NIWA
Taihoro Nukurangi

Toward national guidance for fish screen facilities to ensure safe passage for freshwater fishes

Prepared for SFF Project 4405972: Adoption of good practice fish screening, Milestone 14 - Final Report

May 2023

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NIWA CLIENT REPORT No: 2023060CH
Report date: May 2023
NIWA Project: INZ23501

Revision	Description	Date
Version 1.0	Draft version sent to client	6 April 2023
Version 2.0	Final version	9 May 2023

Quality Assurance Statement		
	Reviewed by:	Helen Rouse
	Formatting checked by:	Rachel Wright
	Approved for release by:	Charles Pearson

Contents

Tables

Figures

Summary

Water intake structures are used throughout New Zealand to supply irrigation, hydro-electric generation, drinking water and industrial needs. Abstracting surface waters can impact fish communities by altering habitat and disrupting migration and spawning movements. Additionally, if surface water intake structures are not properly screened and/or designed/maintained, they can unintentionally damage or remove fish from rivers. This impact on fish at water intakes, termed fish entrainment has been identified as a threat to freshwater fish communities globally.

The regulatory agencies responsible for protecting fish populations and/or approving surface water infrastructure (e.g., regional councils, Department of Conservation, Fish and Game New Zealand) have recognised for many years that there are a wide range of issues concerning water intakes, and improvements to fish screen facility design and management are needed to better protect our species and waterways. Early work by the Canterbury Fish Screen Working Group (CFSWG) resulted in the 'Fish screening: good practice guidelines for Canterbury' (Jamieson et al. 2007; hereafter 'the Canterbury Guidelines'). These guidelines provided an overview of common fish exclusion technologies, reviewed a range of principles associated with water intake practices, and identified seven key criteria as part of a 'whole of intake design' approach to better protect freshwater fish.

Until 2019 there had been limited research addressing the New Zealand-specific knowledge gaps identified by the Canterbury Guidelines. Difficulties remain for abstractors, designers, installers, and operators understanding and seeking to meet the criteria or relevant local planning legislation requirements. In 2019, the Ministry for Primary Industries (MPI), through its Sustainable Food and Fibre Futures programme, funded a research project titled "Adoption of good practice fish screening". The project, administered by Irrigation New Zealand (INZ) on behalf of the New Zealand Fish Screen Working Group (the successor of the CFSWG), sought to develop good practice *national* guidance.

The 'Adoption of good practice fish screening' project aimed to fill key knowledge gaps identified in the Canterbury Guidelines and support the adoption of good practice by developing guidance and demonstrating examples of water intakes, and associated fish screens[1], that meet the criteria from the Canterbury Guidelines and that are thus considered effective in achieving the overall outcome of protecting fish and fisheries. This report summarises locally-developed progress since the Canterbury-specific guidance provided in the Canterbury Guidelines and collates the learnings from the MPI-funded project; it summarises key knowledge gaps filled by the case studies, laboratory and field trials completed during the MPI-funded project and identifies the ramifications of this new knowledge on a national scale.

The Canterbury Guidelines provided seven design criteria for effective and efficient fish screening. They favoured a 'balanced design' for water intakes that gave weight to each of the seven criteria. From testing, it has been found that often the most critical criteria for effective fish screening are the provision, design and connection of a suitable bypass facility, and the correct fitting, maintenance, and operation of screens. Additionally, it has been found that for fish passage requirements, upstream fish passage needs to be considered in any water intake design, so this has been added as an eighth criterion.

Fish screen facilities must be designed to minimise or eliminate the possibility of fish being damaged or removed from the waterway. This can only be achieved when eight key criteria (Table 0-1) are implemented sufficiently.

[1] Hereafter 'fish screen facility' will be used to encompass all aspects required for effective fish exclusion from intakes. This can include, but is not limited to, the diversion, the intake, trash management infrastructure, the bypass, and the physical screen.

Table 0-1: Key criteria required for an efficient and effective water intake and fish screen.

Factor	Description
Intake location	The water intake is located to minimise exposure of fish to the screen and minimises the length of stream channel affected while providing the best possible conditions for the other criteria
Through-screen velocity	The water velocity through the fish screen is slow enough to allow fish to escape entrainment or impingement
Sweep velocity	The water velocity past the fish screen is sufficient to sweep fish past the intake promptly and into the bypass
Fish bypass at water intake	A suitable bypass (where needed) is provided so that fish are taken away from the intake and back into the active waterway
Fish bypass connectivity	There is connectivity between any constructed bypass and somewhere safe, usually the mainstem of the waterway
Gap openings in fish screen facility	Screening material and other joins/edges have openings small enough to exclude fish, and a smooth surface to prevent any damage to fish
Operations and maintenance	The water intake needs be kept operating to a consistent standard with appropriate operation and maintenance, this includes consideration of debris management
Upstream fish passage	EITHER the water intake and fish screen does not impede upstream passage of migratory fish species during all flows and does not increase the risk of predation (see Section 4.1.8) OR the bypass outlet impedes fish passage into the bypass and keeps fish in the natural waterway while fish moving downstream through the bypass are not harmed when returning to the waterway

The fundamental purpose of a fish screen facility is to ensure safe passage for all fishes around the facility within or back to the source waterway. The screening material is only one part of this process. It is also important that the design allows for, and incorporates, known fish behaviours to protect the fish community.

There is no simple recipe for an effective fish screen facility that applies across all situations. The physical conditions (e.g., gradient and flow) and biological conditions (i.e., fish species and life stages present) at every intake are different. The Canterbury Guidelines and this report can help identify issues and considerations, and provide good reference information, but because each case is different, it is not straight forward to go from that fundamental knowledge to a practical solution.

There are usually several fish screen facility designs that could satisfy the key criteria at a site. However, alternative designs need to be balanced against site-specific characteristics including existing infrastructure, biological considerations, client preferences and budgetary constraints. The Fish Screening Facility Guidance Tool[2] (hereafter the 'Guidance Tool'), which replaces the Decision Table in the Canterbury Guidelines, provides a method to document and support selection of applicant/consultant preferred designs that could then be developed for a conceptual design. This report ends by detailing the Guidance Tool and providing examples of its application.

[2] Available at www.irrigationnz.co.nz/KnowledgeResources/FishScreens

1 Introduction

1.1 Water intakes

Globally, freshwater ecosystems are experiencing unprecedented anthropogenic pressure because of competing demands for water resources to meet food, energy, transportation, and recreational needs (Nilsson et al. 2005). Most of these demands use an 'intake' structure to divert water from a river or lake. The basic function of an intake structure is to extract water from the source and then to discharge it to the withdrawal conduit. Extraction of water may require pumping via an intake incorporating a sump, but many intakes are gravity-fed diversions. Water intake structures are used throughout New Zealand to supply irrigation, hydro-electric generation, drinking water and industrial needs (Figure 1-1).

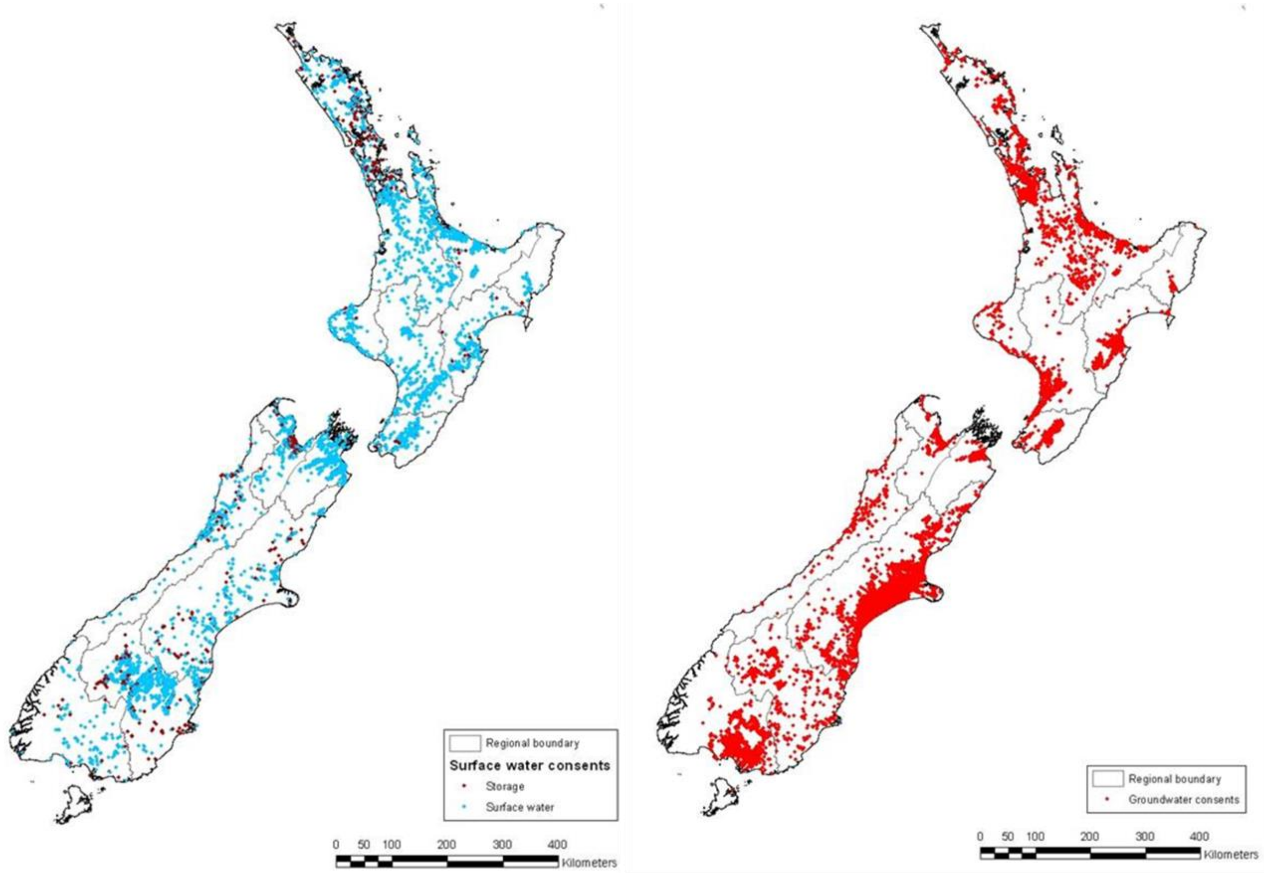

Figure 1-1: Distribution of surface (left) and groundwater (right) consents in New Zealand in 2020. Adapted from Jellyman (2020b).

Irrigation for agriculture accounts for 58% of the total consented water volume used (excluding dedicated hydro-electric usage) in New Zealand, and the proportion of irrigated land has increased rapidly over the last two decades (91% increase from 2002–2019; Stats NZ 2019). Consents for irrigation water have primarily been from east coast regions (Figure 1-1), which are predicted to become drier as the result of climate change reducing water availability for dryland production and adding further pressure to waterways (Ministry for the Environment 2018). This highlights that management of water abstraction to prevent effects on freshwater life, particularly, but not exclusively, impingement and entrainment of fish, is a national issue that needs careful consideration to protect our freshwater fisheries.

Abstracting surface waters can impact fish communities by altering habitat and disrupting migration and spawning movements (Humphries et al. 2002). Additionally, if surface water intake structures are not properly screened and/or designed/maintained, they can unintentionally damage or remove fish from rivers; fish entrainment in irrigation diversions has been identified as a threat to freshwater fish communities globally (Moyle and Williams 1990; Musick et al. 2000; Boys et al. 2021). Evidence of fish entrainment has been found in Canterbury where juvenile salmon and native fish were found in unscreened, or poorly screened, irrigation supply canals (Unwin et al. 2005; Bonnett et al. 2014).

Fish screen facilities, which incorporate the intake, must be designed to minimise, or eliminate the possibility of fish being damaged or removed from the waterway. Evaluating what constitutes an effective fish screen facility design, for fish, is often based on a suite of criteria such as: the site being located to minimise the exposure to fish and distance from the waterway; ensuring the intake can be maintained, effective and connected to the waterway; providing appropriate intake velocity and sweep velocity; using effective and durable screening material; having a bypass that prevents entrainment and impingement; and maintaining the infrastructure over time (Jamieson et al. 2007).

An appropriate fish screen facility design also needs to consider what species and life stages will encounter it, and the location within a catchment and in the water column. There is no national database of the location of fish screen facilities (at water intakes) in New Zealand, however, the geographical distribution of fish screen facilities can be inferred from the distribution of surface water take consents in regions where the rate-of-take would require a screen to be installed (see Jellyman 2020b). Water takes are likely to be more common in the middle of catchments than near the coast — particularly in the South Island — because the race networks distributing water to irrigated farms across the plains and in the lower catchment typically store water and are gravity-fed.

New Zealand's native and sports fish[3] are found across a wide range of habitat types, and these species have different behaviours, swimming abilities and requirements that need consideration to ensure fish are not impinged, entrained, or otherwise damaged or lost to river systems. New Zealand has many diadromous fish species that migrate, mostly as juveniles, between waterways and the sea to complete their lifecycles (McDowall 1993). Some of these species penetrate a long distance inland (McDowall 1990). Many of New Zealand's non-diadromous species still move within waterways during their life history, so the risk of entrainment exists along the length of most rivers (Charteris 2006). However, in the lower catchment, fish screen facilities may need to cater for a greater diversity of juvenile fish with variable body lengths, shapes and swimming ability compared to water intakes in the upper catchment (Charteris 2006).

It has been recognised for many years by the regulatory agencies responsible for protecting fish populations and/or approving surface water infrastructure (e.g., regional councils, Department of Conservation [DOC], Fish and Game New Zealand [FGNZ]) that there are a wide range of issues concerning water intakes and fish screen improvements are needed to better protect our species and waterways. The current regulatory environment means that DOC and regional councils are responsible for managing fish passage in waterways, under the Freshwater Fisheries Regulations (1983)[6] and the Resource Management Act (1991) (including enforcing the Resource Management (National Environmental Standards for Freshwater) Regulations 2020[4]) and National Policy Statement for Freshwater Management[5]. DOC has responsibility for enforcing the Freshwater Fisheries Regulations (1983)[6], which includes assessing whether proposed dams and diversion structures

[3] Sports fisheries in New Zealand are based on introduced species. These include Chinook salmon (South Island rivers), rainbow and brown trout (lakes and rivers nationally), and coarse fish (e.g., perch and tench), mainly in small North Island lakes
[4] www.legislation.govt.nz/regulation/public/2020/0174/latest/LMS364099.html
[5] www.environment.govt.nz/publications/national-policy-statement-for-freshwater-management-2020-amended-february-2023/
[6] www.legislation.govt.nz/regulation/public/1983/0277/19.0/DLM92492.html

require a fish facility[7], and regional councils are responsible for controlling the environmental effects of construction under the Resource Management Act. Rules in councils' regional plans include fish passage and protection for places that are important habitat for native species and sports fish (other statutory requirements apply in some cases).

In 2005, Environment Canterbury (ECan) were facing a rapid increase in applications for approvals to abstract water and realised the extent of disagreement over the issues concerning fish screen facilities in Canterbury. The complexities associated with achieving change were apparent and so ECan assembled stakeholders with functions, responsibilities, or interests in native and sports fisheries under the leadership of the ECan CEO to examine fish screening questions at intakes. This group became the Canterbury Fish Screen Working Group (CFSWG), then later in the 2010s reconvened to become the New Zealand Fish Screen Working Group (NZFSWG). The CFSWG worked primarily to develop criteria, guidelines, and advice to improve water intake and fish screen design culminating in the 'Fish screening: good practice guidelines for Canterbury' (Jamieson et al. 2007; hereafter 'the Canterbury Guidelines'). Later, the NZFSWG became a collaborative technical working group established under the Canterbury Water Management Strategy Regional Committee. The purpose of the NZFSWG is to improve, promote and support best practice standards and provide guidance and direction to fish screen facility design and implementation in Canterbury and across New Zealand to ensure all native and sports fish remain undamaged and unaffected in natural water bodies, and with a particular focus on irrigation intakes.

1.2 Organisations involved in the Fish Screen Working Group

Representatives from:

- DOC
- Environment Canterbury
- FGNZ
- Industry consultants (e.g., Riley Consultants)
- Irrigation companies (e.g., RDR)
- Irrigation New Zealand
- Ministry for Primary Industries
- Ministry for the Environment
- Ngāi Tahu
- NIWA
- Otago Regional Council
- Recreational interest groups (e.g., Salmon Anglers Association).

1.3 Background to this project

Early work by the CFSWG resulted in the 'Fish screening: good practice guidelines for Canterbury' (Jamieson et al. 2007). These guidelines provided an overview of common fish exclusion

[7] A fish facility is any structure or device, such as a fish pass or fish screen that is inserted in or by any waterway, to stop, allow or control the passage of fish through, around, or past any instream structure.

technologies, reviewed a range of principles associated with water intake practices, and identified seven key criteria as part of a 'whole of intake design' approach to better protect freshwater fish. These criteria were designed to assist regulatory agencies when assessing whether fish will be effectively diverted away from intakes without injury. Since the 2007 guidelines were completed, there has been a strong focus on examining whether a range of existing fish screen facilities are operating effectively (see Bonnett et al. 2014 for a review of six different fish screens at water intakes[8]) or meet the seven criteria outlined by the Canterbury Guidelines.

Because of the Canterbury Guidelines, some regional councils have improved their regional plans and compliance programmes (see Jellyman 2020b) to promote better water intake management. For example, immediately following the publication of the Canterbury Guidelines, Environment Canterbury prepared a two page 'planning schedule' to condense the Canterbury Guidelines to planning-relevant criteria (initially Natural Resources Regional Plan Schedule WQL12, which later became Canterbury Land and Water Regional Plan Schedule 2 and Hurunui Waiau River Regional Plan Schedule WQL8). The intent of Schedule 2 was to prescribe critical design elements for fish screen facilities. See Purdon (2023) for discussion paper on policy and practice[9].

Until 2019, there had been limited research addressing the New Zealand-specific knowledge gaps identified by the Canterbury Guidelines. Difficulties remain for abstractors, designers, installers, and operators understanding and seeking to meet the criteria or relevant local planning legislation requirements.

In 2019, the Ministry for Primary Industries (MPI), through its Sustainable Farming Fund[10], funded a research project titled "Adoption of good practice fish screening" (SFF Project 405972). The project, administered by Irrigation New Zealand on behalf of the NZFSWG, sought to develop good practice national guidance and demonstrations of fish screen facilities that achieved the seven criteria identified by the Canterbury Guidelines, including preventing impingement, entrainment, and entrapment of fish and managing debris/algae while operating as an effective water intake. This project aimed to fill key knowledge gaps identified by the Canterbury Guidelines and support the adoption of good practice by developing guidance and demonstrating examples of fish screen facilities, that meet the criteria and that are thus considered effective in achieving the overall outcome of protecting fish and fisheries.

Key parts of the MPI-funded project included:

- Reviewing regional water intake issues and requirements in New Zealand by NIWA. See Section 2 and Jellyman (2020b)[11]
- Laboratory trials to investigate knowledge gaps and confirm design criteria that protect fishes from impingement entrainment, and damage. See Appendix B, Jellyman (2020a, 2021)[11] and Jellyman et al. (2023)
- Field trials to assess the effectiveness of water intake designs compared to the seven key criteria identified by the Canterbury Guidelines
- Producing a clear and straightforward guide to fish screen facilities informed by key learnings. See Section 5.2 and online Fish Screening Facility Guidance Tool[11]

[8] Available at: www.irrigationnz.co.nz/KnowledgeResources/FishScreens
[9] Available at www.irrigationnz.co.nz/KnowledgeResources/FishScreens
[10] After the application was submitted this fund was renamed "Sustainable Food and Fibre Futures (SFF Futures)".
[11] Available at www.irrigationnz.co.nz/KnowledgeResources/FishScreens

- Workshopping several real-world examples of intake designs using the updated Fish Screening Facility Guidance Tool. See Appendix C
- Developing a national policy and practice guidance document for industry, regulatory, and planning use
- Synthesise new knowledge from the above components with the Canterbury Guidelines into a national guidance document.

1.4 Objectives of this report

This report supplements the Canterbury Guidelines. Much of the background information provided in Section 3 and appendices of the Canterbury Guidelines on structural options for fish screen facilities and ecological requirements is dated but still valid, so this report does not replicate that information. There is scope to update the good practice guidance (i.e., Section 4) provided in the Canterbury Guidelines considering knowledge gained from the MPI-funded project. This report summarises locally-developed progress since the Canterbury-specific guidance provided in the Canterbury Guidelines and collates the learnings from the MPI-funded project. It summarises key knowledge gaps filled by the case studies, laboratory and field trials and identifies the ramifications of this new knowledge on a national scale and provides recommendations to improve overall fish screening outcomes. This report does not strive to update the Canterbury Guidelines with reference to ongoing developments of international criteria and guidelines; the Canterbury Guidelines were based on international reviews and criteria that are often now more than 20 years old and have subsequently been extensively improved, i.e., National Marine Fisheries Service (1997) to National Marine Fisheries Service (2011).

2 Regional requirements and national planning direction for fish screen facilities

Jellyman (2020b)[12] reviewed the regional plans of 16 councils to understand what fish screening conditions are currently required by councils around New Zealand, and whether there are any major discrepancies between regions. This report concluded that the many issues associated with water intakes are not evenly represented across councils because surface water takes vary in frequency, volume, and complexity across New Zealand. Council regulations pertaining to water intakes are highly variable across New Zealand, ranging from nearly absent to highly prescriptive; four councils require no fish screening of smaller surface water intakes (Table 2-1). Despite being published over a decade ago, and freely available, most of the seven criteria to maximise fish screen effectiveness listed by the Canterbury Guidelines are not mentioned in most council plans (Table 2-1). The most consistently noted criteria in the plans was an aperture size requirement. The review also identified that the aperture sizes that are allowed to constitute a fish screen varied more than three-fold across different regions of New Zealand despite most regions needing to screen a comparable suite of fish species (Table 2-1). Jellyman (2020b) identified that the effectiveness of water intakes, and associated fish screens, is largely untested around New Zealand; of the eleven councils that responded to a survey, none required any testing to prove that the water intake and fish screen that had been installed was effective – except for Environment Canterbury, which had either scheduled testing investigations (Bonnett et al. 2014) or required this to be done in certain instances (large, novel, or uncertain designs). Jellyman (2020b) found that many councils use the Canterbury Guidelines but had not considered formal adoption of them at the time of the review. Jellyman (2020b) identified the need for viable nationally-consistent solutions — similar to the national fish passage guidelines (Franklin et al. 2018) — with input from more councils and a better understanding of regional issues, and specific nation-wide implementation.

[12] Available at: www.irrigationnz.co.nz/KnowledgeResources/FishScreens

Table 2-1: Summary of fish screen facility requirements in the statutory plans of councils from around New Zealand. Adapted from Jellyman (2020). For councils where proposed plans require fish screening, these are shown in the table.

Council	Screen on minor takes	Site location	Screen aperture (mm)		Approach velocity[1] (ms^{-1})	Sweep velocity (ms^{-1})	Bypass provision	Bypass connectivity	Operation & maintenance	Individual consents reference guidelines	Notes
			Tidal river[2]	Other rivers							
Northland Regional Council	Yes	-	≤ 1.5[3]	≤ 3[3]	< 0.12[3]	< 0.3[3]	-	-	-	?	
Auckland Council	Yes	-	≤ 1.5	≤ 1.5	< 0.3	-	-	-	-	?	
Waikato Regional Council	Yes	-	≤ 1.5[4]	≤ 3[4]	< 0.3	-	-	-	-	?	
Bay of Plenty Regional Council	Yes[5]	-	≤ 3	≤ 5	< 0.3[6]	-	-	-	-	?	
Gisborne District Council	Yes	-	≤ 3	≤ 5	< 0.3	-	-	Yes	Yes	?	
Hawke's Bay Regional Council	No	-	-	-	< 0.3	-	-	-	-	Yes	
Taranaki Regional Council	No	-	-	-	-	-	-	-	-	?	
Manawatu-Wanganui Regional Council	Yes	-	≤ 3	≤ 3	< 0.3	-	-	-	-	?	[7]
Greater Wellington Regional Council	Yes	-	≤ 3[8]	≤ 3[8]	-	-	-	-	-	?	
Tasman District Council	Yes	-	< 5	< 5	< 0.3	-	-	-	Yes	?	
Nelson City Council	Yes	-	< 1.5	< 1.5	0.5 Ls^{-1} (?)	-	-	-	-	?	
Marlborough District Council	No	-	-	-	-	-	-	-	-	Yes	
West Coast Regional Council	Yes	-	-	-	-	-	-	-	-	?	[9]
Canterbury Regional Council	Yes	Yes	≤ 2	≤ 3	< 0.12	Yes	Yes	Yes	Yes	Yes	
Otago Regional Council	No	-	-	-	-	-	-	-	-	Yes	[10]
Southland Regional Council	Yes	Yes	≤ 2	≤ 3	< 0.12	Yes	Yes	Yes	Yes	Yes	[11]

[1] There is poor clarity between councils as to whether 'approach velocity' means through-screen velocity (see Section 4.1.2)
[2] Also coastal rivers in some plans (e.g., < 2 km from sea)
[3] Operative plan aperture ≤ 5 mm, sweep velocity < 0.3 ms^{-1}
[4] For significant indigenous fisheries and fish habitat, otherwise 3 mm (< 100 m.a.s.l.) and 5 mm (< 100 m.a.s.l.)
[5] Under a current Plan Change this would be removed
[6] Specified as 'velocity through the screen'
[7] For larger takes council control the screening requirements
[8] Operative plan has no aperture size specified – values are from the proposed plan
[9] Previous Plan use to have more prescriptive fish screening criteria
[10] A standard consent condition is applied that is aligned with the Canterbury Guidelines
[11] Under the operative plan only the presence of a fish screen is required.

3 Characteristics of different types of fish screen facilities in New Zealand

At the time of writing, there are 12 known fish screen types that are being used, predominately at irrigation water intakes, or that are available, in New Zealand. Each screen type has unique characteristics and/or requirements (Table 3-1) that determine whether it can operate effectively and efficiently at a given site. These characteristics include:

- the range of intake flows (including the bypass and the water intake) at which the facility can operate effectively
- the depth of water that needs to be maintained at the screen for the facility to operate effectively
- the water gradients (head loss) needed for the facility to operate effectively
- whether the screen type and the overall facility requires electricity to operate
- the screen type and the overall facility's ability to handle debris types and the risk of clogging
- the footprint required to install and operate the fish screen facility, including where the water intake can be located to avoid or minimise the distance from diversion to intake
- the proportion of flow required for the facility's bypass (if required) to operate effectively
- the part of the water column where the fish screen operates
- whether the fish screen requires active cleaning to maintain its effectiveness or if it is self-cleaning.

The online Fish Screen Facility Guidance Tool (Section 5.2) considers each of the characteristics of different fish screen facilities (Table 3-1) before identifying the range of appropriate designs and screen type(s) for a particular site.

Table 3-1: Characteristics and considerations that determine appropriate fish screen types for a site (see Section 5.2). It should be noted that this table of characteristics was collated by the Technical Advisory Sub-team while they developed the Fish Screen Facility Guidance Tool (Section 5.2); many of the characteristics and values are based on expert opinion and are unconfirmed.

Screen Type	Intake flow (bypass and take)	Water depth (maintained at screen)	Water gradients (head loss at screen)	Electricity needed	Risk of clogging	Scale of footprint	Proportion of bypass flow required for effective intake	Part of water column screened	Didymo/fine filamentous weed an issue	Required maintenance/ cleaning
Fixed flat	≥ 500 Ls^{-1}	≥ 1 m	Small	Y	Low	Small	10%	Full - but could be variable	Y	Active
Cone	0.25–1.5 m^3s^{-1} per screen	≥ 0.5 m	typically 0.5 m	Y	Low	Small	20%	Base	Y	Active
Rotary cylinder (hydraulic turbine)	0.1–1 m^3s^{-1} per screen	Intake < 250 Ls^{-1}, ≥ 0.8 m Intake > 250 Ls^{-1} ≥ 1 m	typically 0.5 m	N	Low	Small	≥ 20%	Central	Y	Active
Rotary cylinder (electric motor)	0.1–5 m^3s^{-1} per screen	Intake < 250 Ls^{-1}, ≥ 0.8 m Intake > 250 Ls^{-1} > 1 m	typically 0.5 m	Y	Low	Small	≥ 20%	Central	Y	Active
Fixed cylinder	0–1 m^3s^{-1} per screen	≥ 1 m	Small	Y	Medium	Small	≥ 20%	Central/Surface	Y	Active
Travelling flat	≥ 1000 Ls^{-1}	≥ 1.5 m	Small	Y	Low	Small	10%	Full, but could be variable	Y	Active
Floating	0–1000 Ls^{-1}	Can be used in very shallow water depths	None	Y	Low	Small	10%	Surface	Y	Active
Tubular (Bossman)	0.02–2 m^3s^{-1} per screen	≥ 0.5 m	typically 0.5 m	N	Low-Medium	Small	20%	Full	TBC	Self-cleaning
Gallery	All flows	Can be used in very shallow water	0.3–0.6 m	N	Low-High depending on conditions	Large	10–20%	Base	Critical	None
Bund	All flows	≥ 0.5 m	0.3–0.6 m	N	Low-High depending on conditions	Large	10–20%	Full range	Critical	None
Horizontal (Coanda)	100–3000 Ls^{-1}	≥ 0.5 m	1 m minimum	N	Low-Medium	Small	50%	Full	Critical	Self-cleaning
Horizontal or Incline	100–3000 Ls^{-1}	Can be used in very shallow water	Small	N	Low-Medium	Medium	≥ 20%	Base	Critical	Self-cleaning

4 Good practice for fish screen facilities

The concept of using a screen only to exclude fishes from entering a water intake is simple; the design must prevent entrainment and impingement of fishes, while considering other key factors (e.g., sediment, algae, and debris). In practice, getting the fish screen facility design right to avoid effects on fishes is complex. The design phase requires engineering and ecological input. Flowing or still water environments behave in a predictable way – this requires engineering input. Fishes do not necessarily behave in a predictable (and rigid) way – they will not adapt to suit a poorly-designed fish screen facility, so a successful design requires ecological input.

There is no simple recipe for an effective fish screen facility that applies across all situations. The physical conditions (e.g., gradient and flow) and biological conditions (i.e., fish species and life stages present) at every intake are likely to differ. Guidelines, such as the Canterbury Guidelines and this report, can help identify issues and considerations, and provide good reference information, but it is not straight forward to go from that fundamental knowledge to a practical solution.

More regional councils are seeking new and existing water intakes to comply with council plans and resource consents. It is critical to get the initial design and installation of water intakes right. Remediation and retrofitting to transform an ineffective and inappropriate design into an effective fish screen facility (see Table 0-1) is usually more difficult, and always more expensive, than getting it right the first time.

4.1 Key criteria in fish screen facility design and application considerations

The Canterbury Guidelines described seven key criteria for effective and efficient fish screening. Fundamentally, through further research, testing and development these same criteria still apply but new knowledge, acquired in the 16 years since the Canterbury Guidelines were written, requires some reconsideration and improved explanation of application of several of these elements. The criteria were identified as all needing to be considered to establish an effective fish screen facility, but experience since has recognised at times not all criteria can be met at all sites. In these situations, other criteria can often be strengthened to establish an effective solution. The key criteria should be considered as a package rather than that all criteria must be achieved; the Canterbury Guidelines suggested that a "balanced design, which gives weighting to all…the key [criteria], is likely to yield the most effective solution".

From testing, it has been found that often the most critical criteria for effective fish screening at water intakes are the provision, design and connection of a suitable bypass facility, and the correct fitting, maintenance, and operation of screens (Bonnett et al. 2014). Additionally, it has been found that for fish passage requirements, upstream fish passage needs to be considered in any water intake design (see Section 4.1.8), so this has been added as an eighth criterion (Table 0-1). Selecting the location of the fish screen facility requires consideration of how each potential location can best provide for all the remaining criteria to ensure an integrated design. Location is a key component of effective design.

The Canterbury Guidelines favoured a "balanced design" for fish screen facilities that gave weight to each of the key design criteria (Table 0-1). Unfortunately, some subsequent designs and installations have concentrated too much on the physical screening material with not enough focus on the surrounding infrastructure and its functioning. The fundamental purpose of a fish screen facility is to ensure safe passage for all fishes around the facility within or back to the source waterway. The screening material is only one part of this process. It is also important that the design allows for, and incorporates, known fish behaviours to protect the fish community.

4.1.1 Intake Location

The location of a fish screen facility should permit the best design attributes to be achieved for the remaining criteria while maintaining infrastructure and fish within the waterway, or minimising the distance it diverts water and fish away from the natural waterway. The aim is to ensure all native and sports fish remain in natural water bodies where possible, and minimise fish being diverted away from natural habitat.

Seasonal variability in water intake operation and in the fish community need to be considered, particularly for transient, small, migratory life stages (see Table 4-3). Key locations for these groups and life stages can be determined using the New Zealand Freshwater Fish Database[13] and they should be identified within regional planning frameworks.

Different fish species and life stages occupy different locations within the water column at different times of the day/night (Bejakovich 2006; Charteris 2006; Franklin et al. 2018), and depending on what species are present at the location of interest, consideration should also be given to design the fish screen facility to avoid the water column location where the most at risk species will be moving (Table 4-1). Species most at risk are likely to be those moving in a downstream direction into the fish screen facility area, but upstream moving fish may also need to be considered (see Section 4.1.8 and Table 4-1). Generally, it is best to locate water intakes/screens in the middle of the water column to avoid fish entrainment. Many fish species also migrate or reside in the slower water velocities against the riverbank. It is therefore preferable to locate water intakes/screens away from the riverbank for river takes.

An intake channel should ensure that fish exposure time to the screen is minimised, fish exposure time to predators is minimised, the design should seek to avoid predators establishing in the intake or bypass (trout, large eels, shags, etc.) and generally having a shallow fast bypass to return fish promptly to the waterway is preferable to a slow deep bypass. Water intake infrastructure, including intake channels and bypasses, should be designed to pass fish through rapidly and strive not to generate resident fish habitat.

[13] www.niwa.co.nz/information-services/nz-freshwater-fish-database

Table 4-1: Characteristics of some migratory fish of concern at water intakes. Adapted from Charteris (2006).

Fish Species groups	Size	Migration/movement direction	Predominant location in water column	Comment
Glass eels (longfin and shortfin eel)	< 60 mm	Upstream	Bottom	Glass eels migrate along the margins of the river
Elvers (longfin and shortfin eel)	> 60 mm	Upstream	Middle and bottom	
Upstream migrating juvenile whitebait (i.e., īnanga, kōaro, banded kōkopu, shortjaw kōkopu, giant kōkopu) and smelt	< 60 mm	Upstream	Upper and bottom	
Nationally-threatened non-migratory galaxiid larvae within adult habitat or immediately downstream (≤ 1 km)	< 20 mm	Downstream	Surface	Non-migratory galaxiid larvae become benthic at about 25 mm (e.g., dwarf galaxias and alpine galaxias).
Larval whitebait and torrentfish, and *Paratya* shrimp zoea	< 10 mm	Downstream	Surface (day) Bottom (night)	
Lamprey macrophthalmia (juvenile lamprey)	< 120 mm	Downstream	Surface/upper	
Salmonid juveniles within spawning streams	< 25 mm	Downstream	Bottom (trout) Middle (salmon)	Juvenile salmonids seek refuge cover on the bottom and around debris when not feeding. Juvenile salmon feed in the water column during the day but move downstream at night, likely mid-water. Juvenile trout generally associated with the bottom.

4.1.2 Through-screen velocity

The through-screen velocity is critical for the survival and safety of fish in fish screen facilities. The term ‘approach velocity’ was used in North America to refer to the velocity of water moving towards but some distance off the surface of the screen (National Marine Fisheries Service 1997). The CFSWP and NZFSWG chose ‘through-screen velocity’ as the approach velocity criterion rather than velocity a distance off the screen surface because it is more relevant to the behaviour of native fish that readily interact with fish screen surfaces. However, this was not conveyed consistently in the Canterbury Guidelines.

The NZFSWG decided that requiring demonstration of approach velocities “three inches in front of the screen surface” (as described in the North American anadromous salmon criteria, i.e., National Marine Fisheries Service 1997, but omitted from later criteria, i.e., National Marine Fisheries Service 2011) was not feasible and not consistent with the other design approaches, and so decided to adopt calculated through-screen velocity as the approach velocity criterion. This could be empirically measured and verified from desktop design, without onerous field measurement requirements and associated uncertainties. This is the method now more uniformly adopted in most modern international criteria.

The North American approach velocity criterion was widely used in anadromous salmonid passage facility designs (e.g., National Marine Fisheries Service 1997). It was specifically developed for juvenile anadromous salmonid fish; these are actively swimming/migrating pelagic fish species (trout, salmon, char, whitefish, shad, etc.) that sense and respond to accelerating water velocity by turning away from and avoiding the water accelerating towards the screen surface. New Zealand native fish species are not dominated by salmonids, or salmonid-like growth forms and behaviours, and include a range of valued fish with anguilliform movement (eels and lamprey), benthic specialists (torrentfish, bullies, galaxiids such as kōaro), and species favouring backwaters. These fish species groups cannot be expected to inherently respond to an accelerating velocity by instinctively swimming away, but may conversely exhibit ‘clamping, clinging, or climbing’-like behaviours on the screen surface. For this reason, it is particularly important that critical screen velocities for native fish avoid protracted impingement onto the screen surface and enable fish to release themselves from the screen surface to swim away undamaged. The lack of clear velocity requirements for native fish behaviours (other than generic swimming abilities) is another strong reason to consider through-screen velocity to be the appropriate approach velocity for New Zealand fish screen facilities.

To escape from a fish screen, a fish must be capable of swimming against the water velocity drawing fish into the screen surface, and the water velocity through the screen apertures as the fish is carried across the screen by the sweep velocity (see Section 4.1.3). If the water velocity approaching a screen exceeds the sustained swimming ability of a fish (see Franklin et al. 2018 and below) then it will become exhausted and be impinged on the screen where it is then exposed to velocities drawing fish (head or tail first) through the apertures.

Fish are capable of two types of swimming (Crawford et al. 2023). In sustained swimming mode, the fish uses small amounts of red muscle that have good blood supply – these low power muscles can propel the fish for long periods without oxygen deficit and lactic acid build up. When the fish needs to move quickly (to avoid danger or to capture prey), burst swimming mode uses large amounts of white muscle with poor blood supply – these high-power muscles can only propel the fish for a very short period before accumulating damaging lactic acid debt.

Several factors affect the sustained swimming ability of fish:

- the most significant factor affecting sustained swimming ability is fish size (length); smaller fish are not capable of swimming as fast as larger fish
- different species and life stages of fish have different swimming abilities; these correspond to general features such as body shape and swimming action
- water temperature affects swimming performance – sustained swimming speeds decrease significantly at higher temperatures.

Boubée et al. (1999) reviewed the sustained swimming abilities of New Zealand fish species and concluded:

- that there was little difference between species on a speed to length basis
- that fish length was the main factor in determining maximum sustained swimming ability.

For design and operation of fish screen facilities, the one critical factor is determining the appropriate water velocity through the screen after considering the sustained swimming ability of the smallest schooling or free swimming fish present. The anadromous salmonid literature (e.g., Nordlund 1996) suggests that water velocity should not exceed four times the body length of the smallest salmonid fish present per second. In most situations, the smallest salmonid fish at an intake would be ≥ 30 mm in length, so the through-screen water velocity should not exceed 4 × 30 mm per second, i.e., 0.12 ms^{-1}.

There may be some water intakes that need to consider smaller fish, such as intakes located within important habitats for non-migratory galaxiids, rare bully species, torrentfish or elvers. These fish do not generally school or actively swim within the water column, so elevating the water intake off the riverbed may minimise the risk of fish interacting with the screen. This, coupled with suitable through-screen velocities to protect these fish when they rest on or investigate the screen surface trying to find a way through (head butting or nudging the screen surface) will minimise the risk of impingement and entrainment.

It is also important to consider whether other criteria can be strengthened to ensure no entrainment or impingement of the smallest fish species or life stage (e.g., galaxiid larvae). Guidelines do not strive to explicitly protect fish larvae. This is partly because salmonid larvae spend most of their larval (alevin) stage within the gravels and anadromous salmonid criteria (National Marine Fisheries Service 1997, 2011) consider them not susceptible to entrainment and impingement. However, native fish larvae are mobile, migratory, and very small (3–10 mm total length) and would require aperture sizes as small as 0.3 mm to safely exclude them from water intakes (Meredith et al. 1987). The commonest fish screen facility design response to the presence of rare or threatened native fish larvae is to strengthen the sweep velocity criterion.

A through-screen velocity criterion set to account for swimming ability will account for extreme temperatures and for any discrepancies in the swimming performance and behaviour of various fish species. In addition to sustained swimming speeds, swimming ability (i.e., climber, swimmer, jumper) and behaviour (i.e., where in the water column they swim), especially for smaller life stages, may be the most important consideration in fish screen facility design (Charteris 2006; Franklin et al 2018; Table 4-1). It is for these reasons that a through-screen water velocity criterion is more relevant for New Zealand fish screening than swimming ability approaching a screen.

4.1.3 Sweep velocity

Sweep velocity describes the velocity of water moving parallel with the fish screen. Water flowing along the screen moves fish across the screen and minimises the time exposed to risks of impingement or entrainment. Sweep velocity should promptly carry the fish away from the screen and back to the main flow/channel either directly or via a bypass. Generally, placing the screen close to parallel with the direction of the supply flow creates a sweep velocity across the screen that effectively moves fish downstream of the screen into the bypass. There have been suggestions that there is a maximum time that fish should be exposed to screen surfaces (100 seconds – M. Webb, pers. comm.), and that fish should not be circulated back to the screen (i.e., they are only exposed to it for a single pass).

Sweep velocity may be further enhanced using diversion louvers installed in front of the screen to divert fish (and debris) away from the screen. However, there needs to be care that the space between the louvres and screen surface does not create eddies or flow reversals. The absolute value of sweep velocity is important in minimising the period spent traversing the screens, but at times it may often be less important than the sweep velocity : through-screen velocity ratio. To minimise the risk of impingement or entrainment, the sweep velocity should, within reason, be as high as possible relative to the through-screen velocity. Charteris (2006) suggested that sweep velocities > 0.5 ms^{-1} should prevent entrainment of most native fishes, except those that are capable of climbing or clinging, if the through-screen velocity is < 0.3 ms^{-1}.

4.1.4 Fish bypass

Ideally, fish screen facilities do not require a flow diversion; fish should remain within the waterway if possible. If a flow diversion is necessary, fish moving toward the water intake, either voluntarily or involuntarily, must be bypassed back into the source waterway, rather than impinged on the fish screen or entrained into the intake. The purpose of a bypass is to transport fish away from the intake and back into the source waterway quickly and safely. Specifically:

- the entrance(s) to the bypass must be easy for fish to locate. The entrance should be at the downstream end of the screen (or on both sides/ends when the screen is placed across the intake flow) and flush with the screen. One bypass entrance may be sufficient for smaller intake structures, but for large screens several entrances may be required, however it is important that multiple entrances do not compromise velocity into the bypass. The bypass entrance should be designed to attract fish swimming at the surface and benthic fish. Sharp angles, drop structures, and collisions with hard surfaces should be avoided and where possible the bypass should be designed to optimise where the fish would go 'naturally'
- bypass entrances should extend from the base of the intake channel to the water surface (i.e., a graded ramp or slot rather than a pipe). Some fish avoid enclosed/darkened spaces, so the entrance should be open at the top to provide ambient light conditions
- the sweep velocity should draw fish into the bypass entrance, and there should be sufficient velocity into and through the bypass to prevent fish returning to the screen
- where upstream fish passage is not prevented, the bypass should provide easy and seamless fish passage in both directions (see Section 4.1.8). Fish that move into a bypass will not 'turn around' when further passage is blocked and return to a main flow. This is an important design consideration and is another way that fish can become entrained in a fish intake facility.

4.1.5 Fish bypass connectivity

Fish that are diverted into the bypass must be delivered promptly and safely back to the source waterway. The bypass design needs to ensure diverted fish are minimally exposed to predators within the bypass facility (the bypass should not provide suitable habitat for predators to harvest fish concentrating in the screen facility). The bypass should generally be narrow: shallow fast water is preferable to a slow deep bypass. The bypass should have no extreme (un-natural) bends, no obstacles, no rough surfaces, no hydraulic jumps, and no free-falls onto hard surfaces. Excessive turbulence and pressure changes in drop structures can be particularly damaging to fish (Boys et al. 2018). The outfall of the bypass, where it re-joins the source waterway, should not involve excessive free fall or impact onto hard surfaces and/or shallow water but noting it may be appropriate to design the outfall in a way that deters the upstream migration/movement of fishes. The natural characteristics of the waterway should be considered. Fish should be returned to active water and not be exposed to predation from larger fish or birds.

4.1.6 Gap openings

The aperture size of the screening material is critical for the successful through-flow of water and for safe passage of fish past the screen to the bypass. However, another key design consideration is to ensure no other parts of the design, such as hinges or edges, create gaps for entrainment opportunities and well maintained rubber seals are required to avoid gaps being established.

It is intended that fish with a body width greater than the aperture size should physically not be able to pass through the fish screen. However, there is clear evidence that many fish species can squeeze through physical barriers narrower than would be expected based on their body dimensions (Knott et al. 2023). It is important that maximum aperture sizes to exclude specific fish species and life stages are based on experimental laboratory trials using wild and captive-reared fish to allow for fish behaviour (Jellyman et al. 2023).

The Canterbury Guidelines provided a detailed review of maximum aperture sizes for screening native and sports fishes. Most of the information for salmonids was derived from North American and European studies, while the information for native fishes drew heavily on a review by Charteris (2006). Much of the aperture size information provided in the Canterbury Guidelines is still valid, but for some species the experimental work of Jellyman et al. (2023) has revised the maximum apertures size (Table 4-2). For example, the Canterbury Guidelines stated that “3 mm mesh [aperture] would protect a significant proportion of migrating whitebait”; this was based on body measurements and was larger than the 2 mm aperture size recommended by Charteris (2006). Jellyman et al. (2023) used artificial stream channels (see Appendix B) to show that 1.5 mm wedge-wire was needed to exclude all whitebait (including smaller species and smaller individuals; Table 4-2). Likewise, the Canterbury Guidelines stated that “3 mm mesh [aperture] would exclude many elvers from irrigation intakes”, but “intakes closer to the sea would need to be fitted with 1.5 mm mesh to exclude a significant proportion of migrant glass eels and elvers”. Jellyman et al. (2023) showed that < 2 mm wedge-wire and < 3 mm mesh was needed to exclude elvers and < 1.5 mm wedge-wire was needed to exclude glass eels (Table 4-2).

Jellyman et al. (2023) emphasised the need to consider the location of a fish screen facility (regionally and within a catchment) when considering the appropriate aperture size. Jellyman et al. (2023) recommended:

- 1.5 mm wedge-wire screens in lower catchment areas, where whitebait (≤ 50 mm) and glass eels are present
- a transition to 2 mm wedge-wire screens at the point where the water level ceases to fluctuate with the tide
- a transition further inland (depending on the catchment and species present) to ≤ 3 mm wedge-wire screens.

Alternatively, some councils (e.g., Waikato Regional Council) specify an altitude above sea level for the transition between required aperture sizes (i.e., < 100m). This is an alternative approach to distance inland, or tidal influence, but may need to be varied for different waterway types. In North Island rivers, the tidal reach may extend many kilometres inland and an elevation of 100 m may be more than 100 km inland.

All criteria (Table 0-1) must be considered when developing a design to prevent impingement and entrainment of fish. However, it is unlikely that aperture size alone will prevent entrainment and impingement of the smallest fishes (Table 4-1). When small native fish are present, other criteria, like sweep velocity (see Section 4.1.3) and bypass design (see Sections 4.1.4 and 4.1.5), should be strengthened to prevent entrainment and impingement of these life stages.

The ratio of through-screen water velocity to sweep velocity must minimise the likelihood of fish contacting the screen. Additionally, the surface of the screening material must be smooth enough to prevent fish from being impinged or damaged if they do contact the screen. Wedge-wire screening material has been found to be more effective at preventing entrainment and has been found to hold its structure better over the long term than woven wire or perforated plate (Appendix B; Bonnett et al. 2014; Jellyman et al. 2023).

Wedge-wire screening can be constructed so that the wedge-wires are either aligned with the sweep velocity or perpendicular to the sweep velocity. It is not feasible to prescribe one orientation as preferable; the cleaning mechanisms of drum screens require a perpendicular orientation, flat screens will be aligned with the sweep, but travelling vertical screens will require perpendicular orientation.

Table 4-2: Recommended maximum aperture size in fish screen facilities to exclude native and sports fish from freshwater intakes.

Type	Species	Common name	Life stage	Maximum aperture (the Canterbury Guidelines)		Maximum aperture (Jellyman et al. 2023)	
				Wedge-wire (mm)	Mesh (mm)	Wedge-wire (mm)	Mesh (mm)
Sports fish	*Oncorhynchus tshawytscha*	Chinook salmon	Fry	2	3	2[1]	-
	Oncorhynchus nerka	Sockeye salmon	Fry	2	3	-	-
	Salmo trutta	Brown trout	Fry	2	3	-	-
	Oncorhynchus mykiss	Rainbow trout	Fry	2	3	-	3
Native, diadromous	*Anguilla dieffenbachii*	Longfin eel	Glass eel	-	1.5	< 1.5	-
			Elver	-	3[2]	< 2	< 3
			Adult	-	3	-	-
	Anguilla australis	Shortfin eel	Glass eel	-	1.5	< 1.5	-
			Elver	-	3[2]	< 2	< 3
			Adult	-	3	-	-
	Galaxias maculatus	Īnanga	Whitebait	-	3[3]	1.5[4]	-
			Adult	-	3	-	-
	Galaxias fasciatus	Banded kōkopu	Whitebait	-	3[3]	1.5	-
			Adult	-	3	-	-
	Galaxias argenteus	Giant kōkopu	Whitebait	-	3	1.5	-
			Adult	-	3	-	-
	Galaxias postvectis	Shortjaw kōkopu	Whitebait	-	3	1.5	-
			Adult	-	3	-	-
	Galaxias brevipinnis	Kōaro	Whitebait	-	3	1.5[4]	-
			Adult	-	3	-	-
	Gobiomorphus cotidianus	Common bully	Juvenile	-	3[3]	3	3
			Adult	3[3]	3[3]	-	-
	Gobiomorphus hubbsi	Bluegill bully	Juvenile	-	3	3	3[5]
			Adult	-	3	-	
	Cheimarrichthys fosteri	Torrentfish	Juvenile	-	3	-	
			Adult	-	3	-	
	Geotria australis	Lamprey	Ammocoete	-	1.5	-	
			Adult	-	3	-	

Type	Species	Common name	Life stage	Maximum aperture (the Canterbury Guidelines)		Maximum aperture (Jellyman et al. 2023)	
				Wedge-wire (mm)	Mesh (mm)	Wedge-wire (mm)	Mesh (mm)
Native, non-diadromous	*Galaxias vulgaris*	Canterbury galaxias	Juvenile	-	2	3	3
			Adult	-	3	-	
	Neochanna burrowsius	Canterbury mudfish	Juvenile	-	2	-	
			Adult	-	3[3]	-	
Native, other	Various	Flatfish	Juvenile	-	3	-	
	Aldrichetta forsteri	Yelloweye mullet	-	-	3	-	
	Retropinna retropinna	Common smelt	Adult	-	3	-	
	Stokellia anisodon	Stokell's smelt	Adult	-	3	-	

[1]Jellyman et al. (2023) warned that this result was based on limited replication
[2]Charteris (2006) recommended 1.5 mm mesh
[3]Charteris (2006) recommended 2 mm mesh
[4]Jellyman et al. (2023) identified that 2 mm wedge-wire would exclude īnanga and kōaro whitebait in southern regions, where they are significantly larger (Egan 2017 and Yungnickel 2017), but 1.5 mm wedge-wire would be need elsewhere to exclude those species and to exclude the generally smaller banded kōkopu, giant kōkopu and shortjaw kōkopu whitebait
[5]Jellyman et al. (2023) found that 3 mm mesh excluded 96% of > 32 mm bluegill bully

4.1.7 Operations and maintenance

The fundamental purpose of designing and installing a fish screen facility is to exclude and divert fish from the intake with minimal impact. Regular and ongoing maintenance of the whole facility is necessary to ensure that it always works effectively and efficiently. This will involve a well prescribed and detailed plan for regular checking, cleaning, repair or replacement of screens, seals, and bypasses. Specifically:

- ongoing regular inspection of the fish screen surfaces, and other sealed edges, is important to confirm the initial and ongoing performance of fish screen facility designs and to identify maintenance requirements. Depending upon the risks (i.e., frequency of large floods, likelihood of algal growth), this monitoring may need to be prescribed as weekly in response to flow events of or above a certain magnitude
- sediment and debris that collects in or near the fish screen facility, or on trash bars/trash screens that alters flow characteristics will need to be dispersed or removed promptly, particularly if they lead to inappropriate increases in water level, through-screen velocity, or lowered sweep velocity
- the design and installation must incorporate an ability to ensure that the fish screen facility operates efficiently under all flow conditions (floods and low flow). Screening structures must be able to cope with higher water levels, or high sediment/debris loads, that may occur during floods and freshes, without water (and fishes) overtopping the screens. If screens are designed to be submerged, or maintained off the bed, this must be able to be achieved at low flows
- if significant damage from floods and freshes is foreseeable, contingency plans for maintenance or repair need to be agreed in advance with relevant authorities and documented. Structures must be designed so that there is still a working fish screen facility in place during maintenance events. These plans must provide ongoing protection for fishes.

Some fish screen facility design criteria (e.g., location) are established during installation and need little attention throughout its lifetime. However, most criteria (e.g., through-screen velocity, sweep velocity, bypass, and screening materials) will require regular monitoring to identify maintenance needs and to maintain the efficiency and effectiveness of the fish screen facility. A poorly monitored and maintained facility will not always exclude and protect fish.

4.1.8 Upstream fish passage – a new criterion

An unintended consequence of fish screen facilities that use a diversion channel, and the requirement for these facilities to therefore have a bypass that connects to the mainstem of a waterway, is that the bypass is likely to become an alternative pathway for fishes migrating upstream (see Appendix A). It is important to minimise any features of the water intake and bypass that may impede upstream migration of any fish life stages, but this needs to be balanced to not be at a cost to the bypass function. Factors such as vertical drops, high water velocities, sharp corners, overhanging edges, a lack of shallow wetted margins and physical blockages are all features of designed instream structures that will impede the movements (upstream migration) of migratory fishes (Franklin et al. 2018).

Some of the key criteria are more difficult to combine in a successful design. For example, it is likely that the sweep velocity, required to offset a through-screen velocity of ≤ 0.12 ms^{-1}, will present a barrier to the upstream migration of any juvenile fish that enter the water intake via the bypass.

Therefore, there is a need to balance the risk against the problems created by the bypass for upstream migration; this will require detailed knowledge of the resident fish community and the timing and composition of fish migrations past the potential intake site (Table 4-3).

Ideally, the bypass outlet should impede/prevent upstream fish passage to ensure fish remain in the natural waterway. Migration prevention systems should also ensure downstream moving fish are not harmed while being transported back to the natural waterway. If a new weir or diversion structure is established at the bypass outlet, then consideration by DOC will be needed to determine if some type of fish facility will be required. If a culvert or ford is established that likely impedes passage a permit will need to be sought from DOC[14].

Table 4-3: Main migration period(s) of different life stages of common native fish species.

↑ = upstream migration; ↓ = downstream migration; ? = uncertainty; ↔ = adults/larvae migrating within habitats.

Life history strategy	Common name	Life stage	Summer			Autumn			Winter			Spring		
			D	J	F	M	A	M	J	J	A	S	O	N
Anadromous	Lamprey	Adults	↑	↑					↑	↑	↑	↑	↑	↑
		Juveniles				↓	↓	↓	↓	↓	↓			
	Chinook salmon	Adults	↑	↑	↑	↑								↑
		Fry	↓	↓							↓	↓	↓	↓
	Sockeye salmon	Adults			↑	↑								
		Fry						↓	↓	↓				
	Brown trout	Adults					↑	↑	↑					
		Fry									↓	↓	↓	
	Rainbow trout	Adults							↑	↑	↑	↑	↑	
		Fry	↓	↓	↓								↓	↓
Catadromous	Longfin eel	Juveniles								↑	↑	↑	↑	↑
		Adults			↓	↓	↓	↓	↓					
	Shortfin eel	Juveniles								↑	↑	↑	↑	↑
		Adults			↓	↓	↓	↓	↓					
Amphidromous	Giant kōkopu	Juveniles	↑										↑	↑
		Larvae					↓?	↓?	↓?	↓?	↓?			
	Shortjaw kōkopu	Juveniles									↑	↑	↑	
		Larvae					↓	↓	↓					
	Kōaro	Juveniles									↑	↑	↑	
		Larvae				↓	↓	↓	↓					
	Banded kōkopu	Juveniles										↑	↑	↑
		Larvae					↓	↓	↓	↓				
	Īnanga	Juveniles								↑	↑	↑	↑	↑
		Larvae		↓	↓	↓	↓	↓						
	Stokell's smelt	Adults	↑	↑	↑	↑						↑	↑	↑
		Larvae	↓	↓	↓	↓	↓	↓	↓					
	Common smelt	Adults	↑	↑	↑	↑	↑				↑	↑	↑	↑
		Larvae	↓	↓	↓	↓	↓							↓
	Black flounder	Juveniles										↑	↑	↑
		Adults							↓	↓	↓			
	Yellowbelly flounder	Juveniles	↑										↑	↑
		Adults								?	?	?		

[14] https://www.doc.govt.nz/get-involved/apply-for-permits/business-or-activity/fish-passage-authorisations/

Life history strategy	Common name	Life stage	Summer			Autumn			Winter			Spring		
			D	J	F	M	A	M	J	J	A	S	O	N
	Torrentfish	Juveniles						↑	↑	↑	↑	↑	↑	↑
		Adults		↓	↓	↓	↓							
		Larvae			↓	↓	↓	↓						
	Common bully	Juveniles	↑	↑	↑	↑						↑	↑	↑
		Larvae	↓	↓	↓									↓
	Giant bully	Juveniles	↑	↑										↑
		Larvae	↓										↓	↓
	Bluegill bully	Juveniles	↑											↑
		Adults	↓								↓	↓	↓	↓
		Larvae	↓	↓	↓							↓	↓	↓
	Redfin bully	Juveniles	↑	↑								↑	↑	↑
		Larvae										↓	↓	↓
Non-diadromous	Lowland longjaw galaxias		↔?	↔?					?	?	?	↔?	↔?	↔?
	Dwarf galaxias		↔	↔		↔?	↔?	↔?				↔	↔	↔
	Upland longjaw galaxias					↔?	↔?	↔?			↔	↔	↔	
	Bignose galaxias					↔?	↔?	↔?		↔?	↔?	↔?		
	Alpine galaxias									↔?	↔?	↔?	↔?	↔?
	Canterbury galaxias		↔									↔	↔	↔
	Canterbury mudfish		↔						↔	↔	↔	↔	↔	↔
	Upland bully		↔	↔							↔	↔	↔	↔

4.2 Additional considerations in applying the key design criteria

4.2.1 Incorporating fish behaviour

New Zealand's native freshwater fishes are mostly small and benthic (McDowall 1990). Generally, they are relatively poor swimmers (see Boubée et al. 1999) and they often use the stream bed or edge waters for feeding (Cadwallader 1975) and refuge from predators and high water velocities (Mitchell 1989b). There is evidence that many fishes (i.e., shortfin elvers) actively seek shelter within the screening material of fish screens (Jellyman et al. 2023). Most freshwater fishes display positive rheotaxis whereby they turn to face into an oncoming current. In a flowing stream, this behaviour helps them to hold their position rather than get swept downstream by the current.

Any water intake design that relies on fishes:

- making a tight or right-angle turn,
- changing position in the water column,
- entering dark areas,
- actively avoiding the screening material, or
- swimming towards or through turbulent water (e.g., drops or vortices),

will not be effective at ensuring safe passage for fish. These are not normal behaviours for most fishes, and a good fish screen facility design should not rely on fish adapting their behaviours to novel engineered conditions.

4.2.2 Timing

Most fish screen facilities in New Zealand need to operate effectively and efficiently in a dynamic biological and physical environment. New Zealand's maritime climate, combined with many short, steep catchments with large areas above the timber line, and wide plains reaches, produces unstable and unpredictable river flows (Winterbourn et al. 1981) – large floods can and do occur during any month of the year. High and low flow events can lead to 'resetting' of resident fish communities. Additionally, the comings and goings of migratory life stages (Table 4-3), particularly in lower catchment areas, produces fish communities that are in a continual state of flux (see Appendix A).

Under most water abstraction consent conditions, the allowable take of water is reduced or must cease during periods of low flow. It is important to consider the most common take rate and to design a facility that has peak effectiveness and efficiency for the fish species and life stages present at that/those times (see Table 4-3). It is likely that most design elements will be appropriate across a range of take flows, but some elements may need to be altered to provide a suitable sweep velocity : through-screen velocity ratio (see Section 4.1.3) during both the most common intake flow rate, and the most extreme/limiting flow rate.

5 Good practice design process for fish screen facilities

5.1 Collect design data and identify limitations

A wide range of data must be gathered to support fish screen facility concept selection and design (Table 5-1). These data include specific constraints and limitations that may eliminate concepts from consideration because of the site, future operation/maintenance, and cost.

Table 5-1: Data required to support fish screen facility concept selection and design.

Type	Required design data
Biological	Knowledge of fish community near intake site and migratory fishes (both upstream and downstream) that will be present/use the waterway during intake operation
	Appropriate fish exclusion and repulsion requirements
Hydrological	Maps/plans of the sites showing natural water bodies, diversion structures (diversion dams and diversion headworks), canals and constructed waterways, and topography
	Hydraulic characteristics of the site
	Quantities and types of debris and screen clogging materials (algae including *Didymosphenia geminata* [didymo], coarse sediment, debris types, leaves, etc.) and probable times of occurrence
	Sediment loading and probable times of occurrence
Logistical	Consultation with mana whenua and key stakeholders e.g., DOC, FGNZ and community groups
	Drawings and photos of existing structures at the site
	Resource consent documentation
	Site geology review
	Land ownership and potential easement needs for construction access with identification of preferred locations for structure and bypass placement
	Timing of intake season and any operating constraints that would affect construction
	Construction season constraints
	Limitations on access for construction
	Reasonable availability of electricity at the site
	Local maintenance capabilities and acceptable levels of maintenance and operation
	Information on nearby, well-performing fish screens
	Consideration of opportunities to combine intakes

5.2 Identify design alternatives: Fish Screen Facility Guidance Tool

There are usually several water intake designs that could satisfy the key design criteria (see Section 4.1) at a site. However, alternative designs need to be balanced against site-specific characteristics, biological considerations, client preferences and budgetary constraints. The Fish Screen Facility Guidance Tool (hereafter the 'Tool'), which replaces the Decision Table in the Canterbury Guidelines, provides a method to document and support selection of applicant/consultant preferred designs that could be developed for a conceptual design.

5.2.1 Purpose

A draft Fish Screen Facility Guidance Tool[15] was developed by the Technical Advisory Sub-team within the NZFSWG. The Tool shows good promise for providing a structured process to assist landowners, consultants, or other parties to identify and select a preferred location and fish screen type when looking to install, replace or upgrade a water intake. However, the Tool relies heavily on 'weighted scores' for design elements. The draft Tool will benefit from further iterations and consideration of relative and absolute weighted scores.

5.2.2 Application

The Tool is freely available online[15]. It uses a Microsoft Excel spreadsheet to guide users through a three-step process to compare potential water intake locations and screen types:

- Step 1 allows the user to compare multiple sites for the fish screen facility using weighted scores of design elements. These elements include site characteristics (e.g., stability, flow variability, river gradient, space, and land ownership), bypass characteristics (e.g., length, connectivity, need for piping, upstream passage, and flow requirements) and required management (e.g., debris, access, safety, cleaning, and maintenance). By comparing the total scores, based on each of these characteristics, the user can identify the most suitable location for the facility

- Step 2 uses a decision tree structure to identify appropriate screen types using knowledge on characteristics and limits of available screens (Table 3-1). The user characterises various physical characteristics (e.g., intake flow, depth and gradient, availability of electricity, risk of clogging, space availability and need for maintenance). As each characteristic is defined, the list of recommended screen types is refined. In many situations, multiple screen types will remain as viable options. This includes those screen types that are available, or currently being used, within New Zealand. However, there could be other types we are not aware of, or novel designs that should be considered

- Step 3 is a structured Design Guidance Table where the potential screen types identified in Step 2 are contrasted. Multiple designs can be compared for their ability to screen priority fish species (e.g., bypass characteristics, sweep and approach velocities) and for operator safety. By comparing the total scores, based on each of these characteristics, the user can identify the most suitable screen type. The Design Guidance Table also identifies elements (beyond aperture size) and criteria that need to be altered to prevent entrainment and impingement of priority fish species or life stages (sizes).

[15] https://www.irrigationnz.co.nz/KnowledgeResources/FishScreens

Appendix C includes four applications of the Fish Screen Facility Guidance Tool to real world examples. Three of the scenarios are hypothetical but are intended to represent a range of known intakes and locations/habitats where water intakes could and are being proposed. Example 4 represents a physical installation that occurred as part of the project (see Webb 2022 Trial of fish screen effectiveness at Awakino River West Branch irrigation intake, Canterbury [16]).

[16] www.irrigationnz.co.nz/KnowledgeResources/FishScreens

6 Information gaps and recommendations for improving future practices

The 'Adoption of good practice fish screening' project aimed to fill key information gaps identified by the Canterbury Guidelines and support the adoption of good practice by developing guidance and demonstrating examples of water intakes, and associated fish screens, that are effective in achieving the overall outcome of protecting fish and fisheries. Inevitably, while filling some information gaps identified in the 2007 guidelines, new areas that require further knowledge/research were identified. Many of the information gaps listed below also need to be addressed to improve fish passage at artificial structures (e.g., culverts, weirs, and dams). The complementary needs of fish passage and screening work should be considered when undertaking the following work:

- Native fish swimming behaviour. What position in the water column do key fish species and life stages occupy during migration? How is this behaviour affected by the increased velocities and turbulence associated with fish screen facilities? Can fish behaviours be used, in conjunction with intake design and screen type, to reduce the risk of exposure to fish screens?

- Water velocity near screens. What are the fine-scale water velocities close to common screening materials? Do approach velocities measured away from the fish screen, or calculated through-screen velocities, match predicted through-screen velocities? Can some fish species use reduced velocities in the boundary layers at the surface of fish screens to safely traverse the screen? Are fish swept past intakes with velocities > 0.5 ms^{-1}?

- Effects of turbulence on fish survival. Research overseas (Boys et al. 2018) has indicated that exposure of fish to abrupt pressure changes and short-term turbulence (caused by low-head hydropower turbines or undershot weirs) can cause barotrauma and injure or kill large adult fish. Can these sorts of injuries be caused in small NZ native fish, or larval migratory stages, by the high water velocities and turbulence associated with fish screen facility velocities and bypasses? Are such injuries immediately obvious or are the effects not seen until the fish has moved away from the screen?

- Fish behaviour at bypass outlets. Can bypass outlets be manipulated to prevent fish migrating upstream from entering the bypass? Can this be done without impacting on fish moving downstream through the bypass or attracting predators to the bypass outlet?

- Timing and location of fish migration/movements. There is still major uncertainty surrounding the timing and location of migrations/movements in many NZ native fish species. These knowledge gaps increase the risk posed by water intakes to vulnerable life stages by limiting design and management strategies

- Integrating designs into an existing intake. It is recognised that integrating a design into an existing river intake can be a challenging part of the design process and physical (i.e., highly mobile riverbeds) or legal (i.e., land ownership) constraints may be present. A suitable solution for a specific site with these challenges will require a balancing of criteria and needs to extend past the physical fish screen and encompass waterway intake functions (intake, sediment, debris management, flood protection to infrastructure, waterway user and operator safety, meeting social and cultural needs, all whilst ensuring effective fish screening). Better guidance is needed for retrofitting or replacing current intakes with better designs

- Characteristics and considerations of fish screen types. Many of the attributes of different screen types listed in Table 3-1 (and used by the Fish Screen Facility Guidance Tool) are unconfirmed and based on expert opinion. Increased accuracy around these characteristics will improve the performance of Step 1 of the Guidance Tool (see Section 5.2.2)
- Weighted scores of design elements. The Fish Screen Facility Guidance Tool relies heavily of weighted scores against individual design characteristics. The performance of the draft Guidance Tool will be improved by further consideration and testing of relative and absolute weighted scores
- Industry training and upskilling. There are limited specialist training opportunities for those working in the fish screen space. A training course that encompasses biological and engineering expertise and ensures the 'whole of facility' concept is catered for, is in the planning stages. This should improve fish screen facility design in the future
- Continued engagement with mana whenua to better understand cultural impacts of ineffective fish screening needs to be a key focus for further fish screen facility work via Regional Council process
- The links between consenting and compliance process and abstractors and their advisors (designers, engineers, ecologists etc) become very important when improving certainty of outcome. It is important that all parties are satisfied with the design prior to installation, that any installation adheres to that agreed design, and that once installed confirmation that this has been achieved is provided by a suitably qualified person
- The NZFSWG recognise that there is no 'one size fits all' for fish screens in New Zealand. Innovation and investigating alternative approaches to fish screening should be supported and tested where appropriate
- Further consideration and incentivisation of combining intakes
- Further research is needed to refine current criteria to provide improved guidance
- Given the information presented in this report that supports the eight criteria and how to apply them in practice, and notwithstanding the information gaps identified in Section 6, regional councils could consider adoption of the eight criteria for fish screen facility designs into their regional plans through their next notification process
- Improvement in monitoring and compliance of fish screen facilities nationally to ensure fish remain in waterways
- In the <u>very limited circumstances</u> where entrainment is unpreventable, resident fish may be found within the water intake infrastructure (e.g., races and canals). Further guidance is needed on how water levels and habitat can be maintained during periods of no abstraction to avoid harm, and on the provision of safe upstream or downstream passage for these fish so that they can complete their lifecycle.

7 Glossary of terms

Amphidromous	Amphidromous fish are born in fresh water/estuaries, then drift into the ocean as larvae before migrating back into fresh water to grow into adults and spawn, e.g., banded kōkopu
Anadromous	Anadromous fish are born in fresh water, migrate to the ocean as juveniles where they grow into adults before migrating back into fresh water to spawn e.g., lamprey
Aperture size	The aperture size of the screening material. Apertures in woven wire mesh are usually symmetrical. The apertures in wedge-wire are slots that are usually considerably larger in one dimension than in the other
Benthic	Associated with or occurring on the bottom of a water body
Bypass	Route through which fish can safely move from being upstream of a fish screen to a safe location in the source waterway channel
Catadromous	Catadromous fish are born in salt water, then migrate into fresh water as juveniles where they grow into adults before migrating back into the ocean to spawn, e.g., longfin eel
Connectivity	Ensuring the bypass connects with the source channel in a way that allows safe fish passage to a location where fish are not in danger
Diadromous	Fish that migrate between freshwater and marine habitats as part of their lifecycle. Anadromous, amphidromous, and catadromous are all subcategories of diadromous
Entrainment	Fish being transported, along with the flow of water, out of their normal river, lake, or reservoir habitat into unnatural or harmful environments
Fish passage	The ability of the weakest native migratory fish and life history stages to move freely, with minimal stress and without physical or physiological injury, upstream or downstream of an artificial obstruction
Fish screen facility	All parts of a water intake including but not limited to, the diversion, intake, trash/sediment management infrastructure, the physical screen and bypass
Head loss	Reduction in height of water surface or pressure across a fish screen
Impingement	Physical sustained contact of a fish with a barrier structure (screen) due to high intake velocities
Open area	A ratio that reflects how much area of a screening material is occupied by holes (i.e., its porosity). It is normally expressed as a percentage
Rheotaxis	An innate behaviour in fish that leads them to orientate themselves into the flow
Sweep velocity	Speed of water across (or past) the screen
Through-screen velocity	Velocity of water through the screening material
Wetted margin	A shallow, low velocity area along the edges of the water

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Appendix A Diadromy

Many of New Zealand's native and sports fish travel between marine and freshwater environments to access habitats necessary to support different life stages and complete their lifecycle (i.e., they are diadromous). Fish migrating upstream past a water intake may include juveniles of amphidromous species (e.g., whitebait, bullies and torrentfish), juvenile stages of catadromous species (e.g., glass eels and elvers), resident larvae (e.g., migratory galaxiids, non-migratory galaxiids) and adults of anadromous species (e.g., lamprey, trout, and salmon). Each of these species has unique characteristics that may limit their ability to traverse barriers to upstream passage (see Franklin et al. 2018).

Many New Zealand freshwater fish species are amphidromous, and their larvae are born in fresh water and migrate to sea. These migrations can be from up to 100 km inland (Meredith et al. 1987). Aperture sizes required to physically exclude these larvae are very small (0.4 mm) but a package of high sweep velocity and smart placement of fish screens (e.g., mid water column) can minimise their entrainment. Amphidromous species complete their upstream migration during the juvenile life stage when they are very small (~15–60 mm Keith 2003; McDowall 2007). The swimming ability of fishes increases with size (Bainbridge 1958; Nikora et al. 2003). The small size and weak swimming ability of many of these juvenile fish at the time of migration means even seemingly small obstructions can significantly impede upstream passage (Franklin et al. 2018).

New Zealand's catadromous fish fauna (i.e., longfin, shortfin, and speckled longfin eels) migrate upstream initially as glass-eels (in the lower catchment) and then as elvers. Although juvenile eels can climb wetted surfaces quite successfully (McDowall and Beumer 1980) such behaviours can lead to high predation mortality. High water velocities can impede the upstream migration of glass eels and elvers because of their limited swimming ability (Langdon and Collins 2000).

Lamprey and most salmon and trout species (outside of New Zealand) have an anadromous lifecycle. Their larvae rear in fresh water and migrate to the ocean as juveniles. They feed and grow to adulthood in the ocean and then migrate back to fresh water and upstream as adults to spawn and die. In New Zealand, most salmonids are non-diadromous and complete their entire lifecycle in fresh water. Anadromous populations of brown trout and Chinook salmon exist in some river systems, but the other salmonid species are not known to have sea-run populations here. Adult trout and salmon are powerful swimmers that can successfully negotiate high water velocities. Large brown trout are capable of traversing falls of at least 40 cm by jumping (Holthe et al. 2005). Adult lamprey are poor swimmers compared to many other fishes, mainly because they swim using the anguilliform mode of locomotion, where the body is thrown into undulations with each undulation pushing against the water (Webb 1978). However, in high water velocities, lamprey can use a combination of intermittent burst swimming and periods of rest by attaching to the substrate using their oral disc (James 2008). This method also allows lamprey to climb the wetted margins of waterfalls, rapids, weirs, and spillways (McDowall 1990), but they struggle to traverse weirs and spillways if the crest has a sharp lip (Zobott et al. 2015). Where they are required to climb, they can be exposed to high predation mortality, so a climbing requirement is not generally beneficial.

Appendix B Laboratory trials of fish screens

Introduction

The effectiveness of four different types of fish screens (i.e., rocks bunds made from two different rock sizes, 3 mm woven mesh wire and 3 mm wedge-wire; Table B-1) was tested in artificial stream channels (an indoor flume and an outdoor 'stream simulator') by Jellyman (2020a)[17]. The screens were tested for their ability to exclude juveniles of five native fishes: shortfin eel (*Anguilla australis*), common bully (*Gobiomorphus cotidianus*), bluegill bully (*Gobiomorphus hubbsi*), Canterbury galaxias (*Galaxias vulgaris*) and īnanga (*Galaxias maculatus*); as well as juveniles of two introduced salmonids: rainbow trout (*Oncorhynchus mykiss*) and Chinook salmon (*O. tshawytscha)*. Different combinations of species and screen types were used with the fish being forced to interact with the screen as they either swam upstream or downstream in artificial channels. The findings of these experiments were refined using finer wedge-wire screens (1.5 and 2 mm) by Jellyman (2021)[7]. The results and implications of the two sets of experiments were synthesised by Jellyman et al. (2023) and are summarised below.

Table B-1: Specifications of screens used in the laboratory trials.

Screen type	Wire Ø (mm)	Wedge-wire		Support rod		Aperture (mm)	Diagonal (mm)	Open area (%)
		Type	Width (mm)	Type	Centre (mm)			
50–100 mm rock bund	-	-	-	-	-	-	-	-
100–200 mm rock bund	-	-	-	-	-	-	-	-
3 mm woven mesh	0.5	-	-	-	-	2.7 × 2.7	3.9	73.7
3 mm wedge-wire	-	90M	2.3	Q35	19.6	3.0 × 16.3	16.6	56.7
2 mm wedge-wire	-	90M	2.3	Q35	17.0	2.0 × 13.9	14.0	46.6
1.5 mm wedge-wire	-	90M	2.3	Q35	14.0	1.5 × 11.0	11.1	39.6

Rock bunds

Rock bund screens have been constructed at several large water intakes in New Zealand, but little quantitative information is available on their effectiveness (see Bonnett 2013). The laboratory trials showed that of the tested species bluegill bully, Canterbury galaxias, and shortfin elvers were not excluded by rock bunds. These species moved freely through the bunds and sheltered within them, particularly overnight. Rock bunds create attractive habitat where fish take refuge and exploit pockets of reduced flow (Liao 2007). Sheltering substrate is especially important for eels that are adapted to spending large portions of their lifecycle buried within the substrate (Jellyman and Chisnall 1999). Rock bunds may have been especially attractive to fish in the flume experiments where suitable habitat was limited.

Rock bunds do not prevent bluegill bully and shortfin elver from entering a water intake but appear to allow them to exit again almost immediately. However, having penetrated a rock bund, if fish move further into the intake infrastructure, they are likely to encounter pumps or weirs that may cause injury or prevent them returning to the screen to exit. Furthermore, the highly modified habitats in most irrigation schemes are unlikely to be suitable for bluegill bully to survive (McDowall 1990) or spawn (Jarvis et al. 2018). It is also unlikely that bluegill bully larvae will have the behavioural cues or ability to swim counter-current through the rock bund to access the river and the sea to complete their diadromous lifecycle (Jarvis et al. 2018). Shortfin eels have more general habitat requirements than bluegill bully (Glova et al. 1998) and may be able to survive and mature in

[17] Available at: https://www.irrigationnz.co.nz/KnowledgeResources/FishScreens

irrigation canals. However, it is unlikely that mature shortfin eels will migrate counter-current (Todd 1981) or be able to fit through small interstices to traverse the rock bund. This will prevent adult shortfin eels migrating to oceanic spawning grounds and create sink populations (see Hickford and Schiel 2011) behind rock bunds. Both bluegill bully and eels passing through rock bunds are essentially a total loss to their fisheries.

Rainbow trout and common bully were excluded by rock bunds. This exclusion probably relates to their adaptations to pelagic and open benthic habitats respectively (McDowall 2000). However, in New Zealand, decision makers are directed by national policy to consider how aquatic diversity (as part of a broader objective of maintaining ecosystem health) is impacted by operation of a fish screen. While rock bund screens may be effective at behaviourally excluding larger salmonids, preferential flow paths through the bunds are more of a consideration for smaller salmonid life stages that do not have the swimming strength to avoid being entrained. Furthermore, it is difficult to envisage a scenario where the ineffectiveness of rock bunds at excluding native fish is not a serious consideration.

Woven mesh

The laboratory trials showed that 3 mm woven mesh screens excluded bluegill bully, common bully, and Canterbury galaxias. Charteris (2006) reviewed the limited information available at the time and concluded common bully would only be excluded by 2 mm mesh. Although the trials showed that 3 mm mesh is sufficient to exclude juvenile common bully, it is likely that smaller common bully could penetrate even 2 mm mesh screens.

Many rotary drum screens in New Zealand are constructed with woven mesh. The advantages and disadvantages of such drum screens have been documented in the Canterbury Guidelines and Bonnett et al. (2014). A fundamental issue with these screens is that they have often been installed perpendicular to the flow, leading to very limited/no sweep velocity and resultant high fish impingement. Furthermore, there are several practical and engineering limitations that restrict the capabilities of woven mesh screens. These include the difficulties in cleaning woven mesh compared to wedge-wire (Turnpenny and O'Keefe 2005; Jamieson et al. 2007) and the limited strength of woven mesh screens, which damage easily potentially allowing wider apertures to develop or even unrestrained access for small fish (Clough et al. 2014). A rigid screening material, such as wedge-wire, provides greater assurance that smaller fish/life stages will not be entrained over time, but woven mesh could still be an effective fish screen with a high level of skeletal support, regular inspection, maintenance and/or replacement.

For a given aperture width, square woven mesh can be more effective at screening some species (e.g., salmonids) than wedge-wire (Bates and Fuller 1992; Zydlewski and Johnson 2002). In the laboratory trials, 3 mm woven mesh was more effective at excluding shortfin elvers than 3 mm wedge-wire. Elvers can compress their body through bar spacings that are smaller than their body diameter (Environment Agency 2011) and unlike woven mesh, wedge-wire has a longer slot in one dimension that elvers can exploit (Table B-1).

Wedge-wire

Wedge-wire was as effective, or more effective, than other screens at excluding juvenile bully, Canterbury galaxias, īnanga whitebait and Chinook salmon smolt. However, preventing entrainment of glass eel (and elvers) into coastal intakes with wedge-wire is problematic unless other design criteria are optimised and strengthened (Jamieson et al. 2007). Elvers penetrated 3 mm wedge-wire screens, elvers and glass eels penetrated 2 mm screens and glass eels penetrated 1.5 mm screens. The lack of a difference between 2 mm and 1.5 mm wedge-wire for excluding glass eels demonstrates the difficulty of screening larvae of a species. Current New Zealand fish screening efforts generally do not explicitly require screening of eggs or larvae of native fish (but it also does not explicitly require that they are not screened). It also emphasises the importance of considering screen aperture size together with other key design criteria (e.g., sweep velocity) when trying to prevent impingement and entrainment of fishes, and consideration of strengthening one criterion over some of the others to optimise design for prevention of impingement and entrainment.

Screen contacts, impingements, and mortality

Over half of New Zealand's indigenous fish species migrate upstream at a small size (McDowall 1998). Fish swimming upstream are expected to have a longer interaction with a screen than fish swimming downstream. The number of screen contacts is a suitable proxy for the duration of the interaction with a screen. Shortfin glass eels, bluegill bully and common bully moving upstream had a 300–700% increase in the number of contacts with the 2 mm wedge-wire compared to fish moving downstream. For shortfin eel, the 300% increase in screen contacts when swimming upstream past the screen was associated with a 300% increase in penetration rate (passing through the screen). However, there were significant differences in the lengths of shortfin eels tested between experiments (elvers in the upstream experiments vs. glass eels in the downstream experiment).

Screen contacts were seen in all stream simulator experiments, but no sustained impingements occurred during downstream experiments. In contrast, all native species had some extent of impingement recorded when moving upstream. As noted above, the extent of screen contacts was markedly higher during upstream experiments although a proportion of the bully impingements may have been resting behaviour on the surface of the screen. This interpretation in partially corroborated by bluegill bully having the highest number of impingements but the lowest mortality across native species.

Īnanga post-larvae ('whitebait') penetrated 2 mm wedge-wire screens when approaching them from downstream. The widest part of the body of post-larval īnanga preventing screen penetration is the head (Mitchell 1989a). However, this assumption is based on īnanga approaching the screen head-first. Mueller et al. (1995) found that Chinook salmon fry could not fit, headfirst, through 3 mm wedge-wire but did fit when they entered the screen tail first. Video footage confirmed that all īnanga post-larvae that had penetrated the 2 mm wedge-wire did so in a tail-first orientation. It appeared that the swimming ability of this pelagic species had not developed sufficiently in these smaller individuals to overcome the approach velocities entraining the tail when they encountered near and through the screen. Once entrained by the tail fish found it very difficult to swim back through the mesh.

The greater number of screen contacts in the upstream experiments was associated with greater mortality of fish; either immediately or over the next 24 h. The lethal and sub-lethal effects of screen contacts are poorly understood for New Zealand native fish species compared to scaled juvenile salmonids (particularly where many New Zealand species are naturally scaleless). Minimising the risk of screen contact by using appropriate sweep velocities to move fish across and away from the screen will likely reduce impingement- or injury-related mortalities and reduce the risk of entrainment. However, it is crucial that fish screen designs meet all seven criteria listed in the Canterbury Guidelines to minimise the exposure of fish to impingement or entrainment at fish screens.

Screen aperture

Surface waters are abstracted throughout New Zealand and almost all surface abstractions are from rivers where fish are commonly present. Considerations of potential fish entrainment vary markedly depending on the site of the abstraction (i.e., the region, but also the location within a catchment and even the position of the take within the water column). The laboratory trials confirmed the prediction by Charteris (2006) that īnanga whitebait are excluded by a 2 mm wedge-wire screen. However, many īnanga whitebait entering rivers in northern New Zealand (Egan 2017), and banded kokopu whitebait throughout the country (Yungnickel 2017) are considerably smaller than the whitebait used in the laboratory trials. A 1.5 mm screen aperture is recommended in lower catchment areas where whitebait ≤ 50 mm are present. The distance inland where 1.5 mm screens would be necessary to protect whitebait, before moving to 2 mm screens, will vary between regions. An appropriate starting point for this transition point, to adapt regionally, would be the pegged upstream limit of the area where fishing is allowed under the whitebaiting regulations (i.e., where the water ceases to fluctuate with the tide; New Zealand Legislation). However, the tidal variation can be 10s of kilometres upstream in many North Island rivers.

The high level of penetration of even 1.5 mm wedge-wire by shortfin glass eels is highly problematic from a practical screening perspective. However, the upstream migration of glass eels slows in tidal areas while they undergo physical and behavioural transitions into pigmented elvers (Jellyman 1977, 1979). Elvers did not penetrate 2 mm wedge-wire screens, so once upstream of the 1.5 mm īnanga whitebait screening zone, a 2 mm screen should exclude elvers and the juvenile life stages of other species. Again, this can be 10s of kilometres in some rivers.

Based on various tests, 3 mm wedge-wire should exclude salmonids > 40 mm. However, 30% of salmon migrants downstream of the Rangitata Diversion Race (RDR) in the late 1990s were < 40 mm (M. Webb, pers. comm.), so a smaller aperture size would be required to exclude these fish (the RDR fish screen that was installed in 2022 is 2 mm wedge-wire). Shortfin elvers penetrated 3 mm wedge-wire and woven mesh screens, so further work is needed to refine the size threshold where elvers are excluded by 3 mm screens.

With increasing distance inland, other catchment-specific species (e.g., non-diadromous galaxiids and salmonid fry) may become important considerations for screening. Furthermore, where there are waterways or sub-catchments with threatened species present, it may be necessary to apply more restrictive aperture requirements to protect larvae of these species. Thus, where in the catchment it is appropriate to transition to a 3 mm screening requirement is harder to prescribe. However, it is recommended that 3 mm is the largest approved aperture size that is consented across New Zealand.

Many regional councils in New Zealand need to improve their management of water intakes (see Section 2 and Jellyman (2020b)) to better prevent loss of fish and to aid in improvement of the status of freshwater fish and fisheries (Ministry for the Environment 2020). It is acknowledged that screen aperture recommendations may be catchment-specific, and some may be problematic for decision makers to implement. However, many regional councils are making sub-regional plans at the catchment-scale or creating Freshwater Management Units for larger catchments (Jellyman 2020b), so providing screening recommendations at this scale is considered appropriate. It is important that fish screening recommendations that could be applied nationally have a defensible scientific basis and it is recognised that the practicalities of implementing those within a planning framework may require regional adaptation.

Jellyman et al. (2023) found that the artificial stream channels successfully forced fish to interact with the screens to test the effectiveness of different screen types and aperture sizes. However, future research must better characterise the swimming ability of individual native species and life stages (beyond the few summarised in Boubée et al. 1999) and establish how swimming ability, approach velocity and fish behaviour act together to determine whether individuals must interact with fish screens. Jellyman et al. (2023) concluded that because New Zealand's fish fauna is dominated by small, benthic, and often diadromous species, criteria and standards for New Zealand fish screens need to be developed for local species requirements rather than adapted from generic principles conceived overseas often for salmonid species.

Appendix C Worked examples using the Fish Screen Facility Guidance Tool

The NZFSWG's Technical Advisory Sub-team met in August 2022 to workshop examples of a variety of intake scenarios through the Fish Screen Facility Guidance Tool and to make generalised recommendations on best practice solutions. The scenarios assessed were hypothetical but were selected to represent a range of known intake locations.

Example 1 – Hill fed, braided river

Description

The site is 31 km from the coast on the true right bank of a braided, hill fed river (Table C-1). It is a popular recreational site with frequent use by swimmers and anglers. The diversion and abstraction of water is primarily to support rural land use of the catchment via an irrigation scheme.

Table C-1: Characteristics of example site.

Parameter	Description
Distance from Coast	31 km
Purpose of Take	Irrigation, stock water and domestic supply
River characteristics	Hill fed, braided
Diversion rate	1300 Ls^{-1}
Abstraction rate	1100 Ls^{-1}
Percentage of diversion available for bypass flow	15% option 1 or 30% option 2
Recreational Value	Yes, swimming and fishing
Controlled system	Yes, partly via dam reservoir
Extreme flooding risk	Yes
Extreme low flow risk	Yes
Species Present	Chinook salmon, brown trout, upland bully, Canterbury galaxias, tuna/longfin eel, torrentfish, common bully, kanakana
Migration pathways	Upstream and downstream

River hydraulics/statistics

The site is prone to flooding and low flows (Table C-2).

Table C-2: Hydraulic statistics of example site. 7D MALF = 7-day Mean Annual Low Flow.

Parameter	Statistic
Mean Flow	5.22 m^3s^{-1}
Median Flow	3.24 m^3s^{-1}
7D MALF	1.19 m^3s^{-1}
Mean annual flood flow	150 m^3s^{-1}
Lowest recorded flow	0.40 m^3s^{-1}
Highest recorded flow	1020 m^3s^{-1}
1:5 Yr Annual Exceedance Probability flow	200 m^3s^{-1}
1:10 Yr Annual Exceedance Probability flow	300 m^3s^{-1}

Limitations to consider

The current site is on privately owned land, but the river has extensive bank protections in place. The river has episodic nuisance algae and periphyton growth, and high sediment loads. Electricity is available at the intake site.

Table C-3: Limitations of example site.

Parameter	Description
Land Ownership	The area is owned by the consent holder so there are no limitations from land ownership
River protection, plantings, structures	There are many trees and bank protections in place, but they are not limiting the location of the screen. Liaison with Council is required to ensure no effect on river protection work
Algae/Periphyton Risk	The river at this site has moderate nutrient enrichment and is known to contain nuisance algae and periphyton growth
Sediment Deposition	Is an issue for the site with regular high flows depositing large amounts of fine sediment into the intake channel and the stilling pond
Available hydraulic head	Limited with shallow gradient
Electricity Available	Yes
Ability to maintain connection from bypass to flowing braid	Variable as river moves around across the fairway

Figure C-1: River morphology during high flow. Note sediment load, wide river fairway and various bank protection plantings.

Figure C-2: River morphology during low flow. Note dynamic braiding pattern.

Fish Screen Facility Guidance Tool

Step 1 – Site selection

The user compares multiple sites for the fish screen facility using weighted scores of design elements (Table C-4). Elements include site characteristics (e.g., stability, flow variability, river gradient, space, and land ownership), bypass characteristics (e.g., length, connectivity, need for piping, upstream passage, and flow requirements) and required management (e.g., debris, access, safety, cleaning, and maintenance). By comparing the total scores, based on each of these characteristics, the user can identify the most suitable location for the fish screen.

Table C-4: Summary of Step 1 – comparing multiple locations for site selection.

Design element	Consideration	Possible sites			Scores
		In river	Off River (within berm protection)	In canal	
Location	River type	braided	braided	braided	(List all river types)
	Stability of diversion area at waterway	N/A	3	3	N/A = 0, Stable = 1, Medium = 2, Unstable = 3
	Stability of fish screen location	10	2	1	Stable = 1, Medium = 2, Unstable = 3, Unviable = 10
	Flow variability – ability of site and conditions to take flow range (min (low flow) to max) and management of flood, proportion of flow being taken, and ability to create an effective bypass under different take rates	3	2	1	Low = 1, Medium = 2, High = 3
Site	Gradient of river	3	3	3	Steep = 1, Moderate = 2, Flat = 3
	What length of intake is required?	1	1	2	< 100 m = 1, 100–500 m = 2, > 501 m = 3
	Are priority fish species present?	2	2	2	No = 1, Yes = 2
	Is power available?	1	1	1	Yes = 1, No = 2
	Are there any physical limitations e.g., not sufficient space?	1	1	2	No = 1, Yes = 2
	Are there any legal limitations e.g., land ownership?	1	1	2	No = 1, Yes = 2

Design element	Consideration	Possible sites			Scores
		In river	Off River (within berm protection)	In canal	
Combination of intakes	Are there other water takes in the vicinity that could be combined with?	2	2	2	Yes = 1, No = 2
Flood water levels	Is this area vulnerable to flood damage?	5	2	1	N/A = 0, Least = 1, Moderate =2, Greatest = 5
Fish Bypass	Is a Bypass needed because your screen is out of river?	1	2	2	No = 1, Yes = 2
	What length of bypass required?	N/A	1	3	< 100 m = 1, 100–500 m = 2, > 501 m = 3
	Relative distance fish required to navigate for safe return to waterway from diversion point across locations	N/A	2	5	N/A = 0, Least = 1, Moderate =2, Greatest = 5
	Is there good connectivity between the end of bypass and flowing channel?	N/A	1	1	Yes = 1, No = 2
	Does the location provide for effective sweep velocity past the screen to the bypass naturally?	N/A	1	1	Yes = 1, No = 2
	Does any part of the diversion or bypass include a pipe?	N/A	1	2	No = 1, Yes = 2
	Relative to other locations, does this site avoid or provide for upstream fish passage back to the river?	1	2	3	N/A = 0, Greatest = 1, Possible = 2, Least = 3
	Is there sufficient extra water available to be taken for bypass flows?	N/A	1	1	Yes = 1, No = 2

Design element	Consideration	Possible sites			Scores
		In river	Off River (within berm protection)	In canal	
Coarse debris management	Is management of coarse debris needed at the location to protect the screen?	3	2	2	Low need = 1, Medium need = 2, High need =3
	Is coarse debris management viable?	10	1	1	Yes = 1, No = 10
	Is individual trash rack and fish screen combined into one location as close as possible to the water take. E.g., upstream structures can cater for water control and debris management, can't be done downstream. Or no need for it?	2	1	0	No trash rack = 0, Combined = 1, Separate = 2
Operation, maintenance, and monitoring	Does the design of the intake and fish screen need to take account of river user safety (kayaking, rafting, jet boating, fishing, swimming) and access?	2	2	1	No = 1, Yes = 2
	Does the location require a cleaning system?	2	2	2	No = 1, Yes = 2
	Does the screen location, including access to the screen, consider operators of the screen/maintenance and provide for a safe means for operation and maintenance, and compliance to be undertaken?	1	1	1	Yes = 1, No = 2
	TOTAL SCORE (lowest is the most suitable)	51	**40**	45	

Step 2 – Suitable fish screen types

The decision tree structure allows the user to identify the appropriate screen type(s) and for this example this found Fixed flat screen, Cone screen, Fixed cylinder screen, Travelling flat screen, Bossman could all be considered (Table C-5). The user characterises various physical characteristics (e.g., intake flow, depth and gradient, availability of electricity, risk of clogging, space availability and need for maintenance). As each characteristic is defined, the list of recommended screen types is refined. In many situations, multiple screen types will remain as viable options.

Table C-5: Summary of Step 2 - identification of potential screen type(s).

Consideration	Options
What is the intake flow (bypass and take)?	(Multiple Items)
What is the water depth (maintained at screen)?	(Multiple Items)
What are the water gradients (head loss at screen)?	(Multiple Items)
Power	All
What is the risk of screen clogging?	All
Is there a footprint required for fish screen?	(Multiple Items)
What is the proportion of bypass flow required to have an effective intake?	(Multiple Items)
In what parts of the water column will the screen operate?	All
What type of maintenance/ cleaning is required?	(Multiple Items)
Is Didymo, or other fine filament materials, being considered?	All
Potential Fish Screen Type(s):	
Fixed flat screen, Cone screen, Fixed cylinder screen, Travelling flat screen, Bossman	

Step 3 – Fish screen design decision table

A decision table (Table C-6) helps the user to contrast the potential screen types identified in Step 2. Multiple screen types can be compared for their ability to screen priority fish and for operator safety. By comparing the total scores, the user can identify the most suitable screen type. For this example, Fixed flat, Fixed cylinder and Travelling flat screen were recommended, but there was not no difference between scores so any of the four proposed screens could have been considered further. The decision table also identifies design elements and criteria that need to be altered to prevent entrainment and impingement of priority fish species or life stages (sizes).

Table C-6: Summary of Step 3 - fish screen decision table.

Recommended location	Off River within berm protection					
Potential screen type(s)	Fixed flat screen, Cone screen, Fixed cylinder screen, Travelling flat screen					
	Questions	**Fixed Flat**	**Fixed Cylinder**	**Cone**	**Travelling Flat**	**Notes**
Priority species	Changes required to cater for the priority species and life stages?	1	1	1	1	1-No (go to next question) 2-Yes (alterations required)
Fish bypass	Is the entrance of bypass suitable to attract fish?	1	1	1	1	1-Yes (go to next question) 2-No (alterations required)
	Is there sufficient flow to assist with the attraction of fish to the bypass?	1	1	1	1	1-Yes (go to next question) 2-No (alterations required)
	Does the fish bypass and intake enable upstream passage without entrainment?	2	2	2	2	1-Yes (go to next question) 2-No (alterations required to exclude fish or provide passage)
Control of flows	Are there any existing structures that are compatible with good screen designs?	1	1	1	1	1-No (go to next question) 2-Yes (alterations required)
	Is there enough water available to provide appropriate sweep and approach velocities, and sufficient continuous and effective bypass flow?	1	1	1	1	1-Yes (go to next question) 2-No (alterations required)
River user and operator safety	Does the screen design provide for a safe means of operation and maintenance, and compliance to be undertaken?	1	1	2	1	1-Yes (go to next question) 2-No (alterations required)
	TOTAL SCORE (lowest is the most suitable)	8	8	9	8	

Final design recommendations

The Fish Screen Facility Guidance Tool recommended three potential screen types (Table C-7).

Table C-7: Summary of final recommendation compared with design criteria.

Final design criteria	Outcome
1a. Location & Coordinates	N/A
1b. Screen types	Fixed flat, Fixed cylinder, Travelling flat
2. Approach velocity	< 0.12 ms^{-1}
3. Sweep velocity	≥ 5 × approach velocity
4. Fish bypass at screen	30% see diagram
5. Fish bypass connectivity to river	see diagram
6. Screen materials and aperture size	2 mm wedge-wire
7. Operations and maintenance	Self-cleaning. Seasonal instream works required, and resource consent is held. (a) An Operations and Maintenance Plan is required and will need to specify the checks required (and frequency) to ensure there are no risks to the operation, and that failures are avoided. (b) the self-cleaning mechanism is operated appropriately (frequency) and its operation is monitored. (c) Any required in stream works to maintain intake/diversion are consented and appropriately managed. (d) the site and screen are maintained in a safe and accessible manner for both operators and regulatory compliance assessment.

- If an existing resource consent is significantly constraining design aspects, you should investigate amending the consent or applying for a new consent.
- Although the rate of take does not affect design and screen type a great deal within certain ranges, the rate of flow of the bypass makes a significant difference to the screen types that will be appropriate.
- The ability to maintain the diversion and bypass connection to a flowing braid in the river needs to be understood (Figure C-3). All sites involve a mobile river, requiring regular diversion works in stream to maintain the diversion to the intake and the bypass back to flowing water. In a different scenario

where there was a more stable site available, the screen could be positioned as close as possible to the river to minimise the time/distance that fish are removed and returned to the river.

- Figure C-3 shows an intake design that will prevent impingement and entrainment of fish and meets key criteria.

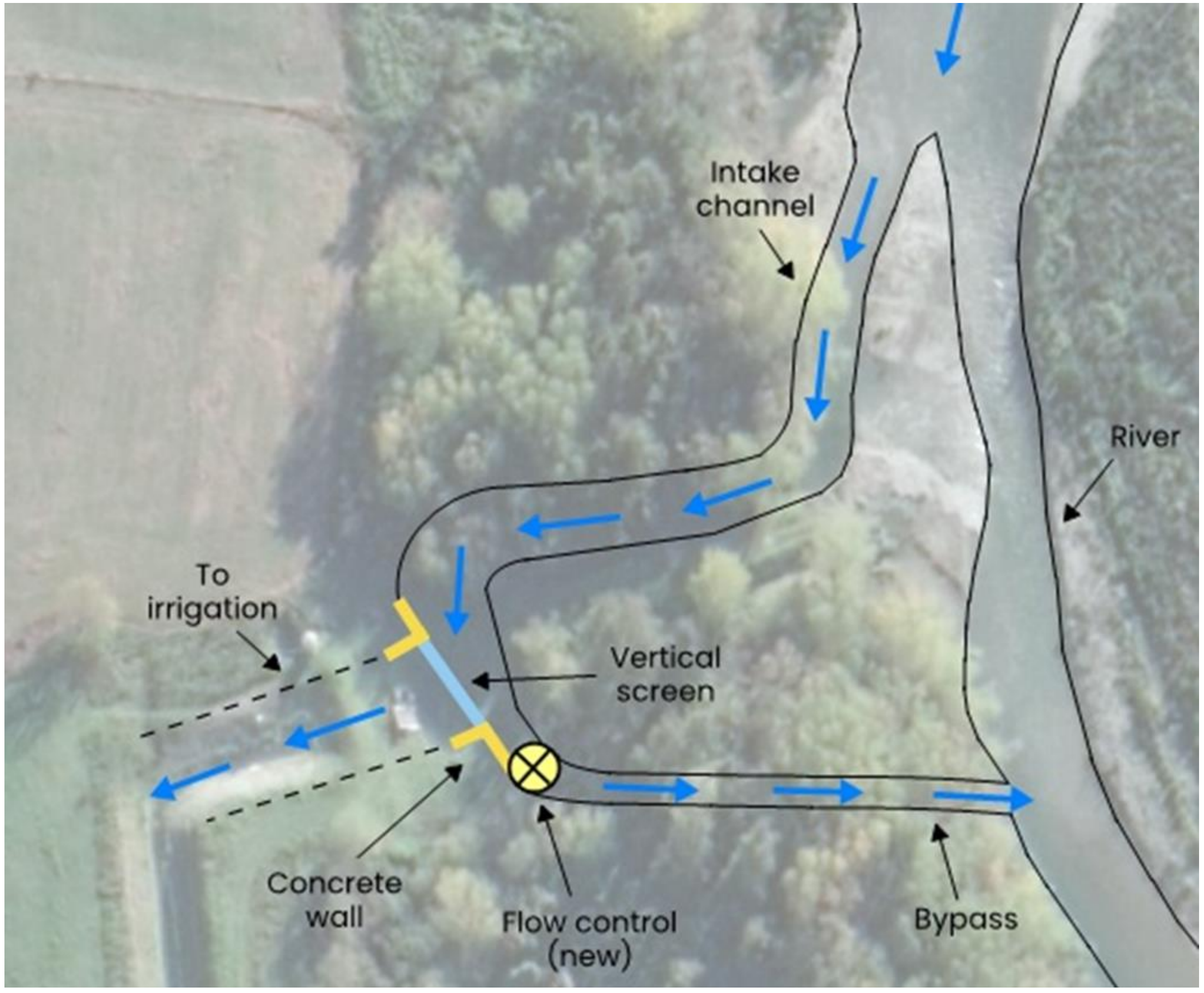

Figure C-3: Schematic diagram of recommended screen design.

Example 2 – Large, alpine river

Description

The site is located approximately 30 km from the mouth (Table C-8). The river is a typical large-scale braided river with a large sediment and gravel load, highly mobile braids and significant fluctuations in flow driven by rainfall in the mountains.

Table C-8: Characteristics of example site.

Parameter	Description
Distance from Coast	30 km
Purpose of Take	Irrigation
River characteristics	Mobile, large alpine river
Diversion rate	2500 Ls^{-1}
Abstraction rate	2000 Ls^{-1}
Percentage of diversion available for bypass flow	20%
Recreational Value	Yes
Controlled system	No
Extreme flooding risk	Yes
Extreme low flow risk	No
Species Present	Chinook salmon, brown and rainbow trout, koura, longfin eel, lamprey, kōaro, upland bully, torrentfish, bluegill bully
Migration pathways	Yes

River hydraulics/statistics

Due to the highly mobile nature of the river (Table C-9), a suitable site for the screen is away from the river.

Table C-9: Hydraulic statistics of example site.

Parameter	Statistic
Mean Flow	118.04 m^3s^{-1}
Median Flow	85.20 m^3s^{-1}
7D MALF	35.58 m^3s^{-1}
Mean annual flood flow	1408 m^3s^{-1}
Lowest recorded flow	21.23 m^3s^{-1}
Highest recorded flow	2909.55 m^3s^{-1}
1:5Yr Annual Exceedance Probability flow	1800 m^3s^{-1}
1:10Yr Annual Exceedance Probability flow	2200 m^3s^{-1}

Limitations to consider

The site is on crown land, but the river has extensive bank protections in place (Table C-10). The site is popular for recreation and infrastructure has been prone to vandalism. Electricity is available at the intake site.

Table C-10: Limitations of example site.

Parameter	Description
Land Ownership	Crown land
River protection, plantings, structures	The potential sites for the screen are limited by council owned river protection plantings, popular recreational access, and proximity to a major town centre (invites visitors and vandalism)
Algae/Periphyton Risk	Low
Sediment Deposition	High
Available hydraulic head	Low
Electricity Available	Yes
Ability to maintain connection from bypass to flowing braid	Yes -provided high diversion rate, although distance is an issue

Final design recommendations

The Guidance Tool recommended two potential screen types (Table C-11).

Table C-11: Summary of final recommendation compared with design criteria.

Final design criteria	Outcome
1a. Location & Coordinates	N/A
1b. Screen types	Fixed flat and Travelling flat
2. Approach velocity	< 0.12 ms^{-1}
3. Sweep velocity	≥ 5 × approach velocity
4. Fish bypass at screen	Yes
5. Fish bypass connectivity to river	Yes, see diagram
6. Screen materials and aperture size	2 mm wedge-wire
7. Operations and maintenance	Self-cleaning. Seasonal instream works required, and resource consent is held. (a) An Operations and Maintenance Plan is required and will need to specify the checks required (and frequency) to ensure there are no risks to the operation, and that failures are avoided. (b) the self-cleaning mechanism is operated appropriately (frequency) and its operation is monitored. (c) Any required in stream works to maintain intake/diversion are consented and appropriately managed. (d) the site and screen are maintained in a safe and accessible manner for both operators and regulatory compliance assessment.

- Large flow variability and potential destructive force requires off-river site (Figure C-4)
- Low gradient means that a long intake channel may be required to generate sufficient head to operate some fish screens
- High numbers of upstream and downstream migrating large and small fish likely present that will need careful consideration
- The angle of the bypass back to the river is not ideal but was positioned like it was (Figure C-4) due to trying to minimise the length and work within land ownership boundaries. Ideally it would be best if this could have not taken such a tight corner after diversion.

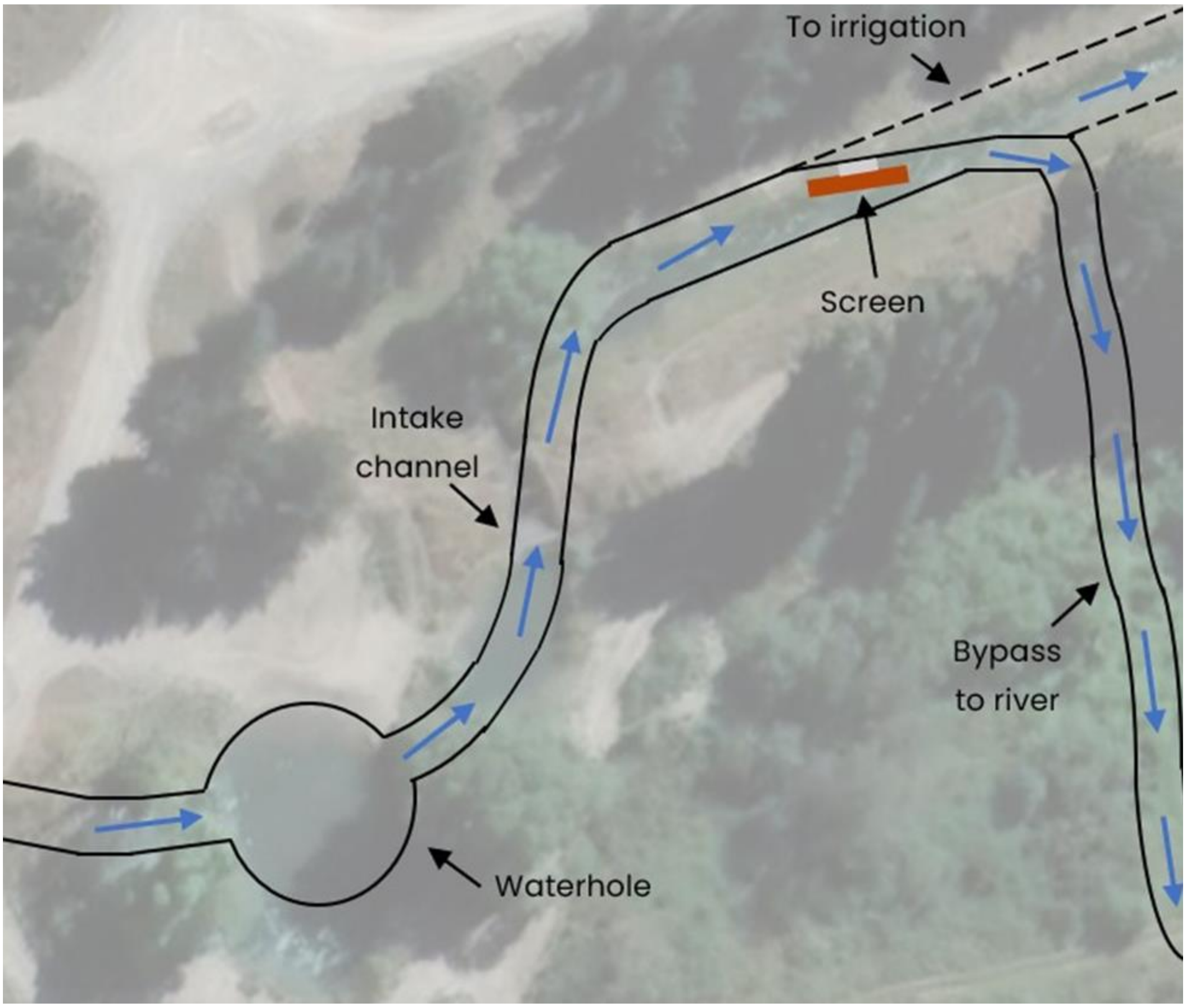

Figure C-4: Schematic diagram of recommended screen design.

Example 3 – Spring Fed River (pumped intake)

Description

This example site is situated in a meandering, slow moving, confined channel that flows into important estuarine habitat that supports a range of bird and fish species. The waterway is fed by a series of springs and drains that originate from suburban fringes and/or traverse farmland. The abstraction is directly from the river and is for the purposes of irrigation. There are two potential example locations for the take – one at 5 km from the mouth and within a tidal reach and one at 8 km from the mouth outside of the tidal reach (Table C-12).

Table C-12: Characteristics of example site.

Parameter	Description
Distance from Coast	5–8 km
Purpose of Take	End of pipe pumped. Irrigation
River characteristics	Spring fed, highly modified
Diversion rate	n/a
Abstraction rate	30 Ls^{-1}
Percentage of diversion available for bypass flow	20%
Recreational Value	No
Controlled system	No
Extreme flooding risk	No
Extreme low flow risk	Yes
Species Present	Kēkewai/Freshwater Crayfish, Tuna/longfin eel, īnanga/whitebait, brown trout, kanakana/lamprey, common bully
Mahinga Kai	Yes
Migration pathways	Upstream and Downstream -important for juvenile life stages particularly in tidal reach - priority species

River hydraulics/statistics

The site is stable and does not experience large flow variations (Table C-13).

Table C-13: Hydraulic statistics of example site.

Parameter	Statistic
Mean Flow	0.84 m^3s^{-1}
Median Flow	0.70 m^3s^{-1}
7D MALF	0.44 m^3s^{-1}
Mean annual flood flow	6 m^3s^{-1}
Lowest recorded flow	0.17 m^3s^{-1}
Highest recorded flow	13.44 m^3s^{-1}
1:5Yr Annual Exceedance Probability flow	9 m^3s^{-1}
1:10Yr Annual Exceedance Probability flow	11 m^3s^{-1}

Limitations to consider

The site is on private land, but the river has extensive and steep bank protections in place (Table C-14). The river is heavily sedimented.

Table C-14: Limitations of example site.

Parameter	Description
Land Ownership	The area is owned by the consent holder so no limitations on land ownership
River protection, plantings, structures	The riverbanks are confined and steep stop banks. No other structures or plantings - farmland
Algae/Periphyton Risk	The river at these sites has elevated nutrients, heavily sedimented bottom substrate and macrophytes
Sediment Deposition	The river is heavily sedimented although sediments drop out of the water column and deposit quickly to the bed. Avoid disturbance of the bed
Available hydraulic head	Limited with shallow gradient
Electricity Available	Yes
Ability to maintain connection from bypass to flowing braid	N/A

Final design recommendations

The Guidance Tool recommended a single screen type (Table C-15).

Table C-15: Summary of final recommendation compared with design criteria.

Final design criteria	Outcome
1a. Location & Coordinates	N/A
1b. Screen types	Fixed cylinder - self-cleaning and mechanism to remove from stream
2. Approach velocity	< 0.12 ms^{-1}
3. Sweep velocity	Lower sweep offset by smaller aperture size or larger area of screen
4. Fish bypass at screen	N/A
5. Fish bypass connectivity to river	N/A
6. Screen materials and aperture size	1.5 mm wedge-wire
7. Operations and maintenance	Maintenance schedule, screen removeable, no in river works required, placement arm ensures mid column deployment and ability to remove and maintain

- Low gradient precludes any screens requiring natural head to be generated
- No need for bypass as intake directly out of main water body
- Surface take to reduce pumping head
- Pumped intake from a deep slow flowing site with gantry to raise clear of high flows and site screen correctly depending on water level
- Migrating species - important to reduce approach velocity
- Maintenance and regular checks required.

Example 4 – Gorge/Alpine

Description

The site is situated in a flashy, mountain river tributary of a large hydro-controlled river. The alpine river example experiences high velocities and fluctuations in river level (Table C-16).

Table C-16: Characteristics of example site.

Parameter	Description
Distance from Coast	75 km
Purpose of Take	Irrigation
River characteristics	Gorge characteristics and subject to orographic rain and snowfall
Diversion rate	150 Ls^{-1}
Abstraction rate	50 Ls^{-1}
Percentage of diversion available for bypass flow	66%
Recreational Value	Yes
Controlled system	No
Extreme flooding risk	Yes
Extreme low flow risk	Yes
Species Present	Rainbow trout nursery and recreational fishery (brown and rainbow). Chinook salmon spawning, upland bully and longfin eel, Canterbury galaxias
Mahinga Kai	Yes
Migration pathways	Upstream and Downstream -important for juvenile life stages particularly in tidal reach - priority species

River hydraulics/statistics

The site is stable and does not experience large flow variations (Table C-17).

Table C-17: Hydraulic statistics of example site.

Parameter	Statistic
Mean Flow	1.135 m^3s^{-1}
Median Flow	0.877 m^3s^{-1}
7D MALF	0.422 m^3s^{-1}
Mean annual flood flow	11 m^3s^{-1}
Lowest recorded flow	0.312 m^3s^{-1}
Highest recorded flow	91 m^3s^{-1}
1:5Yr Annual Exceedance Probability flow	16 m^3s^{-1}
1:10Yr Annual Exceedance Probability flow	39 m^3s^{-1}

Limitations to consider

The previous irrigation system identified that a stable screen site and an intake channel designed to fail during floods, rather than pass sediment to the fish screen was a good design. The intake channel failsafe needs to be retained to protect the fish screen. High natural gradient generates head but absence of power to the site limits screen options. Any fish screen more than 20 m from the stream diversion creates difficulties for the length of bypass channel and its gradient for returning fish to the river. Bypass angles in this case limited by bedrock, always consider the best return for fish via the bypass (Table C-18).

Table C-18: Limitations of example site.

Parameter	Description
Land Ownership	Owned by farmer
River protection, plantings, structures	No river protections, planting, or structures at site
Algae/Periphyton Risk	Low-Medium
Sediment Deposition	Low
Available hydraulic head	High
Electricity Available	No
Ability to maintain connection from bypass to flowing braid	Bedrock banks and boulders – can be achieved refer design

Final design recommendations

The Guidance Tool recommended a single screen type (Table C-19).

Table C-19: Summary of final recommendation compared with design criteria.

Final design criteria	Outcome
1a. Location & Coordinates	N/A
1b. Screen types	Fixed cylinder - self-cleaning and mechanism to remove from stream
2. Approach velocity	0.034 ms^{-1}
3. Sweep velocity	0.76 ms^{-1}
4. Fish bypass at screen	Yes
5. Fish bypass connectivity to river	Yes
6. Screen materials and aperture size	1.5 mm wedge-wire
7. Operations and maintenance	Maintenance schedule, screen can be opened for cleaning, no in river works required, maintenance manual required

A Bossman screen was recommended in this scenario. The screen can be placed out of the river fairway and out of the flood path (Figure C-5). Connection back to the river can be achieved with both bypass systems and the nature of the morphology in a gorge or steep alpine stream means little movement of substrate will affect this long term, requiring less instream works. The diversion angle of both bypasses would not be at such a strong angle as shown in the diagram with irrigation feed water angled back and bypasses more direct. The intake channel should be narrowed to not generate habitat for predatory fish.

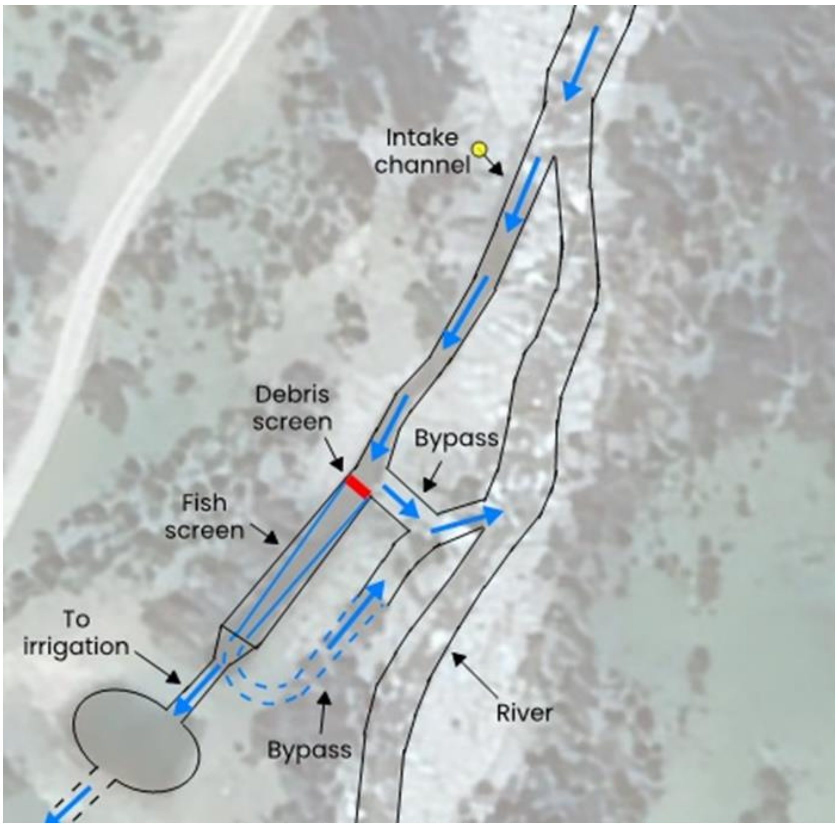

Figure C-5: Schematic diagram of screen design. (Lesser bypass angles would be recommended in scenarios without geological constraints)