Groundwater quantity allocation limits for the West Coast Region: case study in the Upper Grey River Freshwater Management Unit

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National water management regulations, in particular, the new National Policy Statement for Freshwater Management (NPS-FM 2020), direct that regional councils and unitary authorities include water quantity limits into regional plans as soon as reasonably practicable.[1]

National water management regulations, in particular, the new National Policy Statement for Freshwater Management (NPS-FM 2020), direct that regional councils and unitary authorities include water quantity limits into regional plans.

The Ministry of Business, Innovation & Employment, through their Envirolink scheme, contracted GNS Science to provide a roadmap for the development of a groundwater quantity allocation framework for the West Coast Regional Council (WCRC; Mourot and White 2020) and to implement this methodology in a case study site (this study).

Currently, West Coast areas with the largest water allocation volumes and that are the most in need of a water allocation approach are the driest parts of the region: the headwater catchments of the northern Grey River catchment (i.e. Mawheraiti, Stony, and Rough rivers) and the Inangahua and Waimangaroa catchments. After discussion with WCRC freshwater resource managers, the catchments of the Mawheraiti, Stony, and Rough rivers were selected as a case study area for the methodology.

After a phase of data collation, a series of groundwater management zones (GMZ) were delineated for the study area, including a unique GMZ and two GMZs located on each side of the Mawheraiti River. The connectivity of groundwater to surface water bodies was then considered. Baseflow calculations indicated that approximately 50% of the stream flow of the Mawheraiti River (at Atarau Bridge) was baseflow (i.e. fed by groundwater). Protection of river baseflow was preliminarily identified as a management target by WCRC. Accordingly, water budget calculations were undertaken to assess limits that should satisfy this management target. For instance, in a scenario with one unique GMZ (area of 483 km^2), the average mean rainfall was estimated to 2154 mm/yr and the actual evapotranspiration to 655 mm/yr, suggesting that approximately 23 m^3/s of water outflow (groundwater and surface water) was ‘generated’ in the groundwater catchment in a ‘natural state’. Considering that 50% of the stream flow is baseflow, approximately 11.5 m^3/s should therefore be preserved to avoid reducing the Mawheraiti River baseflow. The remaining 11.5 m^3/s would then be available for groundwater recharge (i.e. groundwater residual recharge). Allocating 35% of the groundwater residual recharge would then provide c. 4 m^3/s for abstraction. This would include current and future allocation.

This case study demonstrated the scientific aspects of the allocation framework methodology. The next steps will include WCRC scientists working with the policy team to introduce a groundwater quantity allocation framework in the WCRC Regional Land and Water Plan. Consultation with the Grey FMU Group should then confirm the values and management targets and ensure that it is understood and will deliver the values that are of importance to the community and iwi. Finally, the draft framework identified in this report could be refined to address community needs.

1 Section 80A of the Resource Management Act 1991 requires regional councils to notify freshwater planning instruments by 31 December 2024 if their purpose is to give effect to the NPS-FM 2020.

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1.0 INTRODUCTION

The West Coast Regional Council (WCRC) has the fifth-largest region by area but the smallest rating base in New Zealand, but it must deliver the same services and functions as the other regions. WCRC therefore prioritises its actions in specific topics and areas where the greatest resource pressures occur and as directed by Central Government policies (Beaumont et al. 2018).

Following the NPS-FM 2014, amended 2017, which stated that "setting enforceable quality and quantity limits is a key purpose" (Ministry for the Environment 2017), WCRC has made the improvement of freshwater resource quality in the region one of its main focus points. In 2018, Freshwater Management Units (FMUs) were delineated across the region. The Regional Land and Water Plan outlines the importance of the groundwater resource and its quantity to serve several recognised uses, including domestic and public water supply, stock drinking water, irrigation and industrial uses. Groundwater is further recognised as extensively sustaining surface water flows across the region. Since 2012, the demand for groundwater has doubled in the region and, while no significant negative impacts have occurred, as a result of identified over-allocation, WCRC aims to improve the current management of the groundwater quantity across the region. The objective is to introduce allocation limits, in collaboration with the communities, to protect the freshwater resources and their community values, as per the NPS-FM requirements.

Due to groundwater technical expertise and resource limitation within the WCRC, the Ministry of Business, Innovation & Employment, through their Envirolink Scheme, commissioned GNS Science (GNS) to provide WCRC with a 'roadmap to groundwater quantity allocation' to initiate the development of an allocation framework for the region, which will subsequently lead to the introduction of allocation limits in the Regional Land and Water Plan (Mourot and White 2020), and to implement the roadmap methodology in a 'case study' (this study). WCRC staff expressed their interest in the Upper Grey River FMU as the case study area. The roadmap study integrated the new requirements of the updated NPS-FM (NPS-FM 2020; Ministry for the Environment 2020) to develop an evidence-based framework for regional groundwater allocation (Figure 1.1).

This case study applied the roadmap methodology of Mourot and White (2020) to develop science knowledge[2] (Figure 1.2), i.e. delineation of groundwater management zones, consideration of the connectivity of groundwater to surface water bodies and identification of preliminary management targets in the upper Grey River FMU.

The next steps of the process require WCRC scientists to work with their Policy team to develop the groundwater allocation framework; engage with the Grey River Group and community to define values of importance, actions required to maintain acceptable stream flows and management targets/limits; and integrate these limits in the Regional Land and Water Plan. This limit-setting process could then be rolled out to other areas of the region, with a priority to those under the highest pressures.

2 Mourot and White (2020) also contains an overview of the policy framework as relevant to the development of the roadmap.

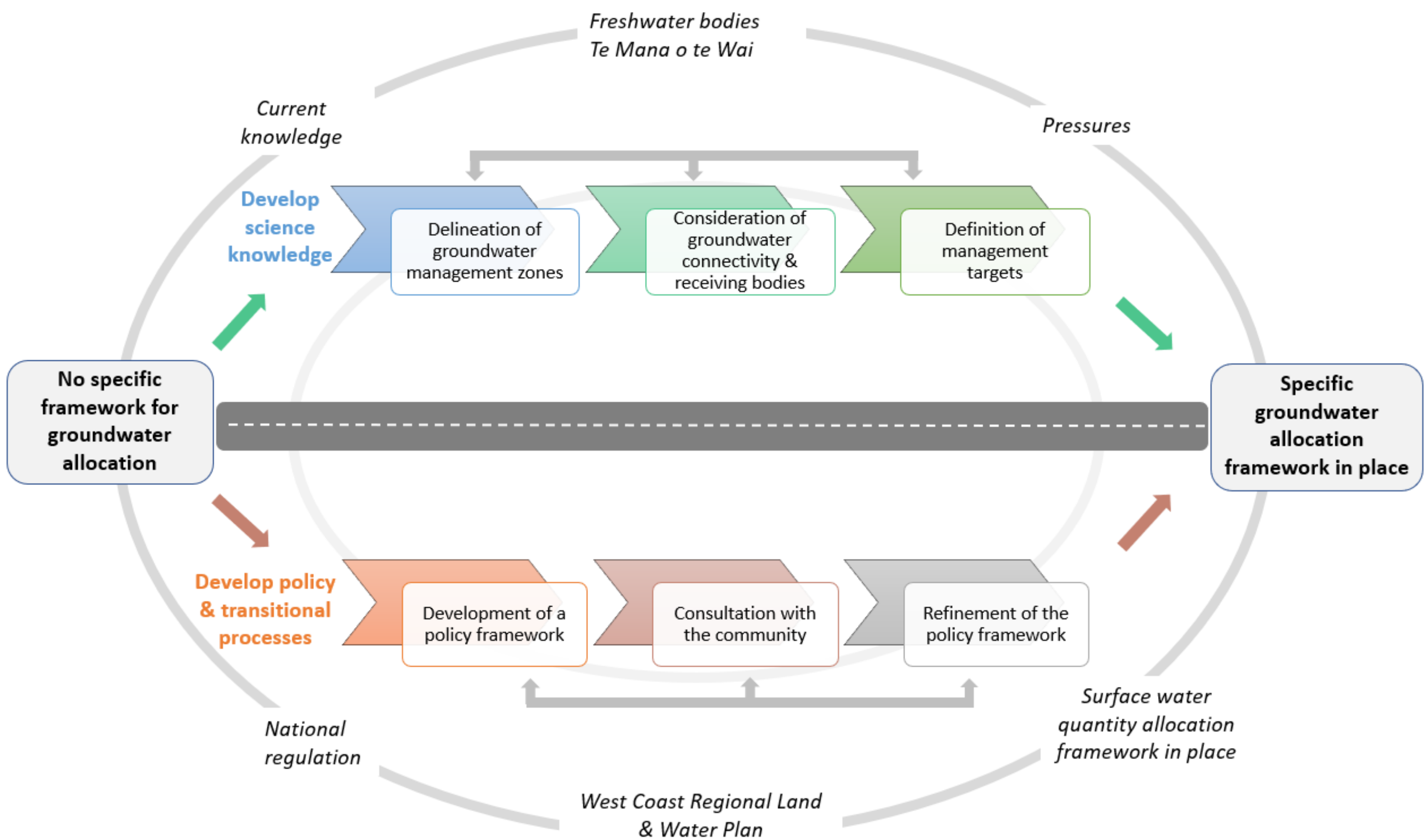

Figure 1.1 Schematic of the proposed roadmap to groundwater quantity allocation for the West Coast region (Mourot and White 2020).

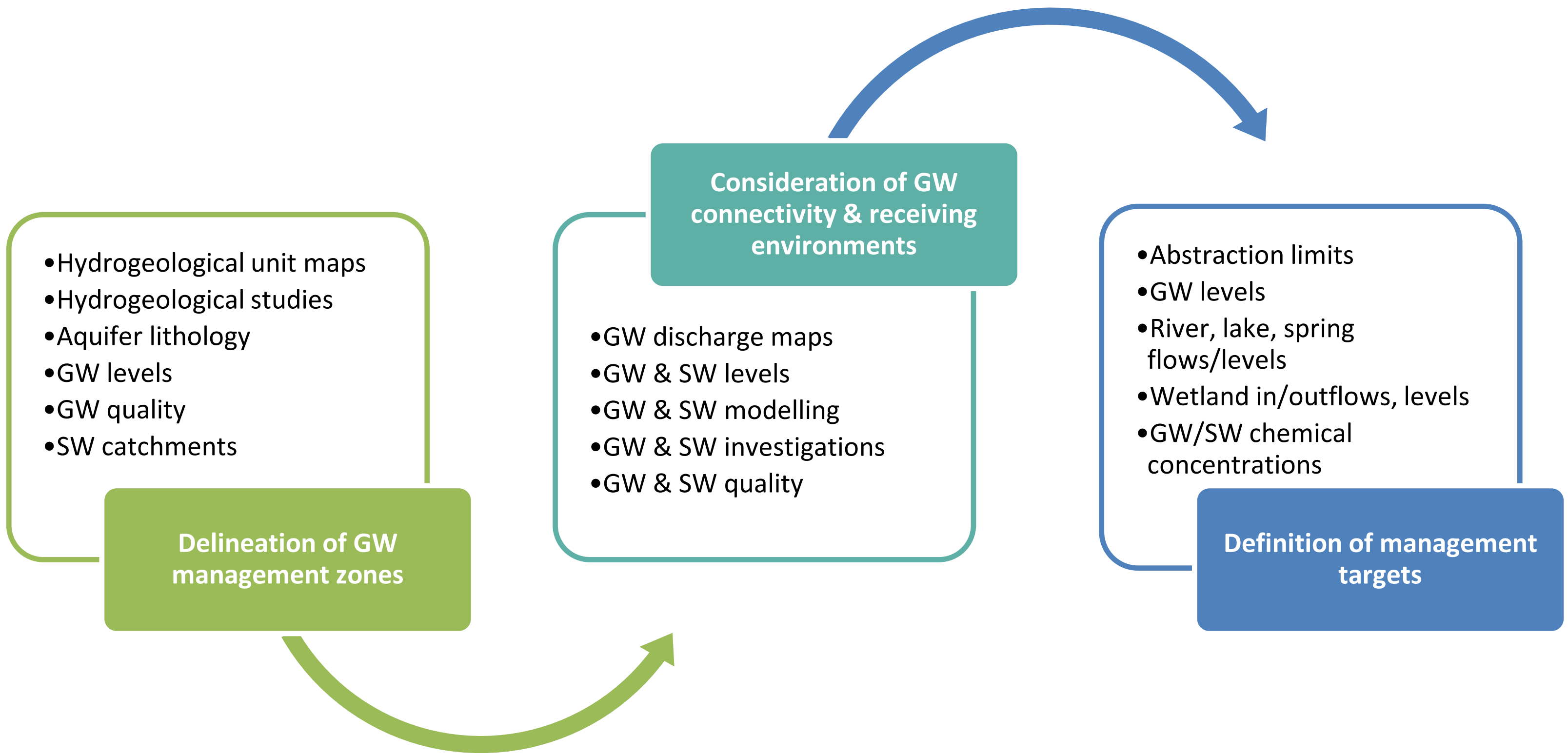

Figure 1.2 Development of science knowledge of the proposed roadmap to groundwater quantity allocation for the West Coast region (Mourot and White 2020). GW: groundwater, SW: surface water.

2.0 INPUT DATA AND METHODS

2.1 Study Area

WCRC scientists selected the upper Grey River FMU (Figure 2.1) for the case study due to the current pressure on the surface water resources during the irrigation season, with a potential interest in promoting abstraction of groundwater if sustainable for the freshwater resources of the catchment.

2.2 Input Data

A combination of regional- and national-scale datasets were used in this case study to delineate groundwater management zones, consider groundwater connectivity and propose management targets and limits; these datasets are described in the following sections.

2.2.1 West Coast Regional Council Datasets

WCRC provided the following datasets for the study area and vicinity (Figure 2.1): rainfall data from four rain gauges (Table 2.1), flow data for the Mawheraiti River at Atarau Bridge (Table 2.2) and consented abstraction bores and metadata (Table 2.3).

Water usage data, collated by Johnson (2019) for the study area from both surface water and groundwater, was utilised for the project (Table 2.4).

Table 2.1 Rainfall monitoring site characteristics located in the vicinity of the study area.

Monitoring Site Name	NZTM Easting	NZTM Northing	Dataset Period	Complete Years of Record
Mawheraiti River at Atarau Bridge	1490439	5319302	11/04/2018 – 21/09/2020	1
Reefton at Township	1505769	5336751	9/12/2016 – 22/07/2020	2
Sirdar Creek at Paparoa	1482344	5345547	9/04/1986 – 30/07/2020	16
Grey River at Conical Hill (old)	1517327	5308851	19/03/1987 – 29/06/2013	11
Grey River at Conical Hill (new)	1517327	5308851	30/03/2016 – 16/08/2018	1

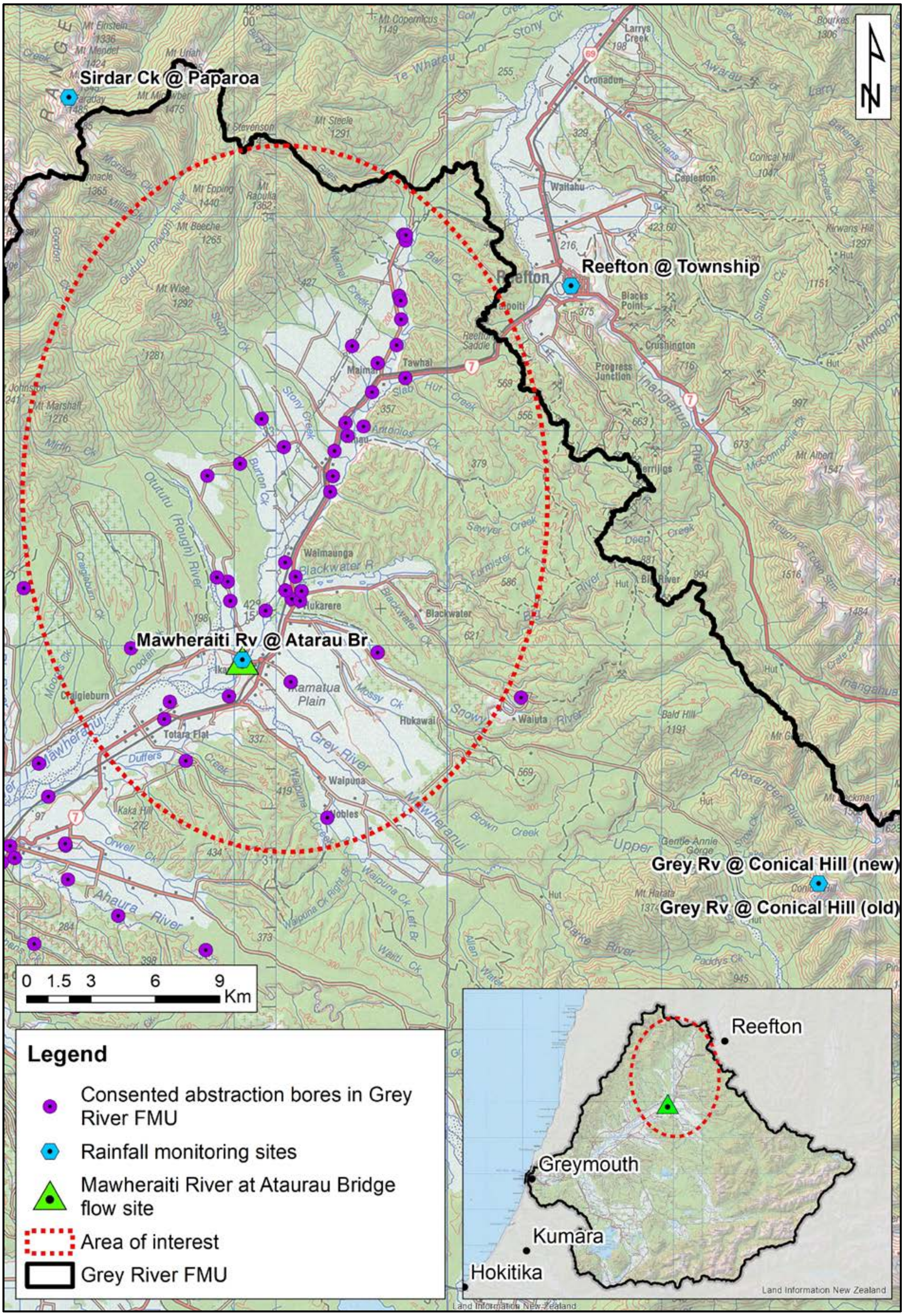

Figure 2.1 Location of the area of interest for the development of the case study.

Table 2.2 Mawheraiti River flow characteristics for Atarau Bridge monitoring site.

Measurement Type	NZTM Easting	NZTM Northing	Monitoring Period	Complete Years of Record	Number of Measurements
Continuous	1490439	5319302	1/01/2015 – 21/09/2020	Almost 6	-
Gauging	1490439	5319302	1/09/2014 – 12/01/2017	-	26

2.2.2 National Datasets

A series of national datasets (Table 3.4) was utilised: (i) to complement the WCRC datasets (e.g. for rainfall) or (ii) in the absence of local data (e.g. for aquifer formation delineation).

Table 2.3 Characteristics of the abstraction bores located in the study area.

Bore ID [1]	NZTM Easting	NZTM Northing	Bore Depth (m bgl) [2]	Bore Diameter (mm)	Bore Use	Consent ID	Max Annual Abstraction Volume (m^3/yr)	Static Water Level (m gl) [2]	Date Measurement Static Level	Bore Drilling Date	Bore Log Available [3]
117	1493136	5322051	5.4	200	Combined/Mixed	-	-	2.4	-	-	No
118	1492436	5323851	5	200	Combined/Mixed	-	-	-	-	-	No
119	1494536	5327150	2.5	200	Combined/Mixed	AUTH-DS502	-	-	-	-	No
120	1496480	5331800	0	200	Stock	-	-	-	-	-	No
121	1498055	5338868	10	150	Combined/Mixed	-	-	-	-	-	No
122	1497825	5336063	2.5	250	Combined/Mixed	-	-	-	-	-	No
123	1497834	5335205	20	150	Combined/Mixed	AUTH-RC10134-1	-	-	-	-	No
124	1497622	5333994	0	500	Combined/Mixed	-	-	-	-	-	No
125	1495547	5333948	5	90	Combined/Mixed	-	-	-	-	-	No
213	1491338	5330549	0	125	Combined/Mixed	-	-	-	-	-	No
215	1494736	5329049	22	125	Stock	-	-	-	-	-	No
216	1495256	5330368	10	150	Combined/Mixed	-	-	-	-	-	No
217	1495336	5329749	9	150	Combined/Mixed	AUTH-DS514	-	-	-	-	No
458	1492374	5329238	12	150	Stock	-	-	3.6	20/03/2002	20/03/2002	Yes
541	1497751	5336288	10	125	-	AUTH-DS525	-	2.69	1/02/2012	1/02/2012	Yes
547	1498064	5339136	24	125	-	AUTH-DS520	-	12	1/07/2008	-	Yes

Bore ID [1]	NZTM Easting	NZTM Northing	Bore Depth (m bgl) [2]	Bore Diameter (mm)	Bore Use	Consent ID	Max Annual Abstraction Volume (m^3/yr)	Static Water Level (m gl) [2]	Date Measurement Static Level	Bore Drilling Date	Bore Log Available [3]
556	1490332	5328452	12	125	Stock	AUTH-DS507	-	1.87	1/03/2007	1/03/2007	Yes
563	1496090	5330204	29	125	-	-	-	2	1/01/2014	1/01/2014	Yes
599	1488807	5327895	42	128	-	AUTH-DS509	-	-	-	1/01/2006	Yes
XX1	1491510	5321600	-	-	Industrial	AUTH-RC07173-5	1734480	-	-	-	-
XX2	1493190	5322510	-	-	Industrial	AUTH-RC05008-1	-	-	-	-	-
XX3	1494648	5327876	-	-	Irrigation	AUTH-RC-2015-0166-L1	1103760	-	-	-	-
XX4	1496737	5319649	-	-	Industrial	AUTH-RC-2015-0174-01	1576800	-	-	-	-
XX5	1497940	5339150	-	-	Irrigation	AUTH-RC06064-4	1898000	-	-	-	-

1 'XX' indicates that the bore did not have an ID.

2 **m bgl:** metres below ground level.

3 The bore logs available could not be retrieved.

Table 2.4 Water usage for surface water and groundwater in the study area.

Primary Source	Authorisation	Max Annual (m^3/yr)	Max Rate (L/s)	Primary Use
Ground water	To take and use groundwater from a bore for the purpose of irrigation, Maimai.	1,103,760	35	Irrigation
Ground water	To divert water from rock groynes, Little Grey River.	1,734,480	55	Industrial
Ground water	To take and use ground water from a bore for the use of irrigation.	1,898,000	60	Stock
Surface water	Water supply for a toilet block.	438	0	Industrial
Surface water	To take water from an unnamed tributary of Stony Creek for irrigation use.	883,008	28	Stock
Surface water	To take water from Rough and Tumble Creek for spray irrigation.	946,080	30	Irrigation
Surface water	To take and use surface water from the Little Grey River for the purpose of irrigation, Maimai.	1,072,224	34	Irrigation
Surface water	To take surface water from Stoney Creek, Mawheraiti for the purpose of irrigation.	473,040	45	Irrigation
Surface water	To take surface water from Ikamatua Stream for the purpose of irrigation.	1,576,800	50	Stock
Surface water	To take and use surface water from a dredge pond for the use of irrigation.	1,898,000	55	Irrigation
Surface water	To take and use surface water from the Little Grey River for the purpose of irrigation, Mawheraiti.	1,892,160	60	Irrigation
Surface water	To take and use water from an unnamed creek (outlet from a historic dredge pond) for irrigation purposes, Hukarere.	2,207,520	70	Irrigation
Surface water	To take and use water from a dredge pond for irrigation purposes, Mawheraiti.	2,838,240	90	Irrigation
Surface water	To take and use surface water from the Little Grey River for the purpose of irrigation, Ikamatua.	6,307,200	200	Irrigation
Sub-total groundwater		**4,736,240**	**150**	
Sub-total surface water		**20,094,710**	**662**	
Total		**24,830,950**	**812**	

Table 2.5 Summary of the national datasets utilised for the case study.

Dataset	Description	References
Hydrogeological-Unit Map	The publicly available Hydrological-Unit Map (HUM; White et al. 2019) dataset consists of two GIS files: a stacked map and an outcropping unit map. This is because differently aged HUM units occur within the same area and therefore are 'stacked' vertically within a given land area. The HUM dataset comprises a classification of geological units in terms of their importance for groundwater flow and storage in an ArcGIS seamless digital map. HUM units are classed into four broad types of hydrogeological unit: aquifer, aquiclude, aquitard and basement, defined as follows: • *Aquifer*: a hydrogeological unit type defined as: "a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. Unconsolidated sands and gravels are a typical example" (Todd and Mays 2005). • *Aquitard*: a hydrogeological unit type defined as a saturated but poorly permeable stratum that impedes groundwater movement and does not yield water freely to wells that may transmit appreciable water to or from adjacent aquifers and, where sufficiently thick, may constitute an important groundwater storage zone; sandy clay is an example (Todd and Mays 2005). • *Aquiclude*: a hydrogeological unit type defined as a saturated but relatively impermeable material that does not yield appreciable quantities of water to wells; clay is an example (Todd and Mays 2005). • *Basement*: a hydrogeological unit type defined as a geologic layer, or group of layers, of Cretaceous age and older; in Northland and on the East Coast, Tertiary age allochthons were included as Basement. However, the definition of an aquifer includes an assessment of 'significant quantities of water', which is a regionally variable property. In the nationally consistent HUM dataset, the classification assesses what is considered 'significant quantities of water' at the national level in New Zealand (i.e. what is defined as an aquifer versus an aquitard).	Ministry for the Environment Data Service (2019a)
Estimated Groundwater Flux, 2019: Discharge	This dataset, developed as part of the groundwater fluxes component of the Groundwater Atlas (Westerhoff et al. 2019), provides national indicative groundwater discharge data, using an existing national groundwater flow model, as well as comparison with a pre-existing gaining/losing stream prediction data set.	Ministry for the Environment Data Service (2019b)
River Environment Classification (REC)	The REC groups rivers and parts of river networks that share similar ecological characteristics, including physical and biological. Rivers that share the same class can be treated as similar to one another and different to rivers in other classes. The REC classification system groups rivers according to several environmental factors that strongly influence or cause the rivers' physical and ecological characteristics (climate, topography, geology and land cover).	Ministry for the Environment Data Service (2010)

Dataset	Description	References
Digital Elevation Model	The New Zealand School of Surveying Digital Elevation Model (NZSoSDEM v1.0; Columbus et al. 2011) is a free Digital Elevation Model (DEM) covering the country at a spatial resolution of 15 m, created by the School of Surveying by interpolating the Land Information New Zealand (LINZ) topographic vector data. This DEM was created as a series of 30 maps whose extent corresponds exactly with the LINZ Topo250 topographic map series.	Columbus et al. (2011)
Mean annual actual evapotranspiration	Annual actual evapotranspiration was estimated by GIS as actual evapotranspiration from the land surface, derived from a national-scale map developed by NIWA for the period 1960–2006 without specific consideration of land use, land cover, soil type or groundwater recharge (Woods et al. 2006; Henderson 2019).	Henderson (2019)
Mean annual rainfall	Average annual rainfall was based on a NIWA dataset derived from the rainfall measurements at individual rainfall stations, interpolated throughout New Zealand by NIWA and averaged for the period 1960–2006 (Tait et al. 2006; Henderson 2019).	Henderson (2019)
Irrigated Land Area	A spatial dataset of the extent of irrigated land in New Zealand, categorised by irrigation system type (where possible), has been created. Mapping the spatial distribution of irrigated areas and irrigation system types represents a substantial improvement on previous estimates of irrigated area, which only provided a total area for the region or district.	Ministry for the Environment Data Service (2017)

2.3 Methods

The methods used to undertake this case study were based on the input data presented, (Section 2.2) with the aim to delineate 'groundwater catchments' (Section 2.3.1), calculate 'baseflow indexes' (Section 2.3.2) and establish 'water budgets' (Section 2.3.3).

2.3.1 Groundwater Catchment Delineation

Our approach to delineate groundwater management zones (GMZ) is based on five steps and requires an iterative process to validate drafted GMZ with community and iwi engagement (Figure 2.2).

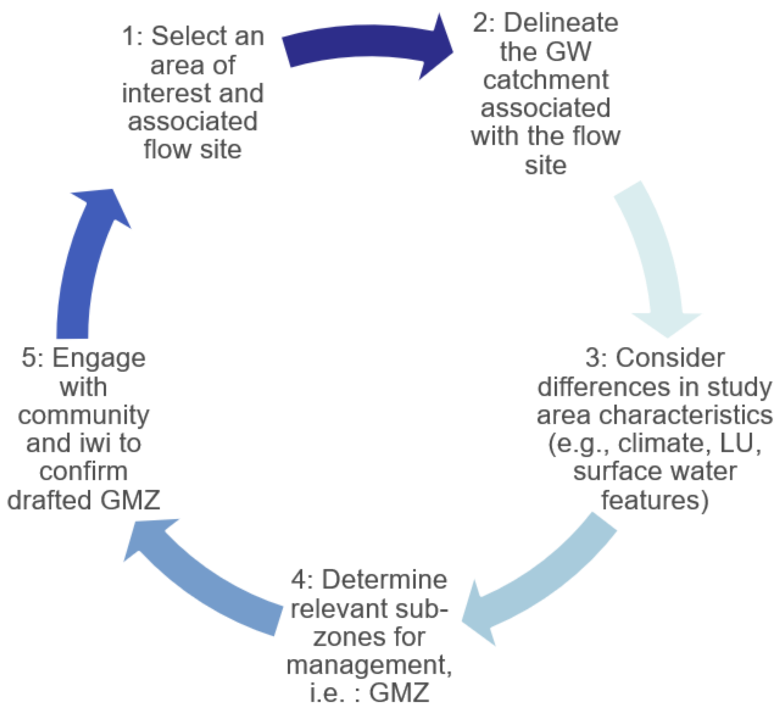

Figure 2.2 Proposed approach and iterative process for the delineation of groundwater management zones. GW: groundwater, GMZ: Groundwater Management Zone, LU: land use.

The delineation of a groundwater catchment (i.e. the catchment contributing to a groundwater source) was assumed to correspond to the surface water catchment, which is often the case. The water table contours are therefore inferred to reflect the surface topography, albeit with a reduced vertical range (Ratnayaka et al. 2009).

The groundwater catchment boundaries were delineated in ArcGIS (Figure 2.3) primarily using topographic data with manual adjustment of polygon vertices to topographic divides identified by the location of 10 m contours derived from the national Digital Elevation Model (Columbus et al. 2011).

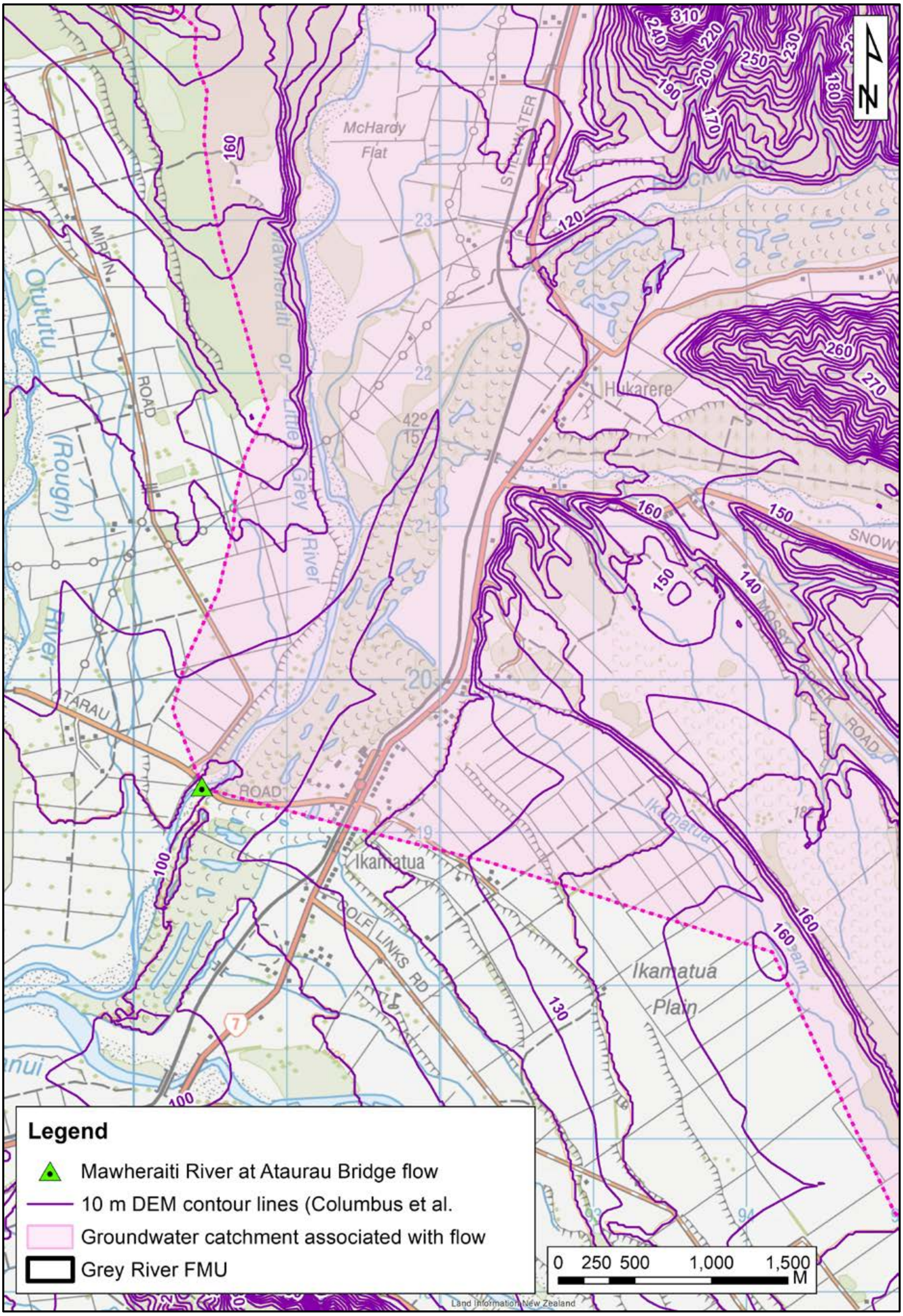

Figure 2.3 Delineation of the groundwater catchment associated with the flow site.

2.3.2 Stream Flow and Baseflow Index Calculations

Surface water flow is represented by baseflow (Q^{SW}_{BF}) and runoff or quick flow (Q^{SW}_{QF}) components:

$$Q^{SW}_{OUT} = Q^{SW}_{BF} + Q^{SW}_{QF}$$ Equation 2.1

Baseflow is the portion of stream flow that contains groundwater flow and flow from other delayed sources (Singh et al. 2019).

The baseflow index (BFI) is represented with:

$$BFI = Q^{SW}_{BF} / Q^{SW}_{OUT}$$ Equation 2.2

As a simplified approach, it was assumed for this case study that the mean of recorded flows estimates Q^{SW}_{OUT} and the median of recorded flows estimates Q^{SW}_{BF}. Then, Q^{SW}_{QF} is calculated with Equation 2.2 and BFI is estimated with:

$$BFI = Q_{Median} / Q_{Mean}$$ Equation 2.3

2.3.3 Water Budget Calculations

Like the GMZ delineation process, an iterative approach was used to define management targets for the GMZ. This included data collation, development of a conceptual model, water budget calculations, proposed management targets and engagement with the community and iwi (Figure 2.4).

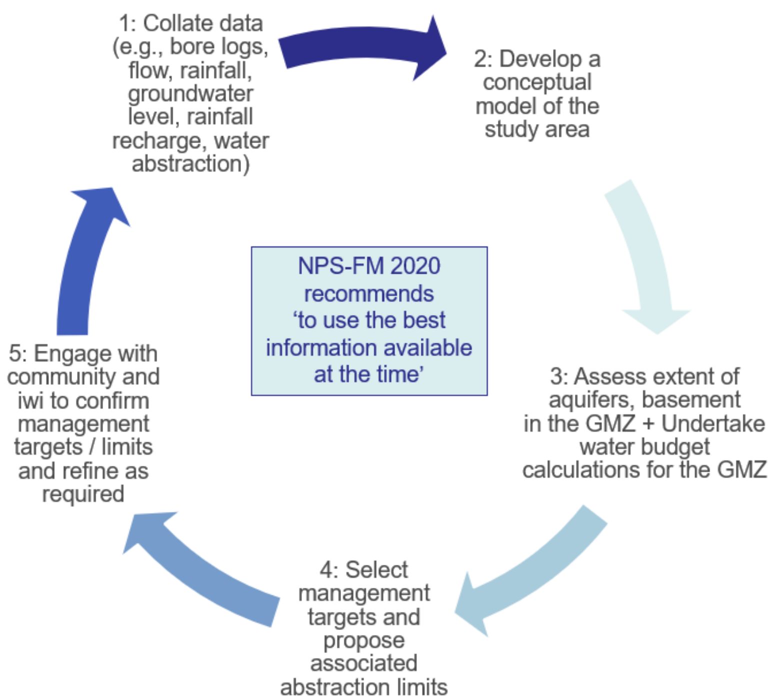

Figure 2.4 Proposed approach and iterative process for the definition of management targets and limits.

Water budgets were developed to assess a series of options for different potential groundwater management zones. A general water budget equation describes the relationships between water inflow, water outflow and water storage within a defined area of a catchment (Scanlon et al. 2002; Scanlon 2012).

water inflow = water outflow Equation 2.4

i.e.

$$P + Q_{IN} = AET + Q_{OUT} + \Delta S$$ Equation 2.5

P = precipitation.

Q_{IN} = water inflow, i.e. surface water (Q^{SW}_{IN}) and groundwater (Q^{GW}_{IN}).

AET = actual evapotranspiration.

Q_{OUT} = water outflow, i.e. surface water (Q^{SW}_{OUT}) and groundwater (Q^{GW}_{OUT}).

ΔS = change in water storage.

These budgets aim to represent headwaters catchments over the long term, i.e. Q_{IN} and ΔS are assumed as zero.

Natural Conditions

The first set of water budget calculations aimed to represent natural conditions, i.e. water use was therefore assumed as zero. Therefore:

$$P = AET + Q^{SW}_{OUT} + Q^{GW}_{OUT}$$ Equation 2.6

Mean annual rainfall (P) and mean annual actual evapotranspiration (AET) values were estimated as the averages for the period 1960–2006 using QGIS and nationwide rainfall and AET datasets (Henderson 2019; Tait et al. 2006; Woods et al. 2006). Long-term surface water outflow was assessed with calculations of means and medians of observed flow, taken to represent Q^{SW}_{OUT} and baseflow, respectively. Groundwater outflow was calculated as the residual P, AET and Q^{SW}_{OUT}, Equation 2.6.

Water Abstraction Conditions

A second series of water budget calculations were undertaken to simulate abstraction scenarios in the catchment. Equation 2.6 therefore needs to be completed by a water usage term (U):

$$P - AET = Q^{SW}_{OUT} + Q^{GW}_{OUT} + U$$ Equation 2.7

To determine the water usage, two options were investigated:

1. Consideration of the irrigated area, the length of the irrigation season and the type of culture to infer related annual water demand; or
2. Utilisation of the water use data collated by Johnson (2019) and the maximum annual consented amounts to infer maximum water usage in the area of interest.

Both options were considered and the larger water usage utilised for our water budget calculations.

Water usage for the water balance zone areas were estimated using ArcGIS.

3.0 RESULTS

3.1 Groundwater Allocation Zone Delineation

The groundwater catchment associated with the Mawheraiti River flow site at Atarau Bridge has an approximate area of 483.1 km^2 (Figure 3.1). It is bordered by mountain ranges to the west and northeast.

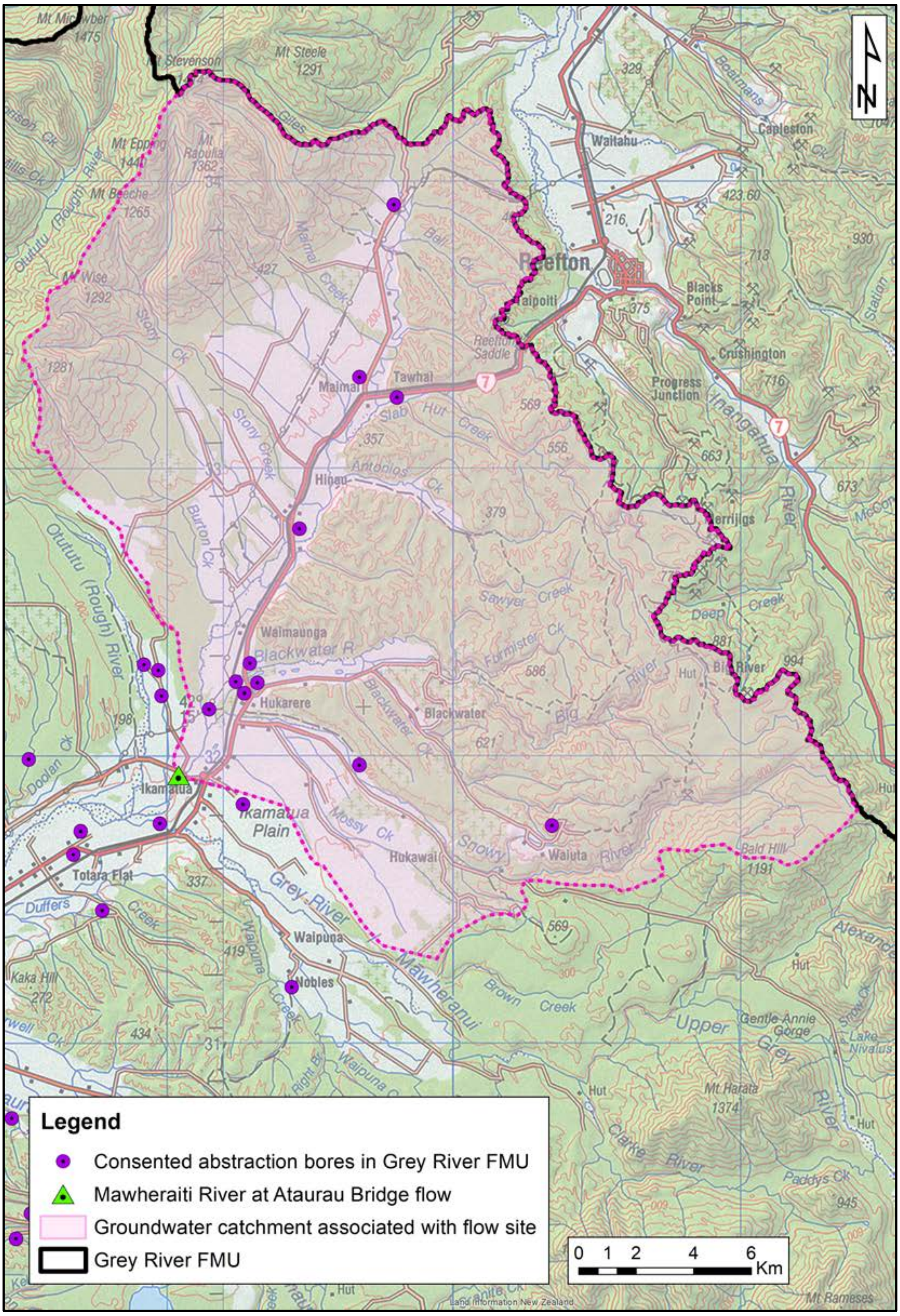

Figure 3.1 Groundwater catchment associated with the Mawheraiti River at Atarau Bridge flow site.

3.1.1 Groundwater Catchment Characteristics

3.1.1.1 Rainfall and Actual Evapotranspiration

Rainfall

The mean annual rainfall values from the WCRC rain gauge datasets and the values extrapolated from raster images derived from the Henderson dataset at the rain gauge location indicate comparable annual means, with highest values (c. > 6000 mm/yr) on the Paparoa Range and on the western side of the groundwater catchment and lowest values (c. < 2000 mm/yr) near Reefton, near the Mawheraiti River and centre of the groundwater catchment (Table 3.1, Figure 3.2).

Table 3.1 Rainfall monitoring site statistics in the vicinity of the study area.

<table>
<tr><th>Monitoring Site</th><th>Mean Annual Value in mm/yr (WCRC Dataset)</th><th>WCRC Dataset Period</th><th>Mean Annual Value in mm/yr (From Henderson Dataset)</th><th>Henderson Dataset Period</th></tr>
<tr><td>Mawheraiti River at Atarau Bridge</td><td>2055</td><td>11/04/2018 – 21/09/2020</td><td>-</td><td>-</td></tr>
<tr><td>Reefton at Township</td><td>2050</td><td>9/12/2016 – 22/07/2020</td><td>1958</td><td>1996–2006</td></tr>
<tr><td>Sirdar Creek at Paparoa</td><td>5707</td><td>9/04/1986 – 30/07/2020</td><td>6438</td><td>1996–2006</td></tr>
<tr><td>Grey River at Conical Hill (old)</td><td>1963</td><td>19/03/1987 – 29/06/2013</td><td rowspan="2">2448</td><td rowspan="2">1996–2006</td></tr>
<tr><td>Grey River at Conical Hill (new)</td><td>1528</td><td>30/03/2016 – 16/08/2018</td></tr>
</table>

Actual Evapotranspiration

The mean annual AET value estimated for the study area (Figure 3.3) are lowest on the Paparoa Range and on the western and eastern sides of the groundwater catchment (c. 400 mm/yr) and highest near the Mawheraiti River and centre of the groundwater catchment (almost up to 800 mm/yr).

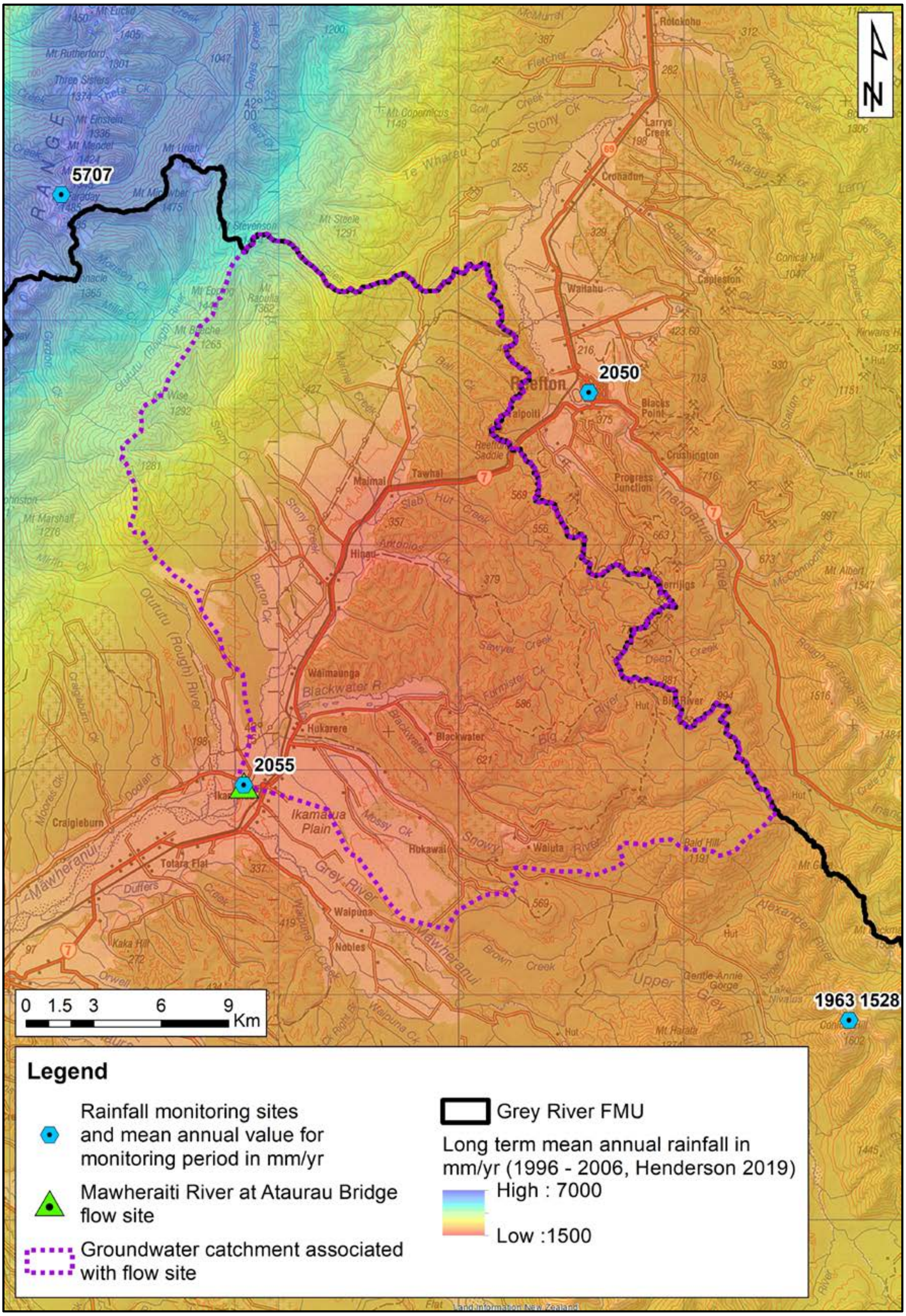

Figure 3.2 Groundwater catchment and mean annual rainfall for monitoring sites and 1996–2006 modelled values (after Henderson 2019).

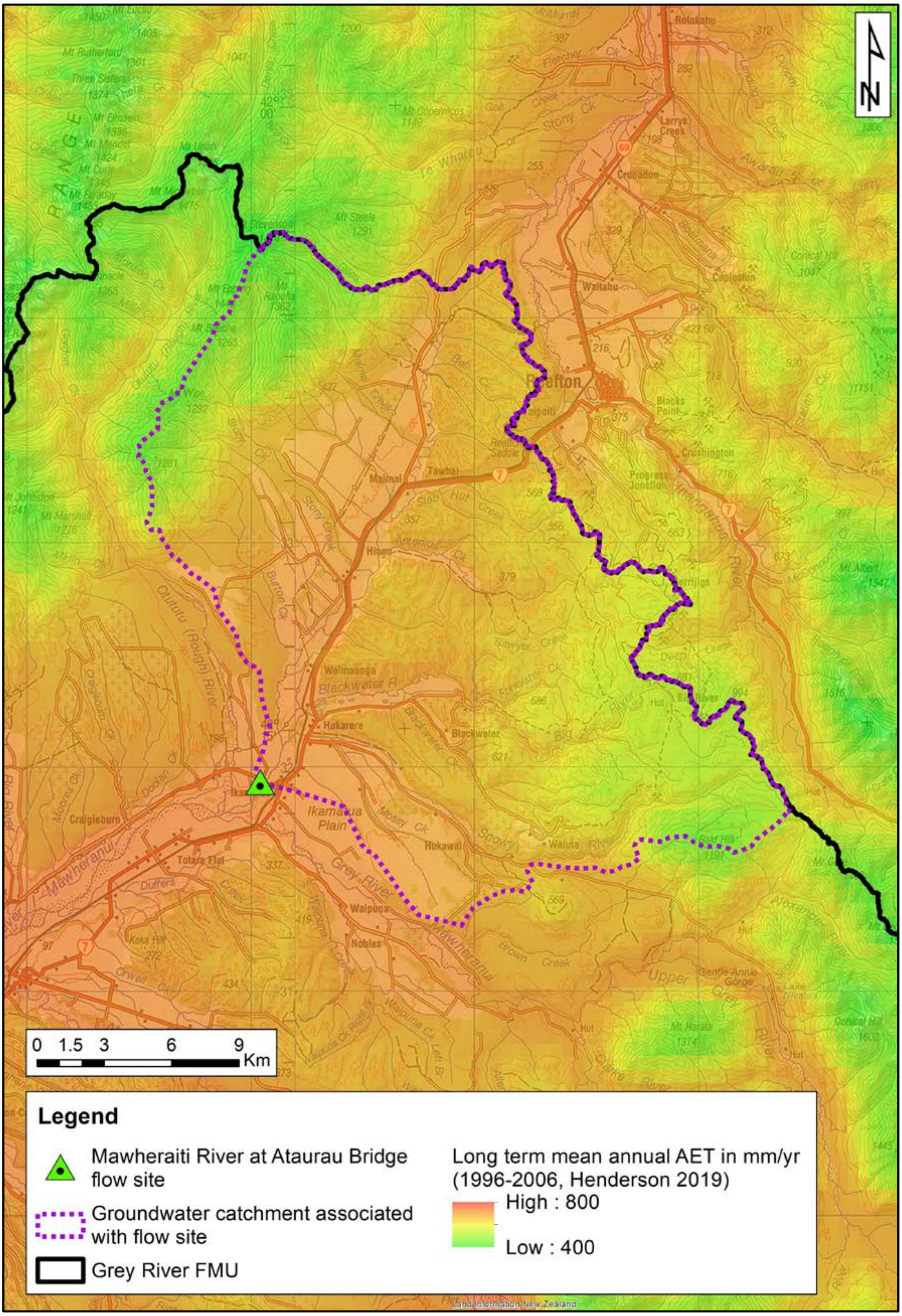

Figure 3.3 Groundwater catchment and mean annual actual evapotranspiration modelled values (after Henderson 2019).

3.1.1.2 Geology and Hydrogeology

The geology in the groundwater catchment comprises Quaternary and Tertiary sediments overlying hard rock basement (outcropping on the eastern and western areas; Figure 3.4) in the central part of the catchment. The units assessed as 'aquifer' are the most recent Quaternary sediments (ages Q1 to Q6), with older units classified as aquitard (sediments older than Q6 and Pliocene) or aquiclude (Miocene, Oligocene and Eocene sediments).

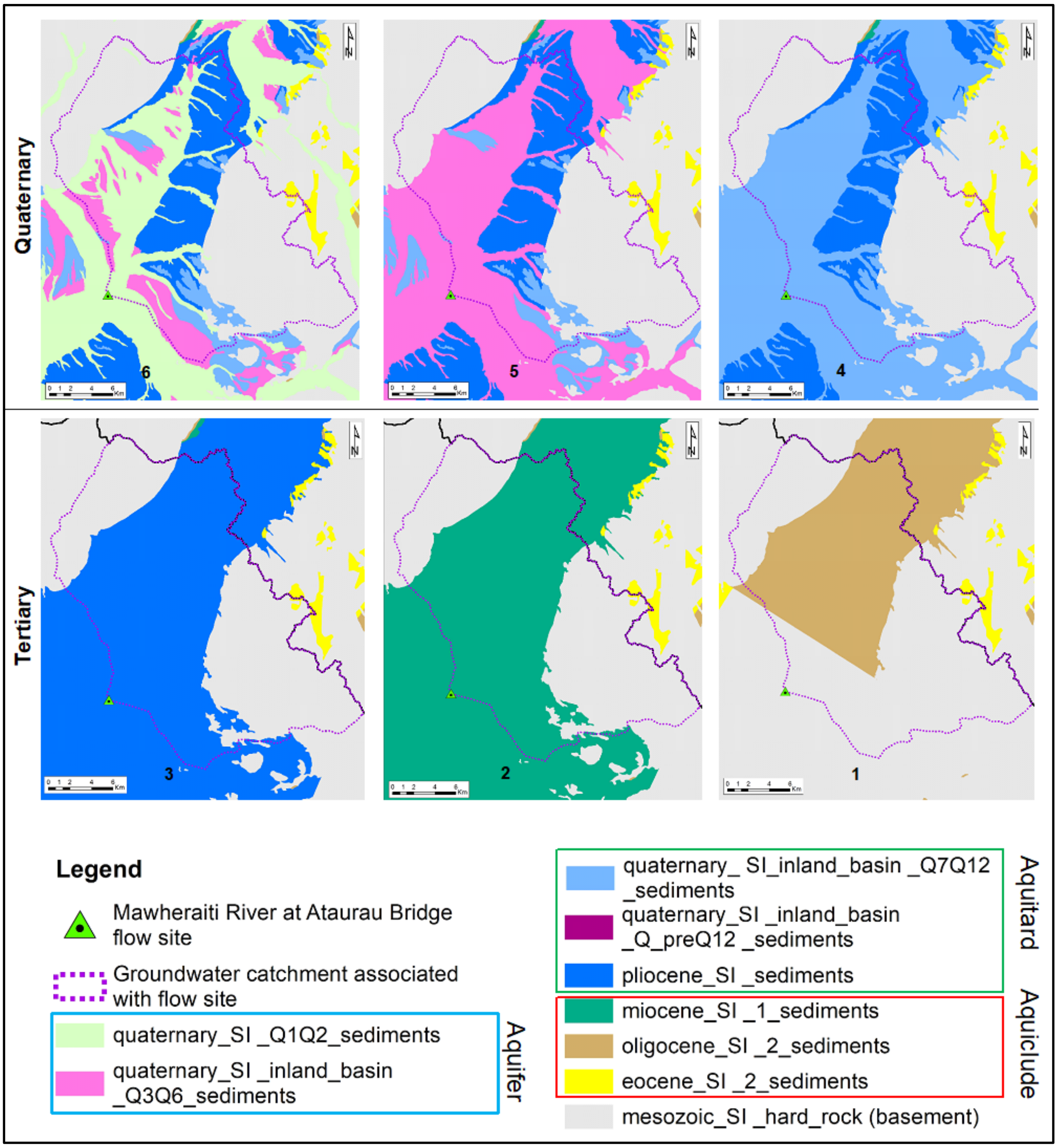

Figure 3.4 Hydrogeological-Unit Map for the groundwater catchment, from the oldest formations (tab 1) to the youngest formations (tab 6) (after White et al. 2019). SI: South Island, Q: Quaternary.

3.1.1.3 Groundwater Abstractions and Irrigation

Consented abstraction bores are mostly located in the central part of the groundwater catchment, with a greater number west (true right bank) of the Mawheraiti River (Figure 3.5). Similarly, the irrigated pastoral land is concentrated in this area; in contrast, the eastern area is mainly forested (Figure 3.6).

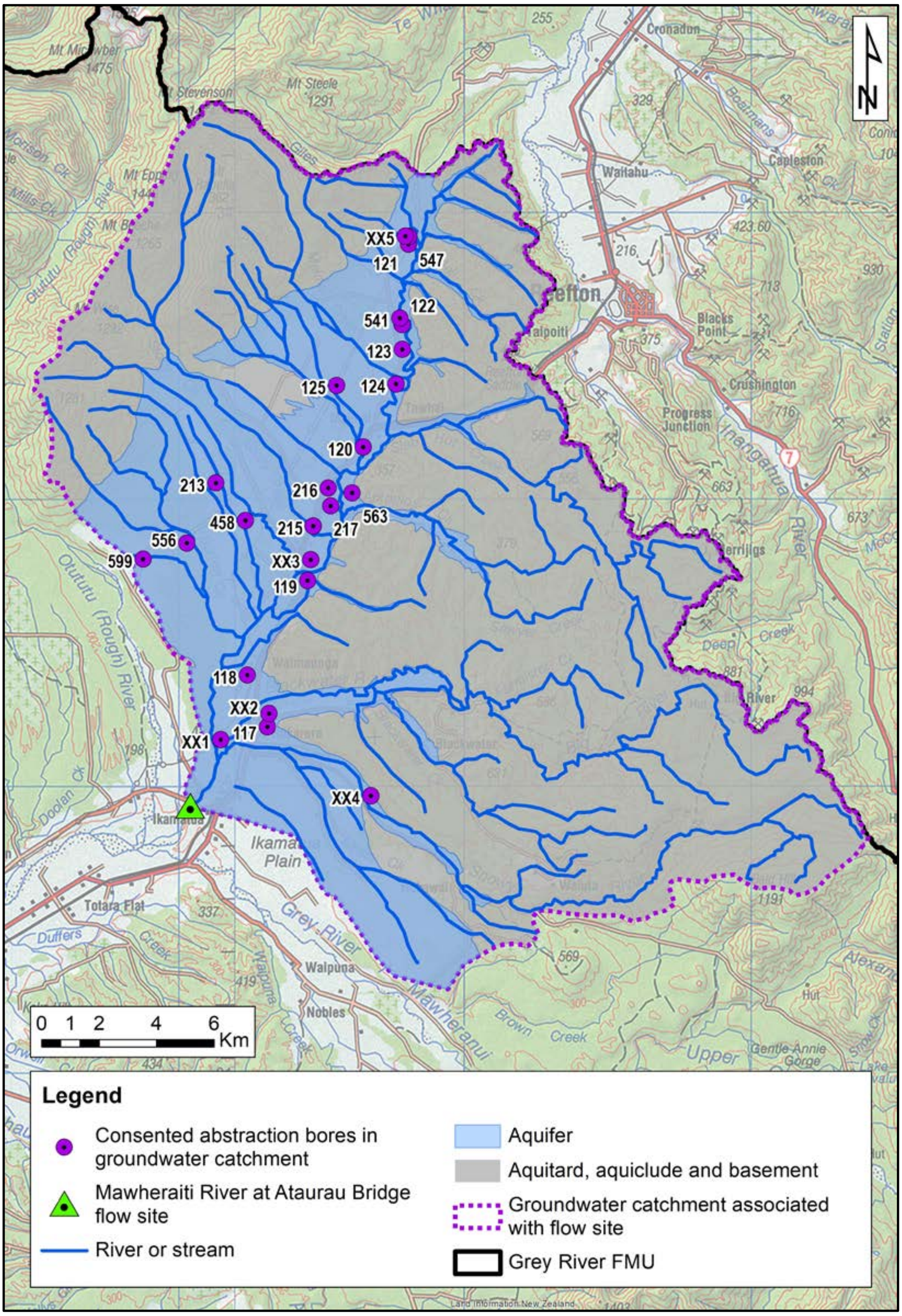

Figure 3.5 Consented abstraction bores, groundwater catchment and delineation of aquifer and poor water bearing formations (aquitard, aquiclude and basement).

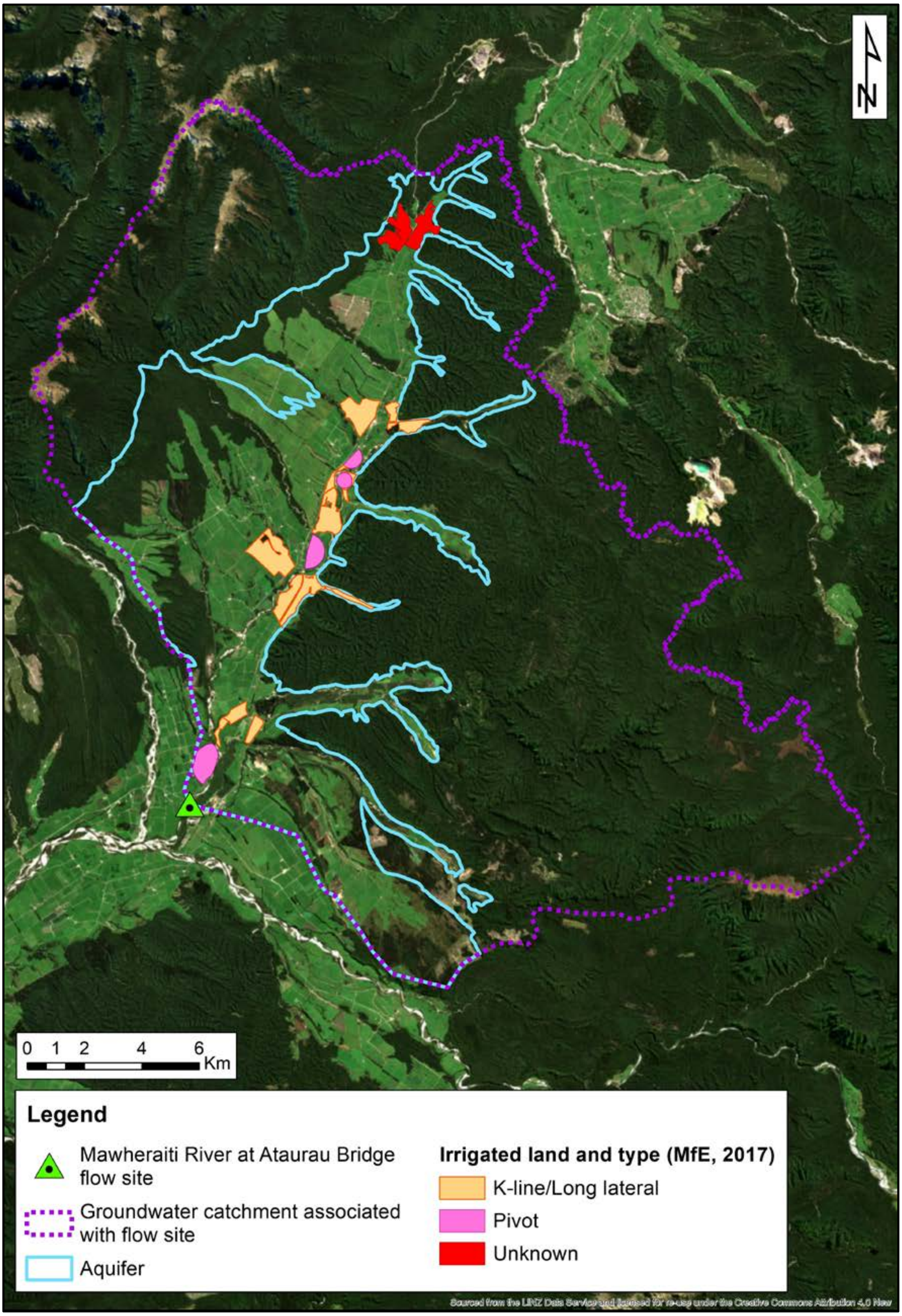

Figure 3.6 Irrigated land and type for the groundwater catchment (after Ministry for the Environment 2017).

3.1.2 Relevance for Sub-Management Zones

There are some clear differences between the western and eastern areas of the groundwater catchment (e.g. rainfall, AET, land use), which support the relevance of delineating sub-management zones, i.e. a West GMZ and an East GMZ, within the groundwater catchment.

3.2 Consideration of Groundwater Connectivity

Two main sources of data were available to consider the groundwater connectivity to surface water: the monitoring data from the Mawheraiti River at Atarau Bridge flow recorder and gaugings, and the discharge probability maps of the estimated groundwater flux discharge dataset.

3.2.1 Stream Flow and Baseflow Index

Statistics based on a six-year dataset for the continuous flow site (Table 3.2) indicate mean and median flow values of 23.53 m^3/s and 10.91 m^3/s, respectively, and a BFI of 0.46, which is close to the national average of long-term stream flow of 0.53 estimated by Singh et al. (2019). This would suggest that approximately 46% of the stream flow is likely to originate from groundwater discharge or other delayed sources.

Statistics from the gauging measurements have also been calculated but are inferred to be less representative of long-term flow statistics because of a limited number of measurements.

Table 3.2 Mawheraiti River flow statistics for Atarau Bridge monitoring site.

Measurement Type	Minimum Value for the Recording Period* (m^3/s)	Maximum Value for Recording Period* (m^3/s)	Mean Value for Recording Period* (m^3/s)	Median Value for Recording Period* (m^3/s)	Baseflow Index
Continuous	2.48	593.03	23.53	10.91	0.46
Gauging	2.50	141.77	21.37	7.72	0.36

* Calculations based on six years of data for the continuous site and 26 measurements for the gauging.

3.2.2 Groundwater Discharge Map

The groundwater discharge map suggests that groundwater discharge to the streams mainly occurs in the lower elevation areas of the catchment. The highest probability classes are observed along the lower reaches of the creeks, especially on the eastern side of the Mawheraiti River (Figure 3.7).

Both the BFI calculations and the groundwater discharge map indicate a clear connection between groundwater and surface water, with groundwater inferred to provide a substantial part of the Mawheraiti River baseflow.

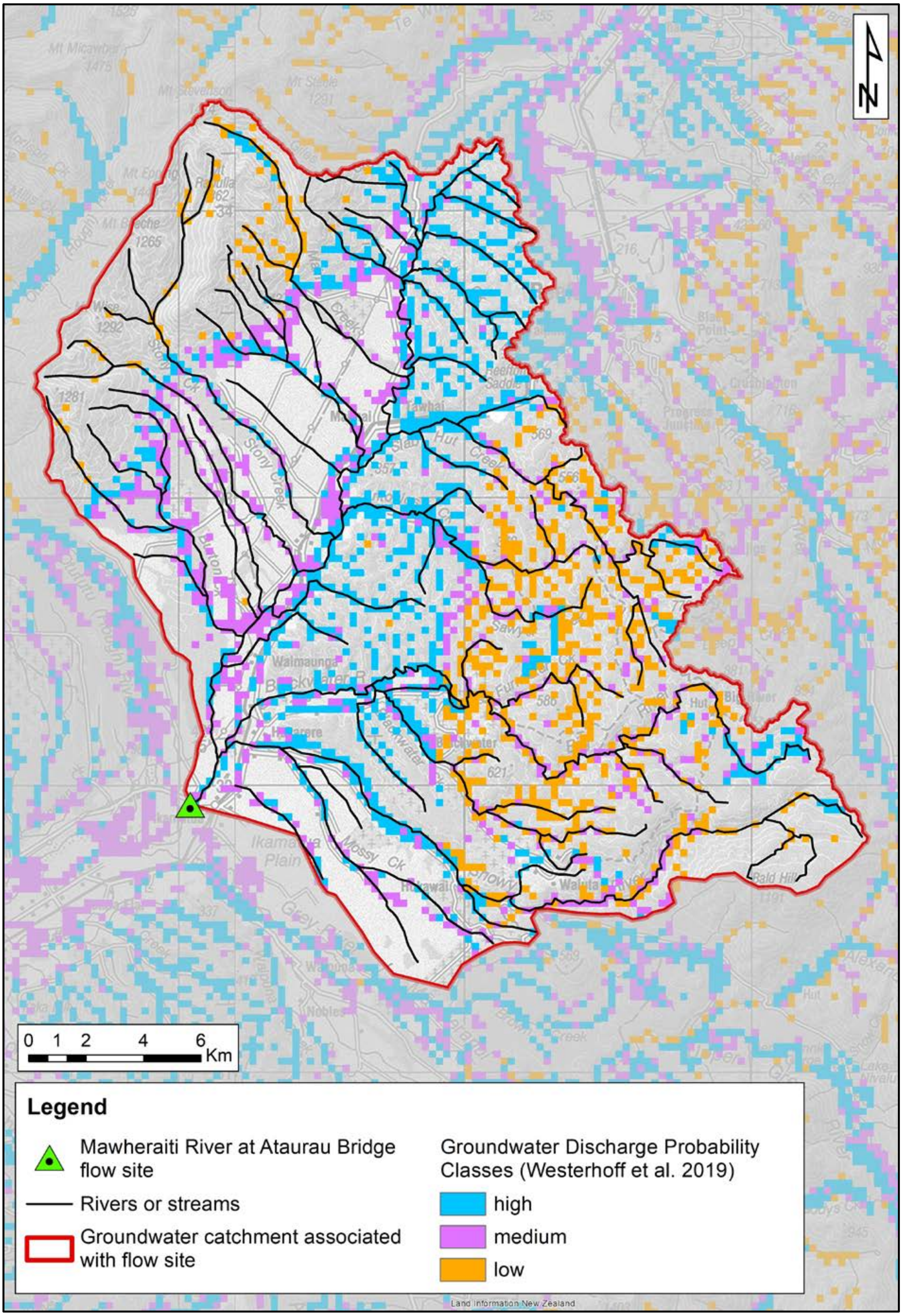

Figure 3.7 Groundwater connectivity of the streams in the study area inferred from the Groundwater Discharge Probability Classes dataset (after Westerhoff et al. 2019).

3.3 Definition of Management Targets

3.3.1 Water Budget Calculations

Water budget calculations have been undertaken for the whole groundwater catchment, considered as one GMZ, and for two GMZs, corresponding to the eastern and western parts of this catchment (Figure 3.8).

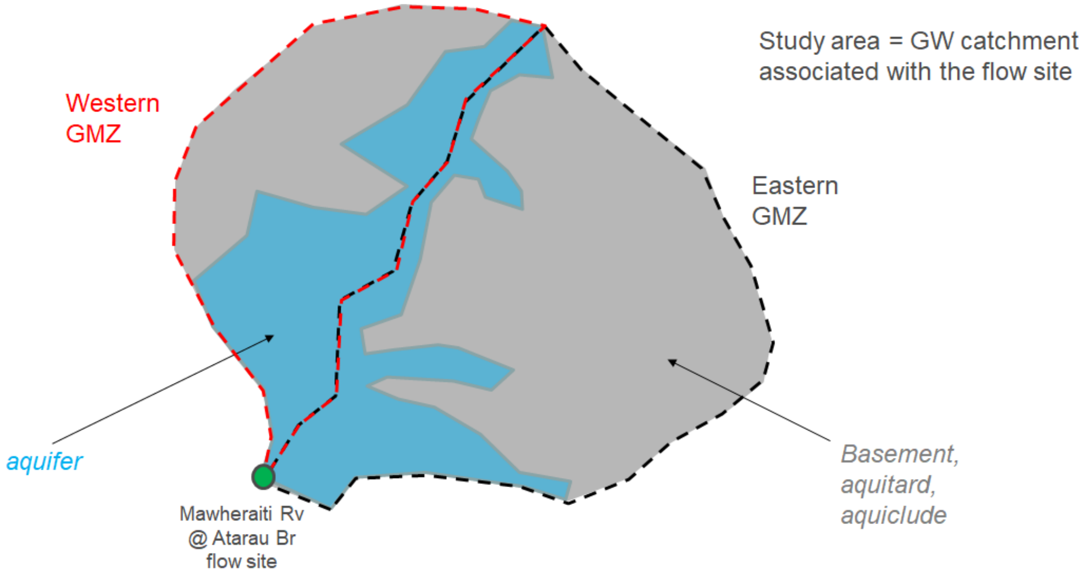

Figure 3.8 Schematic showing the groundwater management zones considered for the water budget calculations.

3.3.1.1 Whole Groundwater Catchment as a Groundwater Management Zone

The 'natural state' water budget for the whole groundwater catchment (Table 3.3) indicates a water outflow via the river and groundwater of 22.97 m^3/s, which is very close to the mean flow values of the Mawheraiti River at Atarau Bridge flow site (23.5 m^3/s). Therefore, the maps of rainfall and AET reasonably represent long-term average observed Mawheraiti River flows.

The estimated abstraction is larger from the water use data than for the estimate irrigation demand; therefore, the water use data was added to the natural state water budgets to simulate water abstraction in the catchment. (Table 3.4). Q^{SW}_{OUT} + Q^{GW}_{OUT} is therefore reduced by approximately 4% in the 'abstraction scenario' compared to the 'natural state', based on the dataset available.

Table 3.3 Water budget for the whole groundwater catchment, natural state.

Input Data			
Item	**Value**	**Unit**	**Source**
Area	483.1	km^2	ArcGIS
P	2154	mm/yr	Henderson (2019)
AET	655	mm/yr	Henderson (2019)
Flow*	21.4	m^3/s	Gauging data
	23.5	m^3/s	Continuous data
Water Budget Calculations			
Inflows (m^3/s)	**Outflow (m^3/s)**		**Balance (m^3/s)**
P	**AET**	**$Q^{SW}_{OUT} + Q^{GW}_{OUT}$**	
33.00	-10.03	-22.97	-

* Mawheraiti River at Atarau Bridge, mean value.

Table 3.4 Water budget for the whole groundwater catchment, abstraction scenario (current).

Input Data				
Characteristics				
Item	**Value**	**Unit**		**Source**
Area	483.1	km^2		ArcGIS
P	2154	mm/yr		Henderson (2019)
AET	655	mm/yr		Henderson (2019)
Flow*	21.4	m^3/s		Gauging data
	23.5	m^3/s		Continuous data
Abstraction				
Item	**Value**	**Unit**		**Source**
Irrigation demand	2480	m^3/ha/yr		Irrigation Reasonable Use Database estimate
Irrigation season length	7	months		
Irrigated area	991.5	ha		Ministry for the Environment irrigated land dataset
Water used for irrigation	0.13	m^3/s		-
Maximum consented water use	0.81	m^3/s		WCRC water use dataset
Water Budget Calculations				
Inflows (m^3/s)	**Outflow (m^3/s)**			**Balance (m^3/s)**
P	**AET**	**U**	**$Q^{SW}_{OUT} + Q^{GW}_{OUT}$**	
33.00	-10.03	-0.81	-22.16	-

* Mawheraiti River at Atarau Bridge, mean value.

3.3.1.2 Two Groundwater Management Zones: Western and Eastern

Examples of water budget calculations undertaken for the western GMZ (Figure 3.8) are provided for the basement part (Table 3.5) and for the aquifer part, including a natural state or under an abstraction scenario (Table 3.6 and Table 3.7, respectively). No abstraction occurs in the basement area.

The component Q^{SW}_{OUT} of the basement water budget corresponds to the surface water flow that will enter the aquifer area, i.e. $Q^{SW}_{IN.}$

Example for the West Groundwater Management Zone

Table 3.5 Water budget for the western groundwater management zone (basement).

Input Data			
Characteristics			
Item	**Value**	**Unit**	**Source**
Area	76.9	km^2	ArcGIS
P	3450	mm/yr	Henderson (2019)
AET	571	mm/yr	Henderson (2019)
Flow*	21.4	m^3/s	Gauging data
	23.5	m^3/s	Continuous data
Abstraction			
Item	**Value**	**Unit**	**Source**
Irrigation demand	2480	$m^3/ha/yr$	Irrigation Reasonable Use Database estimate
Irrigation season length	7	months	
Irrigated area	0	ha	Ministry for the Environment irrigated land dataset
Water used for irrigation	0.00	m^3/s	-
Maximum consented water use	0	m^3/s	WCRC water use dataset

Water Budget Calculations				
Inflows (m^3/s)	**Outflow (m^3/s)**			**Balance (m^3/s)**
P	**AET**	**U**	**Q^{SW}_{OUT} + Q^{GW}_{OUT}**	
8.41	-1.39	0	-7.02	-

QS^{W}_{OUT}	-7.02
As Q^{GW}_{OUT} estimated to zero for basement	

Table 3.6 Water budget for the western groundwater management zone (aquifer), natural state.

Input Data			
Item	**Value**	**Unit**	**Source**
Area	93.6	km^2	ArcGIS
P	2190	mm/yr	Henderson (2019)
AET	705	mm/yr	Henderson (2019)
Flow*	21.4	m^3/s	Gauging data
	23.5	m^3/s	Continuous data

Water Budget Calculations					
Inflows (m^3/s)		**Outflow (m^3/s)**			**Balance (m^3/s)**
P	**Q^{SW}_{IN}**	**AET**	**U**	**$Q^{SW}_{OUT} + Q^{GW}_{OUT}$**	
6.50	7.02	-2.09	0	-11.43	-

Table 3.7 Water budget for the western groundwater management zone (aquifer), with current abstraction.

Input Data			
Characteristics			
Item	**Value**	**Unit**	**Source**
Area	93.6	km^2	ArcGIS
P	2190	mm/yr	Henderson (2019)
AET	705	mm/yr	Henderson (2019)
Flow*	21.4	m^3/s	Gauging data
	23.5	m^3/s	Continuous data
Abstraction			
Item	**Value**	**Unit**	**Source**
Annual mean irrigation demand	2480	m^3/ha/yr	Irrigation Reasonable Use Database estimate
Irrigation season length	7	months	-
Irrigated area	705.12	ha	Ministry for the Environment irrigated land dataset, 2017
Water used for irrigation	0.10	m^3/s	-
Maximum consented water use	0.6	m^3/s	WCRC water use dataset

Water Budget Calculations					
Inflows (m^3/s)		**Outflow (m^3/s)**			**Balance (m^3/s)**
P	**Q^{SW}_{IN}**	**AET**	**U**	**$Q^{SW}_{OUT} + Q^{GW}_{OUT}$**	
6.50	7.02	-2.09	-0.60	-10.83	-

3.3.2 Baseflow Protection as a Management Target

The NPS-FM 2020 (Ministry for the Environment 2020) states that: *"There is a hierarchy of obligations in Te Mana o te Wai that prioritises:*

> *(a) first, the health and well-being of water bodies and freshwater ecosystems*
>
> *(b) second, the health needs of people (such as drinking water)*
>
> *(c) third, the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future."*

WCRC scientists therefore expressed their interest in protecting the stream flow and thus baseflow for the study area.

If we consider the scenario with one unique GMZ and the water budget established for a natural state (Table 3.3), approximately 23 m^3/s of water outflow (i.e. Q^{SW}_{OUT} + Q^{GW}_{OUT}) is 'generated' from the groundwater catchment above the Mawheraiti River at Atarau Bridge flow site. Considering that approximately 50% of the stream flow is baseflow (Table 3.2), approximately 11.5 m^3/s should therefore be preserved to avoid reducing the Mawheraiti River baseflow. The remaining 11.5 m^3/s would then be available for groundwater recharge (i.e. residual groundwater recharge). Considering the hierarchy of obligations of Te Mana o te Wai, an approach similar to the (withdrawn) Plan Change 9 for the Bay of Plenty region (see Mourot and White 2020) would preserve 65% of the residual groundwater recharge to sustain the aquifer and make the remaining 35% (i.e. 4 m^3/s) available for allocation in the groundwater catchment.

4.0 CONCLUSION AND RECOMMENDATIONS

This case study was guided by: (i) the review of current New Zealand freshwater regulations and allocation frameworks and (ii) the roadmap methodology of Mourot and White (2020) for WCRC. The catchments of the Mawheraiti, Stony, and Rough rivers were selected by WCRC resource managers as a case study area due to allocation and climate pressures on these systems.

The case study project involved: data collation, delineation of groundwater management zones and consideration of groundwater–surface water connectivity. Baseflow calculations indicated that approximately 50% of Mawheraiti River flow at Ataurau Bridge was derived from groundwater or other delayed sources. Preservation of river baseflow was identified as a management target by WCRC and proposed allocation limits were tailored for this purpose.

We recommend linking the development of the groundwater allocation framework to surface water allocation, given that characterisation of low flow in the Mawheraiti River (e.g. mean annual low flow) is in development and that the surface water allocation regime is under review. Consideration of how to manage stream depletion and connected groundwater and surface water bodies is required (see Mourot and White 2020).

We encourage WCRC science and policy teams to work closely to initiate the development of the groundwater allocation framework. Engagement with the Grey River Group and community will be critical to refine and confirm the values of importance to the community for the study area, the level of protection required for stream flow and the management targets and associated limits. This knowledge should be integrated in the Regional Land and Water Plan. The introduction of a groundwater allocation framework will contribute to the improvement of WCRC's current freshwater management by 'capping' the current use of the regional groundwater resources with 'interim limits', which should avoid future over-allocation adverse effects (e.g. declining groundwater levels, reduction of stream flow and lake water inflows, deterioration of water quality, increased pumping costs and land subsidence). Improved knowledge of system behaviour may allow 'interim limits' to be replaced by 'tailored limits' in the Regional Land and Water Plan in a refined groundwater framework.

Lastly, we recommend implementing a groundwater limit-setting process to other areas of the region, with a priority to those with the highest pressures.

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