Management Flows for Aquatic Ecosystems in the Pig Burn

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Overview

The Pig Burn is a tributary of the upper Taieri River that drains a small catchment on the Rock and Pillar Range, entering the Taieri River near Patearoa.

Why was this study done?

This report is intended to inform flow management in the Pig Burn catchment. It considers the following:

- The hydrology and existing water allocation in Pig Burn
- The aquatic values of Pig Burn
- The flows that will maintain aquatic ecological values in Pig Burn

What did this study find?

- Hydrological analysis conducted as part of this study estimated the naturalised 7-day mean annual low flow (7-d MALF) for the Pig Burn at the exit of the gorge located above Roberts Road (Top Intake) to be 0.079 m^3/s.
- The consented maximum rate of instantaneous water take is 0.455 m^3/s. However, many of the takes in the catchment are not able to be fully exercised due to insufficient water being available.
- Actual recorded water take time series data for water takes 2002.010 and 2001.136 was not available (Figure 3.2). The naturalised 7-d MALF at Pig Burn at Top Intake was therefore estimated by the combined ratio method outlined in Appendix B.
- Observations made during the study and historically indicated that the Pig Burn does not connect with the Taieri River at times (summers of 2007 and 2010/11).
- The Pig Burn provides spawning habitat for brown trout but doesn't provide for a resident trout fishery. It also provides habitat for longfin eel (classified "At Risk" and "Declining").
- There are eight permitted water takes in the Pig Burn, of which six are Deemed Permits with a total primary allocation of 0.455 m^3/s. The Taieri catchment is over-allocated based on the default allocation limit of 50% of the 7-d MALF in Policy 6.4.2 (Otago Regional Council, Regional Plan: Water for Otago).

- Instream habitat modelling was conducted to determine how changes in flow affect habitat for the fish species present in Pig Burn. The flows recommended to maintain fish habitat in Pig Burn are summarised below:

Location	Naturalised 7-d MALF (m^3/s)	Recommended flow (m^3/s)	Reason
Pig Burn at Top Intake	0.079	0.046	Brown trout fry – 150mm

- The results of this investigation will be used to inform future water management in the Pig Burn catchment.

Technical summary

The Pig Burn is a third order stream that drains into the Taieri River from the slopes of the Rock and Pillar Range near Patearoa. The upper catchment is relatively steep, with a high degree of exposed river bed. The vegetation in the surrounding catchment is dominated by sweet briar rose (*Rosa rubiginosa)* and matagouri scrub (*Discaria toumatou*) with sparsely populated pockets of tussock (*Chionochloa spp*). There is limited grazing of stock in the headwaters. Once the Pig Burn reaches the valley floor of the Maniototo Plain the level of agriculture is intensified. There are currently eight permitted water takes including six "deemed permits" in the catchment.

The objectives of this report were to:

- Present information on Pig Burn that is relevant to determining the flows required to sustain the river's aquatic habitat, including freshwater values, flow statistics, the distribution of water resources within the catchment and the results of in-stream habitat modelling.
- Assess the aquatic values of Pig Burn.
- To present and interpret the results of these analyses to recommend flows required to maintain aquatic ecological values.

The Pig Burn provides spawning habitat for brown trout and potentially contributes juvenile recruitment to the wider brown trout fishery of the Taieri River. It also provides habitat for longfin eel, which are classified as "At Risk" and "Declining" (Goodman *et al.* 2014).

There are eight permitted water takes in the Pig Burn with a consented maximum instantaneous rate of take of 0.455 m³/s. The Taieri catchment is over-allocated based on the default allocation limit of 50% of the 7-d MALF in Policy 6.4.2 (Otago Regional Council, Regional Plan: Water for Otago).

The flows recommended for maintaining fish habitat in Pig Burn are summarised below:

Species	Life history stage	Flows in which the amount of weighted useable area rapidly declines (m³/s)	Flows in which optimum habitat is available (m³/s)
Brown trout	Fry Juvenile Spawning	0.1 0.1 0.15	0.15 0.2 0.2
Longfin eel	> 300 mm < 300 mm	0.05 0.05	n/a 0.05

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1. Introduction

The Regional Plan: Water for Otago (2015; RPW) sets out as one of its objectives 'to retain flows in rivers sufficient to maintain their life-supporting capacity for aquatic ecosystems and their natural character[1]. As a means of achieving this objective, the RPW provides for the setting of minimum and residual flows in Otago's rivers[2].

The Pig Burn is a small stream draining north-western facing slopes of the Rock and Pillar Range near Patearoa. There are limited grazing opportunities in the upper catchment, while most of the lower catchment is more intensively farmed. There are currently eight consented water takes in the Pig Burn catchment, including six "deemed permits".

Schedule 1A of the RPW[3] identifies the ecosystem values that must be sustained in Otago catchments. In the Pig Burn, these include spawning and juvenile rearing for trout. Further to these values, the Pig Burn supports a population of longfin eel.

1.1. Objectives

This report presents information on the Pig Burn that is relevant to determining the flows required to sustain the river's aquatic habitat. This includes freshwater values, flow statistics and the distribution of water resources within the catchment in addition to the results of in-stream habitat modelling.

[1] Objective 6.3.1 of the Regional Plan: Water for Otago (2015), p. 6–7
[2] Policies 6.4.1 – 6.4.11 of the Regional Plan: Water for Otago (2015), pp 6–13 to pp 6–26
[3] Schedule 1A of the Regional Plan: Water for Otago (2015), p. 20–6

2. The Pig Burn catchment

The Pig Burn drains a catchment of 50.8 km^2, approximately 6 km from the township of Patearoa, and enters the Taieri River 3 km downstream of the Ranfurly-Patearoa Road Bridge (Figure 2.1). The highest point in the catchment is 1324 metres. Marginally over half of the Pig Burn catchment is confined to the upper gorge section, whereas the remainder of the Pig Burn flows across the Maniototo Plain.

2.1. Vegetation and land use

Alpine grasses and herb fields in combination with tussock grasslands and grey scrub dominate the mid-upper catchment (Figure 2.2). High producing grassland appears once the Pig Burn enters the valley floor of the Maniototo Plains (Table 2.1).

A mixture of sheep / beef and sheep farming dominate the mid and upper reaches of the Pig Burn. Dairy farming becomes more common on the more arable land on the valley floor of the Maniototo Plain (Figure 2.3).

Table 2.1 Land cover types in the Pig Burn catchment based on LCDB v.4.

Land cover type	Area (ha)	%
Alpine Grass/Herbfield	1460	29
Deciduous Hardwoods	48	1
Gravel or Rock	41	1
Herbaceous Freshwater Vegetation	124	2
High Producing Exotic Grasslands	1240	24
Low Producing Grasslands	852	17
Matagouri or Grey Scrub	96	2
Mixed Exotic Shrub land	27	1
Sub Alpine Shrub land	227	4
Tall Tussock Grassland	961	19

2.2. Rainfall patterns in the Pig Burn catchment

The upper reaches of the Pig Burn receives the greatest amount of rainfall (650 - 700 mm), while the lower part of the catchment receives 400 - 450 mm annually (Figure 2.4).

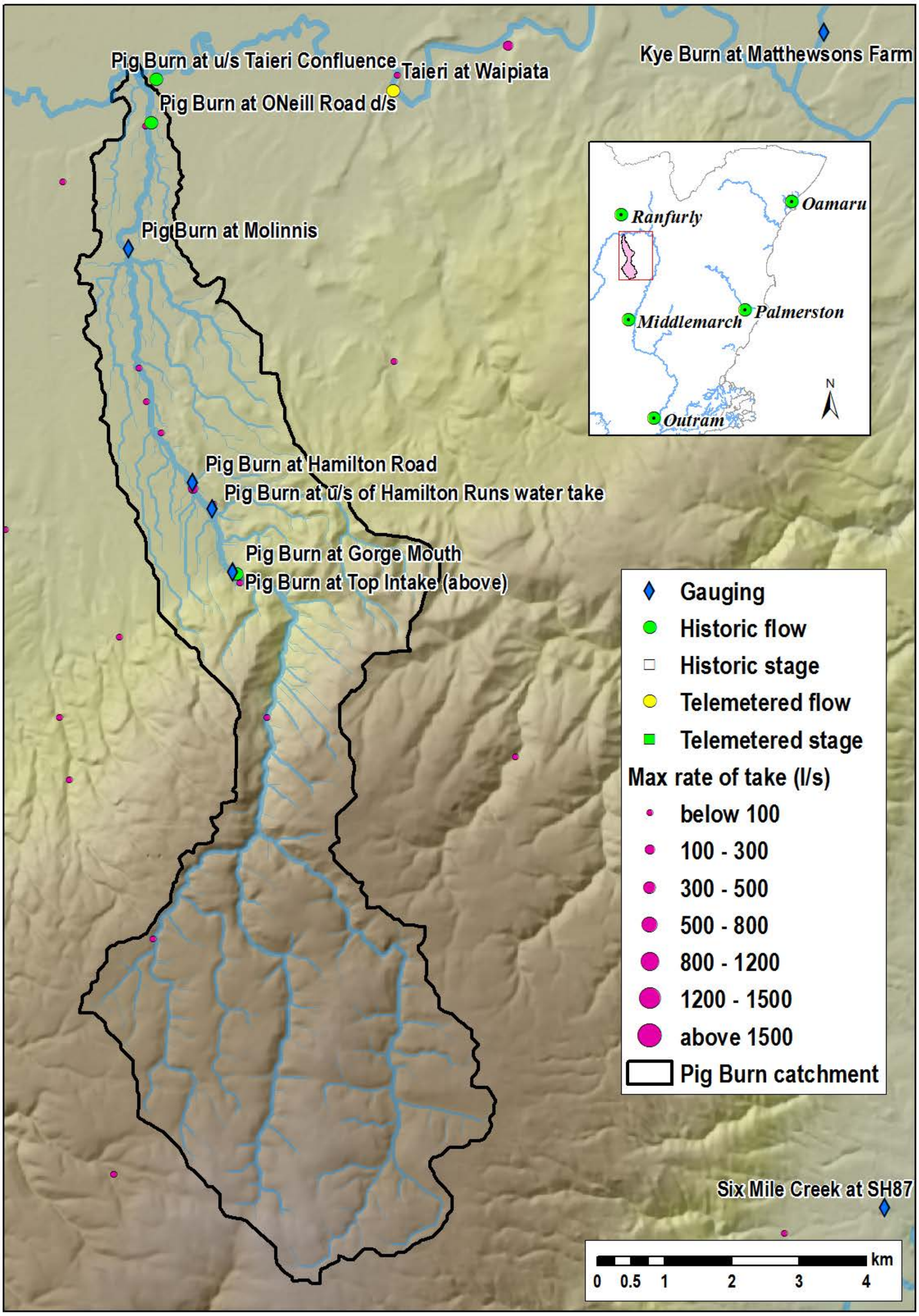

Figure 2.1 **The Pig Burn catchment showing the location of the hydrological monitoring site and flow reference sites.**

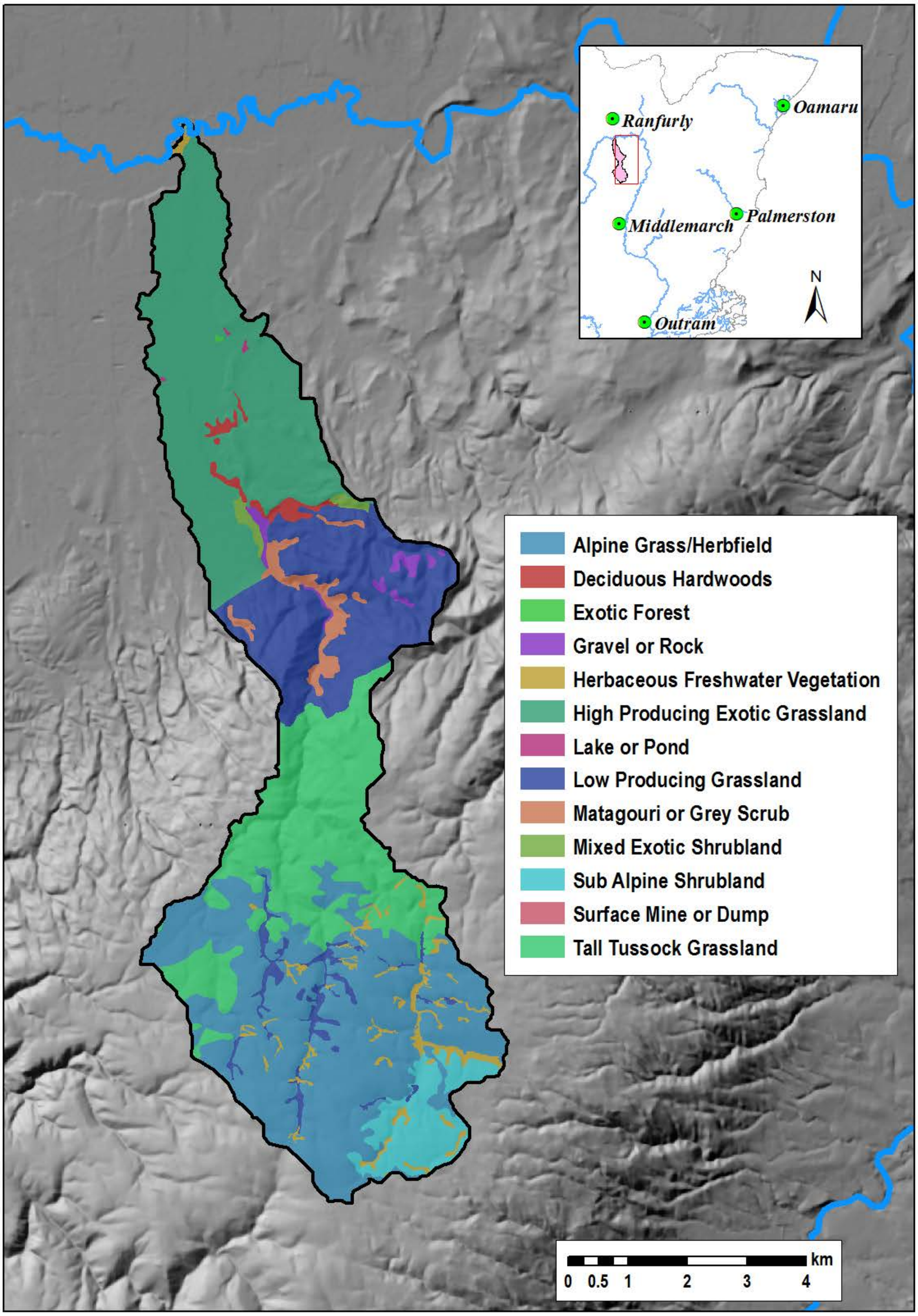

Figure 2.2 **Landcover in the Pig Burn catchment based on Land Cover Database version 4.0 (LCDB v.4).**

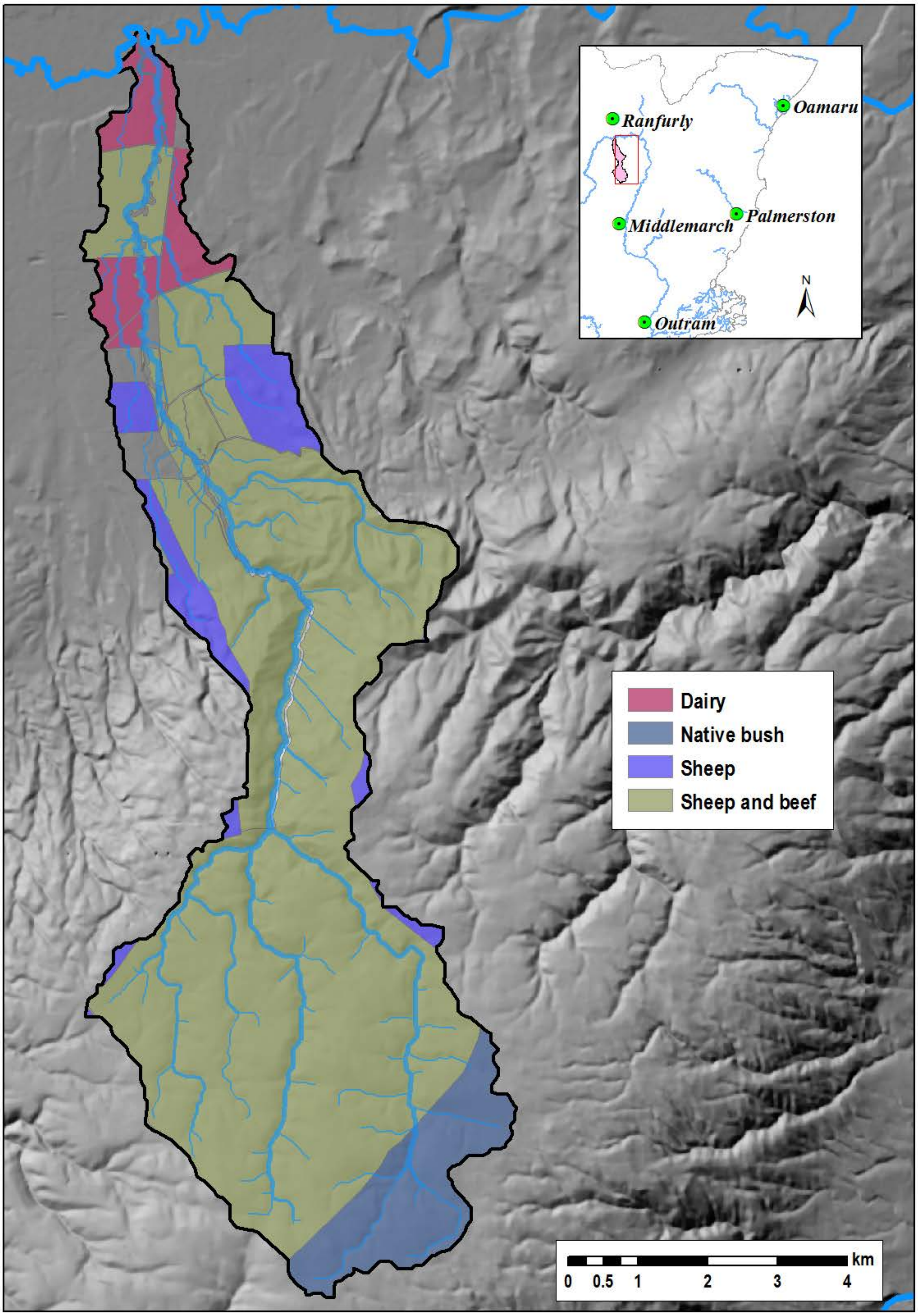

Figure 2.3 **Farm type use in the Pig Burn catchment**

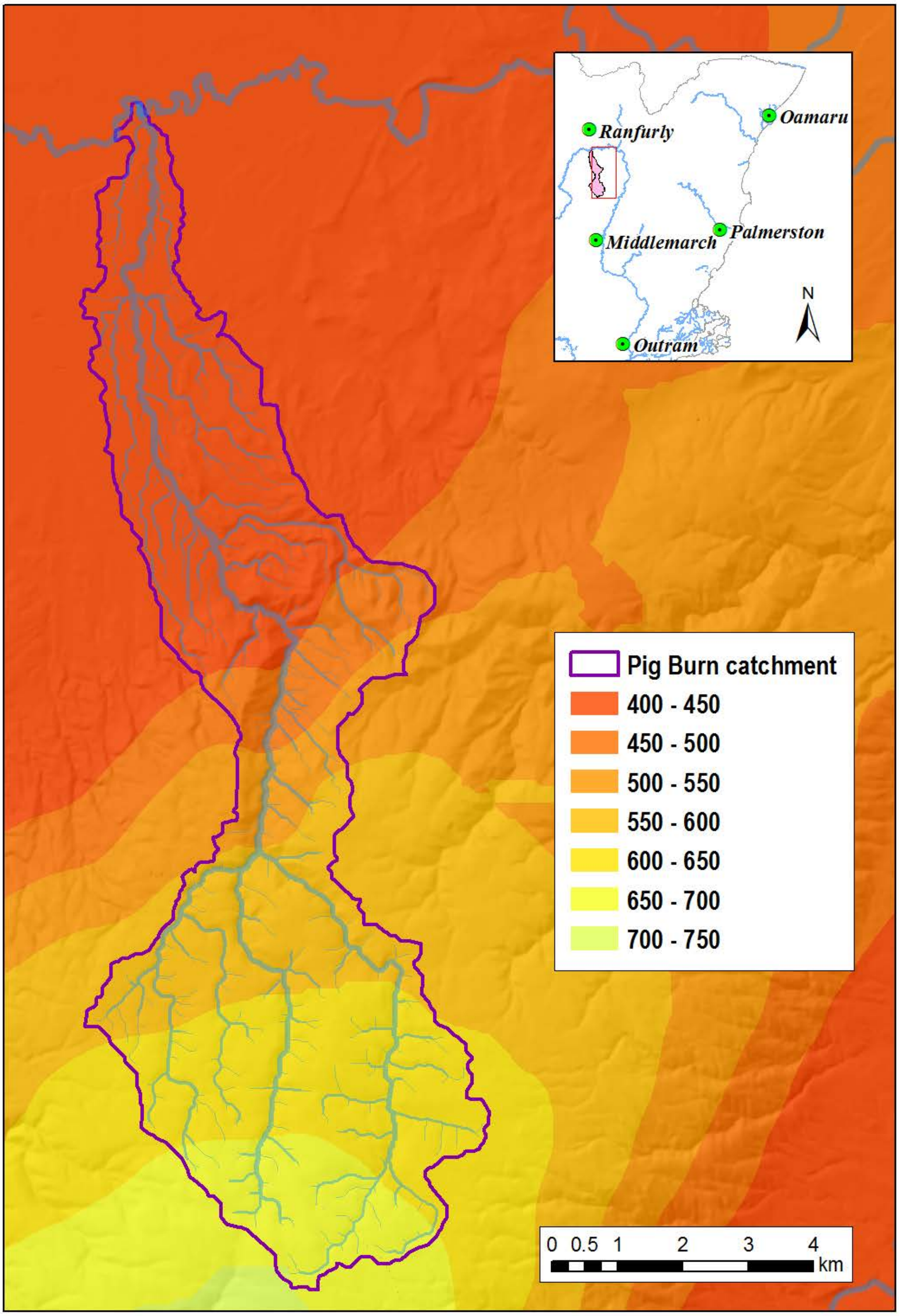

Figure 2.4 **Median annual rainfall in the Pig Burn catchment (from Grow Otago).**

3. River hydrology

3.1. Flow statistics for the Pig Burn catchment

Flows in the Pig Burn were measured at three temporary flow recorders (Figure 2.1) between 24/1/2007 and 7/9/2015 (Figure 3.1). In addition to this concurrent gauging were undertaken at five sites.

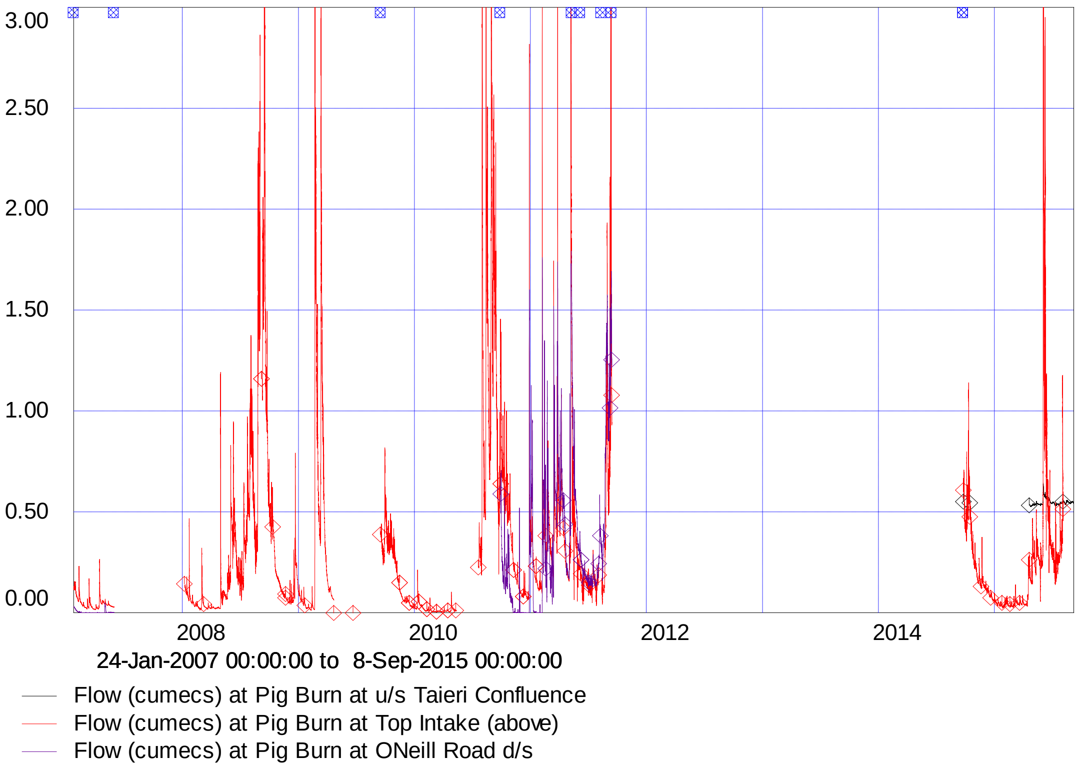

Figure 3.1 The hydrographs for the three flow sites within the Pig Burn catchment

The data availability and flow statistics from these actual flow records from the three temporary sites are listed in Table 3.1.

Table 3.1 Flow statistics (from Hilltop) from flow recorders in the Pig Burn catchment

Monitoring sites	Availability	Min (m^3/s)	Max (m^3/s)	Mean (m^3/s)	Median (m^3/s)
Pig Burn at Top Intake (above)	24/1/2007 ~ 5/8/2015 with data gaps (Figure 3.1)	0.002	25.111	0.307	0.136
Pig Burn at ONeill Road d/s	24/1/2007 ~ 14/9/2011 (Figure 3.1)	0	1.788	0.253	0.145
Pig Burn at u/s Taieri Confluence	21/4/2015 ~ 7/9/2015	0.525	0.643	0.546	0.542

3.2. Water allocation

There are eight permits to take water from the Pig Burn catchment (Figure 3.2), with a consented maximum instantaneous rate of take of 0.455 m^3/s. Three of these water abstractions are located within the upper catchment above Pig Burn at Top Intake, with a total consented maximum instantaneous take of 0.135 m^3/s. Table 3.2 lists all surface water abstractions within the Pig Burn catchment.

Table 3.2 Summary of all water takes within the Pig Burn catchment

Consent number	Maximum rate of take (m^3/s)	Maximum monthly volume (m^3)	Deemed permit
97210	0.056	146081	Yes
96254	0.042	108000	Yes
2000.136	0.086	218880	No
96230.V1	0.111	268800	Yes
96394	0.042	108000	Yes
97128	0.056	145950	Yes
2002.010	0.007	18386	No
2000.498	0.056	144000	Yes

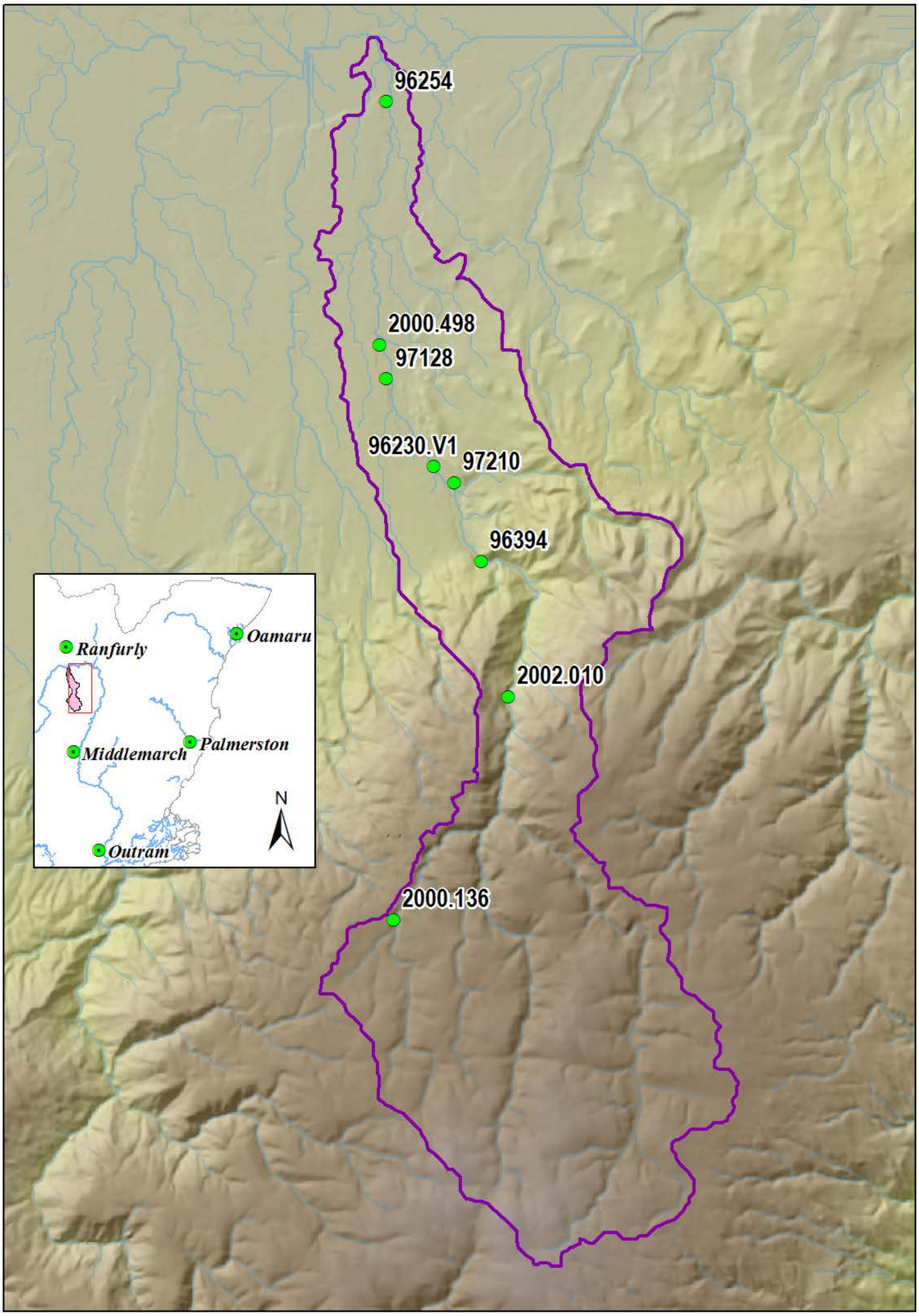

Figure 3.2 **Water takes within the Pig Burn catchment**

3.3. The naturalised 7-d MALF at Pig Burn at Top Intake

The naturalised 7-d MALF at Top Intake would ideally be estimated from the actual flows recorded at the site combined with the water take time series of the three takes upstream of the flow site shown in Figure 3.2. Unfortunately, the water take time series of 2002.010 and 2000.136 are unavailable. Given the absence of water take information, the naturalised 7-d MALF at Pig Burn at Top Intake was estimated by the combined ratio method (Appendix B).

To apply the combined ratio method, a nearby reference flow site with similar catchment characteristics and hydrology with long-term flow records is used to estimate flow statistics for the catchment of interest. Figure 3.3 shows that the flow data from the nearby recorder at Sow Burn at Carr's Intake have a similar flow pattern to those recorded at Pig Burn at Top Intake, indicating that the upstream catchment areas above these two flow recorders are similar in general flow regime. Table 3.3 compares these two upstream catchment areas by topography and general climate.

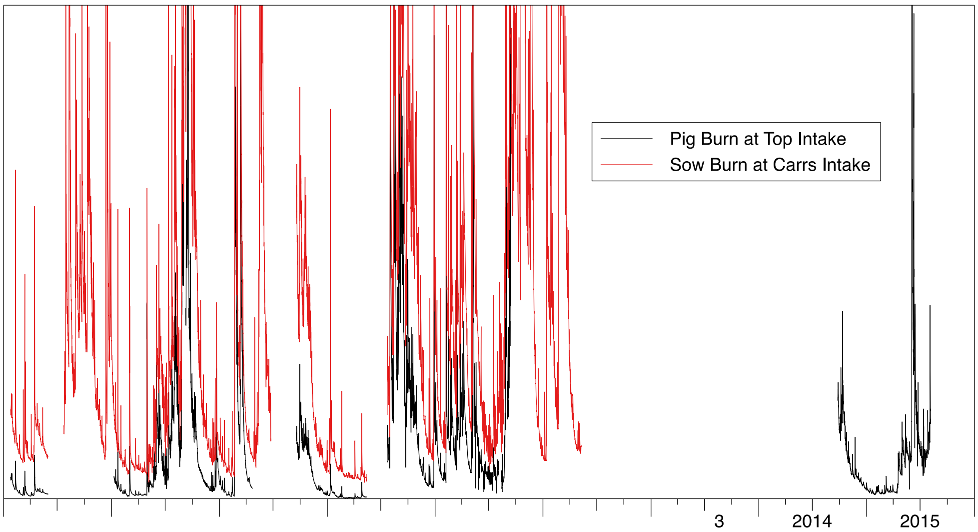

Figure 3.3 **The hydrographs of the flow data at Pig Burn at Top Intake and Sow Burn at Carr's Intake**

Table 3.3 Comparison between the upstream catchment areas of the Pig Burn at Top Intake and the Sow Burn at Carr's Road

	Upstream from Pig Burn at Top Intake	Upstream from Sow Burn at Carr's Intake
Catchment area (km^2)	32.7	66.5
Elevation (m)	470 - 1324	498 - 1448
Median aerial rainfall (mm)	592	707

Table 3.3 indicates that the two upstream catchment areas are similar in topography and general climate. There are currently two surface water takes (95090 and 95092, with an instantaneous rate of take of 0.056 m^3/s) located above Sow Burn at Carr's Intake (Figure 3.4). Both takes are in small tributaries and have very small upstream catchment areas when compared to the total catchment area of the Sow Burn at Carr's Intake. It is therefore assumed that the amount of both takes does not affect the river flows at Sow Burn at Carr's Intake significantly and that flows recorded in the Sow Burn at this point are very close to the natural flow regime. Therefore, the flows actually recorded (between 24/1/2007 and 9/5/2012) at Sow Burn at Carr's Intake are taken as natural and used as a reference for estimating the naturalised 7-d MALF at Pig Burn at Top Intake. The detailed calculations of 7-d MALF at Sow Burn at Carr's Intake are provided as an Excel spreadsheet and it can be requested separately when the report is published.

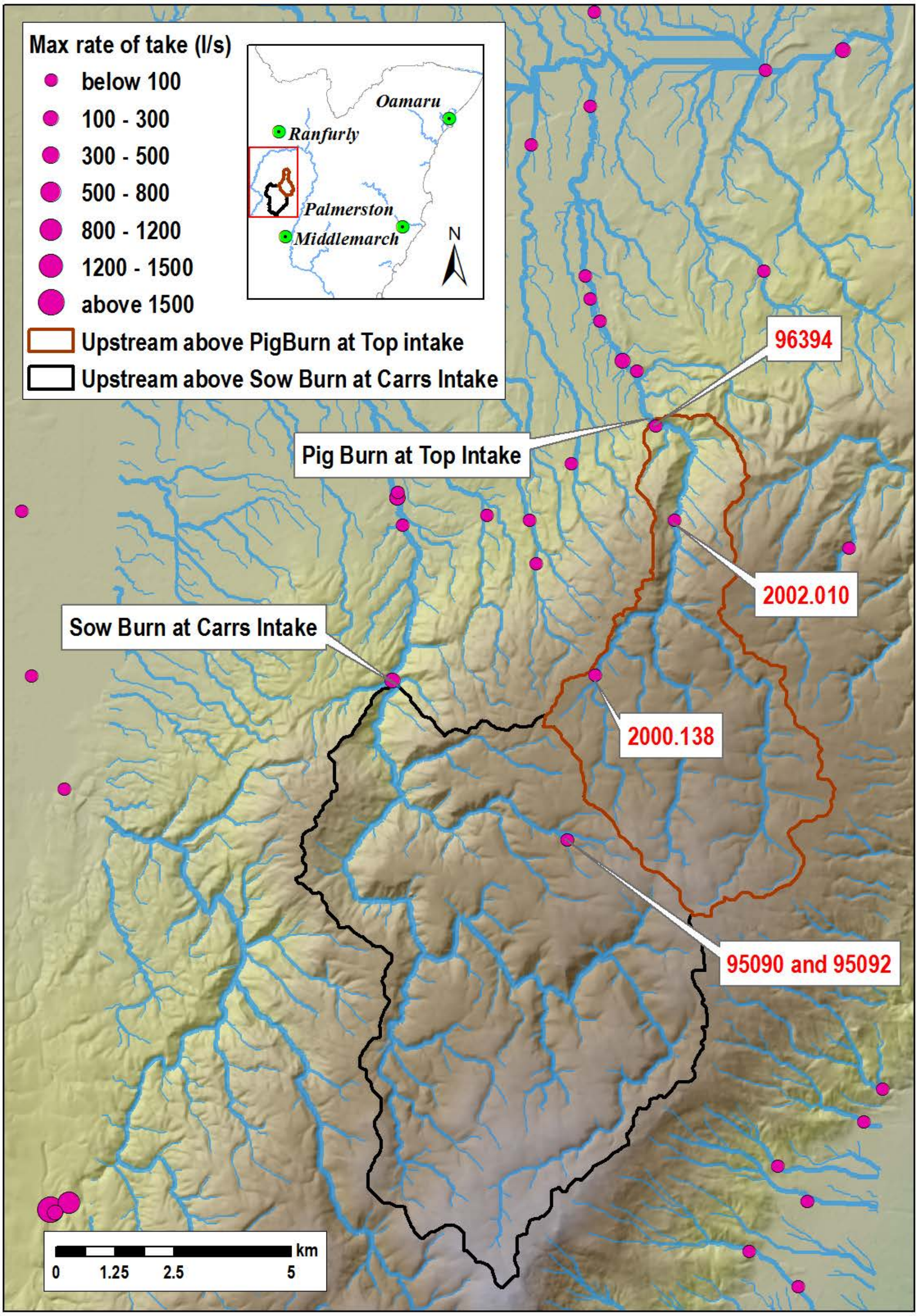

Figure 3.4 The water takes within upstream catchment areas above Pig Burn at Top Intake and Sow Burn at Carr's Intake

The estimated naturalised flow at Pig Burn at Top Intake is summarised in Table 3.4.

Table 3.4 Flow statistics at Sow Burn at Carr's Intake and Pig Burn at Top Intake

Location	Type of flow records	Availability of flow data	7-d MALF (m^3/s)
Sow Burn at Carr's Intake	Actual	24/1/2007 ~ 9/5/2012	0.192
Pig Burn at Top Intake	Actual	24/1/2007 ~ 5/8/2015	0.037
Pig Burn at Top Intake	Naturalised	24/1/2007 ~ 9/5/2012	0.079

3.4. Interaction of surface water and groundwater for the lower reach

Figure 3.5 illustrates the hydrographs and Table 3.5 summarises the daily averaged increase flow between Top Intake and O'Neill Road for the period of May – September 2011. As there are no consented water takes or by-washes occurring nor any contribution from tributaries, it can be assumed that the difference between these sites reflects gains from groundwater. However, further investigations are required to gain a detailed understanding of surface water – groundwater interactions in the lower Pig Burn.

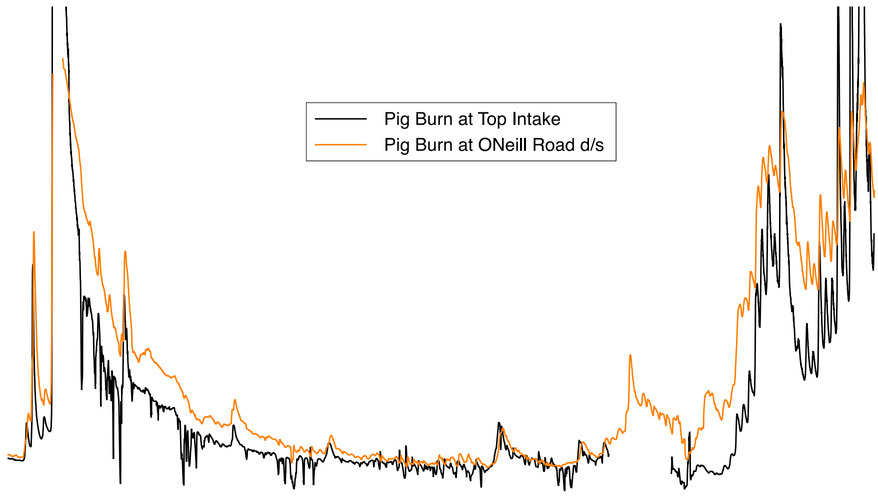

Figure 3.5 **Comparison of water flows of Top Intake and O'Neill Road (May – Sep 2011)**

Table 3.5 The daily average water gained between Top Intake and O'Neill Road during non-irrigation months in 2011

2011	May	Jun	Jul	Aug	Sep
Average water gained (m^3/s)	0.170	0.054	0.019	0.154	0.055

4. Values of the Pig Burn catchment

4.1. Freshwater fish

Two fish species in addition to koura/ freshwater crayfish (*Paranephrops zealandicus*) and Kākahi/ freshwater mussels (*Echyridella menziesi*) have been recorded from the Pig Burn catchment: these being longfin eels and brown trout (Figure 4.1). Of these, longfin eels, koura and freshwater mussels are listed as "At Risk, Declining" in the most recent threat classifications (Goodman et al. 2014, Granger et al. 2014).

Brown trout have been recorded throughout the Pig Burn catchment (Figure 4.1).

4.2. Recreational values

The Pig Burn is not a recognised as a sport fishery but it is likely to be a nursery in providing recruitment for the regionally significant sport fishery of the upper Taieri River (Otago Fish & Game 2015). Angler usage of the Taieri River fell slightly from 2001/2002 to 2007/2008 but remains well above the 1994/1995 season (Unwin 2009).

4.3. Natural Character

The presence of continuous connected surface water is an important component of the natural character of most rivers in the Otago Region. In many situations these connecting flows can be achieved through the resource consent process. Therefore it is assumed that the under natural flows the Pig Burn would expected to be connected with the Taieri River.

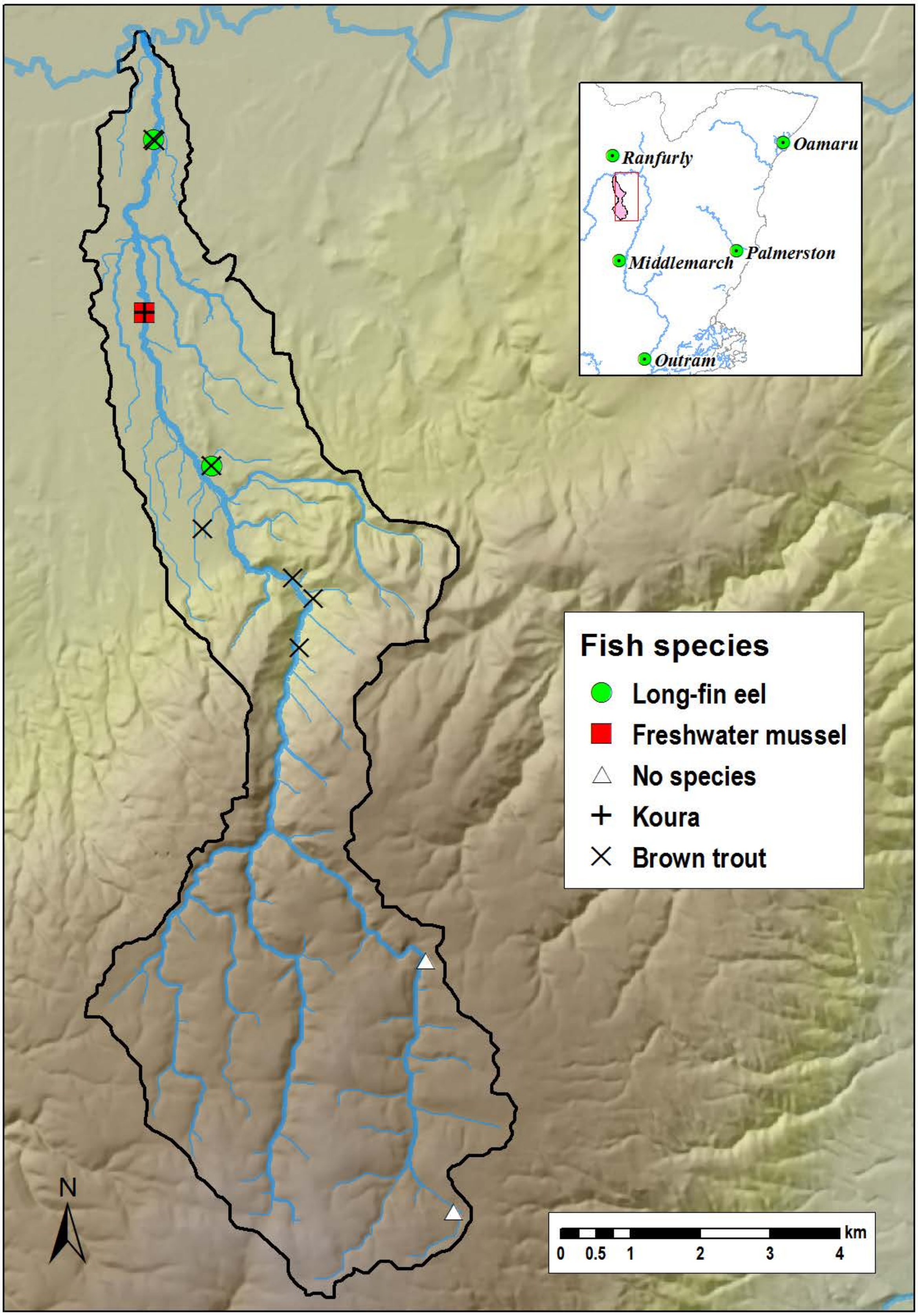

Figure 4.1 **Distribution of fish species in the Pig Burn catchment based on records in the New Zealand Freshwater Fish Database.**

5. Physical habitat

The Otago Regional Council contracted Golder Associates to carry out a study to determine the flows required to maintain acceptable habitat for the fish species present in Pig Burn. The in-stream habitat modelling conducted by Golder Associates (2008) forms the basis for the analyses presented in this section.

5.1. In-stream habitat modelling

In-stream habitat modelling is a means of considering the effects of changes in flow on in-stream values, such as river morphology, physical habitat, water temperature, water quality and sediment processes. As the habitat methods used are based on quantitative biological principles, they are considered more reliable and defensible than assessments made in other ways. The strength of in-stream habitat modelling lies in its ability to quantify the loss of habitat caused by changes in the natural flow regime, which helps to evaluate alternative flow proposals (Jowett, 2005).

Assessing suitable physical habitat for aquatic organisms that live in a river is the aim of in-stream habitat modelling. Habitat methods allow for a more focused flow assessment and can potentially result in improved allocation of resources (Jowett, 2005). However, it is essential to consider all factors that may affect the organism(s) of interest, such as food, shelter and living space, and to select appropriate habitat suitability curves, for an assessment to be credible. Current methods of physical habitat modelling used in New Zealand fail to take into consideration such as biological interactions (such as predation) which can have a significant influence on the distribution of fish species. These factors could or should be considered independently when considering appropriate flow setting regimes.

5.2. Habitat preferences and suitability curves

In-stream habitat modelling requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that if there is no suitable physical habitat provided in a stream for a given species, then the species in question cannot exist (Jowett, 2005). However, if there is physical habitat available for that species, then it may or may not be present in a survey reach, depending on other factors not directly related to flow, or to flow-related factors that have operated in the past (e.g., floods). In other words, habitat methods can be used to set the outer envelope of suitable living conditions for the target biota but cannot provide all the conditions necessary for the biota to live in a stream (Jowett, 2005).

In-stream habitat is expressed as weighted usable area (WUA), a measure of the total area of suitable habitat per metre of stream length. It is expressed as square metres per metre (m^2/m).

5.3. In-stream habitat modelling for Pig Burn

In-stream habitat modelling was undertaken on one reach of Pig Burn (Figure 5.1) using the hydraulic and in-stream habitat model RHYHABSIM (Jowett 1989, Golder Associates 2008).

The study reach extended from Hamilton Road downstream 1.6 kilometres, approximately adjacent to the property known as 'The Beeches'. The survey was conducted between the upper limit of the site to a point upstream of the first downstream irrigation abstraction; this was to minimise effects of water abstraction on the field measurements taken to support the development and running of the model.

The study reach varied in width from 3 - 7 m and had a maximum depth in the pools of approximately 0.7 m. The substrate consisted of gravel and cobbles, with the occasional outcrop of mudstone. Macrophtyes were absent from the stream and the instream cover was provided entirely by the substrate.

The results from the study reach were also applied to the 4.6 km reach immediately downstream of the study site. This is not always applicable as habitats and river morphology may vary between different river reaches of a single waterway and thus impact the assumptions underlying the in-stream habitat model. However, both reaches were morphologically and hydraulically similar enough, that applying across both reaches was sound.

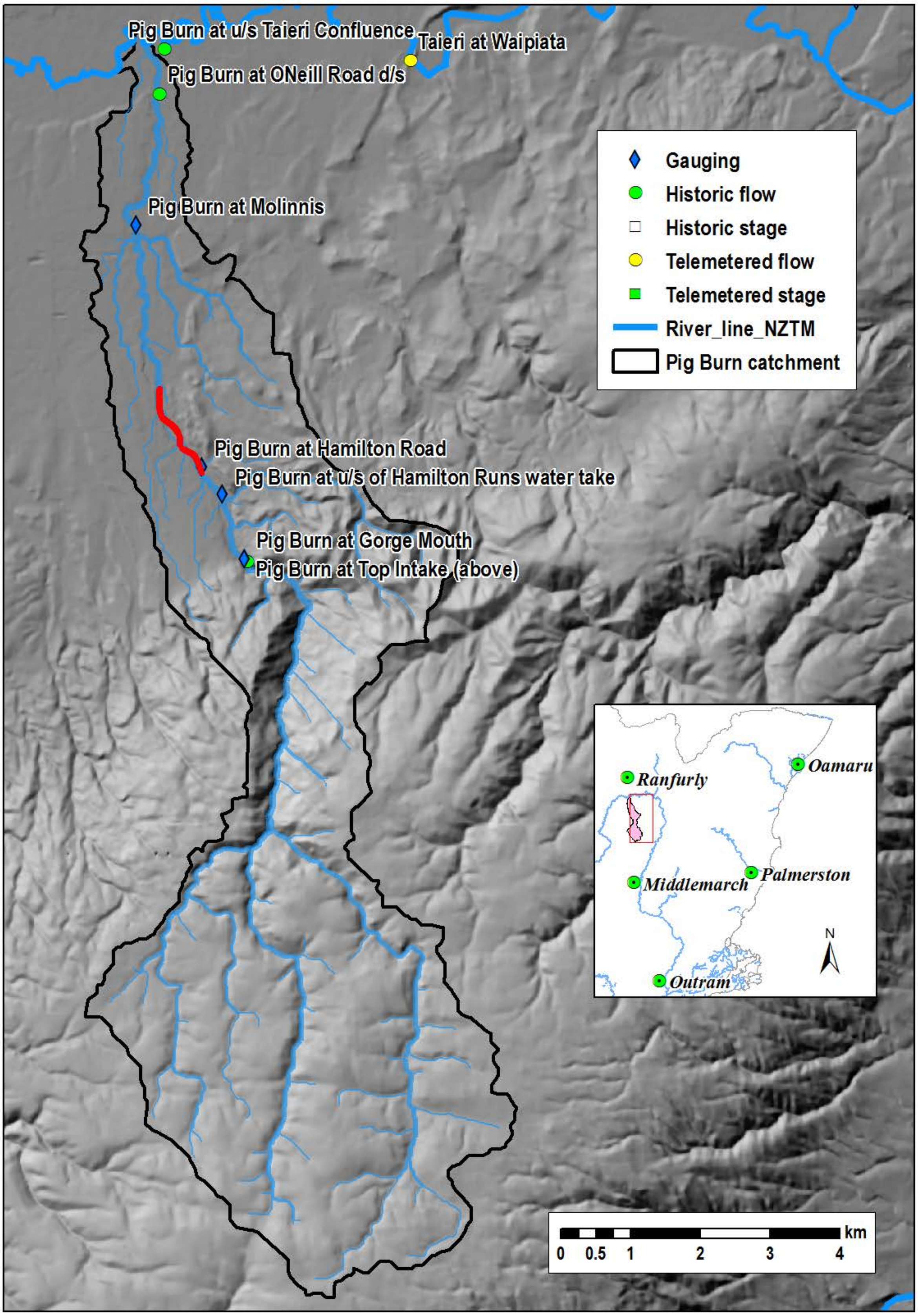

Figure 5.1 **Location of the reach of Pig Burn where IFIM survey was carried out in 2008**

5.4. Pig Burn

5.4.1. Physical habitat

The hydraulic component of instream habitat modelling predicts how water depth, channel width and water velocity change with changes in flow (Figure 5.2). Five of the six habitat preference curves used showed similar distribution of habitat with flow.

The WUA declined steeply for brown trout fry (Figure 5.3) and slowly for juvenile trout (Figure 5.5), as well as yearling and spawning habitat for brown trout (Figure 5.2). Longfin eels WUA increased sharply for small eels (<300mm) from zero to 0.1 m^3/s and continued to rise slowly with flow, with no maximum WUA given. Adult longfin eel (>300mm) WUA declined sharply with no flow.

These results suggest that changes in the physical characteristics of the Pig Burn will be relatively consistent until flows drop 0.15 m^3/s.

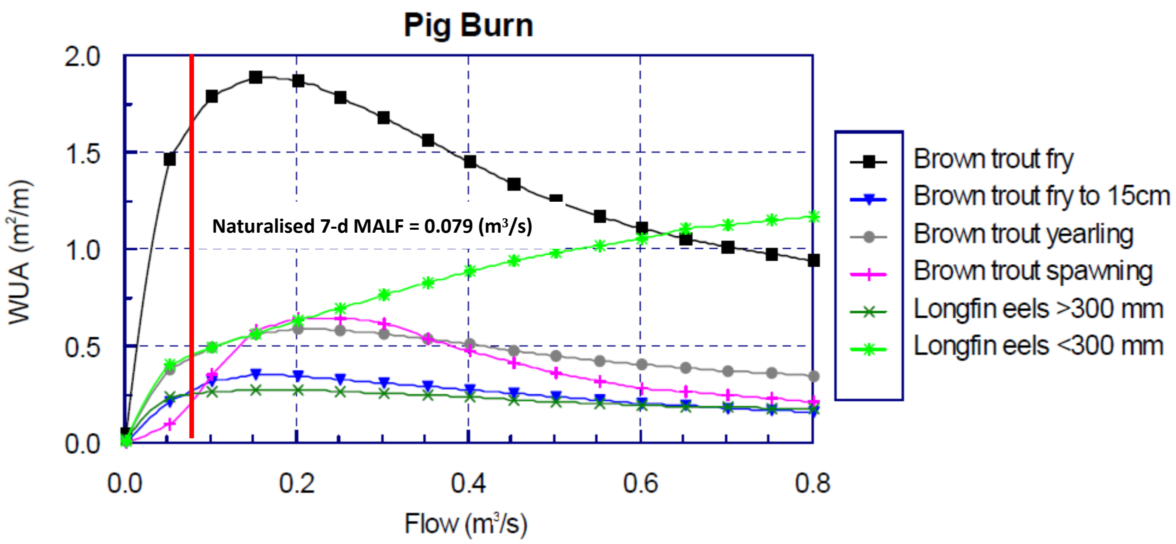

Figure 5.2 **WUA curves for fish species and their life stages in the Pig Burn**

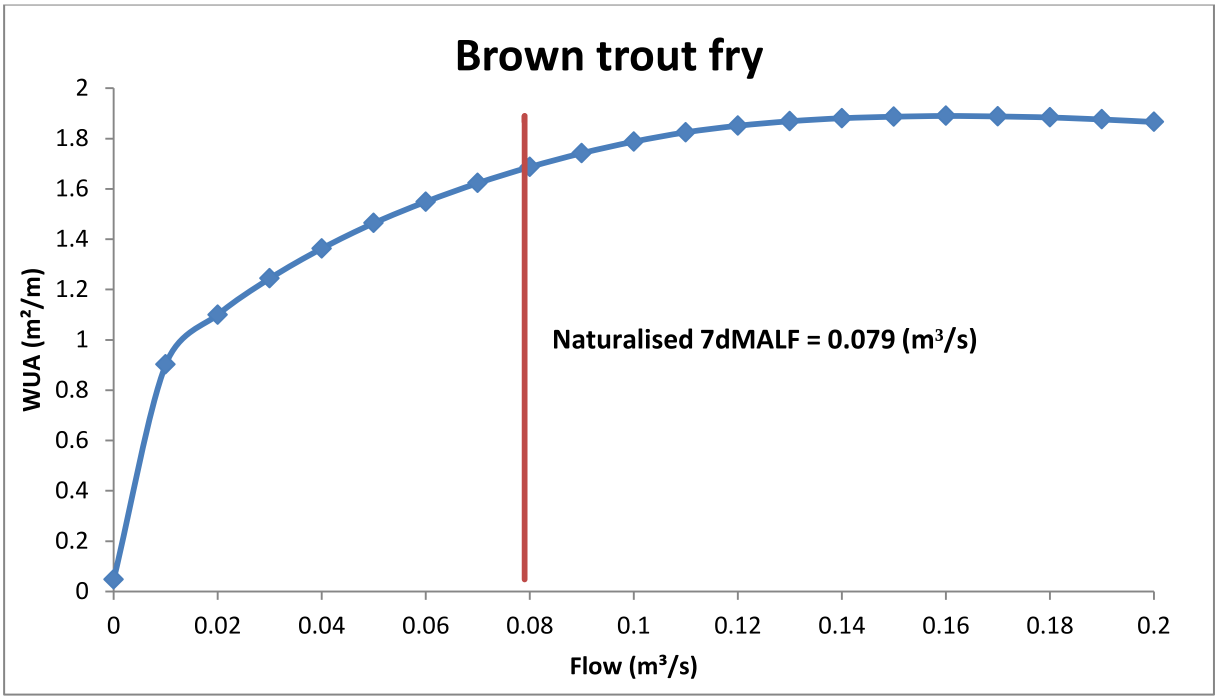

Figure 5.3 **Relationship between flow and potential habitat for brown trout fry in the Pig Burn**

Food producing habitat increased with increasing flows with the optimum flow occurring beyond the modelled range (up to 0.2 m^3/s, Figure 5.4).

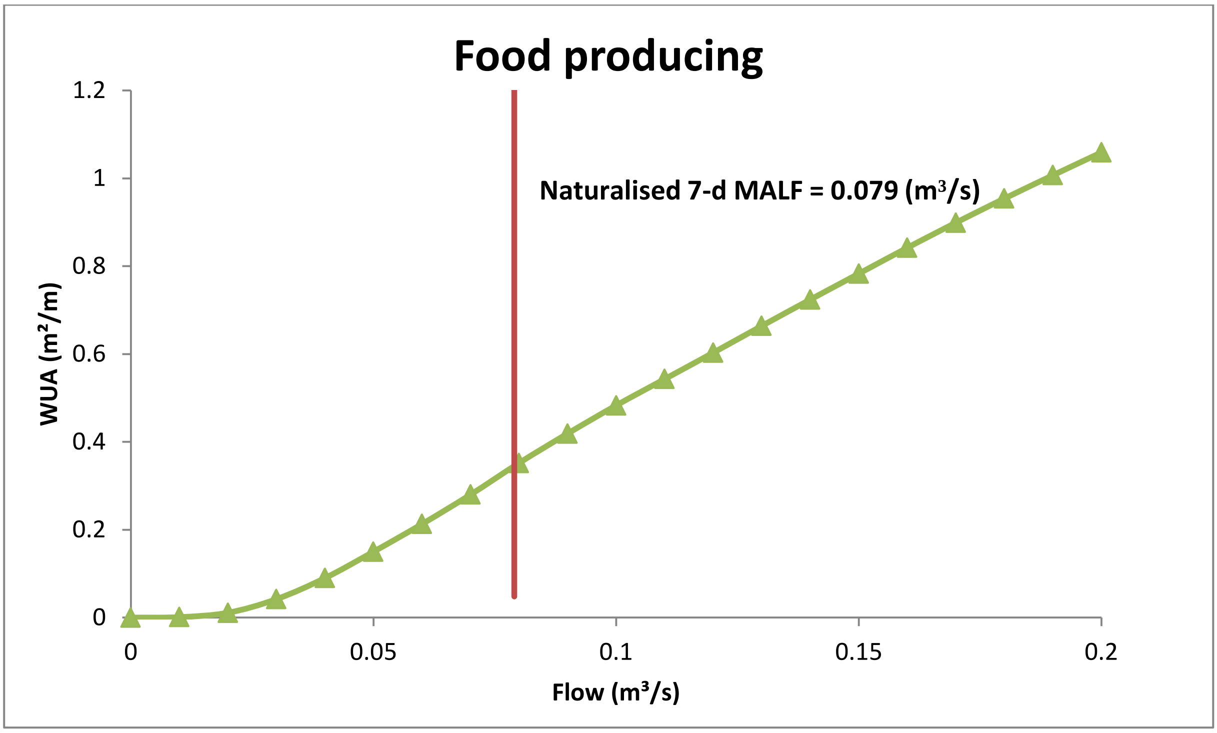

Figure 5.4 **Relationship between flow and potential food producing habitat in the Pig Burn**

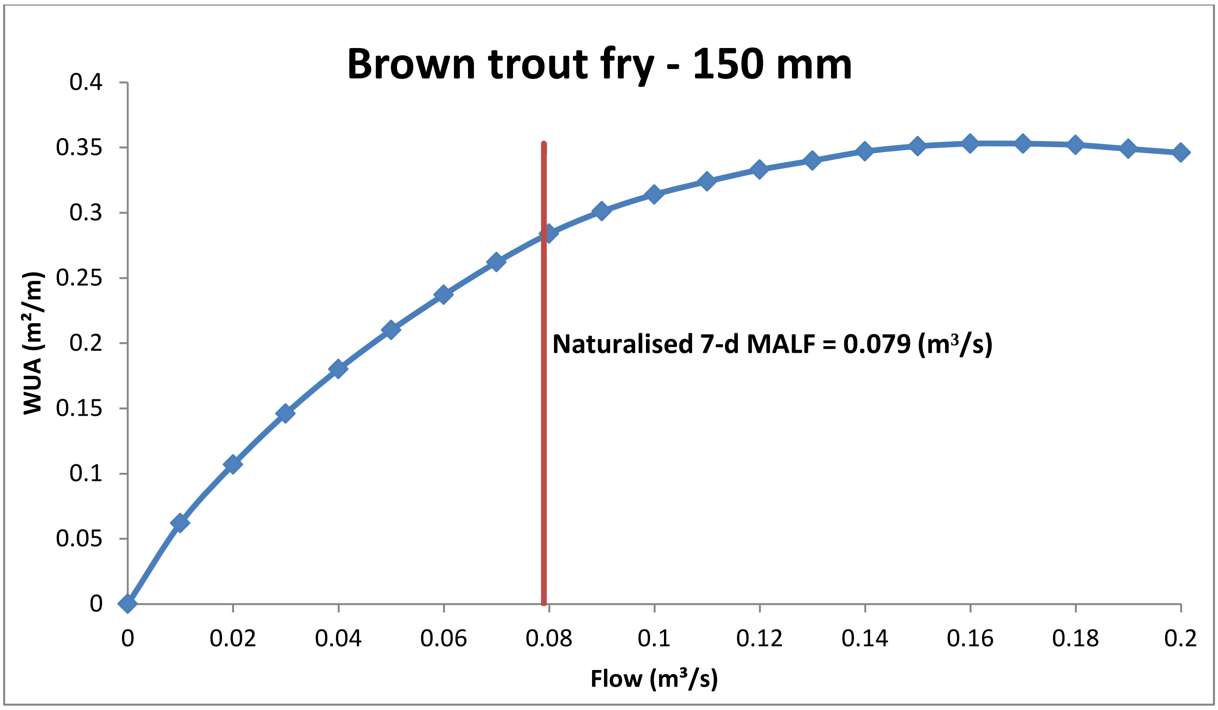

Figure 5.5 **Relationship between flow and potential habitat for brown trout fry – 150 mm**

Based on WUA (Figure 5.2), optimum flow for longfin eel less than 300 mm in length was 0.05 m³/s, whereas for eels of length greater than 300 mm no optimum flows were established. Table 5.1 summarises percentage of habitat retention at flows for different life stages for brown trout.

Table 5.1 **Flow requirements for trout habitat in the Pig Burn based on instream habitat modelling by Golder Associates (2008)**

Species/life stage	Optimum flow (m³/s)	Flow below which habitat rapidly declines (m³/s)	Flow at which % habitat retention occurs (m³/s)			
			60%	70%	80%	90%
Brown trout fry	0.15	0.1	0.015	0.025	0.038	0.056
Brown trout fry - 150mm	0.2	0.1	0.037	0.046	0.056	0.067
Brown trout	0.2	0.15	0.03	0.04	0.051	0.064

5.4.2. Food producing (invertebrate) habitat

Food producing habitat increased with increasing flows with no clear optimum flow within the modelled range (up to 0.2 m³/s, Figure 5.4 and Table 5.2).

Table 5.2 **Flow requirements for optimal food producing habitat in the Pig Burn based on instream habitat modelling by Golder Associates (2008)**

Species/life stage	Optimum flow (m³/s)	Flow below which habitat rapidly declines (m³/s)	Flow at which % habitat retention occurs (m³/s) below 7dMALF (0.079 m³/s)			
			60%	70%	80%	90%
Food producing	> 0.2	-	0.059	0.064	0.069	0.074

5.5. Summary of in-stream habitat modelling

Values assessment is an important part of the flow-setting process and can be used to determine the level of protection required for different values based on their significance within the catchment. Flow-dependent values were assessed for the Pig Burn and appropriate levels of protection assigned following the approach of Jowett & Hayes (2004). The outcome of these assessments are summarised in Table 5.3.

The Pig Burn provides no recreational benefit to trout anglers but it may provide a nursery for the upper Taieri River brown trout fishery.

Table 5.3 Assessment of instream habitat values at sites in the Pig Burn with recommended levels of habitat retention (based on the approach of Jowett & Hayes 2004).

Value	Significance	Habitat retention	Flow (m^3/s)
Brown trout spawning	Regionally significant†	70%	0.120
Brown trout fry -150 mm	Regionally significant ɣ	70%	0.046
Brown trout fry	Regionally significant	70%	0.025
Food producing	Life supporting capacity	70%	0.064

† Based on the assessment in Otago Fish & Game Council (2015)
‡ Based on Goodman *et al.* (2014)

6. Conclusions: Flow requirements for aquatic ecosystems in the Pig Burn

The Pig Burn provides spawning habitat in the lower catchment for brown trout but doesn't attract much effort from recreational anglers. However, it is likely to contribute to recruitment to the regionally significant trout fishery in the upper Taieri River. It also provides habitat for longfin eel, which are classified as "At Risk and Declining" in the most recent assessment of the conservation status of New Zealand freshwater fish (Goodman *et al.* 2014).

Instream habitat modelling predicts that flows to provide 70% habitat retention for trout fry and trout fry to 150 mm are 0.055 m^3/s. This level of habitat retention is seen as a suitable level of habitat protection for a regionally significant trout fishery based on Jowett and Hayes (2004). The retention of 100% of trout spawning habitat during winter and spring (May to September) would require flows of 0.2 m^3/s.

The analysis of the Pig Burn was undertaken using two complete irrigation seasons. This small dataset has limitations when used to estimate naturalised 7-d MALF. Data of 30 years' duration or more is often recommended as a minimum record length for flow analysis (for example, Tallaksen *et al.*, 2004). Pragmatically, hydrologists often have to manage with data of much shorter duration: a minimum record length of 5 years is commonly specified; however, data of fewer years' duration can sometimes be useful, especially if important events are captured in an otherwise under-gauged region and if the data can be correlated with longer time series from nearby gauging stations (Manual on low-flow estimation and prediction, 2008). Therefore, flow statistics for the Pig Burn at Top Intake were estimated from the actual flows recorded in the Sow Burn at Carrs Intake.

The hydrological analysis conducted as part of this study estimated the naturalised 7-d MALF at the Pig Burn at Top Intake to be 0.079 m^3/s. There are eight permitted water takes in the Pig Burn catchment with a combined maximum instantaneous rate of 0.455 m^3/s

This study did not consider surface water and groundwater interactions in the lower the Pig Burn in detail and further targeted investigations would be required to gain a detailed understanding of these interactions.

7. Glossary

Abstraction
See water abstraction.

Allocation limit or allocation volume
The maximum flow or quantity of water in a water body, which is able to be allocated to resource consents for taking.

Catchment
The area of land drained by a river or body of water.

Instream Flow Incremental Methodology (IFIM)
An instream habitat model used to assess the relationship between flow and available habitat for fish and invertebrates.

Instantaneous take
All takes of water occurring at a particular time.

Irrigation
The artificial application of water to the soil, usually for assisting the growing of crops and pasture.

Main stem
The principal course of a river (i.e., does not include tributaries).

Seven-day Mean Annual Low Flow (7-d MALF)
The average of the lowest seven-day low flow period for every year of record

Minimum flow
The flow below which the holder of any resource consent to take water must cease taking water from that river.

Primary allocation
The volume of water established under Policy 6.4.2 of the RPW that is able to be taken, subject to a primary allocation minimum flow.

Reach
A specific section of a stream or river.

Return period
An estimate of the average interval of time between events (e.g., flood or low-flow event).

River
A continually or intermittently flowing body of fresh water that includes a stream and modified watercourse, but does not include any artificial watercourse (such as an irrigation canal, water supply race or canal for the supply of water for electricity power generation and farm drainage canal).

Taking
The taking of water is the process of extracting the water for any purpose and for any period of time.

Vegetation
Plant cover, including trees, shrubs, plants or grasses.

Water abstraction
The extraction of water from a water body (including aquifers).

Water body
Fresh water or geothermal water in a river, lake, stream, pond, wetland or aquifer, or any part thereof, which is not located within the coastal marine area.

Water permit
A permit granted under the Resource Management Act (1991) to take water.

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Appendix A

Habitat suitability curves used in instream habitat modelling presented in this report

Species	Habitat suitability curve
Brown trout adult	Hayes & Jowett 1994
Brown trout yearling	Raleigh et al 1986
Brown trout spawning	Shirvell & Dungey 1983
Brown trout fry to 15cm	Raleigh et al 1986
Brown trout fry	Bovee 1978
Longfin eel (>300 mm)	Jellyman et al. 2003
Longfin eel (<300mm)	Jellyman et al. 2003
Food producing	Waters 1976

Appendix B

Combined ratio method for flow naturalisation

To apply the combined ratio method, there are assumptions for the catchments in comparison:

Catchments in comparison are reasonably hydrological comparable or similar, i.e., similar general annual rainfall.

The total long-term annual rainfall (in volume) is proportional to its naturalised river flows at the catchment outlet.

Therefore, the naturalised flows at a point of interest can be estimated by using the naturalised flows at the outlet of another catchment which is hydrological similar.

Specifically, the steps described below can be followed:

- Use GIS application to identify the estimated long-term annual **m**edian **a**erial **p**recipitation (MAP) between the successive isohyets (R), by multiplying its respective area (A), and the long-term rainfall in volume for the catchment can be found as $[\sum_{i=1}^{m}(R_i\, A_i)]_I$
- Repeat the last step for a chosen catchment with naturalised flows available, to derive the long-term MAP in volume, which is $[\sum_{j=1}^{n}(R_j\, A_j)]_{II}$
- Apply the mentioned assumption:

$$\frac{[\sum_{i=1}^{m}(R_i\, A_i)]_I}{(Flows@Outlet)_I} = \frac{[\sum_{j=1}^{n}(R_j\, A_j)]_{II}}{(Flows@Outlet)_{II}}$$

Therefore, the estimated long-term naturalised flow at Outlet of catchment$_{II}$ can be calculated as:

$$(Flows@Outlet)_{II} = (Flows@Outlet)_I \times \frac{[\sum_{j=1}^{n}(R_j\, A_j)]_{II}}{[\sum_{i=1}^{m}(R_i\, A_i)]_I}$$