ngaruroro 4	**Statistic value**	Statistic value	Change from Ngaruroro 5	**Statistic value**	Statistic value	Change from Ngaruroro 6
Full record statistics									
Record length (Years)	17	17	-	17	17	-	17	17	-
Total % restriction	2.2%	2.2%	-	4.7%	4.8%	0.1%	5.6%	5.7%	0.1%
Average no. days restriction per year	5.9	5.9	-	12.9	13.2	0.29	15.4	15.6	0.29
Recurrence interval for year with period of ≥3 consec. days restriction (Years)	3.4	3.4	-	1.9	1.9	-	1.7	1.7	-
Recurrence interval for year with period of ≥10 consec. days restriction (Years)	17	17	-	5.7	5.7	-	4.3	4.3	-
Example dry year statistics - Climate equivalent to 2012-2013									
No. days restriction	52	52	-	63	65	2	66	68	2
No. periods of ≥3 consec. days restriction	3	3	-	4	4	-	5	5	-
No. periods of ≥10 consec. days restriction	2	2	-	2	2	-	2	2	-

For the Tūtaekurī River, no changes to restriction were predicted as a result of abstracting groundwater to augment and enhance lowland streams. Therefore, the reliability of supply for existing water abstractors in the Tūtaekurī catchment was not impacted under the augmentation scenarios.

In the Ngaruroro River, abstracting groundwater for stream augmentation was not predicted to affect restriction when the cease-take trigger flow is 2400 l/s. Restriction was affected when simulating the higher trigger flows of 3600 l/s and 4000 l/s, however the effects were very small with less than one extra day of restriction predicted.

5.4.3 Flow regime analysis

The MALF and Q95 low flow statistics are presented for the augmentation scenarios and the equivalent cease-take trigger flow scenarios (without augmentation), for the Tūtaekurī River at Puketapu HBRC Site in Table 5-11, and for the Ngaruroro river at Fernhill in Table 5-10. The percentage change to MALF and Q95 between scenarios is also provided in the tables for each site. All flow statistics are based on the analysis of hydrological years (Jul-Jun) for the simulation period 2015 to 2032.

Table 5-11: Tūtaekurī groundwater augmentation to surface water scenarios – MALF and Q95 comparison. The MALF and Q95 have been calculated for scenarios with groundwater abstraction for augmentation and compared to scenarios without augmentation. All flow statistics are based on the analysis of hydrological years (Jul-Jun) for the simulation period 2015 to 2032.

	Scenario								
	Tūtaekurī 4	Tūtaekurī 10		Tūtaekurī 6	Tūtaekurī 11		Tūtaekurī 8	Tūtaekurī 12	
	Modified Base Case	Modified Base Case_GW Augmentation		Tūtaekurī 75% Habitat Trigger Flow	Tūtaekurī 75% Habitat Trigger Flow_GW Augmentation		Tūtaekurī 90% Habitat Trigger Flow	Tūtaekurī 90% Habitat Trigger Flow_GW Augmentation	
Tūtaekurī River at Puketapu HBRC Site	River Flow (l/s)	River Flow (l/s)	% change from Tūtaekurī 4	River Flow (l/s)	River Flow (l/s)	% change from Tūtaekurī 6	River Flow (l/s)	River Flow (l/s)	% change from Tūtaekurī 8
MALF	3658	3658	0.0%	3658	3658	0.0%	3728	3728	0.0%
Q95	3563	3563	0.0%	3563	3563	0.0%	3575	3575	0.0%

Table 5-12: Ngaruroro groundwater augmentation to surface water scenarios – MALF and Q95 comparison. The MALF and Q95 have been calculated for scenarios with groundwater abstraction for augmentation and compared to scenarios without augmentation. All flow statistics are based on the analysis of hydrological years (Jul-Jun) for the simulation period 2015 to 2032.

	Scenario								
	Ngaruroro 4	Ngaruroro 9		Ngaruroro 5	Ngaruroro 10		Ngaruroro 6	Ngaruroro 11	
	Modified Base Case	Modified Base Case_GW Augmentation		Ngaruroro 70% Habitat Trigger Flow	Ngaruroro 70% Habitat Trigger Flow_GW Augmentation		Ngaruroro 80% Habitat Trigger Flow	Ngaruroro 80% Habitat Trigger Flow_GW Augmentation	
Ngaruroro River at Fernhill	River Flow (l/s)	River Flow (l/s)	% change from Ngaruroro 4	River Flow (l/s)	River Flow (l/s)	% change from Ngaruroro 5	River Flow (l/s)	River Flow (l/s)	% change from Ngaruroro 6
MALF	3837	3821	-0.4%	3935	3914	-0.5%	3967	3949	-0.4%
Q95	4220	4207	-0.3%	4231	4221	-0.3%	4243	4230	-0.3%

Table 5-13: Ngaruroro groundwater augmentation to surface water scenarios – Q95 comparison. The Q95 has been calculated for scenarios with groundwater abstraction for augmentation and compared to scenarios without augmentation. The Q95 and percentage change to Q95 is provided. All flow statistics are based on the analysis of hydrological years (Jul-Jun) for the simulation period 2015 to 2032.

There were no predicted changes to low flow statistics (MALF or Q95) in the Tūtaekurī River that result from the abstraction of groundwater to augment and enhance lowland streams.

Ngaruroro augmentation scenarios, predicted very small adverse impacts on the low flow regime, where low flow statistics were predicted to decrease no more than 0.5%.

5.5 Groundwater augmentation to surface water scenario modelling: Discussion and summary

A range of groundwater augmentation to surface water scenarios was simulated across all SOURCE modelled catchments to explore the effects of abstracting groundwater to augment and enhance flows in lowland streams within the Heretaunga Plains. Analyses were undertaken to identify the positive and negative effects on river flows and the reliability of supply for existing water abstractors, as a consequence of groundwater abstraction for lowland stream flow augmentation and enhancement. To achieve this, augmentation scenarios were compared to the equivalent cease-take trigger flow scenarios in which groundwater augmentation is not activated.

Karamū Catchment

Groundwater augmentation for stream flow enhancement was simulated for streams within the Karamū Catchment and, consequently, low flow statistics in these streams are predicted to increase. The scenarios were designed to trigger augmentation when stream flows were at or below the cease-take trigger flow (at the associated flow management site) and to maintain flows at cease-take trigger flows.

The stream network downstream of any augmentation point would benefit from augmentation, providing there are no losing reaches in the downstream network.

The following summarises the key findings for each stream considered:

- ***Awanui Stream*** – Low flows in the Awanui Stream were predicted to increase as a consequence of the augmentation and enhancement of flows upstream in the Karewarewa Stream.
- ***Karamū Stream*** – The Karamū Stream would also benefit from the augmentation of upstream tributary flows. The upstream augmentation increased flows in the lower Karamū reaches, thus reducing the additional augmentation required to maintain the Karamū flow at the 1100 l/s cease-take trigger flow. Most streams within the Karamū Catchment were predicted to benefit from the augmentation from groundwater.
- ***Karewarewa and Mangateretere Streams*** – The greatest increase in flow was predicted for the Karewarewa and Mangateretere streams, where both MALF and Q95 increased by more than 200% from the Base Case scenario (equating to increases in flow of more than 60 l/s).
- ***Louisa Stream*** – There were no predicted changes to flow in the Louisa Stream, because augmentation was not simulated upstream of the Louisa Stream flow management site.
- ***Raupare Stream*** – Low flows were predicted to decrease in the Raupare Stream by up to 2.3%. This small decrease is likely to be caused by additional stream depletion resulting from the abstraction of groundwater to augment the lowland streams across the plains.

It was anticipated that abstracting groundwater for augmentation purposes may cause slightly increased stream depletion from rivers and streams across the Heretaunga Plains. However, in a ‘real life’ situation with an established augmentation scheme, operation of the scheme could be adjusted in response to real time monitoring data, to ensure augmentation also compensates for this additional stream depletion.

For all flow management sites within the Karamū Catchment, no changes to restriction were predicted as a consequence of abstracting groundwater to augment and enhance lowland streams. Therefore, the reliability of supply for existing water abstractors was not compromised under the augmentation scenarios. At some sites, the simulated groundwater augmentation was predicted to increase flow above the cease-take trigger flow, however the intent of the modelled augmentation scheme was only to increase/improve flow and not to provide water for additional abstraction for out of stream uses.

Ngaruroro tributaries

The simulation of the augmentation scenario predicted no impact on flow or restriction at the Maraekakaho Stream D/S Tait Rd flow management site. This site is located in a reach outside the Heretaunga Plains aquifer boundary and groundwater model domain, which indicates it is unlikely to be hydraulically connected to the main Heretaunga Plains aquifer system. Consequently, simulated changes to groundwater abstractions within the groundwater model do not affect this site.

For the Tūtaekurī-Waimate Stream, there were no predicted impacts on restriction, whereas very small reductions were predicted to the MALF and Q95 (up to 0.7%). These very small reductions are attributed to the increased stream depletion resulting from groundwater abstraction for augmentation purposes in the lowland streams.

Tūtaekurī River

For the Tūtaekurī River, no impacts were predicted on flow or on the reliability of supply for existing water abstractors, as a result of abstracting groundwater to augment and enhance lowland streams.

Ngaruroro River

In the Ngaruroro River, the abstraction of groundwater to augment lowland streams was not predicted to affect restriction when the cease-take trigger flow is 2400 l/s. Effects on restriction were predicted when higher trigger flows of 3600 l/s and 4000 l/s were simulated, however the potential adverse effects are very small with less than one extra day of restriction predicted.

Ngaruroro augmentation scenarios predicted very small adverse impacts on the low flow regime. The predicted impacts on flow and water take restrictions, are likely to be caused by additional stream depletion resulting from the abstraction of groundwater to augment and enhance lowland streams across the Heretaunga Plains.

6 Emergency water allocation scenario modelling

The purpose of modelling a range of emergency water allocation scenarios was to identify the potential impacts on river flow.

A flow management option considered by the TANK Stakeholder Group is one that enables limited water abstraction to continue when a river flow is less than or equal to the cease-take trigger flow. This type of abstraction would be intended only for emergency purposes and can be referred to as an 'emergency water allocation'. An emergency water allocation could include water required for rootstock protection or survival (e.g. permanent crops, trees, vines, etc.) to help avoid long-term economic impacts if rootstock crops were lost due to drought. It could also include water needed to maintain water supply for stock drinking water, where use is in excess of permitted quantities.

The TANK Stakeholder Group suggested an emergency water allocation could apply to abstractions subject to cease-take management rules (i.e. surface water abstractions and stream depleting groundwater abstractions), with the emergency water allocation limited to 10% of the current primary allocation.

The potential impact of a 10% emergency water allocation has been modelled on the Ngaruroro and Tūtaekurī Rivers. For the purposes of estimating the potential impact, the 10% emergency water allocation has been modelled for all groundwater abstractions located within the proposed Stream Depletion Zone 1, along with all surface water abstractions located upstream of the Ngaruroro at Fernhill and Tūtaekurī at Puketapu flow management sites.

For each flow management site, a 10% emergency water allocation has been calculated based on combining:

- 10% of the maximum modelled stream depletion effect from groundwater abstractions within Zone 1, along with
- 10% of the maximum daily allocation for all upstream surface water abstractions.

The 10% emergency water allocation that has been calculated and modelled at each flow management site is shown in Table 6-1. The breakdown of the groundwater and surface water components that are combined to calculate the 10% emergency water allocation is also shown. The groundwater component for both rivers is very small (7.7 l/s) when compared to the surface water component.

Table 6-1: Calculated 10% emergency water allocation. Allocation based on a total of the calculated groundwater and surface water components.

River flow management site	10% of max SD effect from GW abstractions in SD zone 1 (l/s)	10% of max daily upstream SW allocation (l/s)	Total 10% emergency water allocation (l/s)*
Ngaruroro River at Fernhill	7.7	161.0	169
Tūtaekurī River at Puketapu HBRC Site	7.7	82.6	90

NB: SD = Stream depletion, GW = Groundwater, SW = Surface water
Total 10% emergency water take rounded to nearest l/s

6.1 Emergency water allocation scenarios

The emergency water allocation scenarios modelled for the Ngaruroro and Tūtaekurī flow management sites are presented in Table 6-2. Each scenario combines the calculated 10% emergency water allocation with different trigger flows.

Table 6-2: Modelled emergency water allocation scenarios. Each scenario combines the calculated 10% emergency water allocation with different trigger flows.

River flow management site	Scenario ID	Trigger flow (l/s)	10% emergency water allocation (l/s)*
Ngaruroro River at Fernhill	Ngaruroro-EWA1	2400	169
	Ngaruroro-EWA2	3600	169
	Ngaruroro-EWA3	4000	169
Tūtaekurī River at Puketapu HBRC Site	Tūtaekurī-EWA1	2000	90
	Tūtaekurī-EWA2	2500	90
	Tūtaekurī-EWA3	3300	90

When simulating the abstraction of a 10% emergency water allocation under each scenario, the abstraction would only occur when the river flow was at or below the trigger flow. Consequently, only flow at or below the trigger flow was modified.

6.2 Emergency water allocation modelling results

The predicted effects from abstracting a 10% emergency water allocation are provided for each scenario in Table 6-3. The simulated abstraction only modifies the river flow regime when flow is at or below the trigger flow, hence, Table 6-3 identifies the minimum change to flow based on the change from the trigger flow, and the maximum change based on the change from the lowest daily mean flow in the simulated record.

Table 6-3: Modelled percentage change to river flow. Predicted change to river flow resulting from the abstraction of a 10% emergency water allocation.

River flow management site	Scenario ID	Trigger flow (l/s)	10% emergency water allocation (l/s)	Predicted change to river flow					
				Minimum change (from trigger flow)			Maximum change (from lowest flow)		
				Un-modified flow	Modified flow	% change	Un-modified flow	Modified flow	% change
Ngaruroro River at Fernhill	Ngaruroro-EWA1	2400	169	2400	2231	**-7%**	1255	1086	**-13%**
	Ngaruroro-EWA2	3600	169	3600	3431	**-5%**	1255	1086	**-13%**
	Ngaruroro-EWA3	4000	169	4000	3831	**-4%**	1255	1086	**-13%**
Tūtaekurī River at Puketapu HBRC Site	Tūtaekurī-EWA1	2000	90	2000	2000	**0%**	2511	2511	**0%**
	Tūtaekurī-EWA2	2500	90	2500	2500	**0%**	2511	2511	**0%**
	Tūtaekurī-EWA3	3300	90	3300	3210	**-3%**	2814	2724	**-3%**

For the Ngaruroro River, the predicted impact on flow resulting from the abstraction of a 10% emergency water allocation ranges between a 4% and 13% reduction in river flow.

Simulated flows in the Tūtaekurī River never go below the 2000 l/s or 2500 l/s trigger flows, meaning a 10% emergency water allocation is never required under scenarios with these trigger flows. Flows in the Tūtaekurī River were predicted to drop below the highest trigger flow of 3300 l/s (although infrequently) and, with this trigger flow, the abstraction of a 10% emergency water allocation was predicted to reduce river flow by no more than 3%.

The restriction statistics generated from the cease-take trigger flow scenarios were previously presented in Section 4.3.2. These statistics indicate the predicted periods of restriction under different trigger flows and thus also indicate the periods when flow is predicted to be at or below the trigger flows.

Under scenario Ngaruroro-EWA3, river flow was predicted to be at or below the 4000 l/s trigger flow for an average of 15.4 days per year and up to 73 days in a dry year (Table 4-4). This indicates the potential duration of the impact from a 10% emergency water allocation. For the Tūtaekurī River, river flow was predicted to be at or below the 3300 l/s trigger flow (Tūtaekurī-EWA3) for an average of 8.7 days per year and up to 35 days in a dry year (Table 4-3).

An example of the potential impact from abstracting a 10% emergency water allocation from the Ngaruroro River is demonstrated in Figure 6-1. The example shows a short period of river flow record modelled where all abstractions were fully restricted and where a 10% emergency water allocation was abstracted. A similar example is presented for the Tūtaekurī River in Figure 6-2. Both Figure 6-1 and Figure 6-2 show the impact of the abstraction based on using the highest trigger flow for each river (4000 l/s for the Ngaruroro River and 3300 l/s for the Tūtaekurī River).

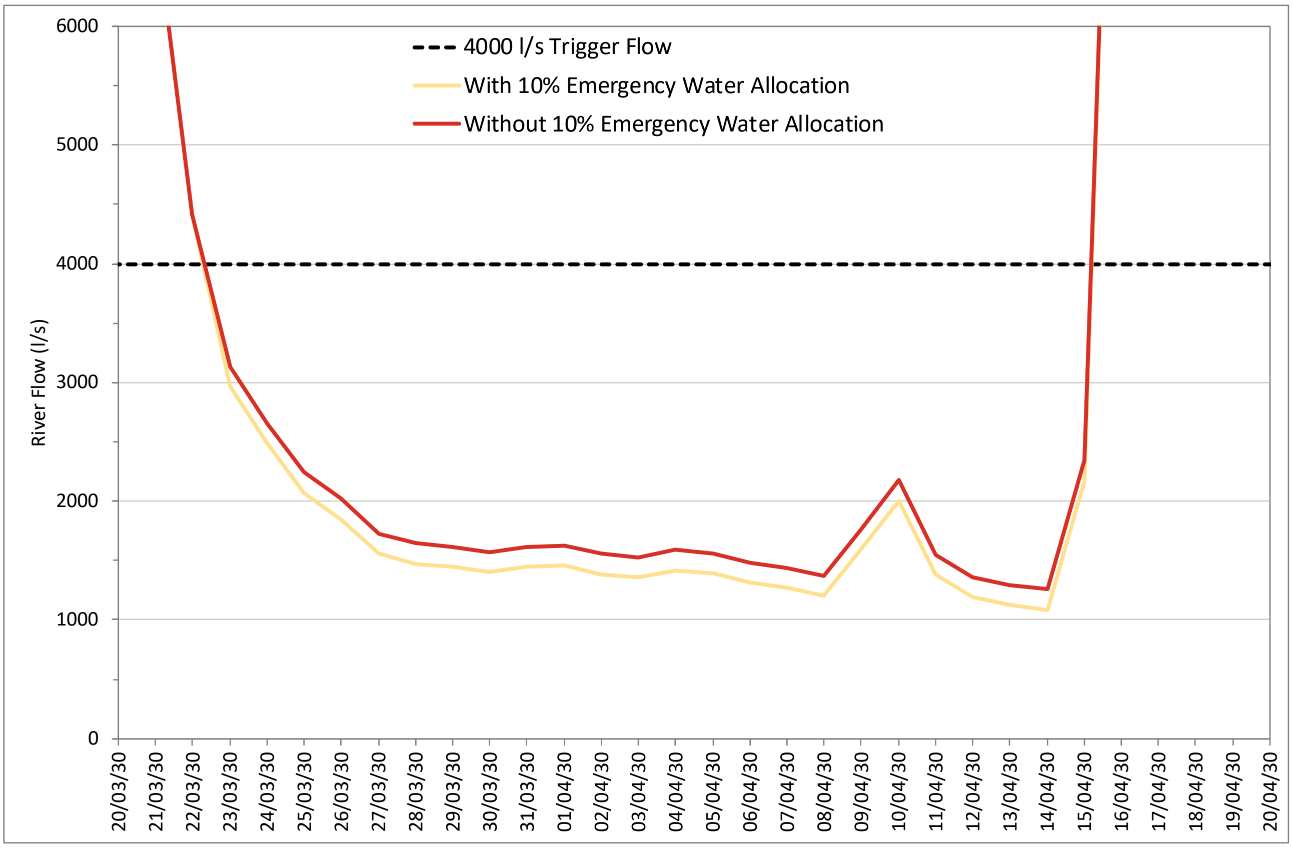

Figure 6-1: Modelled impact of abstracting a 10% emergency water allocation from the Ngaruroro River. An example of the potential impact from abstracting a 10% emergency water allocation from the Ngaruroro River when flow is less than the highest modelled trigger flow of 4000 l/s.

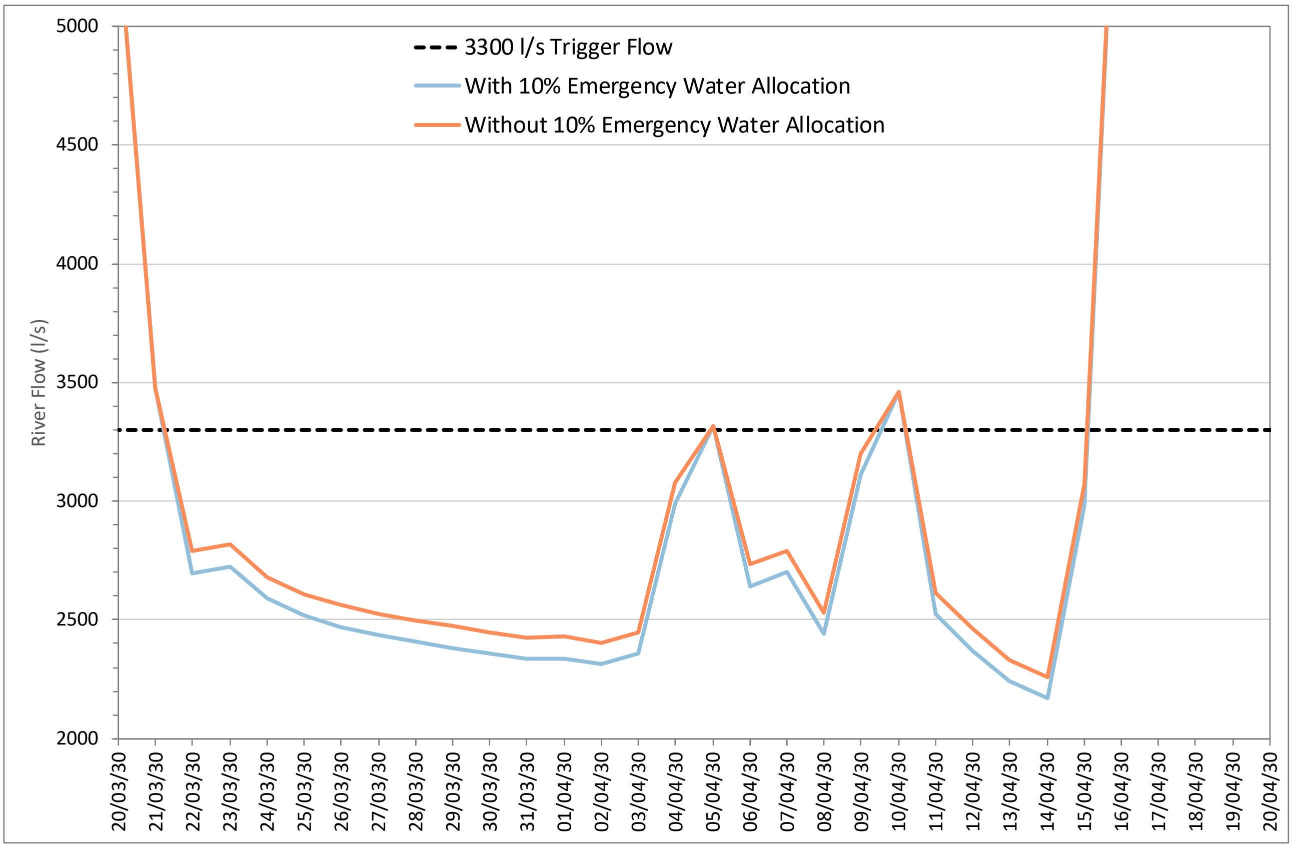

Figure 6-2: Modelled impact of abstracting a 10% emergency water allocation from the Tūtaekurī River. An example of the potential impact of abstracting a 10% emergency water allocation from the Tūtaekurī River when flow is below the highest modelled trigger flow of 3300 l/s.

7 High flow allocation scenario modelling

The purpose of modelling high flow allocation scenarios on the Ngaruroro River, was to assess the potential impacts on flushing flows and assess the capacity of the modelled high flow allocation to meet potential new demand.

High flow allocation enables water to be abstracted/harvested from a river during periods of higher flow and stored for later use, for example during periods of restricted low flow abstraction or for river flow enhancement. Abstracting water at higher flows outside of typical low flow conditions helps to minimise any impact of the abstraction on instream values and protects the reliability of low flow abstractions relating to primary allocation.

A high flow allocation will typically have a relatively high cease-take trigger flow, to ensure that low flows in a river are not affected. An example of this is shown in Figure 7-1. The figure presents naturalised and modified daily mean flow records for the Ngaruroro River at Fernhill, simulated using the HBRC SOURCE model. The figure shows a 20,000 l/s cease-take trigger flow for an 8000 l/s high flow allocation and the current 2400 l/s trigger flow for primary allocation. The modified river flow demonstrates the effect of abstracting water at high flows, which only modifies the flow regime when the river flow is above 20,000 l/s. Low flows are unaffected by the high flow abstraction because this abstraction ceases when river flow is less than or equal to 20,000 l/s.

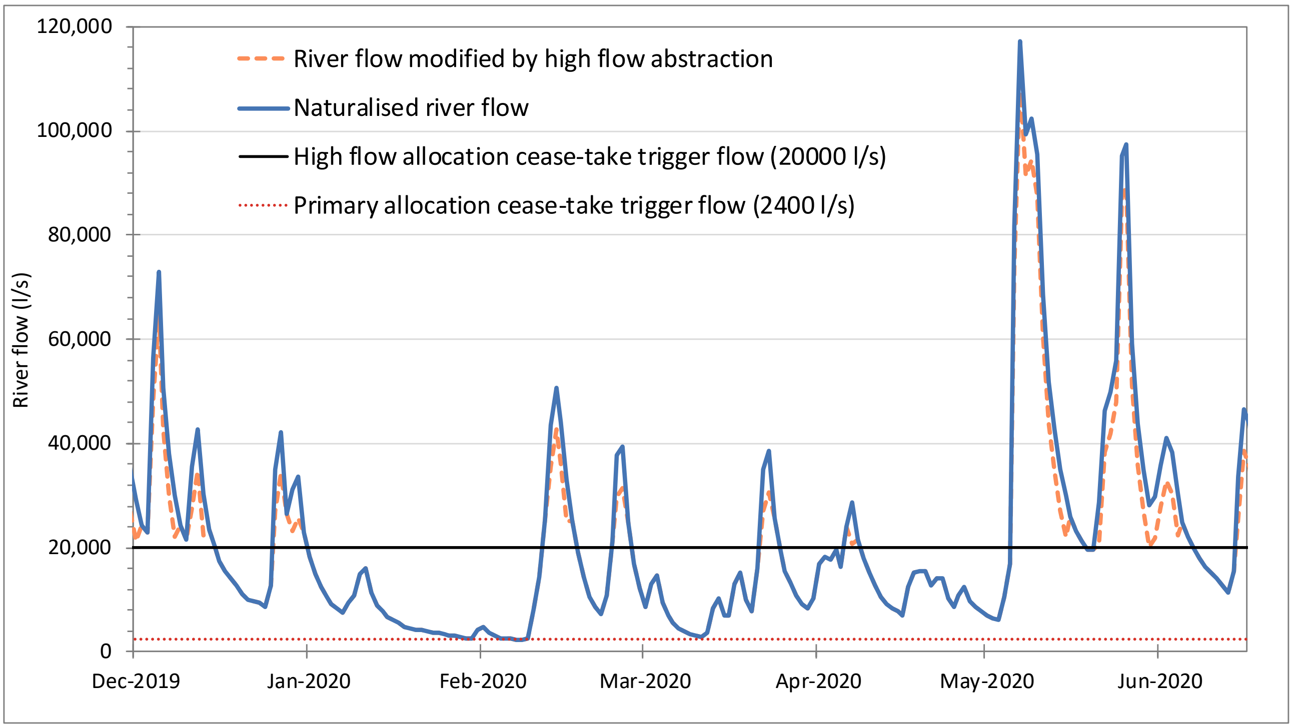

Figure 7-1: Simulated flows for the Ngaruroro River showing the effect of an 8000 l/s high flow allocation.

There are a number of approaches to setting high flow allocation in New Zealand rivers, these are summarised by Harkness & Forbes (2008). These approaches include the use of high flow trigger flows (also referred to as minimum flows), allocation blocks and the implementation of flow sharing arrangements. In other regions, high flow allocation may be referred to as supplementary allocation or B/C block allocations.

The Ngaruroro River currently has a high flow allocation of 2000 l/s, with a 20000 l/s cease-take trigger flow. The current high flow allocation is based on a report by Harkness (2010) along with consideration of historical demand for high flow allocation. Approximately 1000 l/s of the current high flow allocation is authorised for abstraction.

During the TANK plan change process, potential demand for additional high flow allocation from the Ngaruroro River (in addition to the current 2000 l/s of allocation) has been identified. The additional allocation may be required for potential new irrigation (Pickens 2010), or for augmenting the Ngaruroro river flow during low flow conditions.

Pickens (2010) reported that potential new irrigation within the Heretaunga Plains and Ngaruroro river flats may be up to 3500 ha, and this demand may be met with 17.5 million cubic metres (Mm^3) of storage. However, even with adequate storage the current high flow allocation (2000 l/s) would be insufficient to meet this demand.

The assessment of the irrigable area by Pickens (2010) was a high level screening exercise to provide understanding about the possible scale of future demand and potential storage options. Other reasons for advancing storage proposals include for creation of aquatic habitat, flow enhancement, increasing reliability of water supply or meeting other water demand such as for urban development. However, none of these were included in the analysis by Pickens (2010).

7.1 Potential impacts of high flow allocation on flushing flows

It is important to ensure that high flow allocation does not compromise in-stream values that are dependent on flushing flows to remove periphyton biomass and maintain macroinvertebrate structure. Harkness (2010) modelled several scenarios to determine a high flow allocation for the Ngaruroro River that could be abstracted without adversely affecting instream ecological requirements.

A key metric used to assess the scenarios modelled by Harkness (2010), was the FRE_3 flood frequency statistic. The FRE_3 is a measure of flow variability that represents the frequency of flood events with flows greater than three times (3x) the median flow. These 3x median flow events are considered to provide a flushing function, removing excessive periphyton growth and limiting periphyton accrual (Clausen and Biggs 1997).

An example of 3x median flow events is shown in Figure 7-2. This figure presents a period of naturalised daily mean flow record for the Ngaruroro River at Fernhill (simulated using the HBRC SOURCE model). The median flow and 3x median flow are also shown in this figure. During this sample period of record, there were 3 flow events where flow was greater than the 3x median flow. These events are examples of those used in the calculation the FRE_3 statistic.

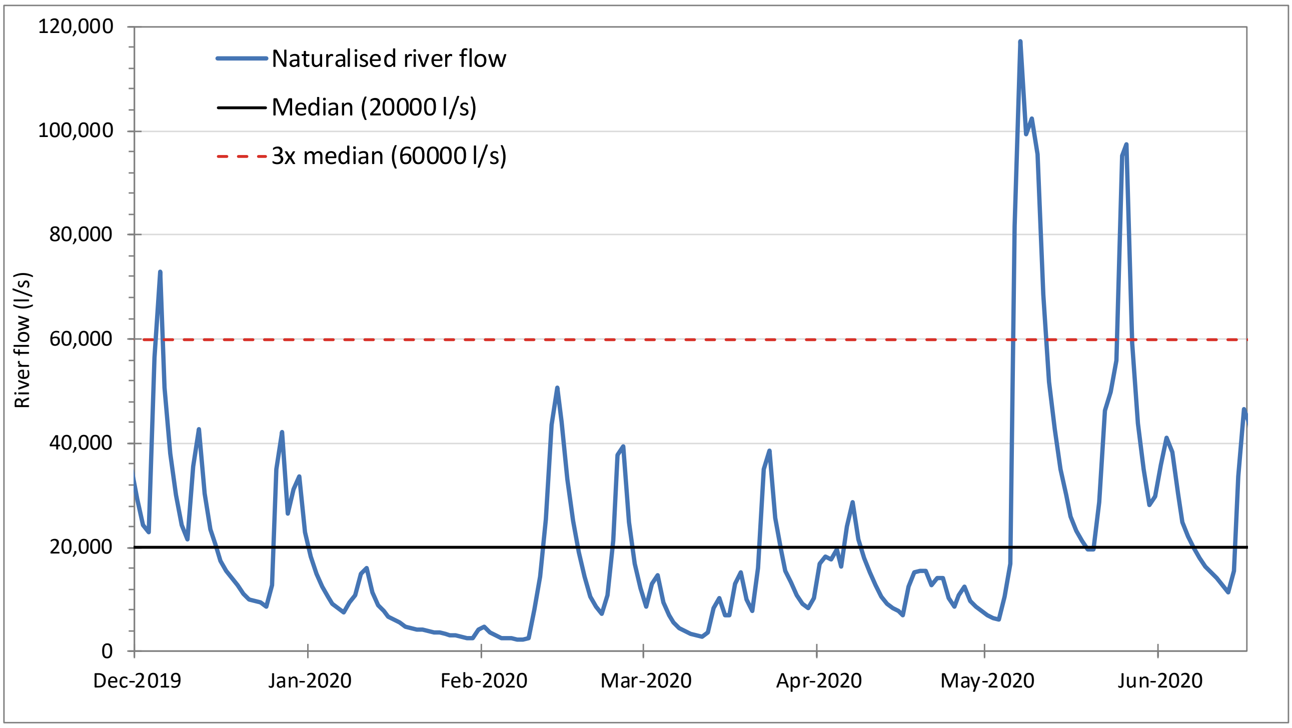

Figure 7-2: Example of 3x median flow events. Naturalised daily mean flow record for the Ngaruroro River at Fernhill, simulated using the HBRC SOURCE model.

Clausen & Biggs (1997) undertook a study to identify the most ecologically relevant hydrological indices for characterising hydrological regimes in New Zealand streams. As a measure of the frequency of flood disturbance events, FRE_3 was identified as having a clear mechanism of control on biota, where periphyton biomass decreased with increasing FRE_3.

Duncan & Woods (2004) characterised rivers in New Zealand with a low FRE_3 (<5) as having a stable flow regime with few floods, whereas rivers with a higher FRE_3 (>10) have a more variable flow regime. These rivers tend to drain high rainfall areas and may have frequent, large floods that disturb the riverbed. Duncan & Woods (2013) calculated a FRE_3 of 10.4 for the lower Ngaruroro River, indicative of a river with a more variable flow regime.

Harkness (2010) analysed the FRE_3 statistic for all modelled scenarios and used it as the ecological basis for the broad assessment of potential biological consequences of all scenarios. The percentage of change to FRE_3 from a naturalised flow regime to a modified flow regime provided an estimate of the potential impact on instream biological communities from the flow regime change.

Harkness (2010) recommended that in order to maintain instream ecological values and limit the risk of impact on the aquatic environment, high flow allocations that reduce the FRE_3 flood frequency by less than 10% would be supported as being suitable allocation methods for maintaining ecological instream values of the Ngaruroro River.

7.2 High flow allocation scenarios

7.2.1 Scenario configuration

The high flow allocation scenarios modelled for Ngaruroro River at Fernhill are presented in Table 7-1. Each scenario combined an allocation with a cease-take trigger flow. An exception is the HFA Zero scenario, which simulated river flow without any high flow allocation.

All scenarios were based on the modified base case scenario (described in Section 4.3).

The current high flow allocation cease-take trigger flow is 20,000 l/s, which is based on the median flow at Ngaruroro River at Fernhill. The current cease-take trigger flow was used in scenarios HFA 1 to HFA 4.

Scenarios were developed to model the current high flow allocation with and without potential new additional allocation, with abstraction of this allocation simulated to occur only when the Ngaruroro River flow was greater than 20,000 l/s.

Table 7-1: Modelled high flow allocation scenarios. Each scenario combines a maximum allocation with a cease-take trigger flow.

Scenario	High flow allocation (l/s)	Cease-take trigger flow (l/s)	High flow allocation description
HFA Zero	0	NA	Zero allocation
HFA 1	2000	20000	Current allocation
HFA 2	4000	20000	Current allocation + 2000 l/s additional allocation
HFA 3	6000	20000	Current allocation + 4000 l/s additional allocation
HFA 4	8000	20000	Current allocation + 6000 l/s additional allocation

Two types of assessment were undertaken based on the scenario modelling results and data:

1. *Impact of high flow allocation on flushing flows*

In this study, high flow allocation scenarios that reduce the FRE_3 by less than 10% are considered to be low risk in terms of their potential impact on ecological instream values.

2. *Capacity of high flow allocation to meet demand*

Pickens (2010) reported that new demand for irrigating 3500 ha would require 17.5 Mm^3 of storage. High flow allocation scenarios for meeting this irrigation demand are evaluated in Section 7.3.2.

7.3 Assessment of effects

7.3.1 Impact of high flow allocation on flushing flows

A modelled daily mean flow record (2016-2031) for the Ngaruroro River at Fernhill was generated by the SOURCE model for each scenario. Each modelled record was analysed to identify changes to the FRE_3 (number of 3x median flow events per year).

Change to the FRE_3

The FRE_3 was calculated from the flow records modelled under each high flow allocation scenario, with the results presented in Table 7-2. The percentage change to FRE_3 from the HFA Zero scenario to each of the scenarios with a high flow allocation is also presented in Table 7-2 and Figure 7-3.

As expected, FRE_3 reduced under all allocation scenarios: from 12.6 events per year under scenario HFA Zero to 11.9 under scenario HFA 4, which had the largest high flow allocation of 8000 l/s. The reduction in FRE_3 ranged from 1.5% under scenario HFA 1 up to 5% under scenario HFA 4.

The changes to the number of 3x median events for individual years of modelled record under each scenario are presented in Appendix I.

Table 7-2: FRE_3 calculated for each high flow allocation scenario. Statistics are based on the analysis of calendar years (Jan-Dec) from 2016 to 2031.

Scenario	High flow allocation (l/s)	FRE_3 (no. of 3x median flow events per year)	Change from HFA Zero	% Change from HFA Zero
HFA Zero	0	12.6	-	-
HFA 1	2000	12.4	-0.19	**-1.5%**
HFA 2	4000	12.4	-0.19	**-1.5%**
HFA 3	6000	12.1	-0.44	**-3.5%**
HFA 4	8000	11.9	-0.63	**-5.0%**

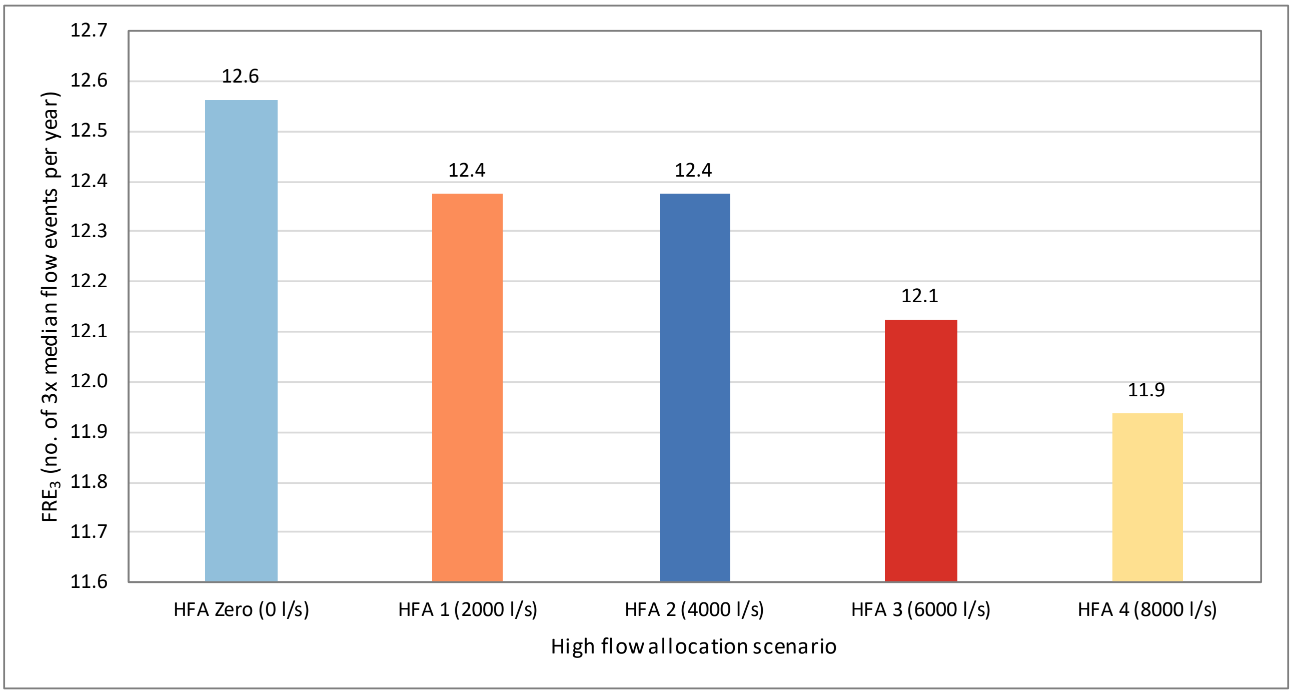

Figure 7-3: FRE$_3$ calculated for each high flow allocation scenario. Statistics are based on the analysis of calendar years (Jan-Dec) from 2016 to 2031.

High flow allocations that reduce the FRE$_3$ by less than 10% are considered to be low risk in terms of their potential impact on ecological instream values (an approach consistent with Harkness 2010). The high flow allocations simulated under all scenarios, were predicted to reduce FRE$_3$ by less than 10%, therefore, all of the modelled high flow allocations are considered to be low risk.

7.3.2 Capacity of high flow allocation to meet demand

The second part of the high flow allocation scenario assessment was to identify a high flow allocation that may be sufficient to meet the irrigation demand for 3500 ha with 17.5 Mm^3 storage, as reported by Pickens (2010). Since storage and demand modelling relies on a specific scenario, this is a hypothetical exercise because the location(s) and geometry(ies) of reservoirs are unknown. The location of land that may potentially be irrigated from the storage also is unknown. Therefore, the modelling approach adopted avoided the need to make a number of assumptions with respect to variables such as soil properties and climate that have a major influence on irrigation demand modelling and, consequently, releases from storage during the irrigation season. Note also that other reasons for developing water storage are not considered in this analysis.

For each high flow allocation scenario, the volume of water available during the winter and spring period from June to September, was calculated for each year of the modelled flow records from 2016 to 2031. It was assumed that if 17.5 Mm^3 of water was available for harvest during each winter, there would be sufficient water to fill the storage required to meet demand for irrigating 3500 ha.

High flow events often result in very turbid water with high sediment loads that have adverse effects on pumping and storage utility. Based on advice from the TANK Water Augmentation Working Group, river flows greater than 60,000 l/s would be unsuitable for harvesting from the Ngaruroro River due to technical challenges with high sediment load in the river. Therefore, for this assessment, abstraction was assumed to be available only when flow in the Ngaruroro River was less than 60,000 l/s and greater than the 20,000 l/s cease-take trigger flow.

Assumptions and limitations

The following assumptions and limitations relate to the analysis:

- It was assumed that a full 17.5 Mm3 reservoir at the start of an irrigation season would be sufficient to meet demand for 3500 ha of land
- It was assumed that the entire allocation (i.e. up to 8000 l/s) is capable of being transported to the storage reservoir(s). In practise, this may present technical challenges, but may be achieved if a suitable tributary was available for storage, or if several smaller storage facilities were developed with a combined capacity of 17.5 Mm^3
- Evaporation losses from storage reservoir(s) have not been accounted for, because storage geometry is unknown. Based on potential storage sites identified by Pickens (2010), net evaporation losses may be in the order of 500,000 m3 during an irrigation season
- Leakage losses from the storage and distribution infrastructure have not been included. In practise these losses are non-trivial and this uncertainty should be considered when interpreting results

This analysis is not intended as a feasibility study for a storage and irrigation scheme. The purpose of the analysis is a high level comparison of the potential for each high flow allocation option to supply a hypothetical storage reservoir, on the basis of the assumptions listed above.

Analysis results

The analysis ignored the existing 2000 l/s high flow allocation because at the time of undertaking the analysis, the existing 2000 l/s of allocation was considered to be unavailable for the potential 17.5 Mm^3 storage scheme, due to:

- approximately 1000 l/s of the existing allocation being currently allocated; and
- the remainder of the existing allocation is being explored for potential use in a Ngaruroro River augmentation proposal.

Therefore, winter/spring abstraction volumes were only calculated for the additional high flow allocations that may be used for future demand: 2000 l/s, 4000 l/s and 6000 l/s modelled in scenarios HFA 2, HFA 3 and HFA 4 respectively. The results are plotted in Figure 7-4.

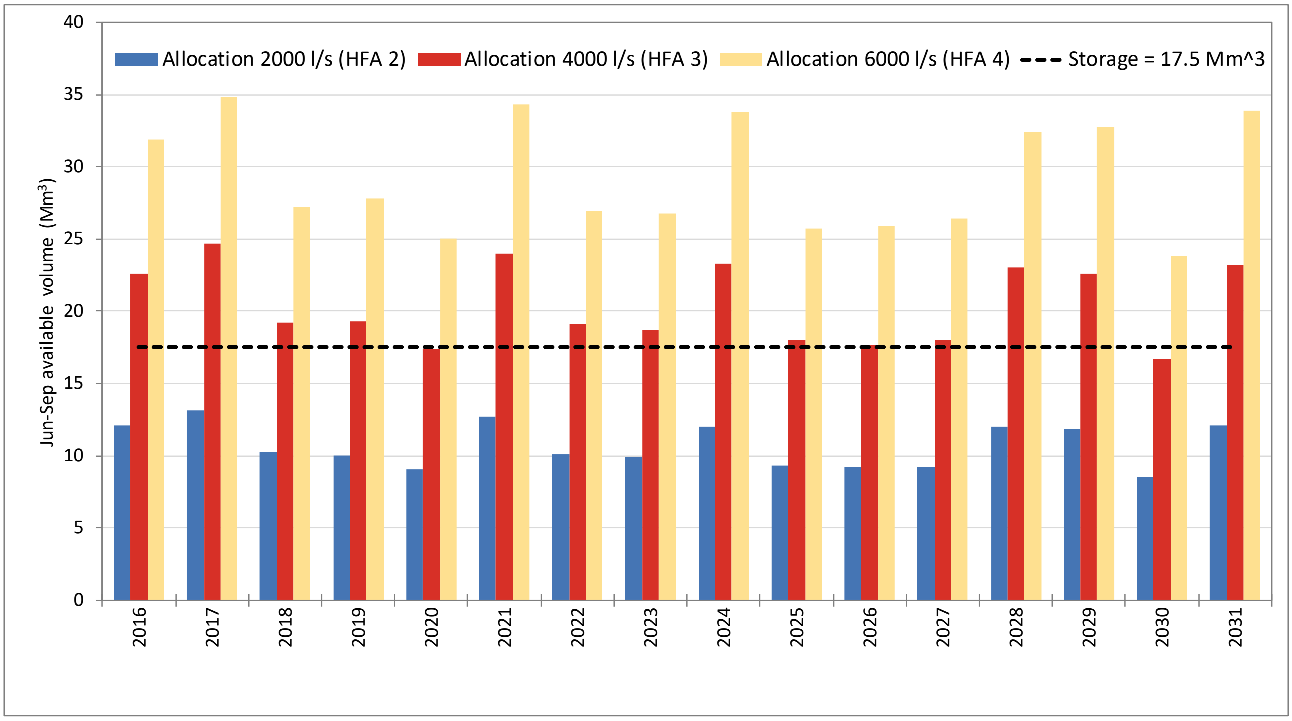

Figure 7-4: Modelled annual volumes of water available for harvesting. Annual volumes of water available for harvesting between June and September, for additional high flow allocations of 2000 l/s, 4000 l/s and 6000 l/s. The current 2000 l/s high flow allocation is excluded. The dotted black line indicates the storage capacity reported by Pickens (2010) as sufficient to meet demand for 3500 ha of new irrigation.

Figure 7-4 shows that an additional high flow allocation of 2000 l/s (HFA 2) would not be sufficient to satisfy the potential storage capacity. An additional allocation of 4000 l/s (HFA 3) may be sufficient to fill the reservoir capacity during most, but not all, years of the simulated flow record. An additional allocation of 6000 l/s (HFA 4) is predicted to be satisfactory for filling 17.5 Mm^3 of storage during all years of the modelled flow record.

7.4 High flow allocation modelling: Discussion and summary

A range of high flow allocation scenarios for the Ngaruroro River was modelled to identify the potential impact of each scenario on flushing flows and to assess the capacity of the modelled high flow allocation to meet potential new demand.

All of the modelled scenarios predicted less than a 10% reduction to FRE_3. Therefore, in terms of the potential impact on flushing flows and associated ecological instream values, all high flow allocation scenarios (with total allocation ranging from 2000 l/s to 8000 l/s) are considered to have a low risk of adverse impacts.

A total high flow allocation of 6000 l/s (which combines 2000 l/s of existing allocation with 4000 l/s of additional allocation) may be sufficient to provide water for potential new irrigation to 3500 ha in most years. However, there is greater certainty (given the assumptions and limitations listed in Section 0) of a total high flow allocation of 8000 l/s providing for potential future demand to irrigate 3500 ha. Furthermore, a total high flow allocation of 8000 l/s is the most likely scenario to provide additional volume to store water for environmental purposes, such as augmentation of surface water bodies during low flow periods.

It is important to note that one of the primary reasons for considering a high flow allocation in the draft TANK plan, is to provide for water harvesting in the future, if storage is considered for meeting additional demand and improving reliability of supply. If the TANK plan fails to make this provision, it will be far more onerous to implement a storage scheme in future.

Along with demand for irrigation, there may be environmental benefits from harvesting high flows for storage. For example, offline (i.e. non-mainstem) storage may be considered for augmenting the Ngaruroro River during periods of low flow. This augmentation may be valuable for environmental benefits or to offset the effects of run-of-river abstractions during low flow periods. In addition, harvesting high flows from the Ngaruroro River for storage, may be required in the future for lowland stream augmentation: particularly for streams with technical challenges to augmentation from groundwater such as the Paritua and Karewarewa.

The purpose of this analysis was to identify high flow allocation options that may be sufficient to meet future demand for storage, without the potential for causing adverse effects from this abstraction. Depending on the intended purpose of any future storage scheme, there is also likely to be a need to consider environmental effects from the use of stored water. For example, there may be potential for water quality effects caused by land use change. These other potential environmental effects would require full assessment as part of the resource consenting process.

It is not necessary to speculate here on the potential uses of water harvested for storage, or the environmental effects of those uses, because those issues would be fully assessed when applications are made for resource consents to take and use water.

Similarly, it is important to note that the provision of a high flow allocation does not as of right permit the development of any dam or storage facility. Construction of a storage reservoir is a separate activity to the abstraction of harvesting flow and would require a resource consent in its own right.

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- Thomas Wilding (HBRC)
- Emily Diack (Williamson Water Advisory)
- Jon Williamson (Williamson Water Advisory)

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Appendix A SOURCE model log

SOURCE Model File Name	File Type	Extension	Modeller	New Model Construction Files Relating to Model Version	Original GW Model File Names	Description
Base Case_All Losses (6.1) 20170927 GW Data	River System project file	.rsproj	RW	-	-	Finalised base model from WWA (HBRC worked with WWA to fix an issue with GW input data in a previous model version provided by WWA)
Base Case_All Losses (6.2) 1980-2032	River System project file	.rsproj	RW	Base Case_All Losses (6.2) 1980-2032_SMWBM_Model_Config	-	Replaced all original base case datasets with new extended datasets covering period 1980-2032
				Instream_Gains_ls_Base_Case_1980_2032_20170927	M3_M5_daily_HPM_M5_d_base_minus.csv	Added new future irrigation abstraction data
				Instream_Losses_ls_Base_Case_1980_2032_20170927	M3_M5_daily_HPM_M5_d_base_plus.csv	Added new future irrigation abstraction data which will relate to new future water user nodes that are planned to be added to model
				Irrigation Demand Condensed_l_s_1979-2032	-	Added base case minimum flows which will be used to restrict future irrigation abstraction at future water user nodes
				Ngaruroro_FernHill_Abstractions_l_s_1979_2032	-	Replaced the unaccounted for GW dataset with new extended dataset covering period 1980-2032
				Poukawa_Stream_at_Stock_Road_DMF_m3s_1979_2032	-	
				SC_SOURCE_Future_Irrigation_Abstraction_l_s_v2_2MC_1980_2032	-	
				SOURCE_Base_Case_Minimum_Flows_1980_2032	-	
				SOURCE_PET_All_SCs_1979_2032	-	
				SOURCE_Rainfall_All_SCs_1979_2032	-	
				Unaccounted_for_GW_m3s_mv6.2_20170927_1980_2032	-	
Base Case_All Losses (6.2.1) 1980-2032 Extra Gauges	River System project file	.rsproj	RW	No new files added to scenario	-	Extra gauge nodes added which will be required for abstraction functions
Base Case_All Losses (6.2.2) 1980-2032 Extra Gauges + Future Water Users	River System project file	.rsproj	RW	No new files added to scenario	-	Future water user nodes added (in addition to the extra gauge nodes) which will be required for abstraction functions
Base Case_All Losses (6.2.3) 1980-2032 Abstraction Functions	River System project file	.rsproj	RW	SC_SOURCE_Future_Irrigation_Abstraction_l_s_v2_2MC_1980_2032_Rounded1dp	-	Changed future irrigation abstraction dataset to new dataset with data values rounded to 1 decimal place
						Abstraction functions added for all minimum flows sites and future water user nodes:
						1 - Minimum flow site minimum flow as time series variable (e.g. MFS_MinFlow.$Ngaruroro_River_at_Fernhill_1)
						2 - Minimum flow site restriction index as a function (e.g. MFS_RestrictionIndex.$RI_Ngaruroro_River_at_Fernhill_1)
						3 - Minimum flow site river flow as a modelled variable (e.g. MFS_RiverFlow.$Ngaruroro_River_at_Fernhill)
						4 - Water user abstraction demand as a time series variable (e.g. WU_AbstractionDemand.$AD_SC_057_Ngaruroro_River_at_Fernhill_1)
						5 - Water user abstraction rate as a function (e.g. WU_AbstractionRate.$AR_SC_057_Ngaruroro_River_at_Fernhill_1)
Base Case_Estimated Demand (8.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_Base_Case_Minimum_Flows_1980_2032_Ngaruroro_Offset	-	Changed base case minimum flows dataset to include an offset applied to the Fernhill minimum flows
Base Case_Estimated Demand (8.1) 1980-2032	River System project file	.rsproj	RW	SOURCE_Base_Case_Minimum_Flows_1980_2032_v2_Ngaruroro_Offset	-	Changed base case minimum flows dataset to include the Fernhill 15128 min flow and changed the reference to the minimum flow value (e.g. …Fernhill_2400 changed to …Fernhill_1
						Added functions relating to the Fernhill 15128 min flow
Base Case_Estimated Demand (8.1_SDC) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20170927_8.1_SDC.csv	M3_M5_daily_sc8v2_minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting current SD GW abstractions
				Instream_Losses_ls_Base_Case_1980_2032_20170927_8.1_SDC.csv	M3_M5_daily_sc8v2_plus.csv	
Base Case_Estimated Demand (8.1_SDZ1) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20170927_8.1_SDZ1.csv	M3_M5_daily_sc8_z1_minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1
				Instream_Losses_ls_Base_Case_1980_2032_20170927_8.1_SDZ1.csv	M3_M5_daily_sc8_z1_plus.csv	
Base Case_Estimated Demand (8.1.1_SDZ1) 1980-2032	River System project file	.rsproj	RW	SC_SOURCE_Future_Irrigation_Abstraction_l_s_v2_2MC_Max_Allocation_1980_2032_Rounded1dp_v2_10%.csv	-	Test Scenario - Continued modelling of 10% emergency water take outside of SOURCE
						Changed functions to simulate abstractions continuing (based on a rate equivalent to 10% of max allocation) when river flow is at or below minimum flow
				Instream_Gains_ls_Base_Case_1980_2032_20170927_8.1.1_SDZ1.csv	-	Added future irrigation abstraction dataset based on 10% of max allocation
				Instream_Losses_ls_Base_Case_1980_2032_20170927_8.1.1_SDZ1.csv	-	Added modified MODFLOW gains and losses which have been adjusted reflect 10% abstraction in SDZ1 still occuring when river flow at or below minimum flows
Base Case_Estimated Demand (8.2) 1980-2032	River System project file	.rsproj	RW	SOURCE_Base_Case_Minimum_Flows_1980_2032_v2_Ngaruroro_Offset_Inc_Irongate	-	New base case minimum flows dataset which now includes Irongate Stream at Clarkes Weir
						Added functions relating to the Irongate Stream at Clarkes Weir
Base Case_Estimated Demand (8.3) 1980-2032	River System project file	.rsproj	RW	SOURCE_Base_Case_Min_Flows_1980_2032_v2_Ngaruroro_Offset_Inc_Irongate_Mangateretere.csv	-	New base case minimum flows dataset which now includes Mangateretere Stream at Napier Road
						Added GW augmentation inflow nodes to subcats 104, 109, 123, 127 and 128
Base Case_Estimated Demand (8.3_SDZ1) 1980-2032	River System project file	.rsproj	RW	SOURCE_GW_Augmentation_Inflow_8.3_SDZ1_m3s.csv	SOURCE_GW_Augmentation_Inflow_8.3_SDZ1_m3s.csv	Added GW augmentation inflow datasets for the scenario
				Instream_Gains_ls_Base_Case_1980_2032_20170927_8.3_SDZ1.csv	M3_M5_daily_sc8.3_diff_comb__minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1 and additional stream depletion resulting from GW augmentation to lowland streams
				Instream_Losses_ls_Base_Case_1980_2032_20170927_8.3_SDZ1.csv	M3_M5_daily_sc8.3_diff_comb__plus.csv	
Base Case_Max Allocation (9.0) 1980-2032	River System project file	.rsproj	RW	SC_SOURCE_Future_Irrigation_Abstraction_l_s_v2_2MC_Max_Allocation_1980_2032_Rounded1dp_v2.csv	-	Changed future irrigation abstraction dataset to abstraction demand based on max allocation
Base Case_Max Allocation (9.1) 1980-2032	River System project file	.rsproj	RW	SOURCE_Base_Case_Minimum_Flows_1980_2032_v2_Ngaruroro_Offset_Inc_Irongate	-	New base case minimum flows dataset which now includes Irongate Stream at Clarkes Weir
Base Case_Max Allocation (9.2) 1980-2032	River System project file	.rsproj	RW	SOURCE_Base_Case_Min_Flows_1980_2032_v2_Ngaruroro_Offset_Inc_Irongate_Mangateretere.csv	-	New base case minimum flows dataset which now includes Irongate Stream at Clarkes Weir and Mangateretere Stream at Napier Road
Base Case_Max Allocation (9.2_SDC) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20171109_9.2_SDC.csv	M3_M5_daily_sc9v2_diff_comb__minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1
				Instream_Losses_ls_Base_Case_1980_2032_20171109_9.2_SDC.csv	M3_M5_daily_sc9v2_diff_comb__plus.csv	
WCO_Estimated Demand (10.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_WCO_Minimum_Flows_1980_2032_Ngaruroro_Offset_v2.csv	-	New minimum flows dataset for scenario based on base case except with Ngaruroro based on WCO application (2400 l/s)
NT MF 70% Habitat_Estimated Demand (11.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_NT_MF_70%_Habitat_Minimum_Flows_1980_2032_Ngaruroro_Offset_v2.csv	-	New minimum flows dataset for scenario based on Ngaruroro and Tutaekuri MF 70% Habitat at MALF
NT MF 70% Habitat_Estimated Demand (11.0_SDZ1) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20170927_11.0_SDZ1.csv	M3_M5_daily_sc11_z1_minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1
				Instream_Losses_ls_Base_Case_1980_2032_20170927_11.0_SDZ1.csv	M3_M5_daily_sc11_z1_plus.csv	
NT MF 80% Habitat_Estimated Demand (12.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_NT_MF_80%_Habitat_Minimum_Flows_1980_2032_Ngaruroro_Offset_v2.csv	-	New minimum flows dataset for scenario based on Ngaruroro and Tutaekuri MF 80% Habitat at MALF
NT MF 80% Habitat_Estimated Demand (12.0_SDZ1) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20170927_12.0_SDZ1.csv	M3_M5_daily_sc12_z1_minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1
				Instream_Losses_ls_Base_Case_1980_2032_20170927_12.0_SDZ1.csv	M3_M5_daily_sc12_z1_plus.csv	
NT MF 90% Habitat_Estimated Demand (13.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_NT_MF_90%_Habitat_Minimum_Flows_1980_2032_Ngaruroro_Offset_v2.csv	-	New minimum flows dataset for scenario based on Ngaruroro and Tutaekuri MF 90% Habitat at MALF
NT MF 90% Habitat_Estimated Demand (13.0_SDZ1) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20170927_13.0_SDZ1.csv	M3_M5_daily_sc13_z1_minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1
				Instream_Losses_ls_Base_Case_1980_2032_20170927_13.0_SDZ1.csv	M3_M5_daily_sc13_z1_plus.csv	
NT MF MALF_Estimated Demand (14.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_NT_MF_MALF_Minimum_Flows_1980_2032_Ngaruroro_Offset.csv	-	New minimum flows dataset for scenario based on Ngaruroro and Tutaekuri MF at MALF
NT MF MALF_Estimated Demand (14.0_SDZ1) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20171109_14.0_SDZ1.csv	M3_M5_daily_sc14_z1_diff_comb__minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1
				Instream_Losses_ls_Base_Case_1980_2032_20171109_14.0_SDZ1.csv	M3_M5_daily_sc14_z1_diff_comb__plus.csv	
NT MF 70% Habitat_3 Stage Reduction (15.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_NT_MF_70%_Habitat_3_Stage_Reduction_Minimum_Flows_1980_2032_Ngaruroro_Offset.csv	-	New minimum flows dataset for scenario based on Ngaruroro and Tutaekuri MF 70% Habitat at MALF combined with 3 stages of reduction set at MALF, 90% and 80% MALF habitat
						Modified functions to simulate the restrictions based on a 3 stage reduction set-up
Natural_Zero Abstraction (7.0) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Natural_1980_2032_20170927.csv	M3_M5_daily_HPM_M5_d_zero_minus.csv	Scenario based on version 8.0 but wih all water user and water supply nodes disabled
				Instream_Losses_ls_Natural_1980_2032_20170927.csv	M3_M5_daily_HPM_M5_d_zero_plus.csv	Replaced instream gain/loss datasets with naturalised versions generated by MODFLOW scenario with no abstraction (i.e. natural)
Natural_Zero Abstraction (7.1) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Natural_1980_2032_20170927.csv	M3_M5_daily_HPM_M5_d_zero_minus.csv	Scenario based on version 8.3 but with all water user and water supply nodes disabled
				Instream_Losses_ls_Natural_1980_2032_20170927.csv	M3_M5_daily_HPM_M5_d_zero_plus.csv	Replaced instream gain/loss datasets with naturalised versions generated by MODFLOW scenario with no abstraction or GW augmentation (i.e. natural)
N MF 70% T MF 75% Habitat_Estimated Demand (16.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_N_MF_70%_T_MF_75%_Habitat_Minimum_Flows_1980_2032_Ngaruroro_Offset_v2.csv	-	New minimum flows dataset for scenario based on Ngaruroro MF 70% and Tutaekuri MF 75% Habitat at MALF
N MF 70% T MF 75% Habitat_Estimated Demand (16.0_SDZ1) 1980-2032	River System project file	.rsproj	RW	Instream_Gains_ls_Base_Case_1980_2032_20170927_16.0_SDZ1.csv	M3_M5_daily_sc16_z1_minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1
				Instream_Losses_ls_Base_Case_1980_2032_20170927_16.0_SDZ1.csv	M3_M5_daily_sc16_z1_plus.csv	
N MF 70% T MF 75% Habitat_Estimated Demand (16.1) 1980-2032	River System project file	.rsproj	RW	SOURCE_N_MF_70%_T_MF_75%_Habitat_Min_Flows_1980_2032_Ngaruroro_Offset_v2_Inc_Irongate_Mangateretere.csv	-	Minimum flows dataset for scenario based on Ngaruroro MF 70% and Tutaekuri MF 75% Habitat at MALF and now includes Mangateretere Stream at Napier Road
						Added GW augmentation inflow nodes to subcats 104, 109, 123, 127 and 128
N MF 70% T MF 75% Habitat_Estimated Demand (16.1_SDZ1) 1980-2032	River System project file	.rsproj	RW	SOURCE_GW_Augmentation_Inflow_16.1_SDZ1_m3s.csv	SOURCE_GW_Augmentation_Inflow_16.1_SDZ1_m3s.csv	Added GW augmentation inflow datasets for the scenario
				Instream_Gains_ls_Base_Case_1980_2032_20170927_16.1_SDZ1.csv	M3_M5_daily_sc16.1_diff_comb__minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1 and additional stream depletion resulting from GW augmentation to lowland streams
				Instream_Losses_ls_Base_Case_1980_2032_20170927_16.1_SDZ1.csv	M3_M5_daily_sc16.1_diff_comb__plus.csv	
NT MF Base Case_N 3SR (17.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_NT MF Base Case_N 3SR_Minimum_Flows_1980_2032_Ngaruroro_Offset.csv	-	New minimum flows dataset where all MF sites are the same as base case except the Ngaruroro MF is combined with 3 stages of reduction based flows that are est to be separated by 2 weeks in a typical recession
						Modified functions relating to the Bgaruroro in order to simulate the restrictions based on the 3 stage reduction set-up
N MF 80% T MF 90% Habitat_Estimated Demand (18.0) 1980-2032	River System project file	.rsproj	RW	SOURCE_N_MF_80%_T_MF_90%_Habitat_Min_Flows_1980_2032_Ngaruroro_Offset_v2_Inc_Irongate_Mangaterere.csv	-	New minimum flows dataset for scenario based on Ngaruroro MF 80% and Tutaekuri MF 90% Habitat at MALF
						Added GW augmentation inflow nodes to subcats 104, 109, 123, 127 and 128
N MF 80% T MF 90% Habitat_Estimated Demand (18.0_SDZ1) 1980-2032	River System project file	.rsproj	RW	SOURCE_GW_Augmentation_Inflow_18.0_SDZ1_m3s.csv	SOURCE_GW_Augmentation_Inflow_18.0_SDZ1_m3s.csv	Added GW augmentation inflow datasets for the scenario
				Instream_Gains_ls_Base_Case_1980_2032_20170927_18.0_SDZ1.csv	M3_M5_daily_sc18_diff_comb__minus.csv	Incorporating modified MODFLOW gains and losses resulting from restriciting SD GW abstractions in SD Zone 1 and additional stream depletion resulting from GW augmentation to lowland streams
				Instream_Losses_ls_Base_Case_1980_2032_20170927_18.0_SDZ1.csv	M3_M5_daily_sc18_diff_comb__plus.csv	
Ngaruroro HFA_Estimated Demand (19.0_SDZ1) 1980-2032	River System project file	.rsproj	RW	SOURCE_Ngaruroro_HFA_Min_Flow_1980_2032.csv	-	Scenario based on version 8.3_SDZ1 but also simulates the abstraction of a high flow allocation from the Ngaruroro River
						Added new functions in order to simulate high flow allocation for the Ngauroro at Fernhill:
						1 - MFS_MinFlow.$Ngaruroro_River_at_Fernhill_4
						2 - WU_AbstractionDemand.$AD_SC_076_Ngaruroro_River_at_Fernhill_4_HFA
						3 - MFS_RestrictionIndex.$RI_Ngaruroro_River_at_Fernhill_4
						4 - WU_AbstractionRate.$AR_SC_076_Ngaruroro_River_at_Fernhill_4

Appendix B Modelled surface water abstraction

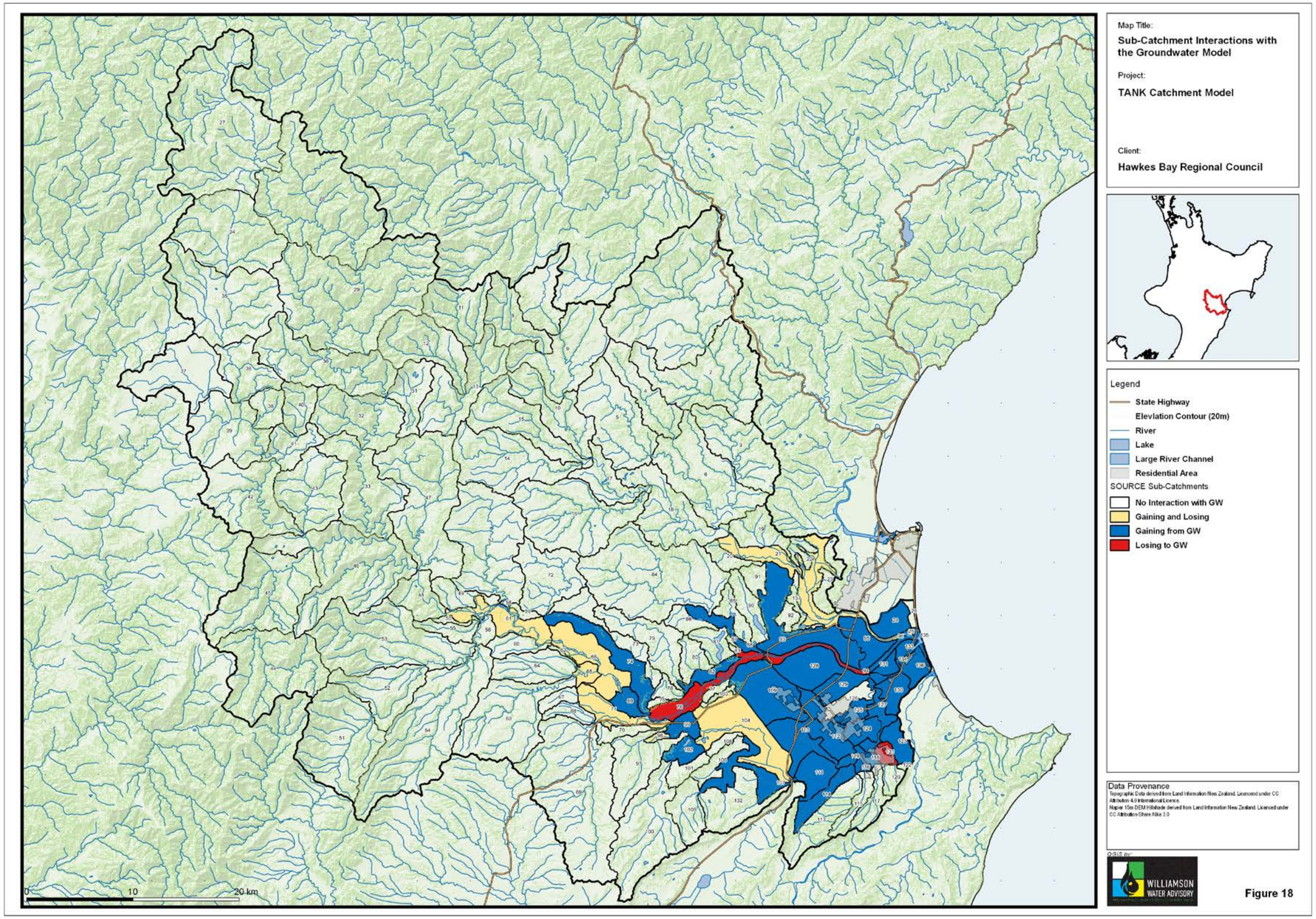
The following table shows the modelled surface water abstraction within the sub-catchments upstream of each flow management site. The table presents the highest total daily rate calculated for each site for the 'estimated future demand' and the 'maximum allocation'.

Catchment	Flow management site	Modelled surface water abstraction upstream of flow management site (highest total daily rate)	
		Estimated future demand (l/s)	Maximum allocation (l/s)
Tūtaekurī	Tūtaekurī River at Puketapu HBRC Site	448	826
Ngaruroro	Maraekakaho Stream D/S Tait Rd	16.9	38.6
	Ngaruroro River at Fernhill	765	1610
	Tūtaekurī Waimate Stm at Goods Bridge	106.9	439.8
Karamū	Awanui Stream at Flume	59.8	127
	Irongate Stream at Clarkes Weir	1.1	7.6
	Karamū Stream at Floodgates	85.8	190.1
	Karewarewa Stream at Paki Paki	59.8	127
	Louisa Stream at Te Aute Road	14.4	25
	Mangateretere Stream at Napier Road	1.5	3.5
	Raupare Drain at Ormond Road	39.6	87

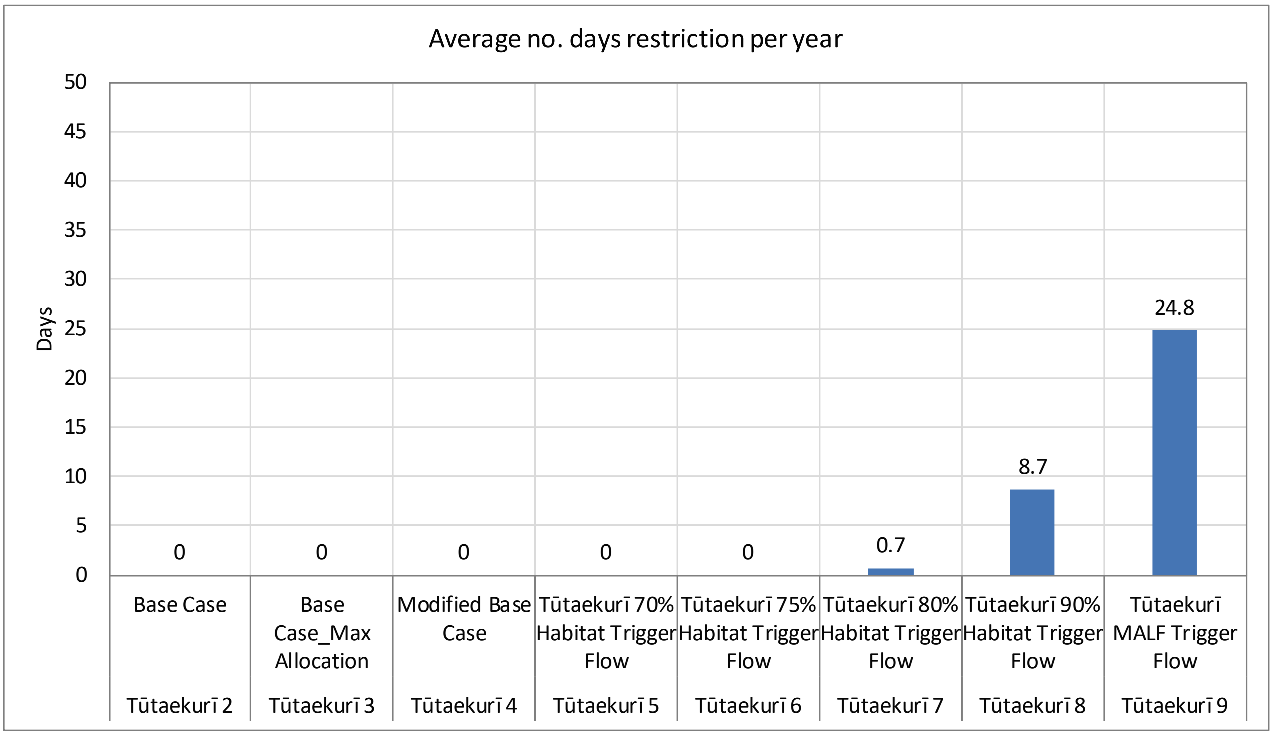
NOTE: Surface water abstractions within the Poukawa sub-catchment are excluded from all modelled abstraction in the Karamu catchment.

Appendix C SOURCE model sub-catchment interactions with the MODFLOW groundwater model

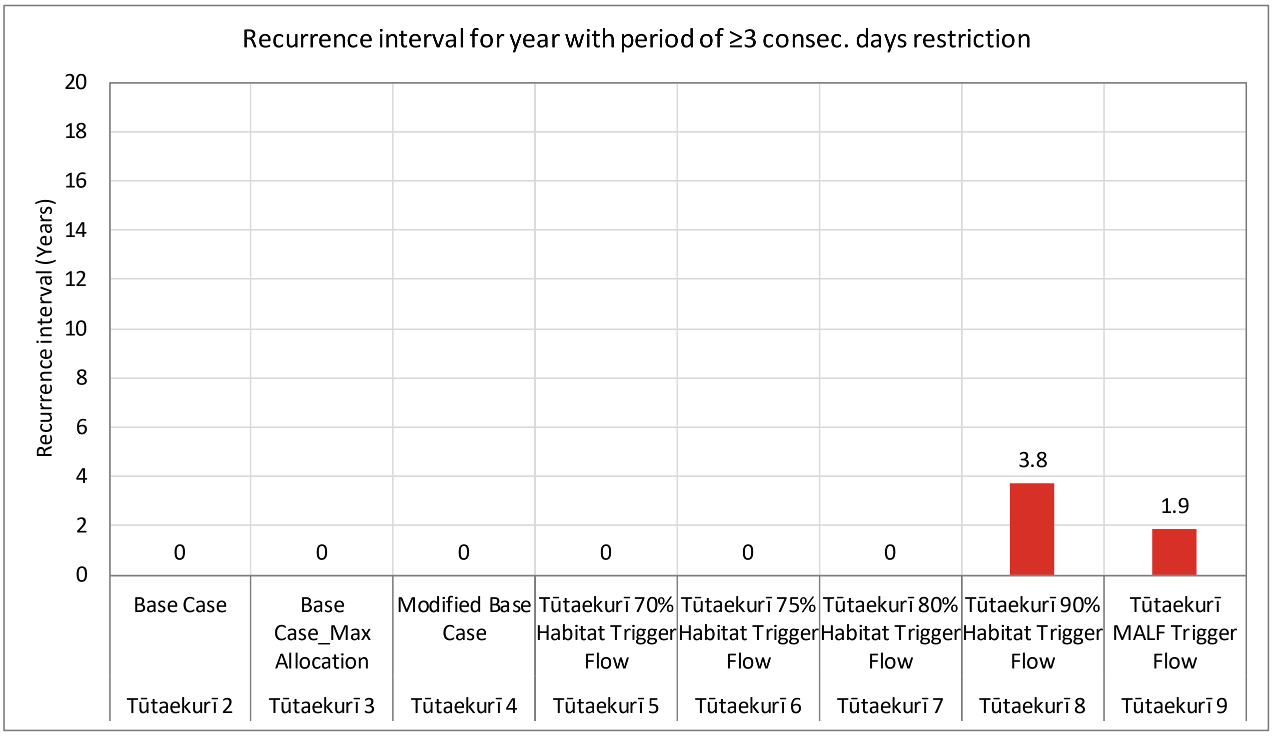
The following map was sourced from Williamson and Diack (2018) and it shows the sub-catchments in the SOURCE model that interact (gaining or losing) with the MODFLOW groundwater model.



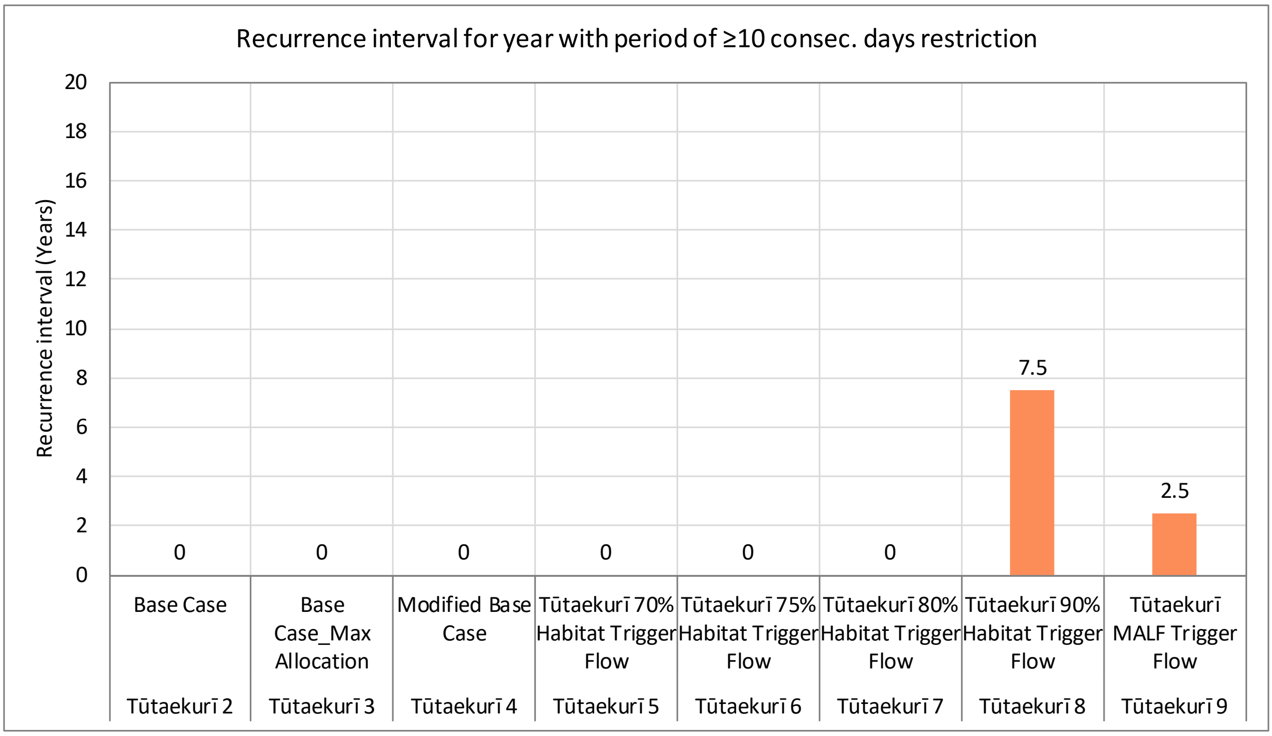
Appendix D Graphed restriction statistics for Tūtaekurī and Ngaruroro cease-take trigger flow scenarios



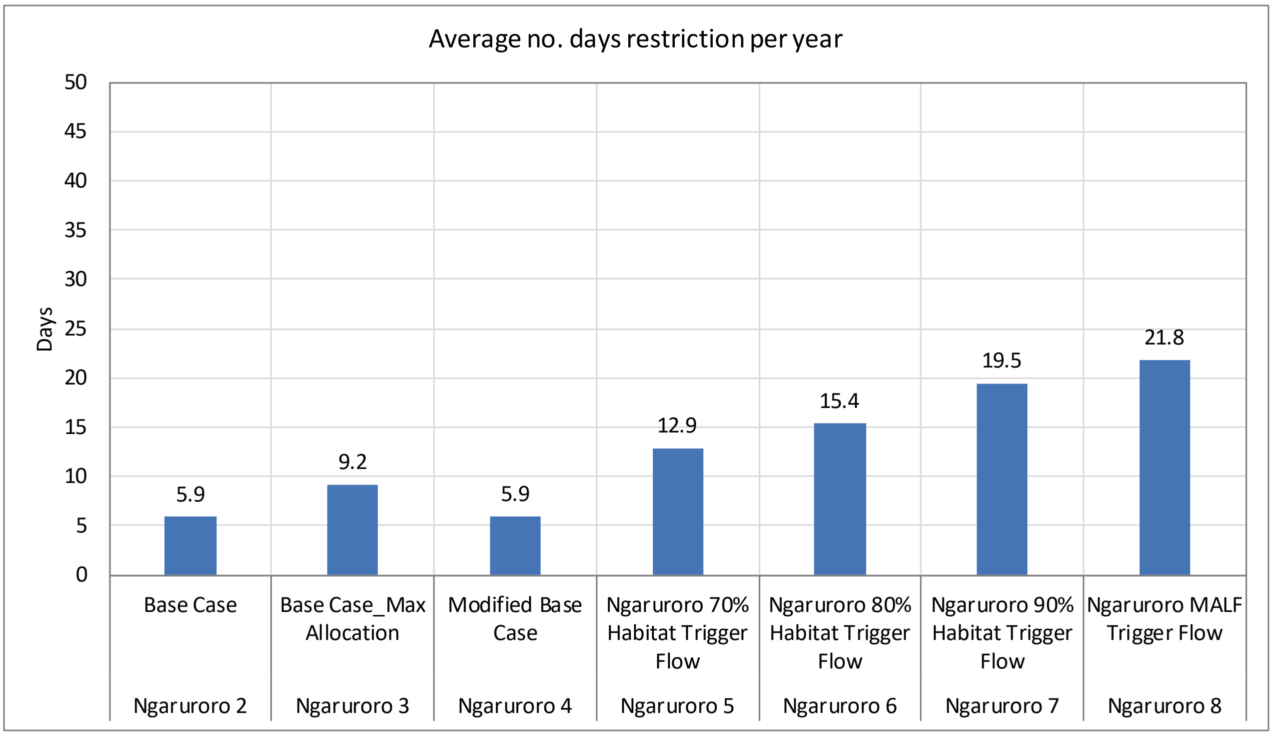
Tutaekuri cease-take trigger flow scenarios – Average number of days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



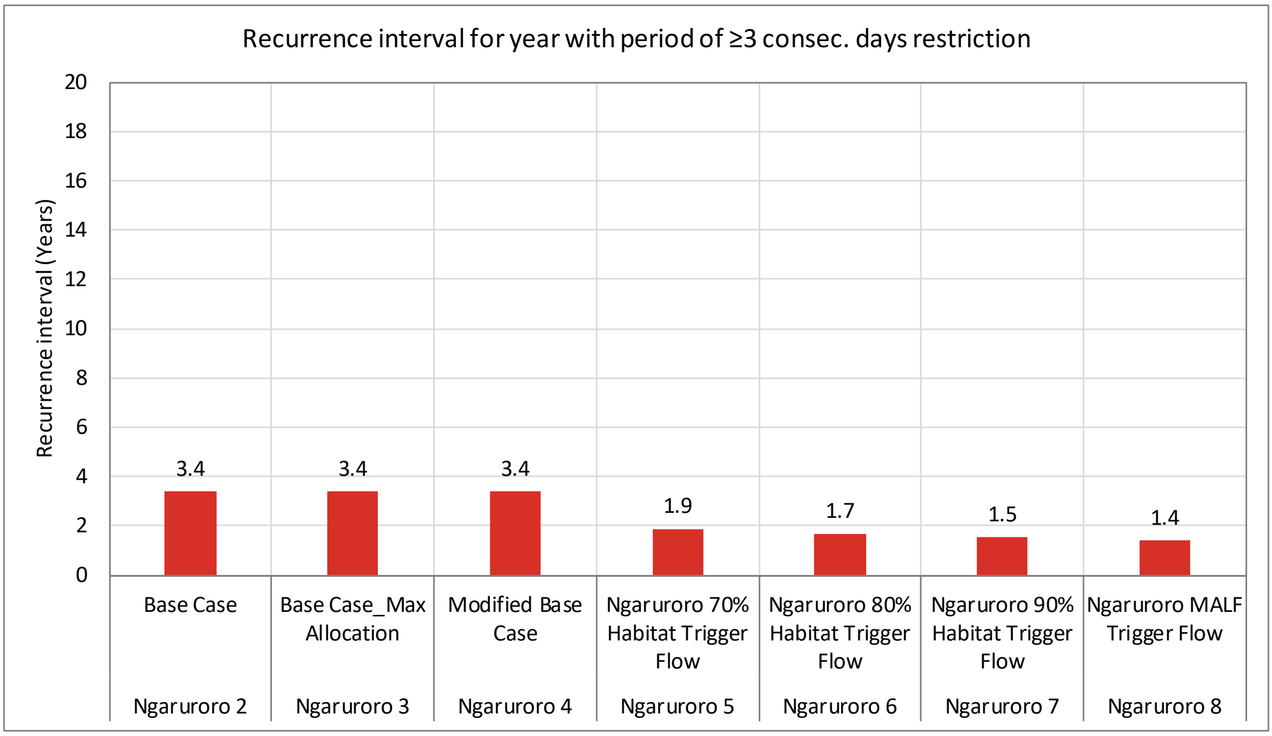
Tutaekuri cease-take trigger flow scenarios – Frequency of a year with period of >=3 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



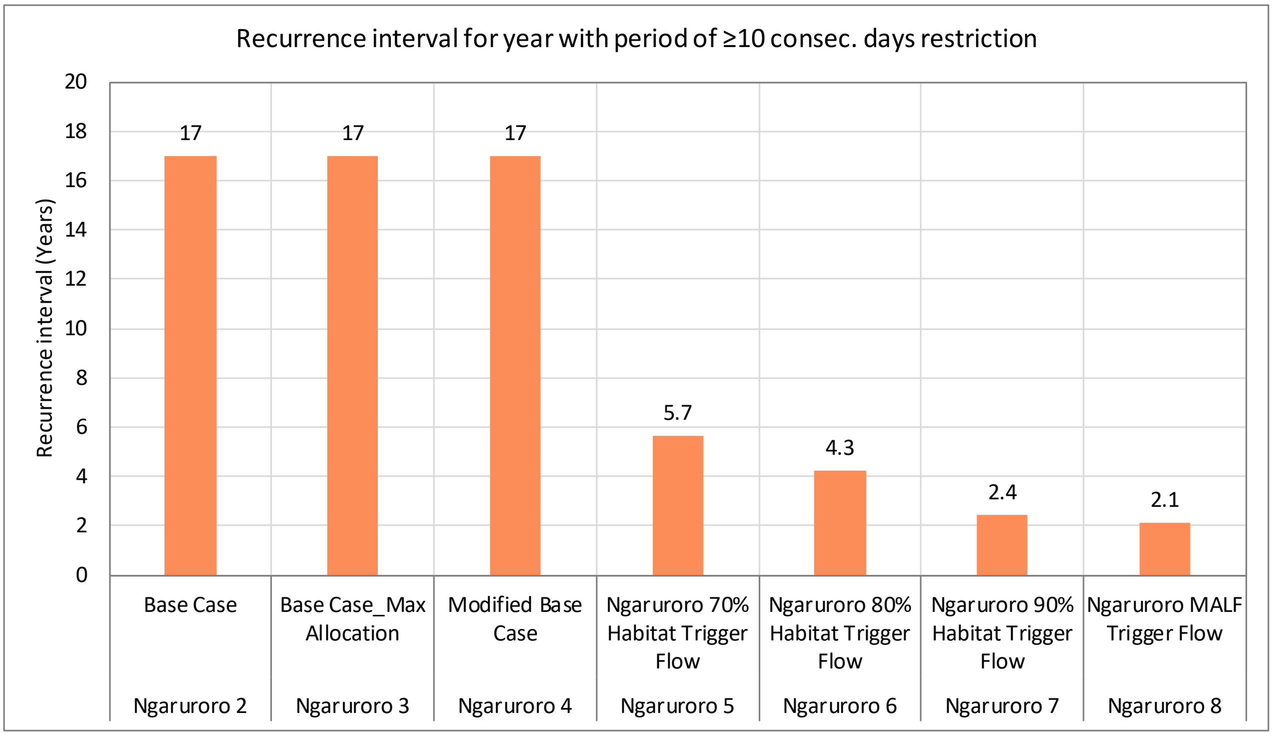
Tutaekuri cease-take trigger flow scenarios – Frequency of a year with period of >=10 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



Ngaruroro cease-take trigger flow scenarios – Average number of days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



Ngaruroro cease-take trigger flow scenarios – Recurrence interval for a year with a period of ≥3 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



Ngaruroro cease-take trigger flow scenarios – Recurrence interval for a year with a period of ≥10 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.

Appendix E River flow statistic definitions

A range of summary river flow statistics has been calculated from the scenario modelled flow records for each flow management site. The summary flow statistics are defined as:

1) Minimum - The lowest daily mean flow over the period of record.

2) Maximum - The highest daily mean flow over the period of record.

3) Mean - A fundamental statistic of a flow record. This is the average flow over the period of record.

4) Median - The flow that is equalled or exceeded for 50% of the time over the period of record.

5) Mean annual low flow (MALF) - Mean annual low flow (MALF) - This is the average of annual low flows (ALF) in a flow record. In this report, ALFs are calculated for each hydrological year (Jul-Jun) from a 7-day moving average of daily mean flows. ALFs are excluded from years with gaps in the flow record at times when the annual minimum may have occurred. Hawke's Bay rivers regularly experience prolonged periods of low flow conditions over the summer months during which the lowest flow typically occurs. A hydrological year is used to calculate ALFs rather than a calendar year (Jan-Dec) so that the lowest flow from each annual summer low flow event is used in the calculation. If the calendar year was used, low flows from the same event could be selected as the lowest value in two different years which would bias the sample of ALFs. A 7-day averaging interval is considered the most relevant when taking into account ecological processes, as it smooths out short term flow fluctuations which are less important to in-stream biota, focussing on longer low flow events that dry out parts of the river bed (Henderson & Diettrich 2007).

6) Q95 - The daily mean flow that is equalled or exceeded for 95% of the time over the period of record. The Q95 is used as a descriptor of the low flow of a river.

7) Q75 - The daily mean flow that is equalled or exceeded for 75% of the time over the period of record. The Q75 is commonly referred to as the lower quartile flow.

8) Q25 - The daily mean flow that is equalled or exceeded for 25% of the time over the period of record. The Q25 is commonly referred to as the upper quartile flow.

9) Q5 - The daily mean flow that is equalled or exceeded for 5% of the time over the period of record. The Q5 is used as a descriptor of the high flow of a river[3].

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[3] In this report, 'Q5' is a high flow statistic, whereas in other regions a 'Q5' flow often refers to a 'one in five year 7-day low flow', which is a flow that has a 20 percent chance of occurring in any one year (or a likelihood of occurrence of once in every five years, also termed a '5-year return period').

Appendix F Full suite of flow statistics for cease-take trigger flow scenarios

All flow statistics are based on the analysis of a full hydrological year (Jul-Jun) for the full modelled record 2015-2032. The definitions of all presented river flow statistics are provided in Appendix D.

Ngaruroro cease-take trigger flow scenarios

Ngaruroro River at Fernhill

	Ngaruroro River at Fernhill					
	Cease-take trigger flow scenario					
	Ngaruroro 1	Ngaruroro 2	Ngaruroro 3	Ngaruroro 4	Ngaruroro 5	Ngaruroro 6
Flow statistic	Naturalised	Base Case	Base Case_Max Allocation	Modified Base Case	Ngaruroro 70% Habitat Trigger Flow	Ngaruroro 80% Habitat Trigger Flow
Minimum	1548	1261	1258	1255	1255	1255
Maximum	8795786	8784913	8784947	8784879	8784879	8784879
Mean	47276	46603	46236	46601	46609	46613
Median	23564	23101	22824	23100	23100	23100
MALF	5035	3842	3419	3837	3935	3967
Q95	5576	4221	3534	4220	4231	4243
Q75	13983	13012	12405	13009	13011	13011
Q25	43738	43410	43233	43409	43409	43409
Q5	105611	105331	105185	105330	105330	105330

Tūtaekurī cease-take trigger flow scenarios

Tūtaekurī River at Puketapu HBRC Site

	Tūtaekurī River at Puketapu HBRC Site					
	Cease-take trigger flow scenario					
	Tūtaekurī 1	Tūtaekurī 2	Tūtaekurī 3	Tūtaekurī 4	Tūtaekurī 6	Tūtaekurī 8
Flow statistic	Naturalised	Base Case	Base Case_Max Allocation	Modified Base Case	Tūtaekurī 75% Habitat Trigger Flow	Tūtaekurī 90% Habitat Trigger Flow
Minimum	2850	2651	2482	2511	2511	2814
Maximum	577820	577814	577814	577814	577814	577814
Mean	17823	17629	17531	17628	17628	17634
Median	7612	7470	7357	7467	7467	7472
MALF	3965	3676	3595	3658	3658	3728
Q95	3843	3566	3503	3563	3563	3575
Q75	5594	5253	5117	5249	5249	5244
Q25	15488	15349	15292	15371	15371	15373
Q5	61195	61230	60989	61135	61135	61230

Karamū and tributaries cease-take trigger flow scenarios

Awanui Stream at Flume

	Awanui Stream at Flume			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	**Naturalised**	**Base Case**	**Base Case_Max Allocation**	**Modified Base Case**
Minimum	213	19	19	19
Maximum	54215	54045	54045	54045
Mean	1188	936	932	935
Median	634	380	376	379
MALF	330	57	54	56
Q95	350	57	57	57
Q75	474	181	179	181
Q25	974	764	760	764
Q5	3464	3261	3231	3261

Irongate Stream at Clarkes Weir

	Irongate Stream at Clarkes Weir			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	**Naturalised**	**Base Case**	**Base Case_Max Allocation**	**Modified Base Case**
Minimum	185	38	30	35
Maximum	4041	3932	3932	3931
Mean	469	327	327	327
Median	429	277	276	276
MALF	208	76	75	76
Q95	200	67	66	66
Q75	313	152	152	151
Q25	544	417	417	417
Q5	870	750	750	750

Karamū Stream at Floodgates

	Karamū Stream at Floodgates			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	**Naturalised**	**Base Case**	**Base Case_Max Allocation**	**Modified Base Case**
Minimum	1483	621	608	619
Maximum	84244	83650	83650	83649
Mean	4303	3495	3490	3494
Median	3411	2582	2579	2582
MALF	1733	872	868	870
Q95	1696	816	814	814
Q75	2524	1562	1557	1559
Q25	4434	3756	3752	3755
Q5	9698	8992	8993	8990

Karewarewa Stream at Paki Paki

	Karewarewa Stream at Paki Paki			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	**Naturalised**	**Base Case**	**Base Case_Max Allocation**	**Modified Base Case**
Minimum	56	0	0	0
Maximum	38517	38346	38346	38346
Mean	753	501	497	500
Median	479	212	209	211
MALF	293	22	21	22
Q95	295	4	4	4
Q75	380	89	86	88
Q25	643	438	431	437
Q5	1676	1481	1484	1481

Louisa Stream at Te Aute Road

	Louisa Stream at Te Aute Road			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	**Naturalised**	**Base Case**	**Base Case_Max Allocation**	**Modified Base Case**
Minimum	24	21	5	22
Maximum	8966	8966	8966	8966
Mean	249	245	244	245
Median	127	122	121	122
MALF	48	43	42	43
Q95	43	37	36	37
Q75	78	74	71	74
Q25	217	216	215	216
Q5	895	891	892	891

Mangateretere Stream at Napier Road

	Mangateretere Stream at Napier Road			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	Naturalised	Base Case	Base Case_Max Allocation	Modified Base Case
Minimum	0	0	0	0
Maximum	1960	1814	1814	1813
Mean	319	181	181	181
Median	348	163	163	163
MALF	87	15	15	15
Q95	114	27	27	27
Q75	196	73	73	73
Q25	413	270	270	270
Q5	514	395	395	395

Raupare Drain at Ormond Road

	Raupare Drain at Ormond Road			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	Naturalised	Base Case	Base Case_Max Allocation	Modified Base Case
Minimum	553	290	271	287
Maximum	4185	4036	4011	4036
Mean	839	674	672	673
Median	780	627	628	627
MALF	589	349	341	346
Q95	575	333	331	330
Q75	672	458	460	456
Q25	915	797	796	797
Q5	1267	1150	1150	1150

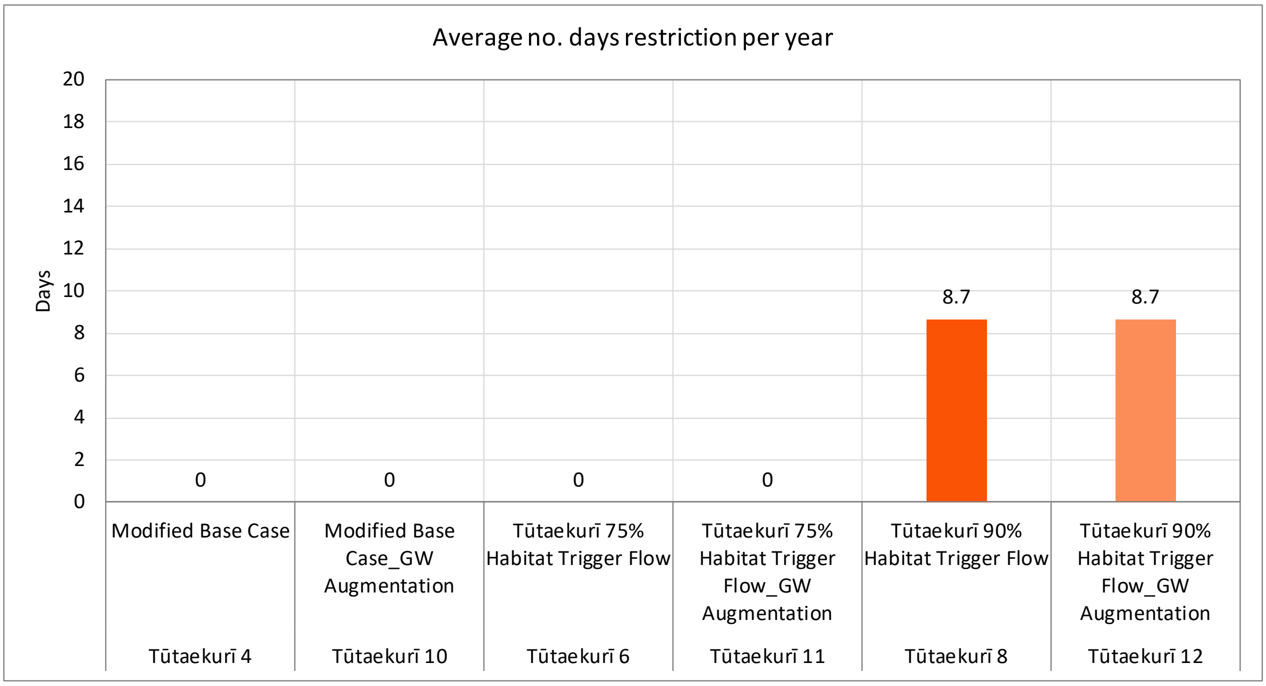
Maraekakaho Stream D/S Tait Road

	Maraekakaho Stream D/S Tait Rd			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	Naturalised	Base Case	Base Case_Max Allocation	Modified Base Case
Minimum	106	106	75	106
Maximum	30687	30687	30687	30687
Mean	758	751	744	751
Median	315	307	297	307
MALF	172	165	152	165
Q95	168	161	150	161
Q75	243	233	223	233
Q25	524	520	515	520
Q5	2537	2536	2536	2536

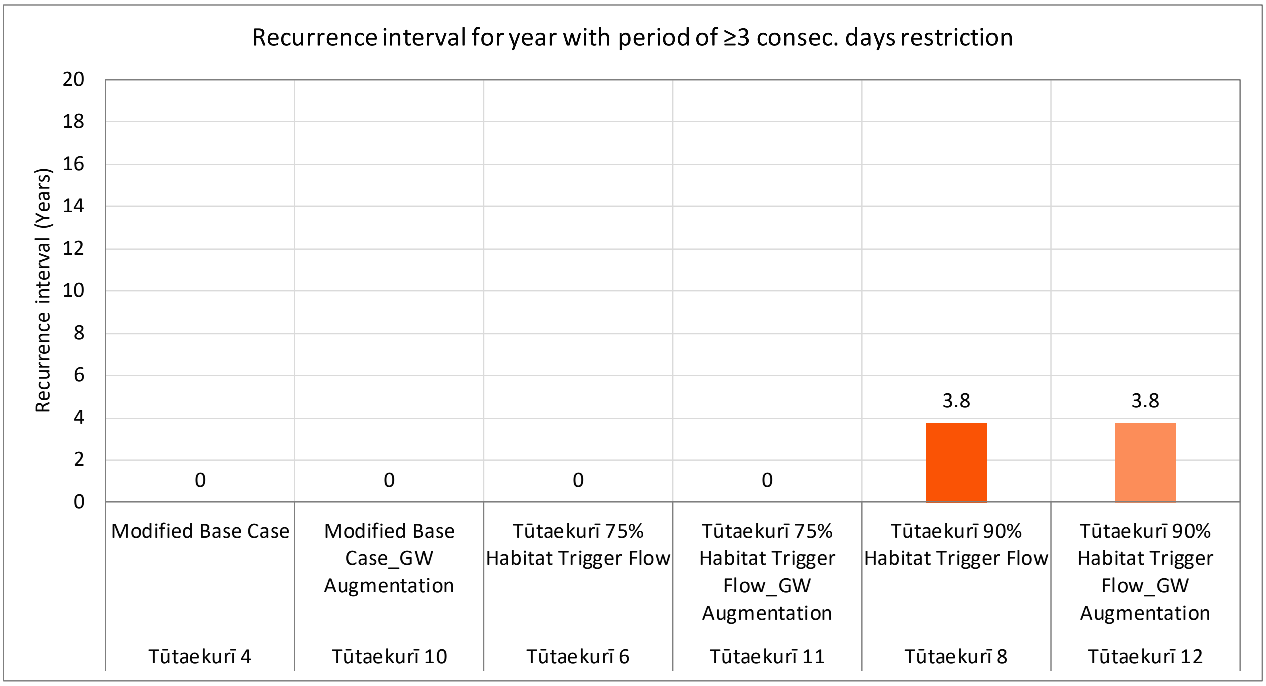
Tūtaekurī Waimate Stm at Goods Bridge

	Tūtaekurī Waimate Stm at Goods Bridge			
	Cease-take trigger flow scenario			
	Karamū+ Tributaries 1	Karamū+ Tributaries 2	Karamū+ Tributaries 3	Karamū+ Tributaries 4
Flow statistic	**Naturalised**	**Base Case**	**Base Case_Max Allocation**	**Modified Base Case**
Minimum	990	735	735	735
Maximum	12812	12660	12660	12660
Mean	3018	2728	2694	2727
Median	2809	2544	2522	2543
MALF	2426	2013	1951	2011
Q95	2427	1970	1895	1967
Q75	2590	2210	2166	2208
Q25	3175	2969	2960	2969
Q5	4172	3967	3963	3967

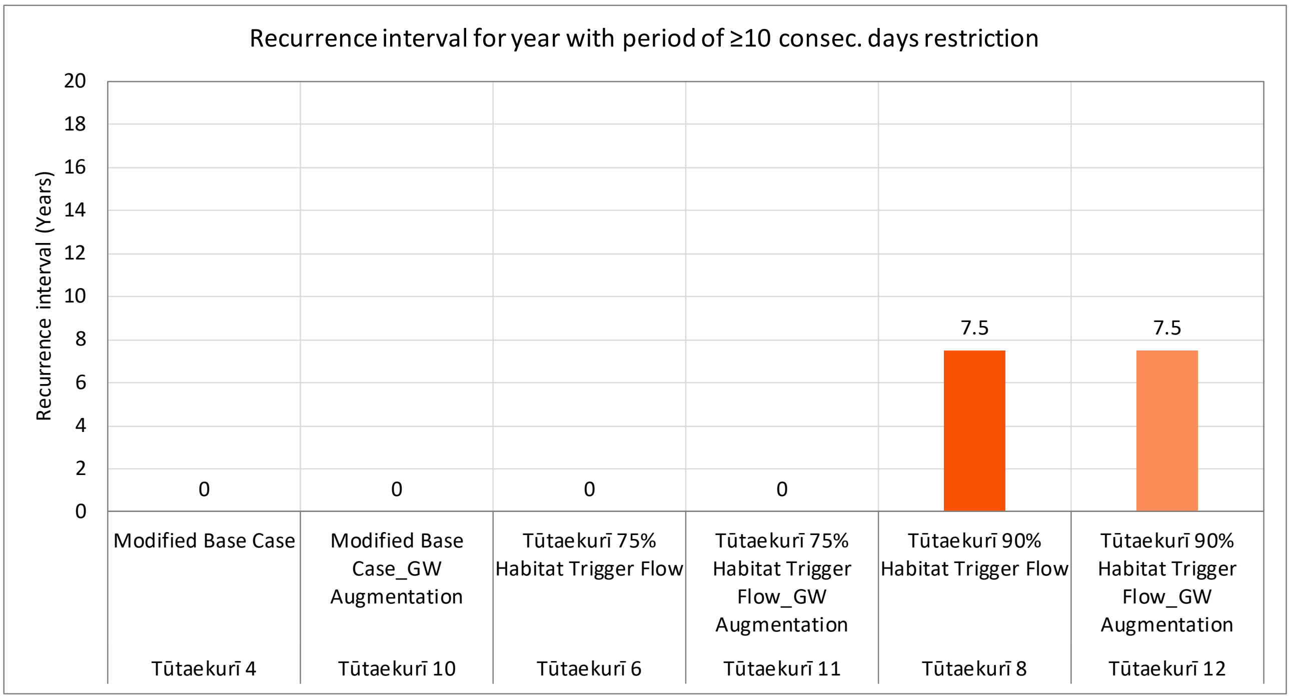
Appendix G Graphed restriction statistics for Tūtaekurī and Ngaruroro groundwater augmentation to surface water scenarios



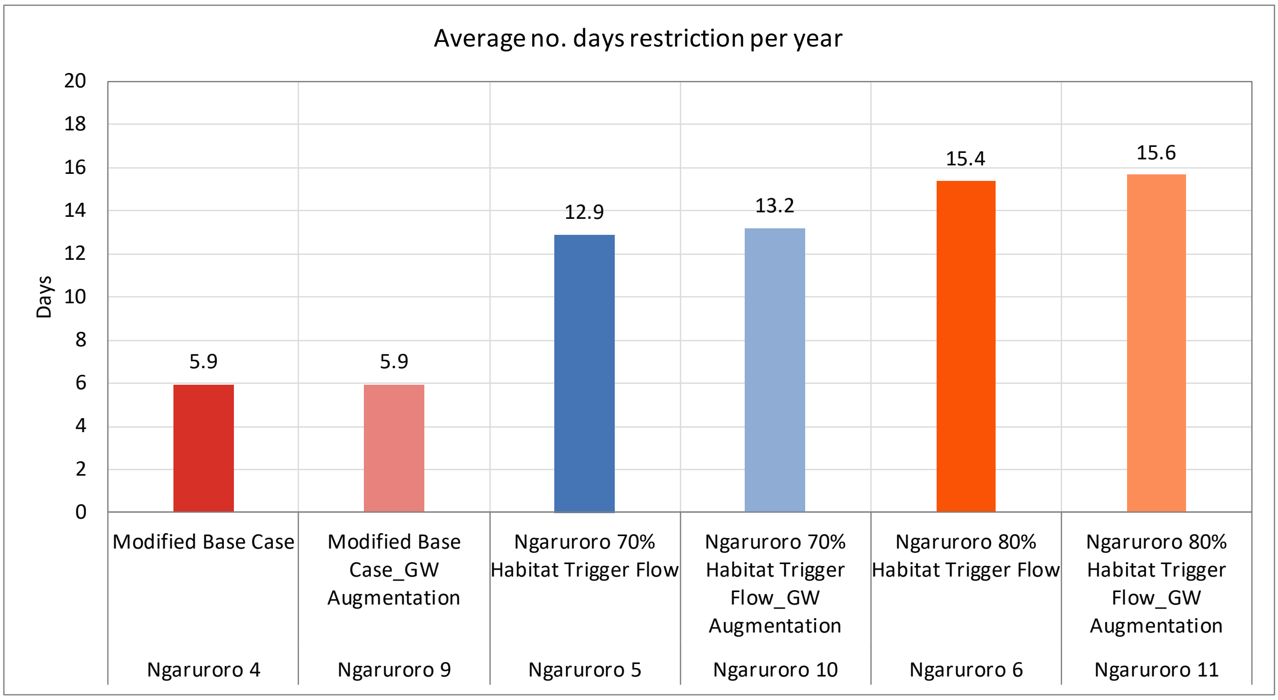
Tūtaekurī groundwater augmentation to surface water scenarios – Average number of days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



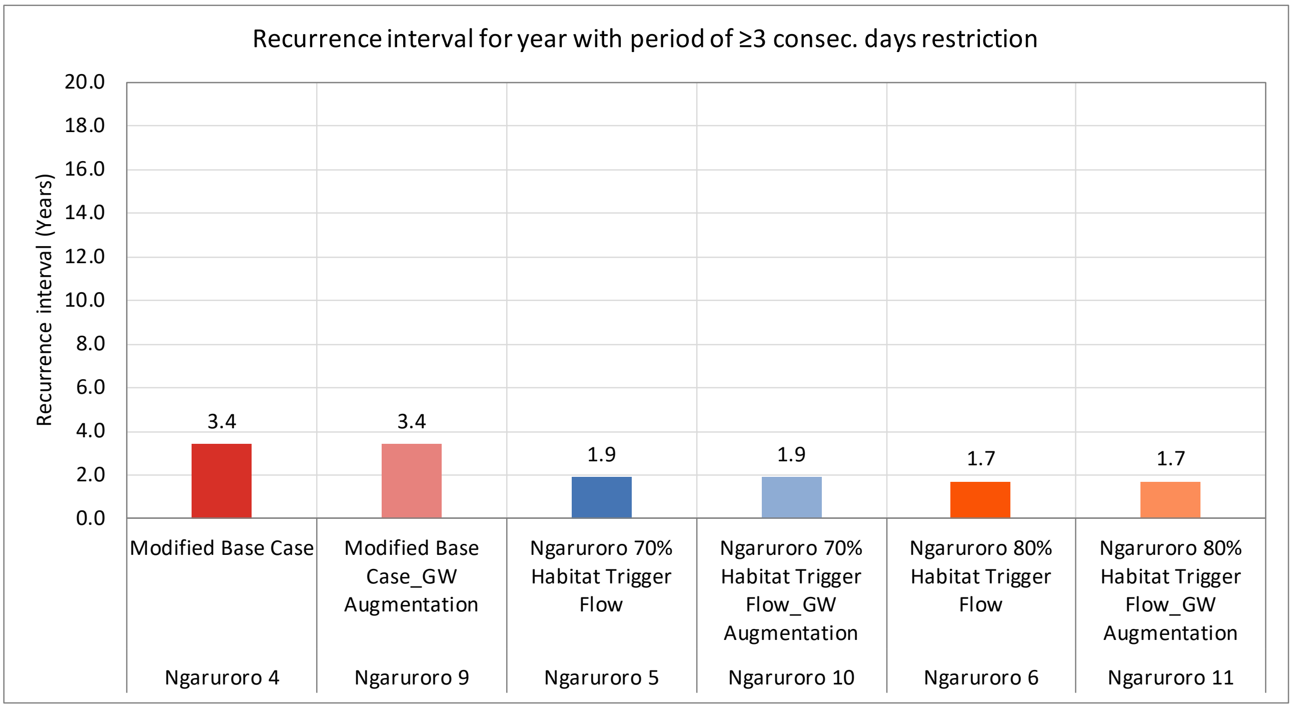
Tūtaekurī groundwater augmentation to surface water scenarios – Recurrence interval for a year with a period of ≥3 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



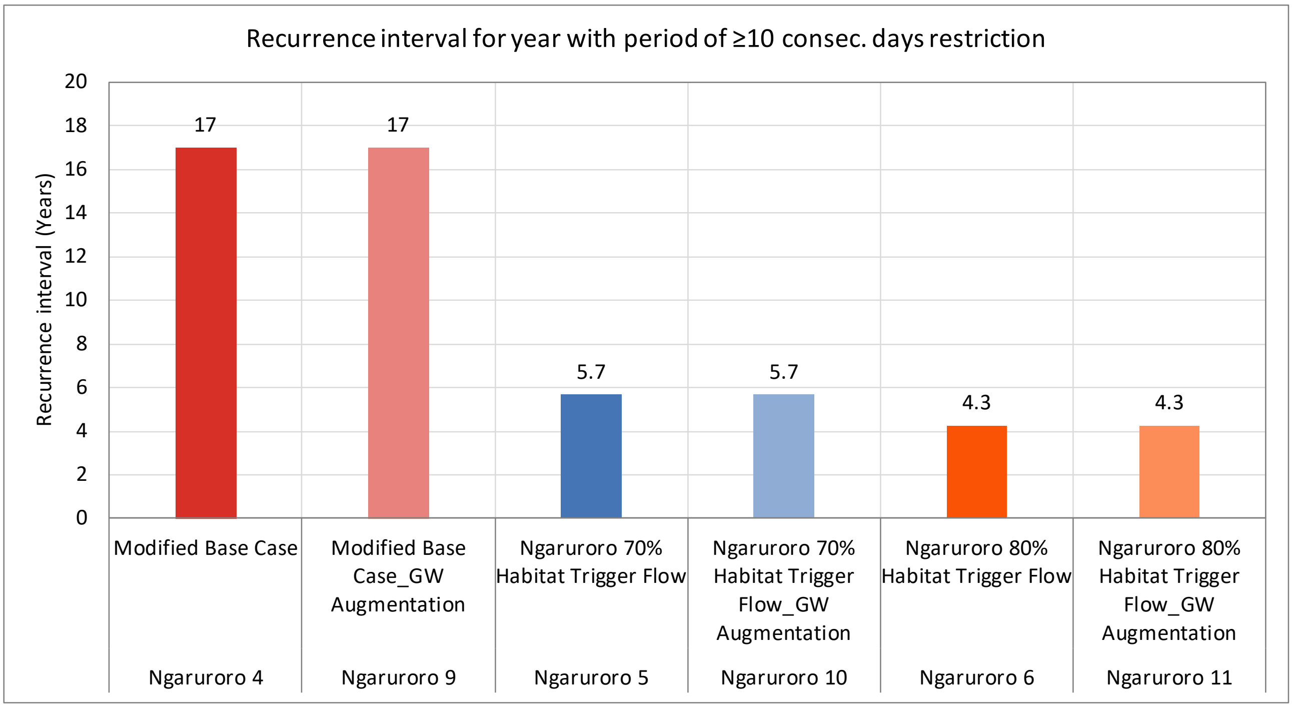
Tūtaekurī groundwater augmentation to surface water scenarios – Recurrence interval for a year with a period of ≥10 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



Ngaruroro groundwater augmentation to surface water scenarios – Average number of days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



Ngaruroro groundwater augmentation to surface water scenarios – Recurrence interval for a year with a period of ≥3 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.



Ngaruroro groundwater augmentation to surface water scenarios – Frequency of a year with period of ≥10 consecutive days on restriction per year. All restriction statistics are based on the analysis of 9 month irrigation seasons from September to May for the modelled simulations between 2015 and 2032.

Appendix H Full suite of flow statistics for groundwater augmentation to surface water scenarios

All flow statistics are based on the analysis of a full hydrological year (Jul-Jun) for the full modelled record 2015-2032. The definitions of all presented river flow statistics are provided in Appendix D.

Ngaruroro groundwater augmentation to surface water scenarios

Ngaruroro River at Fernhill

	Ngaruroro River at Fernhill		
	Groundwater augmentation to surface water scenario		
	Ngaruroro 9	Ngaruroro 10	Ngaruroro 11
Flow statistic	Modified Base Case_GW Augmentation	Ngaruroro 70% Habitat Trigger Flow_GW Augmentation	Ngaruroro 80% Habitat Trigger Flow_GW Augmentation
Minimum	1244	1244	1244
Maximum	8784574	8784574	8784574
Mean	46591	46600	46603
Median	23096	23096	23096
MALF	3821	3914	3949
Q95	4207	4221	4230
Q75	12998	13000	13001
Q25	43404	43404	43404
Q5	105325	105325	105325

Tūtaekurī groundwater augmentation to surface water scenarios

Tūtaekurī River at Puketapu HBRC Site

	Tūtaekurī River at Puketapu HBRC Site		
	Groundwater augmentation to surface water scenario		
	Tūtaekurī 10	Tūtaekurī 11	Tūtaekurī 12
Flow statistic	Modified Base Case_GW Augmentation	Tūtaekurī 75% Habitat Trigger Flow_GW Augmentation	Tūtaekurī 90% Habitat Trigger Flow_GW Augmentation
Minimum	2511	2511	2814
Maximum	577814	577814	577814
Mean	17628	17628	17634
Median	7466	7466	7472
MALF	3658	3658	3728
Q95	3563	3563	3575
Q75	5249	5249	5244
Q25	15371	15371	15373
Q5	61135	61135	61230

Karamū and tributaries groundwater augmentation to surface water scenarios

Awanui Stream at Flume

	Awanui Stream at Flume
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	22
Maximum	54042
Mean	942
Median	376
MALF	92
Q95	112
Q75	183
Q25	761
Q5	3254

Irongate Stream at Clarkes Weir

	Irongate Stream at Clarkes Weir
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	98
Maximum	3930
Mean	330
Median	276
MALF	106
Q95	103
Q75	151
Q25	416
Q5	749

Karamū Stream at Floodgates

	Karamū Stream at Floodgates
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	1112
Maximum	83644
Mean	3537
Median	2577
MALF	1177
Q95	1148
Q75	1579
Q25	3752
Q5	8986

Karewarewa Stream at Paki Paki

	Karewarewa Stream at Paki Paki
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	46
Maximum	38344
Mean	507
Median	208
MALF	67
Q95	66
Q75	85
Q25	435
Q5	1477

Louisa Stream at Te Aute Road

	Louisa Stream at Te Aute Road
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	22
Maximum	8966
Mean	245
Median	122
MALF	43
Q95	37
Q75	74
Q25	216
Q5	891

Mangateretere Stream at Napier Road

	Mangateretere Stream at Napier Road
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	61
Maximum	1811
Mean	196
Median	160
MALF	91
Q95	94
Q75	104
Q25	269
Q5	394

Raupare Drain at Ormond Road

	Raupare Drain at Ormond Road
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	301
Maximum	4035
Mean	671
Median	625
MALF	344
Q95	323
Q75	455
Q25	795
Q5	1148

Maraekakaho Stream D/S Tait Road

	Maraekakaho Stream D/S Tait Rd
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	106
Maximum	30687
Mean	751
Median	307
MALF	165
Q95	161
Q75	233
Q25	520
Q5	2536

Tūtaekurī Waimate Stm at Goods Bridge

	Tūtaekurī Waimate Stm at Goods Bridge
	Groundwater augmentation to surface water scenario
	Karamū+ Tributaries 5
Flow statistic	**Modified Base Case_GW Augmentation**
Minimum	734
Maximum	12659
Mean	2724
Median	2542
MALF	1998
Q95	1954
Q75	2207
Q25	2968
Q5	3966

Appendix I Additional flow statistics for high flow allocation scenarios

Predicted number of 3x median events in the individual years of modelled record under each scenario and the predicted change from zero HFA.

All statistics are based on the analysis of calendar years (Jan-Dec) for the modelled record from 2016 to 2031.

Year (Jan-Dec)	HFA = Zero l/s	HFA = 2000 l/s	*Change from Zero HFA*	HFA = 4000 l/s	*Change from Zero HFA*	HFA = 6000 l/s	*Change from Zero HFA*	HFA = 8000 l/s	*Change from Zero HFA*
2016	13	11	*-2*	10	*-3*	10	*-3*	10	*-3*
2017	12	12	*0*	12	*0*	12	*0*	11	*-1*
2018	10	10	*0*	10	*0*	10	*0*	10	*0*
2019	12	12	*0*	12	*0*	11	*-1*	11	*-1*
2020	11	11	*0*	11	*0*	11	*0*	11	*0*
2021	12	13	*1*	13	*1*	13	*1*	12	*0*
2022	14	14	*0*	14	*0*	14	*0*	14	*0*
2023	11	10	*-1*	10	*-1*	9	*-2*	10	*-1*
2024	15	15	*0*	15	*0*	15	*0*	15	*0*
2025	13	13	*0*	13	*0*	13	*0*	13	*0*
2026	14	14	*0*	14	*0*	14	*0*	14	*0*
2027	16	16	*0*	16	*0*	16	*0*	16	*0*
2028	14	14	*0*	14	*0*	14	*0*	13	*-1*
2029	14	14	*0*	14	*0*	13	*-1*	12	*-2*
2030	11	11	*0*	11	*0*	11	*0*	11	*0*
2031	9	8	*-1*	9	*0*	8	*-1*	8	*-1*