
Waitaki District Council

Proposed Shag River Irrigation Scheme

Ecological Assessment of Reservoir Creation and Downstream Flows



prepared by

Ryder Consulting

May 2005



Waitaki District Council

Proposed Shag River Irrigation Scheme

Ecological Assessment of Reservoir Creation and Downstream Flows

prepared by

Ruth Goldsmith, PhD.
Greg Ryder, PhD.

Ryder Consulting

May 2005

Cover photo: Shag River downstream of 'The Grange' road bridge

Ryder Consulting Limited
PO Box 1023
Dunedin
New Zealand
Ph: 03 477 2119
Fax: 03 477 3119

Table of Contents

ACKNOWLEDGEMENTS	4
1. Introduction	5
1.1 Background	5
1.2 Shag River irrigation scheme.....	5
1.3 Objectives	6
2. Shag River catchment	6
2.1 Historic setting	6
2.2 Existing habitat characteristics	7
2.3 Water quality	8
2.4 Periphyton	8
2.5 Fish distribution	10
2.6 Benthic macroinvertebrate communities.....	14
2.7 Water-dependent bird communities	16
2.8 Conservation value.....	18
3. Effects of proposed scheme enhancement	20
3.2 Reservoir creation	20
3.2 Fish passage.....	22
3.3 Downstream river.....	23
4. Low Flow Assessment.....	24
4.1 Site selection	24
4.2 Species modelled.....	25
4.3 Results & Interpretation.....	26
4.3.1 Camp Armstrong.....	26
4.3.2 Goodwood Pump	29
4.4 Implications for reservoir management.....	32
5. Conclusions	33
6. References	36
Appendix One: IFIM Assessment Methods.....	39

ACKNOWLEDGEMENTS

Ryder Consulting Limited would like to acknowledge the assistance of the following people and organisations:

Rod Philip, Jim Hinkley, Les Booth, Dave Stewart, Otago Regional Council.

1. Introduction

1.1 Background

The Shag River catchment provides ground and surface water for residential water supplies and irrigation in the Shag Valley. Further development in the valley is somewhat limited though by severe water shortages during droughts, which have occurred regularly over the past 25 years, most recently in 1999. The Waitaki District Council (WDC) have therefore commissioned, via Government AGMARDT funding, an investigation of alternative options for water supply in the Shag River catchment. These include the creation of a reservoir(s) in the middle reaches of the Shag River, which would capture and store water for irrigation and maintenance of downstream flows during dry periods. The proposed irrigation scheme is outlined below.

1.2 Shag River irrigation scheme

The Shag River has its source at the northwest end of the Kakanui Mountains and flows south eastwards to enter the sea approximately 8km downstream of Palmerston, draining an area of approximately 544km². The Shag River catchment is bounded to the north by the Kakanui Mountains and the Horse Ranges (elevation approximately 900-1500m), and to the southwest by lower hills extending from Macraes Flat to Bushey Park (elevation approximately 400-800m). A variety of options for an irrigation scheme in the Shag River area have been investigated, including in addition to the Shag River catchment itself, the Blue Mountain, Stony Creek, Watkins Creek, Trotters Creek and Pleasant River catchments (Hamilton 2002). These investigations have identified the construction of a dam or dams in the middle reaches of the Shag River as the preferred option. Six sites in the area between Shag Valley Station and the Grange bridge on SH85 have been proposed (Table 1). In this area the river passes through several gorges, which would assist in reservoir formation, and the proposed sites are downstream of Deepdell Creek, which would have the benefit of providing additional catchment area (Hamilton 2002). Although some sites are mutually exclusive, the construction of more than one dam progressing up valley with increasing elevation is possible (Hamilton 2002). This would provide the opportunity for creating a base level of storage through an initial dam, with construction of a second or third dam for further storage at a later stage (Hamilton 2002).

Table 1. Proposed reservoir sites in the middle reaches of the Shag River (sourced from Hamilton 2002).

Proposed reservoir site	Map reference	Catchment area (km ²)	Pond level (mASL)	Surface area (ha)	Approx. dam height (m)	Approx. water volume (m ³)	Valley width at river (m)
Grange downstream	I42: 231360	342.8	82	56.9	23	3603667	200
Grange upstream	I42: 218358	337.9	82	28	16	1120000	30
Pineside	I42: 218370	334.1	98	58.7	27	4500333	40
McDonald	I42: 215379	322.9	100	21.8	24	1453333	35
Loop Road downstream	I42: 193386	309	120	68	24	4533333	25
Shag Valley Station ford	I42: 168400	268	160	29.2	27	2238667	25

1.3 Objectives

Ryder Consulting Limited was engaged by the WDC to complete an ecological assessment of the proposed Shag River irrigation scheme in order to determine the nature and magnitude of any effects of reservoir creation and resulting alterations to downstream flows on aquatic species and habitats in the Shag River catchment.

2. Shag River catchment

2.1 Historic setting

The Shag River catchment has a long history of human occupation and as a consequence is highly modified (Otago Regional Council 1991). At the river mouth, the remains of one of the oldest Maori settlement sites are still in existence, dating from 1163 AD. European settlement began in the 1840s, and from 1864 the Shag Valley was used to provide access to the Central Otago goldfields through the ‘Pigroot’. In the 1890s a dam was built in the river near Craig Road bridge, providing water to the Glenpark flourmill. After the mill closed the dam continued to be used as a stock barrier and, when in operation, prevented fish passage. However, over the last decade, use of the dam has stopped and fish passage is continuous throughout the year. Irrigation in the Shag Valley began in the 1930s as the intensity of agriculture increased and the low rainfall was found insufficient to sustain spring/summer plant growth. Water also began to be abstracted from the river to provide the Palmerston and rural drinking water supplies. From the 1940s significant quantities of gravel were extracted from the river resulting in depletion of the gravel resource in the main river and a general lowering of the riverbed with the increased exposure of bedrock. In response, the issuing of new gravel extraction permits for the Shag River has recently ceased. River channel modifications to reduce erosion and control flooding have included the placement of rock on riverbanks and management of riparian vegetation. Willows began to be removed from the lower reaches of the river from the 1960s, and further management has involved selective removal, spraying and some replanting of willows.

2.2 Existing habitat characteristics

The Shag River and its tributaries, which include McCormick's Creek, Deepdell Creek, Sweetwater Creek, Coal Creek and Shingly Creek, are located within a catchment that encompasses valley flats, gently rolling hills and steeper mountain ranges. Much of this land is highly fertile, and pastoral and arable farming are practised over wide areas with a smaller amount of forestry and horticulture. The riparian vegetation is therefore dominated by exotic pastureland with small remnants of native vegetation including scrub and tussocks, especially in the steeper gorge areas. Willows line the banks of the Shag River in its lower reaches (Figure 1), although recently some trees have been removed to assist with water movement during flooding.

In its headwaters the Shag River flows through a narrow valley with a stable bed composed of medium sized gravels. The upper to middle reaches (the area of the proposed reservoir/s) of the river flow through several narrow gorges and the bed consists mainly of bedrock and boulders with areas of unstable gravels and sand. Downstream of the gorges the river is less confined and becomes wider and shallower with long runs, and shorter sections of deep pools and shallow riffles. Here the stream bed is mainly composed of fine to medium sized gravels and coarse sand, although there are also some short sections of bedrock. In the lower reaches near Palmerston, the river follows a more meandering course, with deep pools and long runs. The bed is composed mainly of small to medium sized gravels and sand, and there is extensive macrophyte and algal growth.



Figure 1. Upstream view of Shag River at Wayne's ford; downstream view of Shag River at Craig Road bridge.

2.3 Water quality

Water quality is regularly sampled at two sites in the Shag River by the Otago Regional Council; adjacent State Highway 85 at the Grange (immediately downstream of the proposed reservoir/s area, NZ grid reference 2323400/5535500) and downstream from Palmerston at Goodwood water supply intake (NZ grid reference 2334400/5523500). Dissolved oxygen, pH, temperature, total nitrogen (TN), total oxidised nitrogen (nitrate and nitrite - NNN), ammoniacal nitrogen (NH₃-N), phosphorous (dissolved reactive phosphorus (DRP) and total phosphorus (TP)), suspended solids (SS), turbidity and faecal coliforms (indicator bacteria for sewage) are measured. Benthic macroinvertebrate communities are also sampled at these two sites (refer section 2.6).

Water temperatures in the Shag River during summer can be extremely elevated as a result of low flows and a lack of riparian vegetation (Otago Regional Council 2000). On 8 February 1999, during the most severe stage of the 1999 drought, the water temperature at the Grange was 29°C (Otago Regional Council 2000). Dissolved oxygen and pH in the Shag River are generally within acceptable ranges for instream and human uses (Otago Regional Council 2000). Nitrogen (TN, NNN and NH₃-N) and phosphorous (DRP and TP) levels are also generally below the ANZECC (1992) aquatic ecosystem guidelines (Otago Regional Council 2000). Faecal coliform levels are regularly exceeded though at both sites (Otago Regional Council 2000).

The Otago Regional Council measures water quality at 14 other sites within the North and Coastal Otago catchments, including Water of Leith, Kakanui, MacLennan, Tokomairiro and Waikouaiti rivers, and Careys, Lindsays and Welcome creeks. In comparison to several of these sites, the water in the middle reaches of the Shag River (at the Grange) has generally lower nitrogen, phosphorus and faecal coliform levels and is of higher clarity (Otago Regional Council 2000). This has been attributed to the relatively low intensity of farming in the middle reaches of the river compared to other rivers in the area (Otago Regional Council 2000).

2.4 Periphyton

There have been several studies of periphyton communities¹ in the Shag River (Graham 1989, Ryder 1996, Ryder 1998, Ryder 2000, Ryder 2002). The most recent and regular of these is the ongoing monitoring of algal abundance in the vicinity of the Palmerston sewage land disposal system immediately downstream of Horse Range Road bridge

¹ Periphyton consists mainly of algae attached to the bed of a river or lake, but can also include fungal and bacterial matter, and varies in appearance from a thin brownish or greenish film, to thick, dark-coloured "mats", to masses of streaming green or brown filaments.

(Ryder 1996, Ryder 1998, Ryder 2000, Ryder 2002). Algal communities are described at seven sites every two years. The most upstream site is situated approximately 200m upstream of Horse Range Road bridge (site 1), and the most downstream site is situated approximately 550m downstream of the bridge (site 7) (Ryder 2002). In May 2002, the algal community at five sites was dominated by the diatoms *Cymbella*, *Gomphonema* and *Synedra* (Table 2). Algal cover at one of these sites was extensive, covering 70% of the stream bed. Filamentous green algae were also present at several sites, *Spirogyra* being the most abundant of these species (Table 2). The phytoplankton *Scenedesmus*, which is commonly found in nutrient-rich waters, was present at the site adjacent to the land disposal area (Ryder 2002). Presence of this species could indicate possible leaching of nutrient-rich water into the river (Ryder 2002). In addition, Ministry for the Environment guidelines for nuisance algae were exceeded at four sites (both upstream and downstream of the sewage land disposal area) (Ryder 2002). Prolific growths of periphyton and filamentous algae can cause a decline in the health of benthic macroinvertebrate communities, as was noted in the lower reaches of the Shag River (Goodwood) during severe low flows during the 1999 summer (Otago Regional Council 2000).

Table 2. Algae abundance in the Shag River in the vicinity of the Palmerston sewage land disposal area (sourced from Ryder 2002).

Taxa	Shag River site						
	1	2	3	4	5	6	7
Filamentous green algae							
<i>Cladophora</i>			X		X		
<i>Mougeotia</i>				X			
<i>Spirogyra</i>					XX		
Other							
<i>Scenedesmus</i>				X			
Diatoms							
<i>Cocconeis</i>	X						
<i>Cymbella</i>	XX		XX	X			XX
<i>Eunotia</i>	X			X			
<i>Gomphonema</i>	XX		XX	XXX	XX		XXX
<i>Navicula</i>				X			
<i>Pinnularia</i>	X						
<i>Synedra</i>	XX		X		X		XXX

Notes: X = present, XX = common, XXX = abundant

A less recent study of algal communities in the Shag River, but one that encompassed a broader range of sites, was carried out by Graham (1989). The periphyton community was described at four sites in the lower (Goodwood J43: 331240), middle (Gravel pits I42: 270304, Loop Road ford I42: 194399), and upper (McLeod's Track I42: 082486) Shag River during April. In the upper reach, periphyton was only abundant in fast-flowing riffle areas and filamentous algae was absent (Graham 1989). In contrast, periphyton standing crop biomass was found to be very high in the middle and lower reaches of the

river and several species of filamentous green algae were present, in particular *Cladophora*, which is indicative of nutrient-rich, warm water (Graham 1989). The low autumn flows, higher nutrient loading and lower stream gradient in the middle and lower Shag River were suggested as reasons for the higher periphyton and filamentous algae abundance than in the upper reach (Graham 1989) (Figure 2).



Figure 2. Periphyton growth in lower Shag River near Chisholm Road, September 2004.

2.5 Fish distribution

An examination of the New Zealand Freshwater Fish database and available published information has shown that there are at least 11 freshwater fish species present in the Shag River catchment. Table 3 presents a summary of the available records for this area and they are geographically depicted in Figure 3.

Brown trout (*Salmo trutta*), eel species (mainly longfin or *Anguilla dieffenbachii*) and *Galaxias* species are present throughout the length of the Shag River catchment. Freshwater crayfish (*Paranephrops* species) occur in the upper reaches of the main river and in Deepdell and Tipperary creeks. *Gobiomorphus* species (bluegill, common, redfin and upland bullies), lamprey (*Geotria australis*) and migratory *Galaxias* species including *Gal. brevipinnis* (koaro) and *Gal. maculatus* (inanga) are present in the middle and lower parts of the catchment. There is confusion over the identity of non-migratory *Galaxias* species in the Shag River catchment, with the possible presence of hybrid fish consisting of a cross among several species (*Gal. anomalus*/ *Gal. depressiceps*/ *Gal. vulgaris*, Pete Ravenscroft, DoC pers comm.). DNA testing is being carried out by the Department of Conservation (DoC), which will resolve *Galaxias* species identity and determine if a new species is present.

Table 3. Summary of freshwater fish species present in the Shag River catchment.

Species	Site	NZ grid reference	Location Notes	Year	Source
<i>Gob. cotidianus</i> , & <i>S. trutta</i>	Shag River estuary	2336600 5523800		1989	FWFDB
<i>A. australis</i> , <i>A. dieffenbachii</i> , <i>Gal. maculatus</i> , <i>Geotria australis</i> , <i>Gob. cotidianus</i> , & <i>S. trutta</i>	Shag River	2335100 5523300	At Fleming Road	1989	FWFDB
<i>Galaxias</i> species, <i>Geo. australis</i> , <i>Gob. cotidianus</i> , <i>Gob. hubbsi</i> & <i>Gob. huttoni</i>	Shag River	2334400 5523500	At Fleming Road	1998	FWFDB
<i>Gob. cotidianus</i> & <i>S. trutta</i>	Shag River	2332400 5523600	Horse Range Road	1985	FWFDB
<i>A. australis</i> , <i>A. dieffenbachii</i> , <i>Galaxias</i> species, <i>Gob. breviceps</i> , <i>Gob. cotidianus</i> , <i>Gob. huttoni</i> & <i>S. trutta</i>	Shag River	2333000 5523900	Horse Range Road	1989	FWFDB
<i>A. australis</i> , <i>A. dieffenbachii</i> , <i>Gob. breviceps</i> & <i>S. trutta</i>	Shag River	2326900 5530400	McLew Road	1989	FWFDB
<i>A. australis</i> & <i>Gob. breviceps</i>	McCormicks Creek	2324100 5532200	Confluence with Shag River at Dunback	1989	FWFDB
<i>A. dieffenbachii</i> , <i>Gob. breviceps</i> , <i>Gob. cotidianus</i> & <i>S. trutta</i>	McCormicks Creek	2324900 5532400	Confluence with Shag River	1998	FWFDB
<i>A. australis</i> , <i>A. dieffenbachii</i> , <i>Galaxias</i> species, <i>Gob. breviceps</i> & <i>S. trutta</i>	Shag River	2324000 5535200	At 'Waynes' immediately downstream of Grace Chapman Reserve	1989	FWFDB
<i>Gob. breviceps</i>	Shag River	2323400 5535500	Grace Chapman Reserve	1997	FWFDB
<i>Gob. breviceps</i>	Shag River tributary	2324400 5536500	Park Hill Road	1996	FWFDB
<i>A. dieffenbachii</i> , <i>Galaxias</i> species & <i>Gob. breviceps</i>	Hellene Creek	2319600 5536700	End of McDonald Road	1996	FWFDB
<i>A. dieffenbachii</i> , <i>Gal. brevipinnis</i> , <i>Gob. breviceps</i> & <i>S. trutta</i>	Shag River tributary	2322400 5538800	Adjacent SH 85 immediately downstream of Loop Road	1989	FWFDB
<i>Gal. depressiceps</i> , <i>Gal. brevipinnis</i> & <i>S. trutta</i>	Shag River tributary	2321700 5539400	Adjacent SH85 immediately downstream of Loop Road	1996	FWFDB
<i>G. depressiceps</i>	Shag River & all tributaries	2321700 5539400	Adjacent SH85 immediately downstream of Loop Road		DoC
<i>A. dieffenbachii</i> , <i>Galaxias</i> species, <i>Gal. brevipinnis</i> , & <i>S. trutta</i>	Shag River	2319300 5540000	Loop Road	1989	FWFDB
<i>A. australis</i> , <i>Gal. species</i> & <i>Gob. breviceps</i>	Shag River	2316400 5540500	Shag River Station	1987	FWFDB
<i>A. dieffenbachii</i>	Deepdell Creek	2310100 5537300	Downstream from confluence with Highlay Creek	1990	FWFDB
<i>A. dieffenbachii</i> , <i>Galaxias</i> species, <i>Paranephrops</i> species, <i>S. trutta</i>	Deepdell Creek	2307700 5536000	Golden Point battery	1987	FWFDB
<i>Gal. species</i> & <i>S. trutta</i>	Deepdell Creek	2308700 5536800	Golden Point battery	1989	FWFDB
<i>Gal. species</i> & <i>S. trutta</i>	Deepdell Creek	2307600 5536300	Golden Point battery	1990	FWFDB
<i>Paranephrops</i> species	Deepdell Creek tributary	2309400 5536300	Golden Point Battery	1991	FWFDB
<i>A. dieffenbachii</i> , <i>Galaxias</i> species & <i>S. trutta</i>	Deepdell Creek	2307600 5536500	Golden Point battery	1996	FWFDB
<i>Galaxias</i> species & <i>S. trutta</i>	Deepdell Creek	2307700 5536300	Macraes Flat	1994	FWFDB
<i>Galaxias</i> species	Deepdell Creek	2307200 5535600	Macraes Flat	1996	FWFDB
<i>Galaxias</i> unknown (hybrid)	Tipperary Creek				DoC
<i>Paranephrops</i> species	Tipperary Creek			1997	RC
<i>Gal. species</i>	Happy Valley Creek	2318300 5541300		1991	FWFDB
<i>A. dieffenbachii</i>	Coal Creek	2312100 5547300	Morrisons	2003	FWFDB
<i>A. dieffenbachii</i> & <i>Gal. vulgaris</i>	Huntly Creek	2310500 5548300	Adjacent to Islay Downs, near Waihemo Downs	2003	FWFDB
<i>Gal. vulgaris</i>	Shingly Creek	2310400 5549800	Shingly Creek Station	2003	FWFDB
<i>Gal. species</i> & <i>S. trutta</i>	Shag River	2308200 5536400	At 'no exit' Road immediately upstream of Waihemo Downs	1989	FWFDB
<i>Gal. depressiceps</i> & <i>Gal.</i>	Pig Root Creek	2307600	Near confluence with Siberia Creek	2003	FWFDB

<i>vulgaris</i>		5554000			
<i>Galaxias</i> species & <i>S. trutta</i>	Siberia Creek	2307800 5553700		1989	FWFDB
<i>Galaxias</i> species, <i>Gal. vulgaris</i> & <i>S. trutta</i>	Siberia Creek	2308000 5553700	Immediately upstream of confluence with Pigroot Creek	2003	FWFDB

Notes: DoC – Department of Conservation non-migratory galaxiid database; FWFDB – NIWA Freshwater Fish Database; RC – Ryder Consulting Limited.

Fish species present in the immediate vicinity of the proposed reservoir/s, between Shag Valley Station and the Grange bridge on SH85, are brown trout, flathead galaxias (*Galaxias depressiceps*), koaro (*Galaxias brevipinnis*), shortfin (*A. australis*) and longfin (*A. dieffenbachii*) eels, upland bully (*Gobiomorphus breviceps*) and unidentified *Galaxias* species (Table 3). Trout spawning also occurs in the proposed dam area near Loop Road (Table 4). In addition to these species, Canterbury galaxias (*Galaxias vulgaris*, non-migratory) and koura (freshwater crayfish) are also present upstream of the proposed reservoir area.

The presence of migratory *Galaxias* species (inanga and koaro) in the Shag River provides a regionally significant whitebait fishery and the river has in the past supported a small commercial eel fishery (Otago Regional Council 1991). The brown trout fishery of the Shag River is of local importance on a national basis. It is divided into distinct resident and sea-run populations by the presence of a concrete structure above SH85, which prevents upstream movement of trout (Otago Regional Council 1991). Further upstream movement of trout is prevented by a waterfall above the Pigroot Creek confluence (Otago Regional Council 1991). The lower reaches of the river support an important brown trout fishery, particularly downstream of Horse Range Road bridge near Palmerston. Although densities of trout are low compared to other lowland, coastal Otago rivers, the trout biomass per unit area is considered to be high (Otago Regional Council 1991). Spawning surveys carried out by the Otago Fish and Game Council indicated that redd density was highest in the lower reaches of the river, especially downstream of Glenpark (Table 4). A small amount of spawning also occurs in the lower reaches of Sweetwater Creek (Monty Wright, pers. comm.) There is limited trout spawning upstream of Loop Road, indicating that few sea-run trout travel further upstream to spawn. Redds present in the upper reaches of the catchment are therefore probably those of resident trout populations. Although redd counts show no evidence of a reduction through time, the removal of riparian vegetation and gravels has reduced the amount of habitat available for spawning (Otago Regional Council 1991).

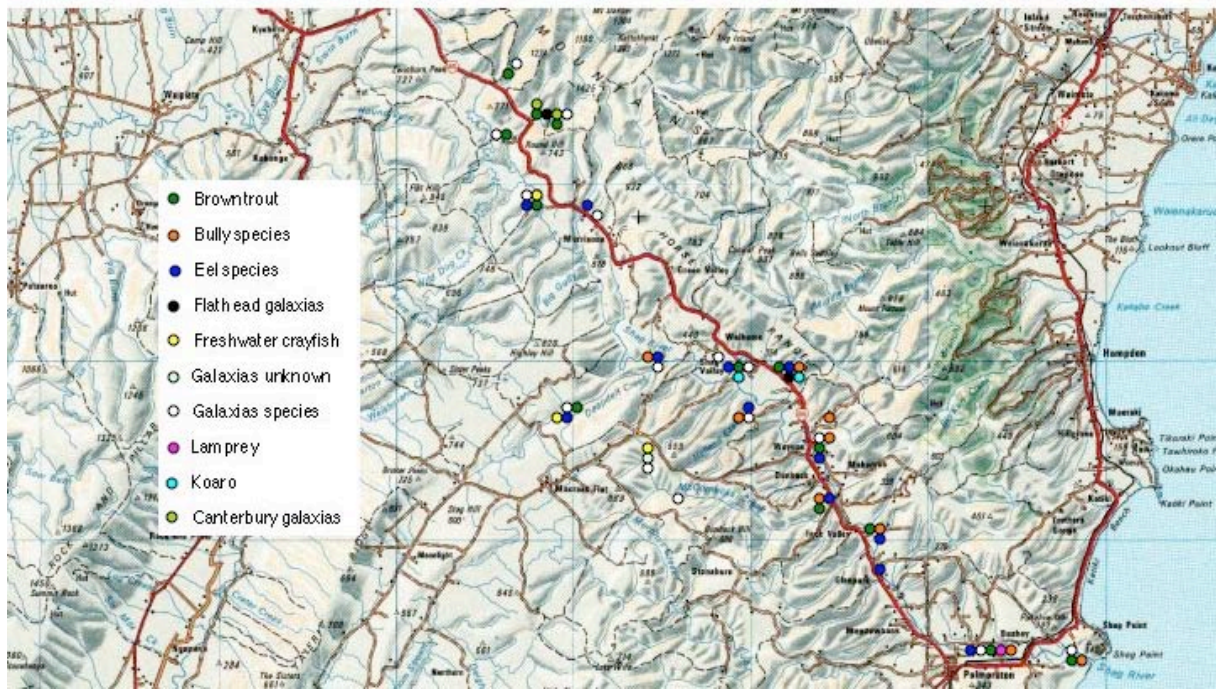


Figure 3. Native fish distribution in the Shag River catchment.

Table 4. Summary of trout redd surveys in the Shag River catchment sourced from the Otago Fish and Game Council.

Trout redds per km			Site	NZ grid reference	Location Notes
1991	2000	2003			
3.3	3.3	0.56	Shag River	2335700 5523700	Rail bridge-Goodwood water supply
20.0	20.0	20.0	Shag River	2330100 5524800	Downstream of Switchback Road
		5.0	Shag River	2329500 5525100	Upstream of Meadowbank
		16.67	Shag River	2327400 5527900	Upstream of Palmerston water supply near Glenpark
3.3	3.3	1.11	Shag River	2328400 5527400	Below Berry Farm Road to Jones Road
	0		Shag River	2323200 5536000	Sweetwater Creek to Main Road at Grace Chapman Reserve
	2.0		Deem Burn	2322200 5538100	Deem Burn upstream
	0		Deem Burn	2322200 5538100	Deem Burn downstream to Shag River
	0		Shag River	2319600 5539500	Lower Loop Road up to clay cliff
	8.3		Shag River	2319300 5539800	Top Loop Road downstream to Fence Creek
	5.0		Pigroot Creek	2306300 5552500	Upstream to cattle crossing at 'no exit' unnamed side road off SH85
	0		Shag River	2306300 5552500	Downstream of confluence with Pigroot Creek
	12.5		Shag River	2305200 5555700	At SH85 immediately upstream of Red Cutting summit
	0		Shag River	2305200 5555700	At SH85 upstream to bluffs

2.6 Benthic macroinvertebrate communities

The Otago Regional Council sample macroinvertebrate communities annually at two sites in the Shag River; adjacent State Highway 85 at the Grange (immediately downstream of the proposed reservoir/s area, NZ grid reference 2323400/5535500) and downstream from Palmerston at Goodwood water supply intake (NZ grid reference 2334400/5523500). From these samples the macroinvertebrate community index (MCI) and semi-quantitative macroinvertebrate community index (SQMCI) are calculated. The MCI uses the occurrence of specific macroinvertebrate taxa to determine the level of organic enrichment in a stream. The SQMCI uses the same approach as the MCI but weights each taxa score based on how abundant the taxa is within the community. Both indexes are interpreted according to Stark's (1998) narrative terminology (Table 5) and are used as measures of community and water quality 'health'.

The values of the MCI and SQMCI index vary among years and between sites (Table 6). MCI scores at the Grange site were generally indicative of waters of 'doubtful quality' in 1996 and 1997 (Table 5 and 6). In 2002 and 2003 MCI scores had increased and were indicative of waters with 'probable moderate pollution' (Table 5 and 6). The most recent MCI scores (2004) indicate though that water quality at the Grange has decreased and is again of 'doubtful quality' (Table 5 and 6). SQMCI scores at the Grange have also decreased recently, from indicative of 'doubtful quality' in 2002 and 2003, to indicative of 'probable severe pollution' in 2004 (Table 5 and 6). At the Goodwood site, MCI scores in all years indicate 'probable moderate pollution' (Table 5 and 6). As at the Grange, SQMCI scores at Goodwood have decreased recently from indicative of 'doubtful quality' in 2002 and 2003, to indicative of 'probable severe pollution' in 2004 (Table 5 and 6). In comparison to region wide averages for North and Coastal Otago monitoring sites during 1996-2000 (in riffles), MCI scores in the Shag River at the Grange were slightly above average and at the Goodwood site below average (Otago Regional Council 2000).

Macroinvertebrate communities at the Grange site are generally diverse with a high taxonomic richness and include several pollution sensitive species. Twenty-five macroinvertebrate taxa were found in the 2004 sample. The macroinvertebrate community was dominated by the snail *Potamopyrgus antipodarum*. Oligochaete worms, Elmids beetles, ostracods, *Deleatidium* mayflies, and the cased caddisflies *Hudsonema amabile* and *Pycnocentroides* were also abundant. Macroinvertebrate communities at the Goodwood site are generally more pollution tolerant than at the Grange site, with a

slightly lower taxonomic richness. Eighteen macroinvertebrate taxa were found in the 2004 sample, which was dominated by Oligochaete worms. Elmid beetles, the dipteran *Orthocladinae*, *P. antipodarum* snails, the mollusc *Gyraulus*, and the cased caddisflies *Oxyethira albiceps* and *Pycnocentroides* were also abundant. The number of macroinvertebrate taxa at both the Grange and Goodwood sites exceed the New Zealand average of 14 taxa (Quinn and Hickey 1990).

Table 5. Interpretation of macroinvertebrate community index values from stony riffles (after Stark 1998).

Interpretation	MCI	SQMCI
Clean water	> 120	> 6.00
Doubtful quality	100 – 119	5.00 – 5.99
Probable moderate pollution	80 – 99	4.00 – 4.99
Probable severe pollution	< 80	< 4.00

Table 6. Macroinvertebrate community index (MCI) and semi-quantitative macroinvertebrate community index (SQMCI) scores for the two Otago Regional Council monitoring sites in the Shag River.

Year	MCI		SQMCI	
	The Grange	Goodwood	The Grange	Goodwood
2004	101	84	3.6	2.6
2003	98	95	5.0	5.6
2002	89	95	4.4	5.3
1997	100	83		
1996	112	88		

Table 7. Macroinvertebrate communities at the two Otago Regional Council monitoring sites in the Shag River in March 2004. Results are shown as the number of individuals per sample.

Sample Location		Shag River @ SH85, the Grange	Shag River @ Goodwood Water Supply Intake
TAXON	MCI score		
COLEOPTERA			
<i>Berosus</i> species	5		12
Elmidae	6	156	492
CRUSTACEA			
Ostracoda	3	108	24
<i>Paracalliope fluviatilis</i>	5		12
DIPTERA			
Chironominae	2	1	
Ephydriidae	4		12
Muscidae	3		12
Orthocladinae	2	24	228
Stratiomyidae	5	12	
Tanypodinae	5	1	
EPHEMEROPTERA			
<i>Deleatidium</i> species	8	228	12
HEMIPTERA			
<i>Sigara</i> species	5	12	
MEGALOPTERA			
<i>Archichauliodes diversus</i>	7	1	1
MOLLUSCA			
<i>Gyraulus</i> species	3	12	180
<i>Physella</i> species	3	48	96
<i>Potamopyrgus antipodarum</i>	4	10332	396
<i>Sphaerium novaezelandiae</i>	3	96	
OLIGOCHAETA	1	780	1716
PLATYHELMINTHES	3	48	
PLECOPTERA			
<i>Stenoperla prasina</i>	10	1	
<i>Zelandoperla</i> species	10	1	
TRICHOPTERA			
<i>Aoteapsyche</i> species	4	24	
<i>Hudsonema amabile</i>	6	384	72
<i>Hydrobiosis umbripennis</i> group	5	12	
<i>Olinga</i> species	9	12	
<i>Oxyethira albiceps</i>	2	24	132
<i>Paroxyethira hendersoni</i>	2		12
<i>Psilochorema</i> species	8	12	
<i>Pycnocentria</i> species	7	24	12
<i>Pycnocentrodes</i> species	5	168	456
Number of taxa		25	18
MCI score		101	84
SQMCI score		3.6	2.6

2.7 Water-dependent bird communities

In 1989 the Otago Acclimatisation Society (Otago Fish and Game Council) carried out a survey of water-dependent bird species in the Shag River catchment (Otago Regional Council 1991). Records note the abundance of each species (i.e., abundant, common, present, or visitor), location within the catchment (estuary, estuary/beach, farm pond, or throughout catchment), legal status (unprotected, protected, or game), and activity (feeding, breeding, or roosting) (Otago Regional Council 1991). Twenty-two bird species were observed during the survey (Table 8). The majority of these species used the catchment for both feeding and roosting, 13 species also bred within the catchment (Table 8). Eleven species occurred throughout the catchment (Table 8). The remainder, with the exception of marsh crake, which was observed in a farm pond, occurred in the estuary or

estuary/beach area (Table 8). Of the 11 species observed throughout the catchment, seven were protected species (black shag, grey teal, little black shag, kingfisher, South Island pied oystercatcher, spur-winged plover and white faced heron), three were game species (mallard, paradise shelduck and pukeko), and one was unprotected (southern black-billed gull) (Table 8). The majority of these species were common, with the exception of pukeko and kingfisher, which were recorded as ‘present’ and ‘visitor’ respectively (Table 8).

A weakness of this data is that it does not provide information on bird communities in the immediate vicinity of the proposed reservoirs. Also, this data was collected approximately 15 years ago during which time bird communities may have changed. However, it does provide an indication of the bird community that can be expected to be present.

Table 8. Shag River catchment water-dependent bird species (sourced from Otago Acclimatisation Society 1989).

Common name	Species	Abundance	Legal status	Use			Occurrence in catchment
				Feeding	Breeding	Roosting	
Black shag	<i>Phalacrocorax carbo</i>	common	protected	Y	Y	Y	throughout
Grey teal	<i>Anas gibberifrons</i>	common	protected	Y	Y	Y	throughout
Little black shag	<i>Phalacrocorax sulcirostris</i>	common	protected	Y	Y	Y	throughout
Mallard	<i>Anas platyrhynchos</i>	common	game	Y	Y	Y	throughout
New Zealand kingfisher	<i>Halcyon sancta</i>	visitor	protected	Y	?	Y	throughout
Paradise shelduck	<i>Tadorna variegata</i>	common	protected/ game	Y	Y	Y	throughout
Pukeko	<i>Porphyrio melanotus</i>	present	game	Y	Y	Y	throughout
Southern black-backed gull	<i>Larus dominicanus</i>	common	unprotected	Y	Y	Y	throughout
South Island pied oystercatcher	<i>Haematopus finschi</i>	common	protected	Y	Y	Y	throughout
Spur-winged plover	<i>Lobibyx novaehollandiae</i>	common	protected	Y	Y	Y	throughout
White faced heron	<i>Ardea novaehollandiae</i>	common	protected	Y	Y	Y	throughout
Marsh crake	<i>Porzana pusilla</i>	present	protected	Y	?	?	farm pond
Banded dotterel	<i>Charadrius bicinctus</i>	visitor	protected	Y		Y	estuary
Black swan	<i>Cygnus atratus</i>	common	game	Y	Y	Y	estuary
Caspian tern	<i>Hydroprogne caspia</i>	visitor	protected	Y		Y	estuary
Eastern bar-tailed godwit	<i>Limosa lapponica</i>	visitor	protected	Y		Y	estuary
Pied stilt	<i>Himantopus leucocephalus</i>	abundant	protected	Y	Y	Y	estuary
Royal spoonbill	<i>Platalea regia</i>	visitor	protected	Y		Y	estuary
Shoveler duck	<i>Anas rhynchos</i>	visitor	game	Y		Y	estuary
White fronted tern	<i>Sterna striata</i>	visitor	protected	Y	?	Y	estuary
Red billed gull	<i>Larus scopulinus</i>	abundant	protected	Y	?	Y	estuary/beach
Variable oystercatcher	<i>Haematopus unicolor</i>	protected	protected	Y	Y	Y	estuary/beach

2.8 Conservation value

The Otago Regional Council's regional water plan (2004) identifies a range of natural (Table 9) and Kai Tahu (Table 10) values supported by streams in the Shag River catchment.

Natural values include ecosystem values, outstanding natural features and landscapes, areas of significant indigenous vegetation and significant habitat of indigenous fauna, and areas with a high degree of naturalness. No outstanding natural features and landscapes, or areas with a high degree of naturalness are identified for streams in the Shag River catchment (Table 9). Shag River, Siberia Creek, Happy Valley Creek and Deepdell Creek are noted though for providing significant habitat for flathead galaxiids (*Galaxias depressiceps*), and likewise the Deem Burn and Shag River are noted for providing significant habitat for koaro (*Gal. brevipinnis*) (Table 9). The Shag River is also noted for providing significant habitat for lamprey (*Geotria australis*), which is uncommon in Otago (Table 9). Lastly, Tipperary Creek is noted for providing significant habitat for the hybrid galaxiid species, discussed previously in section 2.5 (Table 9). Ecosystem values of streams in the catchment include an absence of aquatic pest plants, and a significant presence of indigenous fish species threatened with extinction (Table 9). In addition, the Shag River is noted as providing significant habitat for trout and inanga spawning, the presence of a significant range of indigenous invertebrates (in the middle reaches), and allowing access to the sea that is unimpeded by artificial means (Table 9). The natural values of the Shag River catchment, which are directly related to, and likely to be influenced by, the proposed irrigation scheme include the presence of significant fish species and habitats, and the provision of unimpeded access to the sea. These issues are discussed in section 2.9 below. Other natural values of the catchment, including the absence of aquatic pest plants and the presence of indigenous invertebrates threatened with extinction, are not expected to be affected or affected only a minor way by the proposed irrigation scheme.

Kai Tahu values are the spiritual or cultural beliefs, values or uses associated with water bodies of significance to Kai Tahu. Activities involving water bodies of significance may require consultation with Kai Tahu and granting of their consent. A variety of mana and access/customary use interests have been identified for the Shag River (Table 10). Mana interests involve the notions of guardianship, life force, sacred places and treasured interests, which together define the relationship that Kai Tahu have with the Shag River (Table 10). Access and customary use interests include the provision of food and weaving

resources, the presence of significant spawning and nursery areas for native fish, the location of traditional routes, and sources of water regarded for their purity, healing and health-giving powers (Table 10). These interests are closely related to the natural values identified in Table 9.

Table 9. Natural values of water bodies in the Shag River catchment (sourced from Otago Regional Council, Regional Plan: Water 2004).

Water body	Ecosystem values	Significant indigenous vegetation and significant habitat of indigenous fauna
Shag River (note, the shallow aquifer forms an integral part of the water body)	<p>Large water body supporting high numbers of particular species, or habitat variety, which can provide for diverse life cycle requirements of a particular species, or a range of species</p> <p>Access within the main stem of the catchment through to the sea unimpeded by artificial means, such as weirs, and culverts</p> <p>Bed composition includes the full range of substrata; macrophyte, boulder, gravel, sand, silt/mud and bedrock</p> <p>Free of aquatic pest plants</p> <p>Significant spawning areas for inanga (downstream of J42:403485) and trout</p> <p>Presence of indigenous fish species that are threatened with extinction</p> <p>Significant presence of eels</p> <p>Significant presence of trout</p> <p>Presence of a significant range of indigenous invertebrates</p>	<p>Significant habitat for flathead galaxiid and koaro</p> <p>Significant habitat for lamprey (uncommon in Otago)</p>
Siberia Creek	<p>Free of aquatic pest plants</p> <p>Presence of indigenous fish species that are threatened with extinction</p>	<p>Significant habitat for flathead galaxiid</p>
Deem Burn	<p>Free of aquatic pest plants</p> <p>Presence of indigenous fish species that are threatened with extinction</p>	<p>Significant habitat for koaro upstream of I42:224388</p>
Pigroot Creek	<p>Free of aquatic pest plants</p> <p>Boulder bed composition is important for resident biota</p> <p>Riparian vegetation present of significance to aquatic habitats</p> <p>Presence of indigenous invertebrates threatened with extinction upstream of I42:072530</p>	
Happy Valley Creek	<p>Free of aquatic pest plants</p> <p>Presence of indigenous fish species that are threatened with extinction</p>	<p>Significant habitat for flathead galaxiid</p>
Tipperary Creek	<p>Free of aquatic pest plants</p> <p>Presence of indigenous fish species that are threatened with extinction</p>	<p>Significant habitat for hybrid galaxiid species</p>
Deepdell Creek	<p>Free of aquatic pest plants</p> <p>Presence of indigenous fish species that are threatened with extinction</p>	<p>Significant habitat for flathead galaxiid</p>

Table 10. *Kai Tahu values of the Shag River (sourced from Otago Regional Council, Regional Plan: Water 2004).*

	Beliefs, values and uses	Explanation
Mana interests	Kaitiakitanga	The exercise of guardianship by Kai Tahu in accordance with tikanga Maori in relation to Otago's natural and physical resources; and includes the ethic of stewardship
	Mauri	Life force; for example the mauri of a river is most recognizable when there is an abundance of water flow and the associated ecosystems are healthy and plentiful; a most important relationship that Kai Tahu have with the water bodies of Otago
	Waahi tapu and/or Waiwhakaheke	Sacred places; sites, areas and values associated with water bodies that hold spiritual values of importance to Kai Tahu. Note: Kai Tahu should be consulted regarding the location of these places, sites, areas and vales for a river identified as such
	Waahi taoka	Treasured resource; values, sites, resources that are valued and reinforce the special relationship Kai Tahu have with Otago's water resources
Access/customary use interests	Mahika kai	Places where food is procured or produced
	Kohanga	Important nursery/spawning areas for native fisheries and/or breeding grounds for birds
	Trails	Sites and water bodies which formed part of traditional routes
	Cultural materials	Water bodies that are sources of traditional weaving materials and medicines
	Waipuna	Sources of water highly regarded for their purity, healing and health giving powers

3. Effects of proposed scheme enhancement

3.2 Reservoir creation

At least one and up to three storage reservoirs will be constructed as part of the Shag River irrigation scheme. The creation of large reservoirs (area 22-68ha, Table 1) in the middle reaches of the Shag River will involve the replacement of the existing flowing river environment with a large area of standing water habitat. The impact of reservoir creation on the macroinvertebrate and fish fauna will depend on their ability to adapt to the new standing water environment, and the operating range of the reservoir/s (which is yet to be determined). A reservoir with an operating range of only 1-2m would be most favourable for the development of healthy macroinvertebrate and fish communities, as discussed below. However, this would provide little opportunity for irrigation. Significant fluctuations in the water level of the reservoirs are therefore expected, and much more limited macroinvertebrate and fish communities are expected as a result.

High clarity, generally lower nitrogen, phosphorus and faecal coliform levels in the middle reaches of the Shag River in comparison to other North and Coastal Otago rivers (Otago Regional Council 2000), and the high diversity of macroinvertebrates, suggest that the water in the middle reaches of the Shag River is of good quality. Conditions in the

new reservoirs are therefore expected to be favourable for the development of a healthy macroinvertebrate ‘pond’ community, dominated by snails, small crustaceans (amphipods and ostracods), dipteran and caddisfly larvae, water boatmen and damselfly larvae. These taxa are already present in the area. Populations of koura (freshwater crayfish), which are already present in the upper reaches of the catchment, may also be enhanced. Establishment of this macroinvertebrate community will in turn sustain the development of a fish community. A macrophyte community should also establish at depths below the minimum reservoir level due to the high clarity of the water, but large fluctuations in water level would prevent establishment of macrophytes near the reservoir edges.

Of the fish species present in the vicinity of the reservoirs, brown trout, short and long fin eels, and upland bully are the only species adapted to lake habitats. Populations of trout and eels could be enhanced by the creation of additional lake habitat, although some brown trout spawning habitat in the Loop Road area may be lost. The proposed reservoir sites downstream of Loop Road are less likely to result in loss of trout spawning habitat as the bed sediments in the gorge area are unstable and dominated by bedrock. The possible enhancement of trout and eel populations, and the large size of the reservoirs, provide opportunity for the establishment of a lake trout fishery and/or a mahika kai fishery for eels.

The other fish species present in the vicinity of, and upstream of, the proposed reservoir area are koaro and the non-migratory galaxiids (hybrid, *Gal. anomalus*/*Gal. depressiceps*/*Gal. vulgaris*). Adults of these galaxiid species are not found in standing water environments, so reservoir creation will result in an overall loss of habitat. However, the juvenile life stages are more adapted to still water habitats and therefore it is possible that they may benefit from reservoir creation. The possible enhancement of trout and eel populations through reservoir creation may increase predation on galaxiid species. As both eels and a resident trout population are already occur with galaxiids in the upper reaches of the Shag River and in Deepdell Creek, the increase in predation is not likely to be significant.

Reservoir creation is also expected to enhance habitat for waterfowl. Species already present in the catchment which may make use of this habitat include black and little shags, grey teal, mallards, paradise shelducks and black swans.

Another potential effect associated with reservoir creation is the impact of dam construction on downstream water quality. Dam construction will inevitably involve the

use of heavy earth moving machinery resulting in the mobilisation of soil. While most of this material should be relocated away from the reservoir catchment, some exposed ground will most likely remain and loose sediment associated with it will be washed downstream during rain events. This will discolour the stream, and potentially clog the bed, disrupting fish and macroinvertebrate communities. Such effects however will be temporary and can be mitigated by implementing appropriate sediment control measures and providing flushing flows once dam construction has been completed, to ensure that any significant loose sediment is flushed and dispersed. It would be useful that such a flow coincides with a natural flood event in the catchment to ensure that fine sediments are dissipated well downstream.

The effect of reservoir creation on fish passage and downstream flows are discussed below.

3.2 Fish passage

The Shag River is identified as having significant natural value as a water body that provides unimpeded access to the sea by artificial means, such as weirs, and culverts (Otago Regional Council 2004). Of the 11 fish species present in the Shag River catchment, eight are migratory (sea-run brown trout, inanga, koaro, lamprey, short and long fin eels, and bluegill and redfin bullies), requiring access to the sea to complete their life cycle. The construction of a dam/s will create a barrier to upstream movement of these species in the Shag River and to tributaries that enter the Shag River upstream of the dam. This is of particular concern in the Deem Burn, which has been identified as providing significant habitat for the migratory galaxiid koaro, and also in the Shag River itself, which has been identified as providing significant habitat for koaro and also lamprey (note though that lamprey have to date not been recorded in the vicinity, or upstream of the proposed reservoir/s) (Otago Regional Council 2004). Alternatively, the construction of a dam/s in the middle reaches of the Shag River may have positive impacts on populations of non-migratory galaxiids by preventing upstream movement of trout and eels, which prey on these galaxiid species. Siberia Creek, Happy Valley Creek and Deepdell Creek, which enter the Shag River upstream of the proposed reservoir/s, have been identified as providing significant habitat for non-migratory galaxiids (Otago Regional Council 2004). Construction of a dam may therefore enhance these populations of non-migratory galaxiids by reducing predation risk. This scenario, however, would be negated by the possible enhancement of trout and eel populations through reservoir creation, as discussed previously (refer section 2.9.1), and could have the opposite effect.

Tipperary Creek, which is identified as providing significant habitat for the non-migratory hybrid galaxiid (Otago Regional Council 2004), enters the Shag River downstream of the proposed reservoir area and will therefore be unaffected by alteration to fish passage.

3.3 Downstream river

The proposed Shag River irrigation scheme will reduce average flows in the Shag River downstream of the reservoir/s. The total catchment area of the reservoirs ranges from 268–343 km² (Table 1), which equates to between 49-63 percent of the total Shag River catchment area. Residuals flows of sufficient size to meet minimum flow requirements downstream of the dams, and therefore provide sufficient habitat for existing fish and macroinvertebrate communities, must be maintained.

Existing minimum flow requirements for the Shag River are 150 l/s (0.15 cumecs) at Craig Road and 28 l/s (0.028 cumecs) at Goodwood Pump (Regional Plan: Water, Otago Regional Council 2004). The mean flow of the river at Craig Road is 2359 l/s, the median flow is 746 l/s and the mean annual low flow (MALF) is 254 l/s (Raineffects 2003). The primary allocation limit for the Shag River catchment from the mouth to the headwaters of 280 l/s has already been exceeded and therefore there is no provision for further primary allocation (Otago Regional Council 2004). Existing water takes from the Shag River catchment, where the water taken is used for public water supply purposes, include three public water supplies; Dunback (I43: 274279), Palmerston (J43: 317237) and Goodwood (J43: 343234) (Otago Regional Council 2004). The Shag River alluvium aquifer also provides water for human consumption (with and without treatment), a stock drinking supply and irrigation.

The lowest flows in the Shag River tend to occur in the period January to June, and in summer it is not uncommon for the water flow to naturally fall below the bed level in the lower reaches, leaving only disconnected pools in which fish may become stranded (Otago Regional Council 2000). As a result of low flows, water temperatures in the Shag River during summer can also be extremely elevated and prolific growth of filamentous green algae can occur (Otago Regional Council 2000), both of which may have negative impacts on fish and macroinvertebrate communities. The proposed irrigation scheme will therefore need to incorporate management options for downstream flows to maintain suitable physical habitat for existing fish and macroinvertebrate communities at all times of the year, but especially during summer, and spawning and migration times. If water stored in the reservoir/s can be released to the river during extreme low flow periods

(flushing flows of short duration) temperature and algae growth could be reduced, improving fish and macroinvertebrate habitat over and above that which can develop now under severe low flows. It is also noted, however, that it is during these periods that irrigation demand is likely to be greatest.

To determine the effects of downstream flows on instream habitat, an assessment was undertaken using an instream flow incremental methodology approach (or IFIM). Details of the methodology can be found in Appendix One and the relevant findings are presented in section 4 below.

4. Low Flow Assessment

4.1 Site selection

Habitat hydraulic mapping of the Shag River using IFIM-type methods (Jowett 1996) was undertaken at two reaches; one immediately downstream of the Craig Road bridge at Camp Armstrong (NZ grid reference 2327150/5528450) (Figure 3) and one downstream of the Goodwood water supply pump at Chisholm Road (NZ grid reference 2334570/5523340) (Figure 4). These reaches were chosen to be representative of Shag River habitats following a visual assessment of the river environment, which included most of the reach downstream from the site of the proposed reservoir/s to the SH1 road bridge near the river mouth.

Details of the IFIM assessment of these reaches can be found in Appendix One.



Figure 3. Cross section profiling for an IFIM assessment of the Shag River at Camp Armstrong (left) and Goodwood Pump (right).

Same day flow gaugings at the Camp Armstrong IFIM site were in close agreement with those determined for the ORC Craig Road flow site, which is located immediately upstream (Table 11). Comparison of same day flow gaugings for the lower and upper sites in September 2004 to April 2005 indicated that flow at the Goodwood Pump site was

approximately 1.3 times that of the upper site (Table 11). This figure should be interpreted with caution though as it may be influenced by irrigation abstractions from the river in the area between Craig Road and Goodwood Pump. Raineffects (2003) estimated mean flows independent of irrigation abstractions to be 2380 l/s at Craig Road and 2800 l/s at Goodwood Pump, giving a flow ratio of 1.18, which is similar to that estimated from our same day flow gaugings (Table 11). However, at very low flows (less than approximately 250 l/s at Craig Road), the flow relationship between the sites will not apply due to groundwater losses between Craig Road and Goodwood Pump (Raineffects 2003). At flows less than 250 l/s at Craig Road, flows at Goodwood Pump are similar to those at Craig Road (assuming no irrigation take). As flows at Craig Road drop below 90 l/s, recharge to groundwater decreases and surface outflow and groundwater levels at Goodwood Pump recede (Raineffects 2003). For these reasons, obtaining reliable estimates of mean, median and MALF statistics for the Shag River at Goodwood Pump are difficult (Raineffects 2003).

Table 11. Summary of same day flows (cumecs) for the Shag River at Craig Road, Camp Armstrong and Goodwood Pump, September 2004 to April 2005. ORC site flow data at Craig Road (immediately upstream of Camp Armstrong IFIM site) sourced from the ORC flow website. The flow ratio is calculated from same day gaugings at the Craig Road and Goodwood Pump sites.

Date	ORC flow site Craig Road	Camp Armstrong IFIM site	Goodwood Pump IFIM site	Flow Ratio
8 Sep 04	0.88		1.29	1.47
9 Sep 04	0.86	0.86		
29 Sep 04	1.15		1.64	1.43
1 Oct 04	0.97	1.07		
13 Oct 04	0.56	0.63	0.84	1.50
11 Nov 04	0.53	0.47		
2 Mar 05	0.60		0.66	1.10
8 Mar 05	0.35	0.42	0.45	1.29
8 April 05	0.71		0.80	1.13

4.2 Species modelled

Habitat suitability at the Camp Armstrong and Goodwood Pump sites was modelled against flow using RHYHABSIM software (River Hydraulics and Habitat Simulation, Jowett 1996) for 11 fish and five invertebrate taxa. This included several life stages of brown trout, login and shortfin eel, four species of bully (bluegill, common, redbfin and upland), koaro, inanga, flathead and roundhead galaxias. Lamprey have also been recorded in the river, but there are no published habitat suitability curves for this species.

Flathead and roundhead galaxias habitat preference curves were used for assessing galaxias ‘hybrid’ (see section 2.5) habitat suitability, as these galaxiid species are likely to have some similarities in their habitat requirements. Habitat suitability was modelled for a selection of invertebrate species that have been recorded at the ORC monitoring sites (Table 7), including the mayfly *Deleatidium*, coleopteran *Elmidae*, snail *Potamopyrgus*, and the caddisflies *Pycnocentroides* and *Aoteapsyche*.

4.3 Results & Interpretation

4.3.1 Camp Armstrong

Table 12 provides a summary of model physical outputs for the Camp Armstrong site. The IFIM model shows that river width, depth and velocity all increase slightly over the range of flows modelled (0-2 cumecs) (Table 12).

Table 12. A summary of average hydraulic characteristics for the Shag River at Camp Armstrong for flows ranging up to 2 cumecs.

Flow (m ³ /s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m ²)
0.000	1.434	0.043	0.000	0.324
0.400	13.813	0.444	0.078	6.146
0.800	14.075	0.531	0.126	7.530
1.200	14.143	0.595	0.167	8.494
1.600	14.236	0.641	0.204	9.257
2.000	14.367	0.676	0.237	9.893

Fish

Physical habitat suitability is optimum for adult brown trout above 2 cumecs, for juvenile brown trout at approximately 2 cumecs and for brown trout fry at 1.5 cumecs (Figure 5). Habitat for brown trout spawning is low at flows below 2 cumecs (Figure 5).

Physical habitat for common, redfin and upland bullies is highest within the flow range 0.1 to 0.5 cumecs (Figure 5). Habitat for bluegill bullies is low under all flows modelled, probably due to the narrow range of their depth and substrate habitat suitability criteria (Figure 5).

Adult and juvenile longfin eels have similar optimum physical habitats, peaking in the range of 0.1-0.5 cumecs and decreasing gradually as flow increases to 2 cumecs (Figure 5).

5). Available habitat for juvenile shortfin eels is less than that for longfin eels, but optimum habitat also occurs in the range 0.1-0.5 cumecs (Figure 5).

Optimum physical habitat for inanga is provided at a flow of 0.1 cumecs after which habitat suitability slowly decreases with WUA (weighted usable habitat), decreasing by approximately 60% as flow increases from 0.1 to 2 cumecs (Figure 5). Koaro WUA is low and optimum habitat occurs at a flow above 2 cumecs (Figure 5). Habitat for roundhead galaxias adults and juveniles is highest at flows between 0.2 and 0.4 cumecs, but overall habitat for roundhead galaxias adults is minimal (Figure 5). Adult flathead galaxias WUA is highest at flows around 0.5 cumecs, while optimum juvenile habitat occurs at lower flows in the range 0.1-0.3 cumecs (Figure 5).

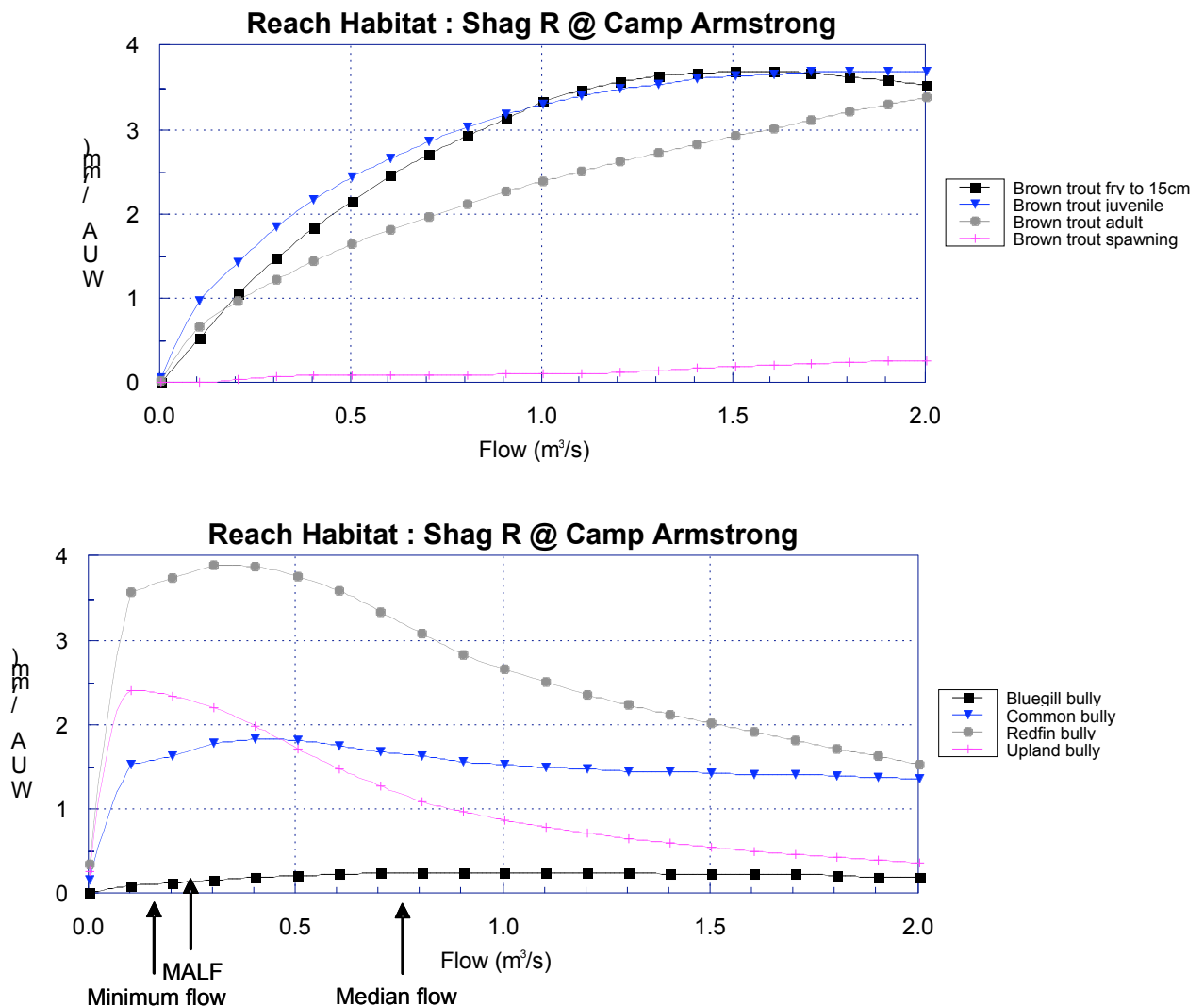


Figure 5. WUA (m² per metre of river channel) for (top) brown trout life history stages and spawning habitat, and (bottom) bullies in the Shag River at Camp Armstrong under flows ranging from 0 to 2 cumecs. The minimum flow (0.150 cumecs), mean annual low flow (0.254) and median flow (0.746) are indicated with arrows.

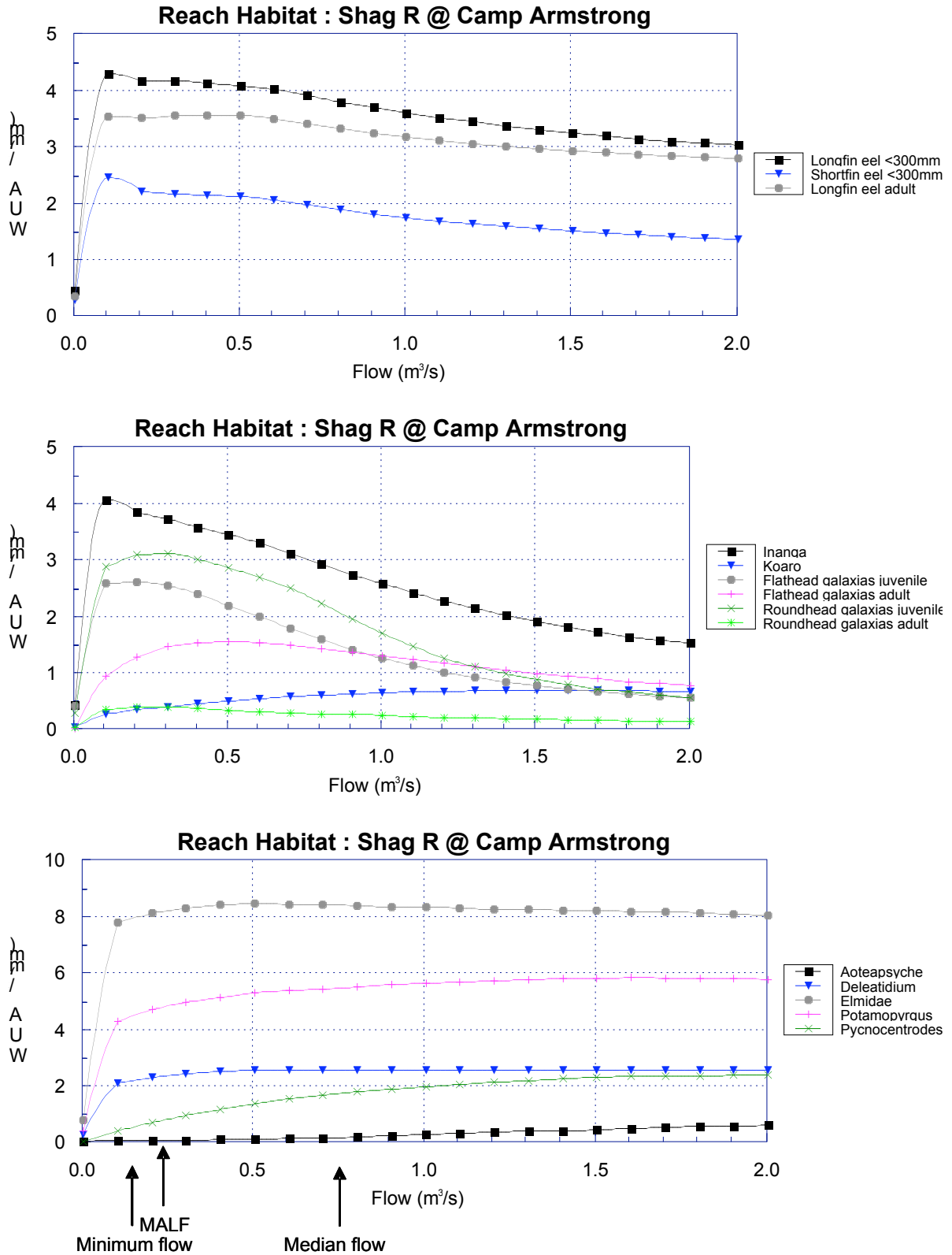


Figure 5 (cont'd). WUA (m² per metre of river channel) for (top) eels, (middle) *Galaxias* species and (bottom) selected invertebrate taxa in the Shag River at Camp Armstrong under flows ranging from 0 to 2 cumecs. The minimum flow (0.150 cumecs), mean annual low flow (0.254) and median flow (0.746) are indicated with arrows.

Macroinvertebrates

Optimum physical habitat for *Deleatidium* mayflies, Elmidae beetles, and *Potamopyrgus* snails is consistently high across the range of flows modelled (Figure 5). Physical habitat increases gradually with increasing flow for *Aoteapsyche* and *Pycnocentroides*, with optimum habitat occurring above 2 cumecs (Figure 5).

The IFIM model indicates that the minimum flow requirement of 0.15 cumecs at Camp Armstrong maintains only a small proportion of optimum habitat for brown trout life history stages and spawning, but maintains a significant amount of the optimum habitat for most native fish and invertebrate taxa (Figure 5). Brown trout fry, juvenile and adult habitat is reduced by approximately 70% as flow decreases from 2 to 0.15 cumecs and spawning habitat is negligible at 0.15 cumecs (Figure 5). However, the 0.15 cumec minimum flow provides close to optimum habitat for common, redfin and upland bullies, eels, inanga, adult and juvenile roundhead galaxias, and juvenile flathead galaxias (Figure 5). Habitat for bluegill bullies, koaro and adult flathead galaxias is not optimum at 0.15 cumecs, but the suitability of this reach for these fish species was already low (Figure 5). Habitat for a range of invertebrate species (*Deleatidium*, *Elmidae*, and *Potamopyrgus*) is supported at this minimum flow (Figure 5).

4.3.2 Goodwood Pump

Table 14 provides a summary of model physical outputs for the Goodwood Pump IFIM site. As for the Camp Armstrong site, there is a gradual increase in the width and depth of the channel and velocity as flows increase to 3 cumecs.

Table 14. A summary of average hydraulic characteristics for the Shag River at Goodwood Pump (Lower site) for flows ranging up to 3 cumecs.

Flow (m ³ /s)	Width (m)	Depth (m)	Velocity (m/s)
0.000	0.049	0.001	0.000
0.500	11.318	0.463	0.219
1.000	12.970	0.610	0.239
1.500	13.261	0.722	0.290
2.000	13.911	0.778	0.328
2.500	14.549	0.837	0.358
3.000	15.348	0.890	0.382

Fish

Physical habitat suitability is optimum for adult brown trout above 3 cumecs and for juvenile brown trout at approximately 2.0-2.5 cumecs. Brown trout fry WUA peaks at 1.5 cumecs (Figure 6), which is the same optimum flow for trout fry at the Camp Armstrong site (Figure 5). Optimum habitat for brown trout spawning occurs between 0.8 and 1.4 cumecs (Figure 6).

Physical habitat for common, redfin and upland bullies is highest within the flow range 0.4 to 0.6 cumecs (Figure 6). Habitat for bluegill bullies is higher than at the Camp Armstrong site and is optimum at 0.8 cumecs (Figure 6).

Physical habitat suitability for both longfin and shortfin eels peaks in the flow range 0.6 to 1.2 cumecs, but is only slightly lower at flows above this in the range 1.5 to 3 cumecs (Figure 6).

Optimum physical habitat for galaxias species (inanga, koaro, flathead galaxias, roundhead galaxias) occurs in the range 0.1-1.0 cumecs (Figure 6). WUA is low for all galaxias species except inanga (Figure 6).

Macroinvertebrates

Optimum physical habitat for *Elmidae* and *Potamopyrgus* is consistently high across the range of flows 0.5-3 cumecs (Figure 6). *Deleatidium* habitat peaks in the range 1.2-1.4 cumecs (Figure 6). Physical habitat increases gradually with increasing flow for *Aoteapsyche* and *Pycnocentroides*, with optimum habitat occurring around 2.5 cumecs for *Pycnocentroides* (Figure 6).

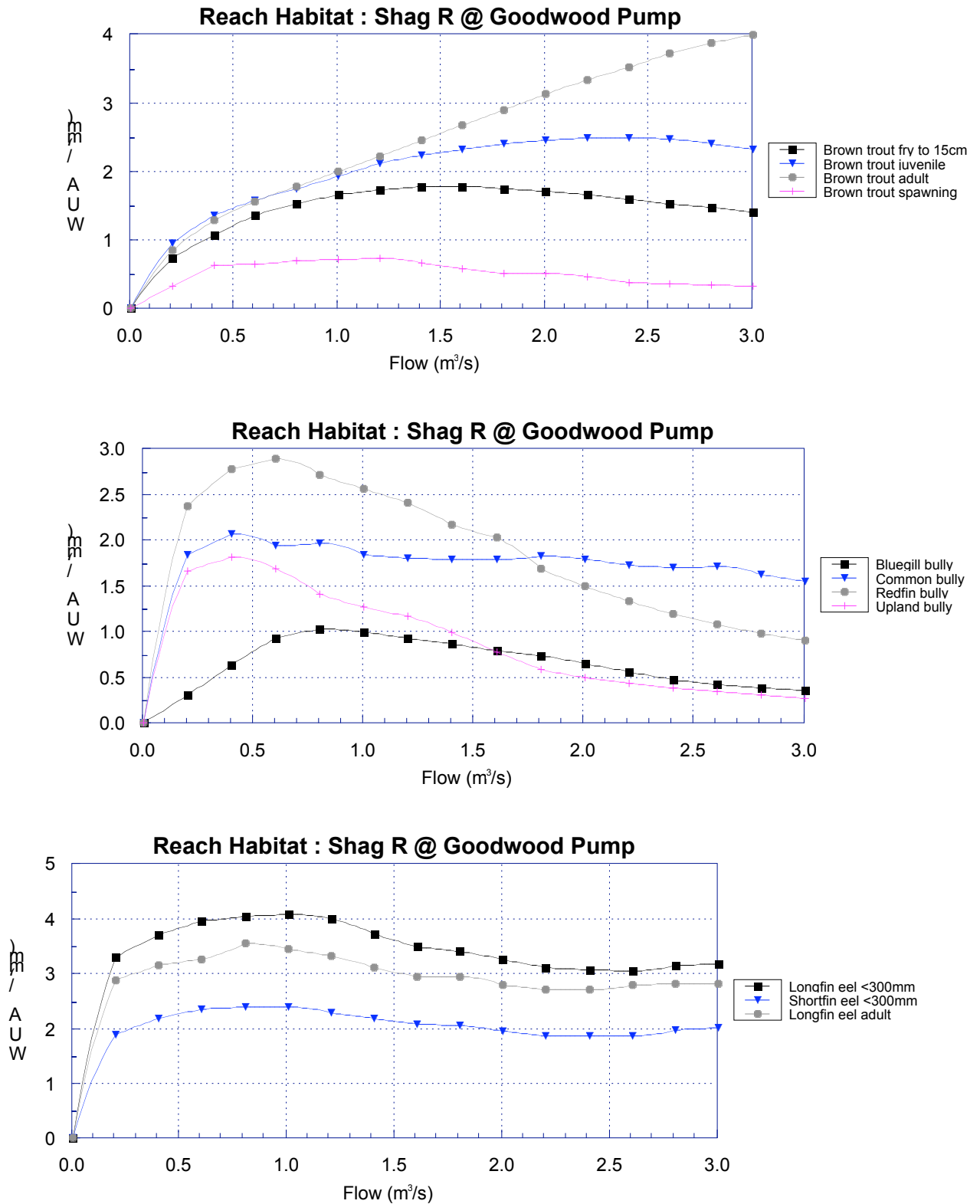


Figure 6. WUA (m² per metre of river channel) for (top) brown trout life history stages and spawning habitat, (middle) bullies and (bottom) eels in the Shag River downstream at Goodwood Pump under flows ranging from 0 to 3 cumecs. The minimum flow (0.028 cumecs) is indicated with an arrow.

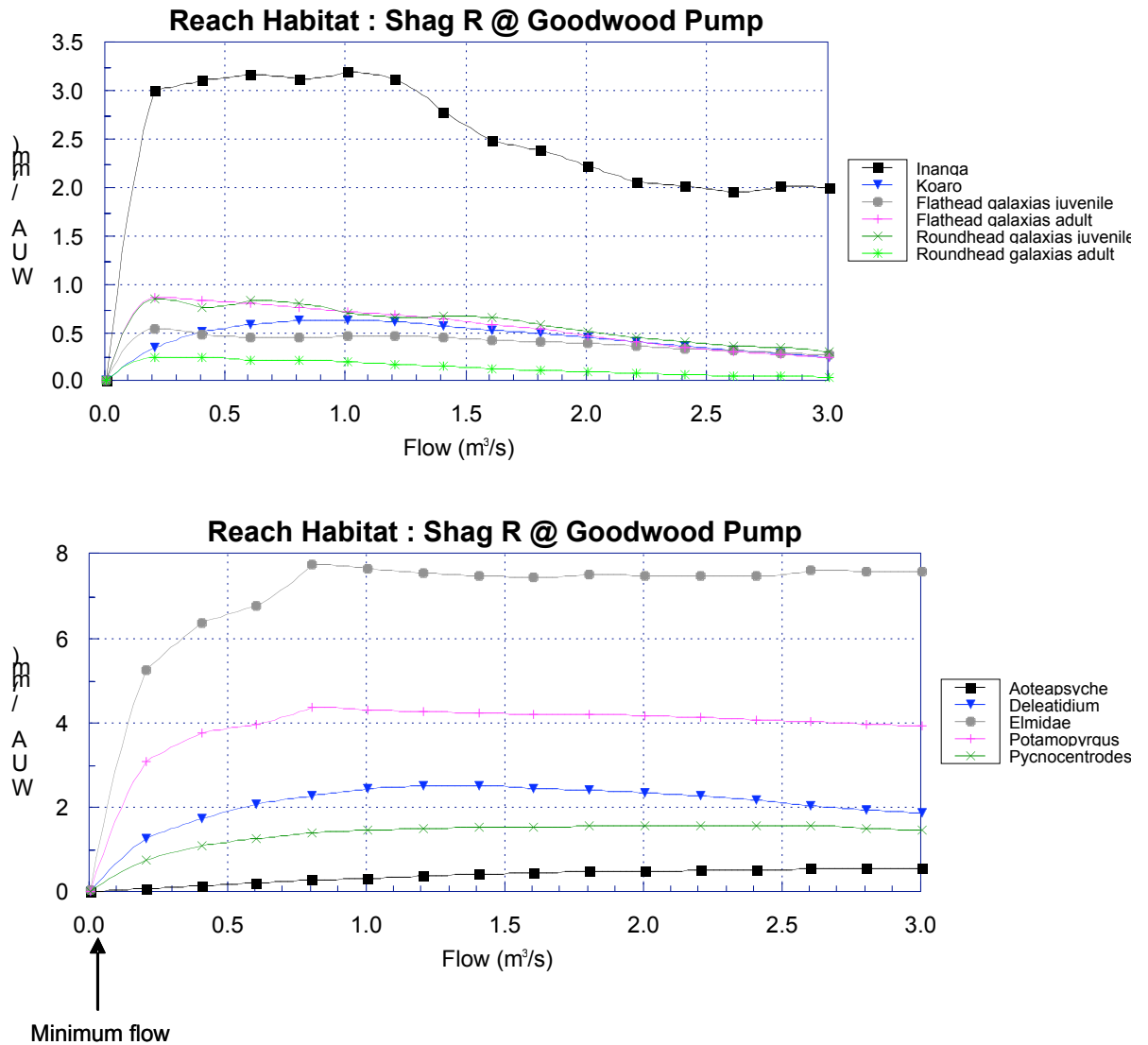


Figure 6 (cont'd). WUA (m² per metre of river channel) for (top) Galaxias species and (bottom) selected invertebrate taxa in the Shag River downstream at Goodwood Pump under flows ranging from 0 to 3 cumecs. The minimum flow (0.028 cumecs) is indicated with an arrow.

The minimum flow requirement at Goodwood Pump has been set at 28 l/s (Regional Plan: Water, Otago Regional Council 2004). The IFIM model indicates that a flow of 0.028 cumecs retains only minimal habitat for 11 fish and five invertebrate species modelled (Figure 6).

4.4 Implications for reservoir management

The Shag River catchment area upstream of the Camp Armstrong IFIM site is approximately 428km² and the catchment area of the proposed reservoirs encompasses between 268-342.8km² of this total area (Table 13). Therefore the reservoir site catchment

represents between 63-80% of the Camp Armstrong catchment. The minimum flow requirement at the Camp Armstrong site is 150 l/s (0.15 cumecs). Back calculating from this flow to the lower reservoir site (upstream of The Grange) using figures of catchment area and yield obtained from Table 12 (Raineffects 2003) equates to a required minimum flow of approximately 112 l/s being released from the lower reservoir to meet this downstream flow. This calculation assumes that there is no primary allocation irrigation take downstream of the reservoir. It should be noted though that during dry weather the water yield from the catchment area between Craig Road and the lower reservoir is negligible and a flow of 150 l/s may be required from the lower dam to meet the minimum flow requirement at Craig Road (Dave Stewart pers. comm.).

Table 13. *Percentage of the catchment area of the Camp Armstrong and Goodwood Pump IFIM sites which is upstream of each of the proposed reservoir sites in the Shag River.*

Proposed reservoir site	Catchment area (km ²)	Percentage of Camp Armstrong catchment area
Grange downstream	342.8	80.1
Grange upstream	337.9	78.9
Pineside	334.1	78.1
McDonald	322.9	75.4
Loop Road downstream	309	72.2
Shag Valley Station ford	268	62.6

5. Conclusions

The establishment of a reservoir on the Shag River would result in several changes to the existing river environment; namely loss of stream habitat, creation of lake habitat and potential changes to downstream flows. These have implications for the existing aquatic ecosystem and would favour those species which can also inhabit lake environments. There are also implications for fish passage (both trout and native species) and possible invasion of tributaries which currently harbour species sensitive to predation (i.e., non-migratory galaxiids).

Reservoir creation

Effects on brown trout would include a loss of spawning and rearing habitat. Sea-run trout would be unable to access past a dam unless a trout pass was provided, but these are generally very expensive to construct for high dams. However, it is possible that these effects could be offset by the creation of a significant lake-type habitat, providing habitat for both juvenile and adult trout. Examples of this are evident throughout Otago (e.g.,

Falls Dam, Loganburn Reservoir, Rutherfords Dam). Depending on the location and height of the dam face, access to tributaries for spawning may be enhanced.

The above potential benefits would very much depend on how the reservoirs were operated, such as lake level fluctuations and operating range. If significantly drawn down on a regular (e.g., annual) basis, these potential benefits are likely to be limited.

The reservoir could also provide a useful habitat for eel. Again, the degree of habitat gained would be dependent on how the reservoir was operated. It would be essential that an elver pass was provided to enable upstream migrating elvers to move unhindered past the dam face. Such a fish pass would also serve koaro and lamprey. It would be equally essential that passage is provided for downstream migrating adult eels, which return to sea to spawn. This can be a more difficult undertaking, given the size of these fish and their tendency to be attracted to the main flow.

Non-migratory galaxiids are one group of fish that may require special attention with respect to reservoir creation. It would be important to ensure that these populations are not exposed to significantly greater threats from habitat loss or predators (eels, koaro and trout) than currently exist. These potential effects could be mitigated by constructing barriers on affected tributaries that contain important populations. These populations would have to be identified prior to construction.

Reservoir water quality would need to be monitored on a regular basis to ensure issues such as low dissolved oxygen levels and the development nuisance cyanobacterial blooms (which can produce toxins) are avoided.

Downstream flows

The Shag River is a water-short catchment and its lower reaches are subject to frequent low flows associated with low rainfall. These low flows can be further exacerbated by losses to groundwater and irrigation demand.

The implications of this to aquatic biota are clear. Potentially good habitat for a variety of fish and macroinvertebrate species is available mainly at flows much higher than what is typically available during summer and autumn, although this is species dependent. Brown trout are probably the key fish species most affected by low flows. In the Craig Road area, habitat for adult and juvenile life stages, and for spawning, are greatest at flows in excess of 1.5-2 cumecs, while habitat for fry is greatest around 1.5 cumecs. Native fish

species fare better, with greatest habitat generally available from between 0.1-0.5 cumecs, with gradual declines thereafter.

Physical habitat for aquatic fish food (i.e., macroinvertebrates) at Craig Road is generally plentiful upwards of 0.1 cumecs, although low flows in summer can result in other factors which may adversely affect macroinvertebrate community abundance and composition despite available habitat (e.g., elevated temperatures, lack of dilution for contaminant inputs, nuisance periphyton and macrophyte growths).

Similar relationships between potential habitat for key fish and macroinvertebrates species and flow exist further downstream in the reach at Chisholms Road, but this reach is more susceptible to low flows.

As such, optimum physical habitat for trout in particular is not often achieved in the lower Shag River, as the flows are frequently well below that required. It appears, therefore, that the lower Shag River is a more favourable habitat for native fish species rather than brown trout. This is not unexpected given the small size of the river and its tendency to get very low on a regular basis. As well as being more adaptable to low flow environments, native fish are also considerably more tolerant of high water temperatures (Thompson and Ryder 2001).

The minimum flows set under the Regional Plan: Water are low and reflect the nature of this river. The minimum flow for Craigs Road (150 L/s) provides limited potential habitat for trout, but should sustain the native fishery and its aquatic food supply, subject to water temperature and nuisance algal growths remaining within acceptable levels. A flow of 150 L/s at the reservoir outlet is therefore considered an absolute minimum to support the downstream ecosystem. Flows of at least 300 L/s would be preferable during the trout spawning season (late April to mid June). Consideration should also be given to periodic releases of more water from the dam during periods of prolonged low flow events, to offset the potential adverse effects of elevated water temperatures and nuisance plant growths in summer and autumn. Such flows would need to last approximately 24 hours and exceed six times the average flow recorded over the previous seven days. The effectiveness of such flows would need to be monitored and possibly revised if necessary.

6. References

- ANZECC. 1992. Australian water quality guidelines for fresh and marine waters. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council, Canberra.
- Baker, C. F., Jowett, I. G., and Allibone, R. M. 2003. Habitat use by non-migratory Otago galaxiids and implications for water management. *Science for Conservation* **221**. 34p.
- Bovee, K.D. 1978. Probability of use criteria for the family Salmonidae. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/07, Instream flow information paper 4.
- Graham, A. A. 1989. Benthic periphyton and oxygen metabolism in the Shag River. Prepared by Alan Graham and Associates for the Otago Catchment Board.
- Hamilton, D. 2002. Review of Irrigation and Water Storage Potential in the Shag Valley. Prepared by David Hamilton and Associates for the Waitaki District Council.
- Hayes, J. W., Jowett, I.G. 1994. Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. *North American Journal of Fisheries Management* **14**: 710-725.
- Jowett, I.G. 1996. Instream flow methods and minimum flow requirements. Unpublished NIWA report.
- Jowett, I.G. 2002. Project Aqua: Environmental Study – Aquatic Ecosystems: instream habitat and flow regime requirements. Prepared for Meridian Energy. NIWA Client Report:MEE02209.
- Jowett, I.G., and Dungey, R.G. 2000. Effect of varying flows on benthic invertebrate and salmonid habitat in the Clutha River below Roxburgh Power Station. NIWA Client Report: COE00224 prepared for Ryder Consulting and Contact Energy.
- Otago Acclimatisation Society. 1989. Fisheries and wildlife values of the Shag River. Otago Acclimatisation Society, Dunedin.

Otago Regional Council. 1991. Shag River Catchment: Resource description, issues and options for management. Otago Regional Council, Dunedin.

Otago Regional Council 2000. North and Coastal Otago River Catchments Monitoring Report. Otago Regional Council, Dunedin.

Otago Regional Council. 2004. Regional Plan: Water. Otago Regional Council, Dunedin.

Quinn, J. M. and Hickey, C. W. 1990. Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *New Zealand Journal of Marine and Freshwater Research* **24**: 387-409.

Raineffects Limited. 2003. Shag River Catchment Water Resources: A comprehensive review of the surface water resources of the Shag catchment. Report prepared for Waitaki District Council by David Stewart, Raineffects Limited.

Raleigh, R.F., Zuckerman, L.D., Nelson, P.C. 1984. Habitat suitability models and instream flow suitability curves: brown trout. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS/-82/10.71.

Ryder 1996. Palmerston Sewage treatment system: Shag River monitoring. Prepared for Waitaki District Council by Robertson Ryder Limited.

Ryder 1998. Palmerston Sewage treatment system: Shag River monitoring. Prepared for Waitaki District Council by Ryder Consulting Limited.

Ryder 2000. Palmerston sewage land disposal system: Shag River nutrient and algae monitoring. Prepared for Waitaki District Council by Ryder Consulting Limited.

Ryder 2002. Palmerston sewage land disposal system: Shag River nutrient and algal monitoring. Prepared for Waitaki District Council by Ryder Consulting Limited.

Shirvell, C.S., and Dungey, R.G. 1983. Microhabitats chosen by brown trout for feeding and spawning in rivers. *Transactions of the American Fisheries Society* **112**: 355-367.

Stark, J. D. 1998. SQMCI: a biotic index for freshwater macroinvertebrate coded

abundance data. *New Zealand Journal of Marine and Freshwater Research* **32**: 55-66.

Stewart, D. 2003. Shag River catchment water resources: a comprehensive review of the surface water resources of the shag catchment. Report prepared for Shag River Catchment Water Supplies Sub-Committee of Waitaki District Council by Raineffects Limited.

Thompson, R., and Ryder, G.I. 2001. Effects of water temperature on aquatic biota: Potential consequences of water abstraction from the Rangitata River. Prepared for the RDR Irrigation Company.

Appendix One: IFIM Assessment Methods

The combination of hydraulic modelling of a river flow with a description of habitat preferences of fish and invertebrates is known as habitat hydraulic modelling or IFIM (instream flow incremental methodology). IFIM provides a way of condensing varied data into a result that describes how the amount of instream habitat changes with changes in flow (Jowett 1996). The two components of an IFIM analysis are the hydraulic simulations of a stream reach and habitat suitability criteria for instream fauna of interest. Hydraulic simulation is used to describe the area of a stream having various combinations of depth, velocity and channel index as a function of flow. This information is used to calculate the Weighted Useable Area (WUA) of the stream segment from suitability information based on field sampling of various species of fish and invertebrates. Habitat suitability criteria are a way of describing what is considered to be 'good' habitat (Jowett 1996). If the range of suitable habitat for a species can be determined it is possible to quantify the area of suitable habitat available within a stream. Once habitat suitability criteria are defined they can be applied to habitat survey data and the amount of suitable habitat calculated.

Habitat hydraulic mapping of the Shag River using IFIM methods (Jowett 1996) was undertaken at two sites:

Camp Armstrong A reach immediately downstream of the Craig Road bridge, adjacent to Camp Armstrong. This reach was chosen to be representative of the river habitat in this section, which consists of a series of long runs (width approximately 15m), with shorter riffle (depth approximately 0.20m) and pool (depth approximately 0.8m) sections.

Goodwood Pump A reach immediately downstream of the Goodwood Pump Station at the end of Chisholm's Road. This reach was chosen to be representative of the river habitat in this section, which consists of a series of long, deep pools/runs, with shorter riffle sections (depth approximately 0.40m).

Representative cross-sections were randomly chosen at each reach; nine at the Camp Armstrong site and seven at the Goodwood Pump site. At Camp Armstrong, two riffle, six run and two pool transects were surveyed. At the Goodwood Pump site, two riffle, three run, and two pool transects were surveyed.

Cross-sections were marked across the river using a level line strung between survey pegs and a steel water-level gauging rod was hammered into the river-bed. River flow, depth and bed substrate-type was measured at a series points across the river (approximately every 1-2m), and bank profile was described to a height of approximately 1m above the water level. After the initial survey was completed at least two further calibration surveys were undertaken at different flows to measure how much the water level fluctuated with flow. Calibration flows were measured at one cross-section and water level was measured against gauging rods at every cross-section.

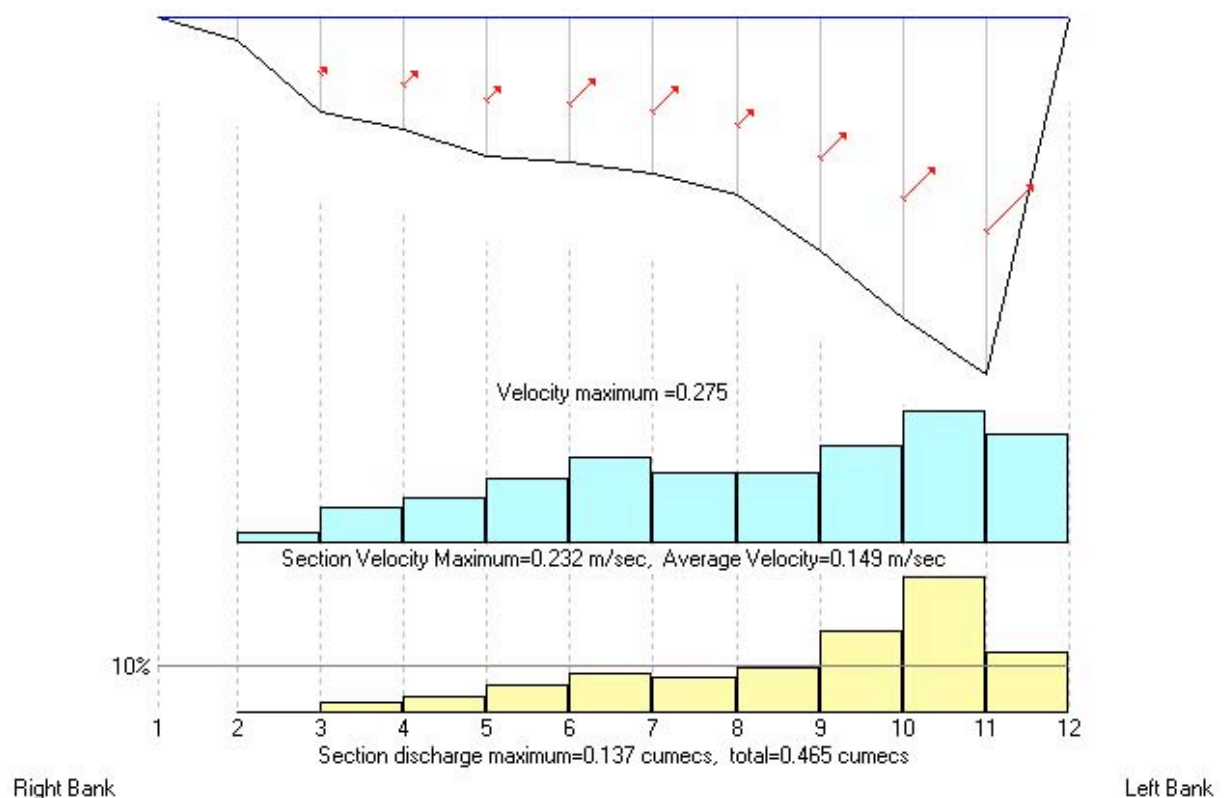


Figure A1.1 Example of IFIM hydraulic data for a cross-section of the Shag River.

Habitat preference curves were obtained from Rhyhabsim (Jowett 1996) and other recent studies of relevant species (e.g., Baker *et al.* 2003) (Table A4.1).

Table A1.1 Habitat suitability criteria used for the Shag River weighted useable area (WUA) assessment.

Species	Life stage	Reference/Source
Fish		
Brown trout	fry to 15cm	Raleigh 1986
	juvenile	Jowett and Dungey 2000
	adult	Hayes and Jowett 1994
	spawning	Jowett and Dungey 2000
Bluegill bully		Jowett 2002
Common bully		Jowett 2002
Redfin bully		Jowett 1996
Upland bully		Jowett 2002
Longfin eel	<300 mm	Jowett 2002
	adult	Jowett 2002
Shortfin eel	<300 mm	Jowett 2002
Koaro		Jowett 2002
Inanga		Jowett 2002
Roundhead galaxiid	juvenile	Baker <i>et al.</i> 2003
	adult	Baker <i>et al.</i> 2003
Flathead galaxiid	juvenile	Baker <i>et al.</i> 2003
	adult	Baker <i>et al.</i> 2003
Macroinvertebrates		
<i>Aoteapsyche</i>	larvae	Jowett 2002
<i>Deleatidium</i>	larvae	Jowett and Dungey 2000
Elmidae	larvae	Jowett 2002
<i>Potamopyrgus</i>		Jowett 2002
<i>Pycnocentroides</i>	larvae	Jowett and Dungey 2000