Prioritisation of Fish Barriers for Remediation in Christchurch

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EXECUTIVE SUMMARY

Many of New Zealand's native fish species are migratory, moving between freshwaters and the sea to complete their life history. However, through the introduction of artificial instream structures, many of these migration paths have been disrupted, threatening migratory fish species. The recently published National Policy Statement for Freshwater Management 2020 requires regional councils to identify and prioritise such structures for remediation. This report identifies and prioritises instream structures in the Christchurch district for fish passage enhancement.

A prioritisation model was developed using the Fish Passage Assessment Tool (FPAT) as the starting point. The FPAT tool provides a nationally-standardised method for assessment of structures. Assessments are uploaded to a publicly available national database, which produces a remediation priority based on structure and geographical attributes. The model used in this report extends on the FPAT database by including the locations of structures in Christchurch City Council (CCC) asset databases, as well as other ecological data. Our model then categorised structures as either: a) requiring an FPAT assessment, b) requiring a fish survey, or, if the requirements of the previous steps are satisfied c) requiring remediation. Priority values in each category were assigned via a decision tree model, incorporating elements including: FPAT priorities, catchments considered priorities by CCC and Environment Canterbury, and fish communities local to the structure. This process was automated, followed by manual adjustments based on expert opinion.

The model identified 38 structures as high priorities for remediation or fish surveys, of which 20 were CCC assets. Of the CCC assets, culverts were the most common structure type, accounting for 50% of all high priority structures. Culvert perching was identified as a common issue on Banks Peninsula, affecting 62% of high priority structures. Weirs, dams, and flow restrictions were the second most common CCC asset types that were high priorities for remediation, accounting for a further 29% of structures. These structures are often associated with stormwater treatment facilities.

The Ōtūkaikino Creek catchment stood out as the priority catchment most heavily impacted by instream barriers, with some native fish species excluded from up to 35 km of habitat by artificial structures (particularly weirs). Notable structures that were identified as potentially having major impacts on fish passage outside of priority catchments include the Mona Vale weir in the Avon River and the Waikākāriki / Horseshoe Lake pumpstation and tide gates. Piped networks were also noted as having potentially significant impacts on fish passage, although they were not represented in the current prioritisation model.

Based on the results of the prioritisation model, and through a review of remediation case studies, we recommend the following: remediation designs are discussed for the eight CCC high remediation priority structures; fish surveys are carried out at the 12 CCC high priority fish survey structures; discussions with other asset owners to address non-CCC high priority structures; further investigation into high risk structures in non-priority catchments; targeted fishing and ecological surveys in stormwater treatment facilities; fish remediation projects should coincide with renewals when possible; follow up fish surveys be carried out after remediation projects, but only when remediation success is expected to be quantitatively measured.

1. INTRODUCTION

1.1. Background

Many of New Zealand's native fish species are migratory, moving between freshwaters and the sea to complete their life history. However, migration paths may be interrupted through the construction of artificial structures, often designed to control water levels, mitigate flood risks, or to allow for infrastructure to pass above waterways. Examples of such structures include weirs, flap gates, and culverts. It is estimated that 20–40% of existing structures in waterways impede fish passage, due to impacts of the structures on fall height (e.g., perched culverts), high water velocities, shallow water depths, or the creation of physical blockages (Franklin *et al.* 2018).

Recent development of the Fish Passage Assessment Tool (FPAT; Franklin 2018) has created an opportunity for asset managers to catalogue and prioritise structures in waterways for remediation. The free FPAT mobile application allows users to carry out assessments of structures using nationally-standardised field methods. Collected data are uploaded into a national database and structures are prioritised for remediation.

Under the National Policy Statement for Freshwater Management 2020 (NPSFM), regional councils must develop a work program for the remediation of existing instream structures (Section 3.26.7; Ministry for the Environment 2020). Briefly, this plan must include the identification of existing structures, evaluation of their risk to fish passage, and prioritisation of these structures for remediation. Fish passage requirements for the creation of new instream structures, or the alteration, extension, or reconstruction of existing structures, are stipulated in the National Environmental Standards for Freshwater (NESF; Parliamentary Counsel Office 2020). Together, these pieces of legislation require the assessment of all new and existing instream structures for effects on fish passage, as well as the prioritisation of existing structures for remediation.

Assessment of waterway structures in the Christchurch district is ongoing. Numerous structures have already been assessed for fish passage with funding from Christchurch City Council (CCC) and Environment Canterbury (ECan), as well as contributions from private organisations. Some of these structures have been discussed previously in reports on fish passage barriers in Christchurch city (Instream Consulting 2020b) and Banks Peninsula (Instream Consulting 2019b; Instream Consulting 2020a). However, there has not yet been a district wide review of the assessed barriers to determine remediation priorities. Furthermore, assessments to date have lacked fish community information, critical to guiding fish passage enhancement projects.

1.2. Scope

This report describes a desktop prioritisation of fish barriers for remediation across the Christchurch district. The prioritisation process combined information from the FPAT database, CCC asset data, freshwater fish records, priority catchments identified by CCC and ECan, and expert judgement. Structures identified as high priorities for fish passage enhancement or further investigation are tabulated and mapped. A range of remediation case studies are also included, to provide guidance for future remediation projects.

2. METHODS

2.1. Overview

The barrier prioritisation model in this report incorporates and builds on ecological criteria given in the Fish Passage Guidelines (Franklin 2018). Some of these criteria are included natively in the FPAT model (e.g., proximity to coast and potential habitat gain), and others were added through an additional prioritisation process (Table 1). This additional process included incorporating knowledge of local fish communities and giving additional weighting to structures in priority catchments. Priority catchments were provided by CCC and ECan, and they typically include catchments with higher biodiversity value and stakeholder interest. These catchments included: Ōtūkaikino Creek, Styx River, Cashmere Stream, Rāpaki, Whakaraupō, Wairewa, Peraki Bay, Wainui Bay, Takamātua Stream, and Ōkaruru (Goughs Bay) (Figure 1). The processes in which these additional criteria were included into the prioritisation model are described in the sections below.

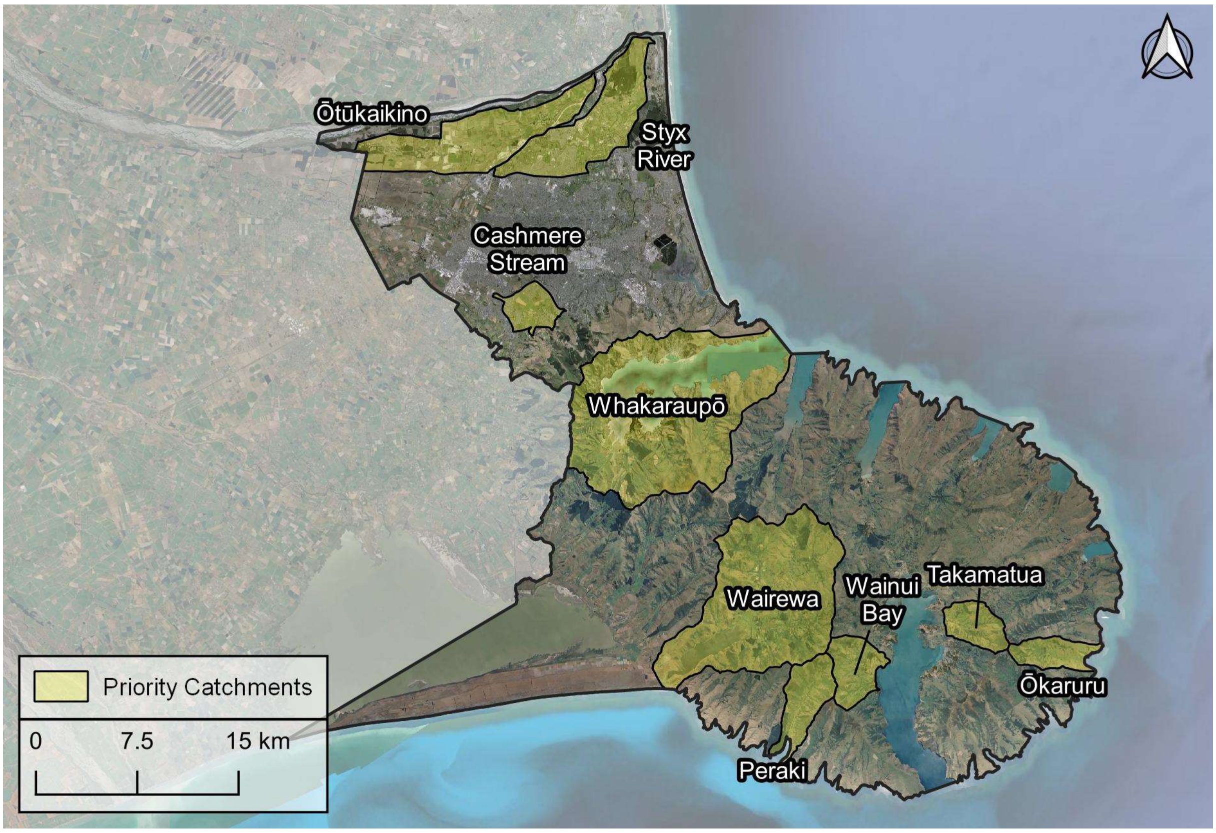

Figure 1: The priority catchments provided by CCC and Environment Canterbury. Note that the Rāpaki priority catchment is located within the greater Whakaraupō catchment.

Table 1: Ecological criteria for prioritising structures for fish passage remediation. The Criteria and Explanation columns are from Table 5.1 of the New Zealand Fish Passage Guidelines (Franklin et al. 2018), which was incorporated by reference in the NPSFM.

Criteria	Explanation	Inclusion in this Prioritisation
Proximity to coast	Barriers that are closer to the coast not only block access to a greater proportion of upstream habitat, but they also generally block a larger number of fish species.	• Part of the FPAT prioritisation • Expert judgement for sites without FPAT prioritisation
Potential habitat gain	The greater the total length of accessible river upstream of the barrier, the greater the potential habitat gain.	• As per above comment.
Habitat quality	Restoring access to higher quality instream habitat should be prioritised over providing access to degraded sites.	• Structures were given a higher priority if they fell within catchments considered high priorities for protection by CCC and ECan. These catchments typically have higher biodiversity value than degraded sites.
Proximity to protected areas	Connection with protected area networks may provide added benefits (e.g. constraints on fishing).	• As per above comment.
Number of species likely to benefit	Some sites are expected to naturally support a greater number of species than others, e.g. sites at low elevation close to the coast. Sites that are expected to support many species may be of higher priority than those expected to support few species.	• The FPAT prioritisation gives greater priority to waterways close to the coast. • Expert judgement also took this into account with reference to fish records.
Conservation status of species	Sites expected to support species with a higher conservation status may be of higher priority for restoration of connectivity.	• Expert judgement with reference to fish records.
Preventing spread of exotic and invasive species	Maintaining boundaries on the spread of exotic and invasive species may be a desirable outcome of retaining barriers and should also be considered in prioritising restoration actions.	• Expert judgement with reference to fish records. • There are very few examples of locations where this applies in Christchurch.
Protects threatened species	Barriers may protect populations of threatened fish species by preventing access to competing species, e.g. trout. Existence and protection of threatened fish populations should also be considered.	• Expert judgement with reference to fish records. • Applies to few locations in Christchurch, as there are few Threatened fish species in the district (lamprey and Canterbury mudfish are the main threatened species present).

2.2. Dataset Description and Preparation

The NIWA FPAT database was the foundation of the current study. As of 24 May 2021, the FPAT database included records of 1,902 potential fish barriers in the Christchurch district. Included in this total are assessments carried out over the summer of 2020–21 after preliminary data analysis identified numerous high priority CCC assets lacked assessment. A summary of these summer assessments is provided in Appendix 1.

The FPAT database contains two types of structure data, which we have termed complete records and incomplete records. Complete records are those uploaded via the FPAT application and incomplete records are data collated from external sources. Complete records include structure information collected following the FPAT standardised protocol, including relevant water and structure measurements, as well as photographs of the structure. Incomplete records were added to the FPAT database by NIWA during the period of June–August 2020. These data include FPAT test data (assessments made during FPAT development and testing), river-road intersects (where potential barriers may be located, but have not been ground truthed), historic assessments pre-dating the FPAT protocol, as well as various structure datasets from Toitū Te Whenua Land Information New Zealand and Waka Kotahi NZ Transport Authority. Incomplete records varied in the amount of information provided about a structure, ranging from just the potential location of a structure (e.g., river road intersects), to some details and notes regarding the structure and its risk to fish passage. Incomplete data, however, always lacked photographs. By matching field photographs provided by ECan to historic fish passage assessments pre-dating the FPAT application, we shifted 139 structures from the incomplete to the complete data category. After carrying out various GIS routines to identify and filter double ups of structures, the final database contained 1,741 FPAT records, of which 583 (34%) were complete records and 1,158 (66%) were incomplete records. Each of these record classes was treated independently during the prioritisation process, described below in Section 2.3. Details of FPAT assessments for structures discussed in this report can be found by searching for the FPAT ID in the online FPAT database (https://fishpassage.niwa.co.nz).

In addition to the structure data in the FPAT database, the current study also included CCC assets. Asset data were collated by selecting relevant layers from CCC's stormwater and watercourse asset databases that may represent potential fish passage barriers. Within each layer, various GIS routines were performed to remove structures that were not potential barriers within waterways (e.g., structures associated with pipe networks). The included layers and GIS processes are described in detail in Appendix 2.

The FPAT and CCC asset databases (FPAT and CCC assets) were joined to create a complete structure database for prioritisation. This database is henceforth referred to as the "prioritisation database". FPAT records within 20 m of CCC assets were attributed with the asset ID and assumed to be the same structure. This method prevented the inclusion of double-ups between FPAT records and CCC assets, as well as identifying which FPAT assessed structures were CCC assets. Asset IDs and ownership status was sourced from the relevant CCC GIS layers, unless alternative ownerships were provided by CCC.

The resulting prioritisation database comprised 2,528 structures (Table 2).

2.3. Structure Prioritisation

Prioritisation of the 2,528 structures was a two-step process. First, priorities were automatically assigned to all structures using a decision tree model, then priority scores were manually adjusted. Each of these processes is described in detail below.

Table 2: The structure of the prioritisation database.

Data category	CCC owned	Other	Total
FPAT records			
Complete records	338	245	583
Incomplete records	321	837	1,158
Additional CCC assets	625	162	787
Total	**1,284**	**1,244**	**2,528**

Note: All 'Additional CCC Assets' are by default incomplete records.

2.3.1. Decision Tree Model

Every structure in the prioritisation database was automatically assigned an alphanumeric code. The alphabetic character in the code represented an action, while the numeric character represented a priority. Action categories included: FPAT Assessment (A) of the potential barrier, a Fish (F) survey (including habitat measurements) in the vicinity of the potential barrier, and Remediation (R) of the barrier. The alphabetic character represents a level in the workflow of structure remediation, from identifying the potential risk of a structure (A), to determining the potential benefit of barrier remediation by sampling the local fish community (F), and finally by combining the information from the previous two levels, the priority for the barrier for remediation (R). The numeric priority ranged from 1 (lowest priority) to 5 (highest priority).

Automatic assignment of the A, F, and R codes followed a decision tree model (Figure 2). The first decision in the model separated the structures into complete and incomplete records. To qualify as a complete record, the structure must have had a fish passage assessment and photographs in the associated database. Thus, CCC asset data was treated as incomplete data, unless it could be associated with a completed FPAT assessment.

Structures that had not been FPAT assessed (incomplete records) were prioritised for FPAT assessment based on the structure type, and whether they were situated in a priority catchment. Structure type was used to infer risk to fish passage, a modified version of the rule-based risk assessments of Franklin (2018). The highest risk structures were considered to be pump stations, flap gates, valves, weirs, flow restrictions, and dams, as these structures are most likely to limit fish passage (Franklin 2018). Culverts, pipes, and fords were treated as medium risk, as they can be high risk or low risk, depending on their specifications. Bridges and structures of unknown type were treated as the lowest risk structures, presenting a low or unknown risk to fish passage. Based on these rule-based risk categories, each group was assigned a priority number for FPAT assessment, as per Figure 2.

Structures that had complete records were assigned priorities for either a Fish survey (F) or Remediation (R). The first step in this process was categorising the data by FPAT priority score (Figure 2). The FPAT priority score is automatically generated by FPAT and it provides a simple prioritisation of barrier removal or remediation, based on the potential ecological benefits. This priority score incorporates barrier risk to fish passage, downstream connectivity (relating to the number and risk of downstream barriers), catchment position (the proportion of catchment above the barrier), and accessible upstream habitat (the proportion of catchment before the next upstream barrier) (Franklin 2018). As these calculations rely on NIWA's River Environment Classification (REC) model (Snelder *et al.* 2004), structures not located on REC river lines are not assigned an FPAT priority score. For these 92 non-prioritised structures, a priority was assigned using expert judgement, with the corresponding priority categories 'Low', 'Medium', or 'High' (Figure 2). These priorities were subjectively estimated by considering the attributes included in the FPAT model, and through experience with the FPAT prioritisation system. Structures were then passed through the priority catchment filter, which simply adjusted the remediation priority based on whether the structure is in one of the priority catchments.

The remaining filters focused on fish communities local to the structure, which attempt to determine if the structure fulfils various ecological criteria for barrier prioritisation, outlined in Table 1. The first step in this process was separating the structures into those with fish data in the vicinity and those without fish data. For this purpose, the New Zealand Freshwater Fish Database was used (NZFFD; Richardson 2005). Structures with recent (< 20 years) fishing records in their vicinity were assigned a Remediation (R) priority, while structures without fishing data were assigned a Fish (F) survey priority. Whether local fishing data was suitably appropriate was determined manually on a case-by-case basis, and included consideration of elevation changes, number of records, and other potential barriers in the area.

The final filter imposed on structures with relevant fishing data available, was whether there were inanga (*Galaxias maculatus*) records near the structure. This 'At Risk – Declining' species (Dunn *et al.* 2018), was chosen as an indicator species as it is migratory and a very poor climber (Jowett and Richardson 2003). The presence of this species near a structure therefore indicates that passage up to the structure is relatively unobstructed for most species, increasing the number of species that are likely to benefit from structure remediation. Furthermore, having a species that is highly sensitive to passage obstruction in the vicinity greatly increases the chance of a structure being a barrier. Thus, such structures were assigned the highest priorities for remediation.

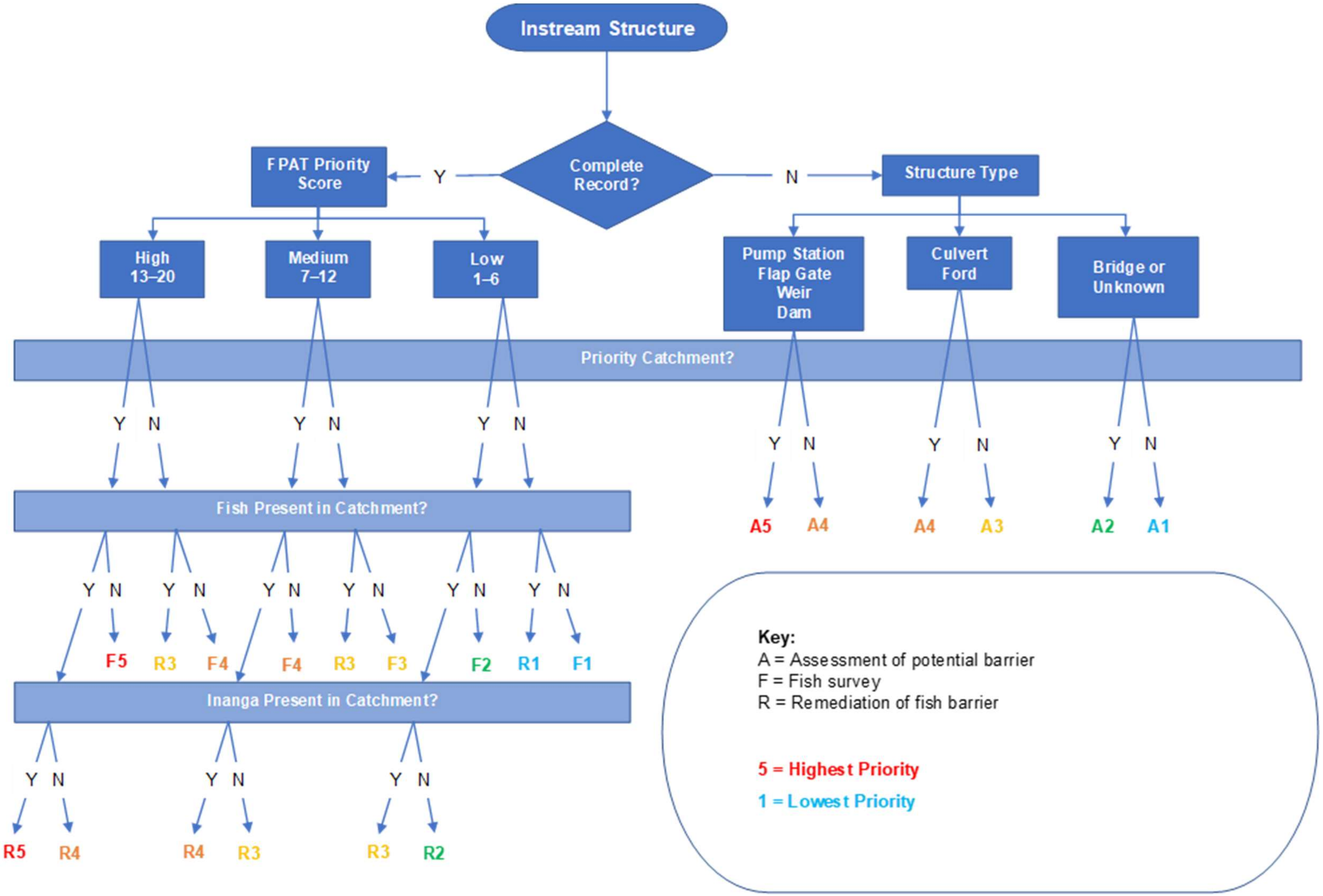

Figure 2: The decision tree model used to assign actions and priorities to structures in the prioritisation database. Y=yes, N=no.

2.3.2. Manual Adjustment

Following the automatic prioritisation model, a manual adjustment process was carried out for every complete record. Automatic values assigned to complete records were checked and adjusted on a structure-by-structure basis. Adjustments were then made to the priorities if it was decided that the value was not representative of the potential ecological benefits of remediating a structure. A summary of the reasons why a structures priority may have been manually altered, and the number of affected structures, is presented in Table 3.

Table 3: Reasons for adjusting structure priority scores.

Code	Explanation	Structures Affected
LR	Low Risk: Priority reduced as the structure presents a very low risk to fish passage.	252
DR	Dry: Priority reduced due to upstream channel being dry.	61
LF	Low Flow: Priority reduced due to low flow providing limited habitat availability upstream.	55
HR	High Risk: Priority increased due to structure creating a very high risk to fish passage.	24
UPL	Upstream Potential Low: Priority reduced due a small amount of habitat availability upstream. This may be due to other barriers upstream, or pipe networks.	18
NAT	Natural barrier: Priority reduced to minimum as no remediation is required.	15
DB	Downstream Barriers: Priority reduced due to barriers downstream requiring attention first.	8
UPH	Upstream Potential High: Priority increased due to having a large, unobstructed catchment upstream.	8
MIR	More Information Required: Priority or action changed until more information is available on structure or surrounding structures.	6
UPS	Unassessed Structures reducing Priority: Priority increased. Nearby structures that are unassessed and are unlikely to be a risk to fish passage (e.g., a bridge), are reducing the structures FPAT priority.	3
	Total Complete Records Adjusted:	**387**
	Total Complete Records Unadjusted:	**196**

Note: Structures may be adjusted for more than one reason, and these structures have more than one code.

By far the most common reason for adjusting a priority score was due to the structure presenting a low risk to fish passage yet having a high FPAT priority score, which accounted for 65% of adjustments. This was a common adjustment due to the way in which the FPAT model calculates its priority scores. The FPAT priority score is the sum of four scores, with each of these scores representing a different attribute of the structure or its position in the catchment. Franklin (2018) terms the four scores the 'downstream connectivity score', 'catchment position score', 'accessible upstream habitat score', and the 'barrier score'. Briefly, these scores are affected, respectively, by a) the number of barriers downstream, b) the relative proportion of catchment upstream of the barrier (irrespective of upstream barriers), and c) the length of upstream habitat, and d) the degree of risk to fish passage the barrier poses. Every structure is scored on a scale of 1–5 for each of these attributes, with the sum of these attributes being the final FPAT priority score (i.e., 5–20). Structures that have a low barrier score (i.e., very low risk to fish passage), may still have a priority of up to 16 (out of a maximum of 20) if they receive maximum scores for the other three attributes. For example, two bridges in Ōkaruru (Goughs Bay) were determined to be very low risk to fish passage, however, due to their catchment position, both received relatively high FPAT priorities of 14 (Figure 3). As Ōkaruru is a priority catchment and there are NZFFD records of inanga in the area, the current automatic model produces priorities of R5 for both structures, the maximum score for remediation (Figure 2). The manual adjustment process allowed for these structures to be reduced to R1 priority, on the basis that the structures present a 'Low Risk' to fish passage.

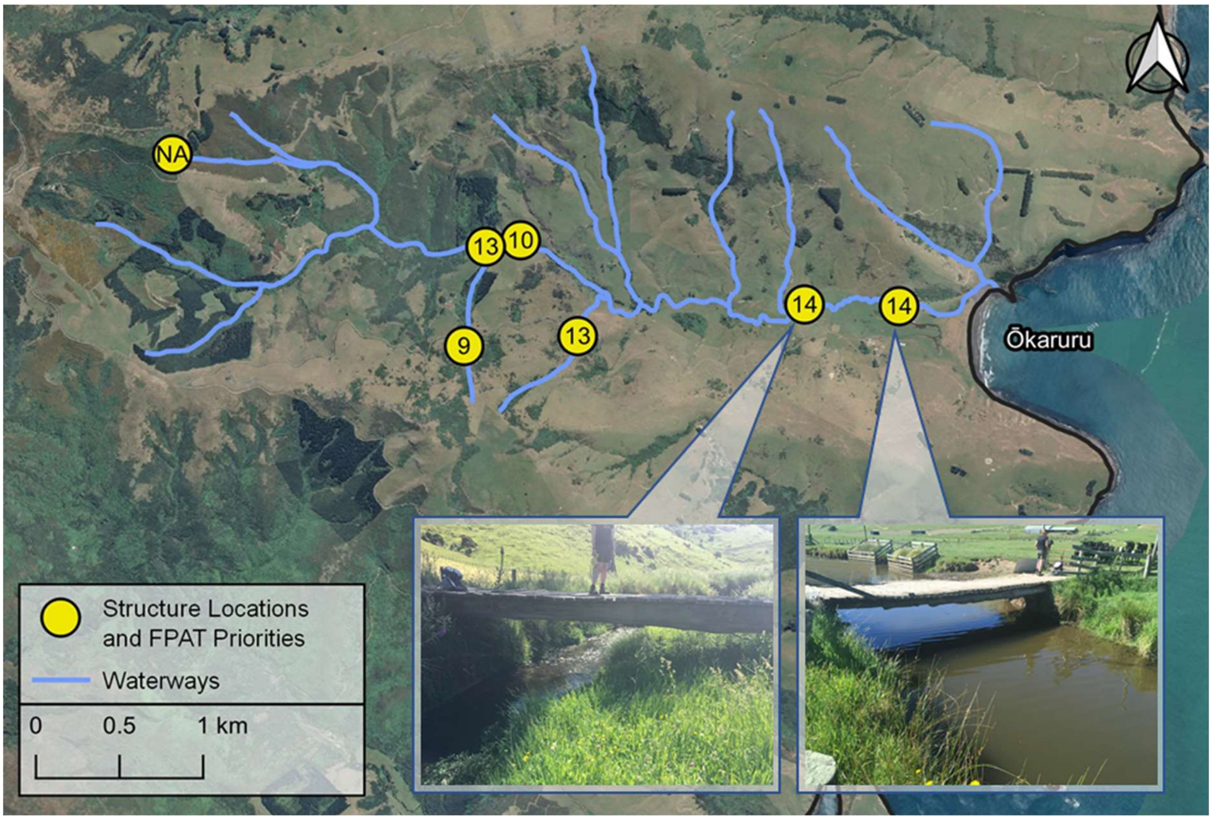

Figure 3: Two structures that required manual priority adjustments due to having high FPAT priority scores, despite presenting no risk to fish passage.

3. RESULTS AND DISCUSSION

3.1. Structure Priorities

The distribution of the assigned priorities for remediation and fishing was heavily skewed towards the lower priority categories (Figure 4). Only 38 (6.5%) of FPAT assessed structures were high priority (i.e., had priority scores of 4 or 5). Eight CCC assets were among the high priority structures for remediation (i.e., R4 or R5), with a further 12 identified as high priority for fish surveys (i.e., F4 or F5). All CCC assets in the high priority categories for remediation and fishing are described in Table 4. A complete list of high priority structures of all ownerships, including their coordinates, is included in Appendix 3.

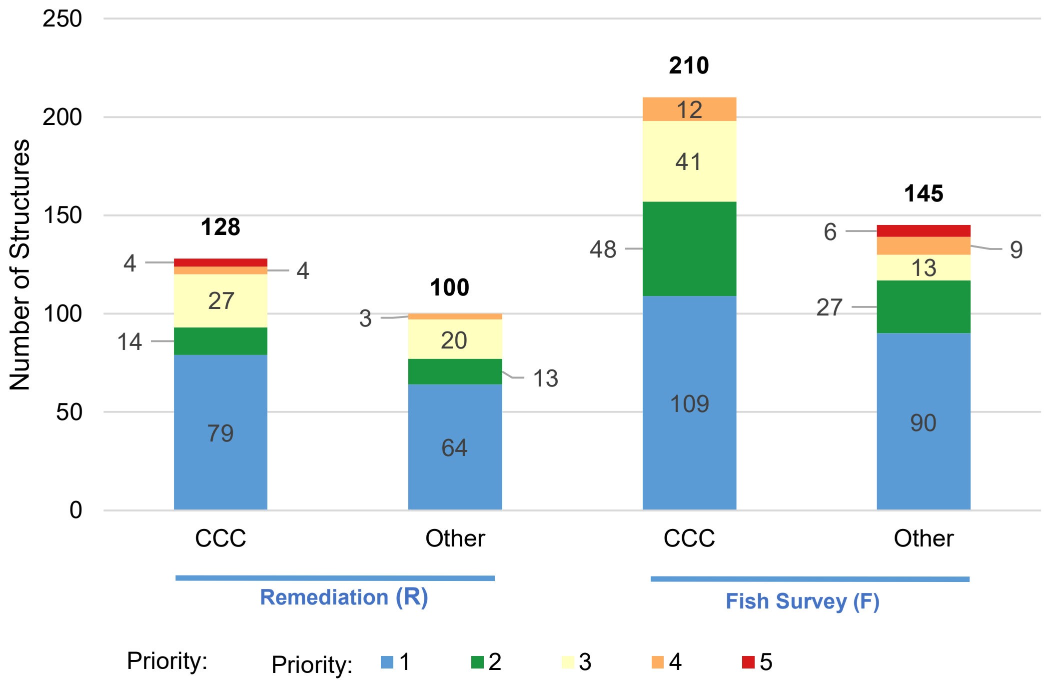

Figure 4: The number of structures in each of the prioritisation categories, with '1' being lowest and '5' being highest priority. Data are separated by asset owner, where 'other' includes unknown ownership.

A total of 1,945 structures in the database had not yet been FPAT assessed (Figure 5). Of the 244 high priority assessment structures (i.e., A4 or A5), 64 (26%) were identified as CCC assets. Of the 64 high priority CCC assets for assessment, 40 were visited during the summer 2020–21 assessment project, but were unable to be assessed for a variety of reasons, which are described in Appendix 1. A further 14 represent culverts in priority catchments that were added after the summer assessments were carried out.[1] Of the 180 high priority assessment structures for assessment that were not identified as CCC assets, a large proportion were weirs, dams, or flow restrictions (61%), with the remainder being flap gates or culverts (the

[1] Wainui Bay, Ōkaruru / Goughs Bay, and Pireka Bay were added to the list of priority catchments after the 2020/21 field assessments were completed.

latter in priority catchments). The weirs ranged from single boards in the bed of the waterway to more substantial structures such as v-notch weirs and plate weirs.

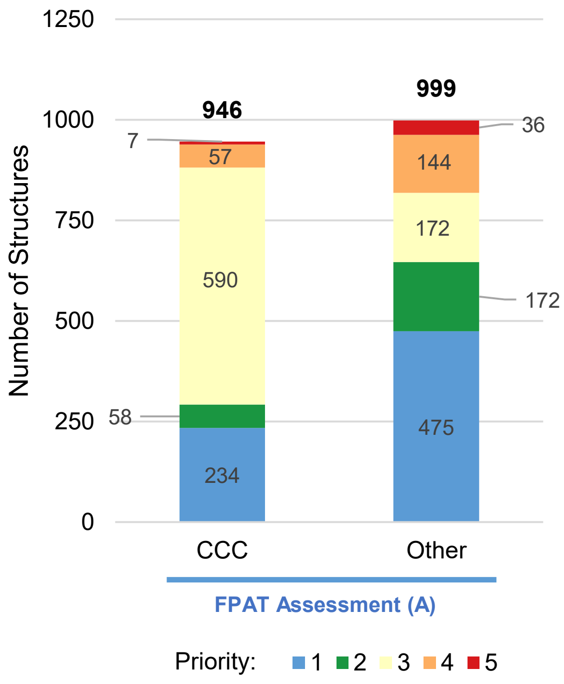

Figure 5: The number of structures assigned a priority for FPAT assessment (i.e., incomplete records), with '1' being lowest priority and '5' being highest. Data are separated by asset owner, where 'other' includes unknown ownership.

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Table 4: All high priority (R5, R4, F5, and F4) structures owned by CCC. The location of each structure is indicated below in Figure 6. Structures are ordered firstly by action (i.e., Remediation or Fishing) and secondly by priority score. Structures with the same priority score have been ordered from highest priority to lowest priority, based on expert ecology judgement and local knowledge. The CCC Asset refers to the relevant GIS layer and asset number of each structure.

Waterway (Catchment)	FPAT ID	Structure Type	CCC Asset	Priority Score	Comments	Photographs
Ōtūkaikino Creek (Ōtūkaikino Creek)	130047	Weir	WcWeirs 199	R5	The most substantial barrier in the Ōtūkaikino catchment. Distribution of fish database records indicates that the structure is a total barrier for inanga. Velocities over fish ladder are too high for inanga.	
Takamātua Stream Branch No 7 (Takamātua Stream)	1411	Weir	Unknown	R5	Upstream of CCC bridge A33. A fish survey in 2020 identified abundant native fish downstream, including bluegill bully, redfin bully, longfin eel, and whitebait. No fish were caught upstream, confirming poor passage.	
Pūharakekenui / Styx River (Pūharakekenui / Styx River)	131907	Flap gate with culvert	WcValve 27	R5	High risk structure near the coast. The most significant barrier in the Styx catchment. Recommend an investigation into the gate's operation (opening frequency and duration) and impacts on fish movements and salinity (and associated implications for plant communities and inanga spawning).	
Wainui Valley Stream (Wainui Bay)	1140	Weir	WcWeirs 242	R5	ECan currently investigating fish passage enhancement options.	
Storer Diversion (Ōtūkaikino Creek)	130043	Culvert	SwPipe 46740	R4	There is another significant structure upstream (see next structure below). These would both need to be remediated to gain the full benefit. Structure would exclude most native species. Asset ownership is uncertain.	
Fisher Drain (Ōtūkaikino Creek)	130044	Pump station	WcWeirs 200	R4	Historical pump station (not in service) containing a substantial weir barrier. Gravity fed bypass ends in flap gates. Substantial culvert barrier downstream, these would both need to be remediated to gain the full benefit.	
Okuti River Branch No 9 (Lake Forsyth (Wairewa))	278	Weir	RAMM W11	R4	Weir situated under bridge W11, but not listed in CCC weir database. Likely owned by CCC. Would need to remediate at the same time as another (presumably private) weir immediately upstream.	
Dunbar Waterway (Cashmere Stream)	132979	Culvert	SwPipe 45899	R4	Structure may be scheduled for replacement with proposed waterway realignments in the area. This needs to be confirmed by CCC engineers prior to remediation.	
Totara Stream (Pigeon Bay Stream)	1050	Culvert	SwPipe 60168	F4	Large upstream catchment. The waterway this tributary flows into contains records of numerous native fish, including bluegill bullies and longfin eels.	
Opuahou Stream Branch No 14 (Lake Forsyth (Wairewa))	295	Culvert	SwPipe 58366	F4	Structure c. 500 m upstream should be assessed at the same time as fishing this structure to determine the amount of potential upstream habitat.	
Le Bons Stream Branch No 13 (Le Bons Stream)	1326	Culvert	SwPipe 61976	F4	No fishing records present in this waterway, but numerous native species (including lamprey) recorded in the Le Bons Bay mainstem.	
Owhetoro Stream Branch No 4 (Port Levy (Potiriwi) / Koukourarata)	1194	Culvert	SwPipe 59843	F4	Stream has good flow. Fish community is unsampled in both Branch No 4 and the mainstem.	
Kinloch Stream (Lake Forsyth (Wairewa))	1234	Culvert	RAMM W17	F4	High risk private ford with culvert located c. 200 m upstream. Fishing required upstream of both structures, with a remediation plan for both structures.	

Waterway (Catchment)	FPAT ID	Structure Type	CCC Asset	Priority Score	Comments	Photographs
Rifle Range Waterway (Estuary of the Heathcote and Avon Rivers / Ihutai)	134912	Flap gate with culvert	SwValve 306	F4	As per the CCC GIS layer, the normal position of the flap gate is closed. Likely a substantial barrier to fish migrating upstream, however, the fish community has not been sampled.	
Raupō Stream (Raupō Bay)	1105	Culvert	SwPipe 60656	F4	Substantial barrier and is the only known barrier in the catchment. Fish community has not been sampled.	
Stream Reserve Drain (Lyttelton Harbour / Whakaraupō)	134866	Culvert	SwPipe 76048	F4	Fish passage improvements through the culvert, but surveyors noted a large drop off the apron. Fish community sampled downstream, which includes eels, kōaro, and banded kokopu, but no fish sampling upstream.	
Charlesworth Drain (Estuary of the Heathcote and Avon Rivers / Ihutai)	136467	Flap gate with culvert	SwValve 501	F4	Potential inanga spawning habitat upstream with low gradient banks and dense groundcover vegetation.	
Miln Drain (Cashmere Stream)	130166	Other	SwPipe 87535	F4	Fishing required to determine if this structure is a substantial barrier. Investigation into other structures built as part of the new stormwater infrastructure and waterway realignments is recommended.	
Cass Bay Drain (Lyttelton Harbour / Whakaraupō)	317	Weir	SwPipe 57165	F4	Recommend further fish investigation. A recent survey found no fish upstream, however, this coincided with a very dry summer and reduced aquatic habitat.	
Church Lane Drain (Lyttelton Harbour / Whakaraupō)	286	Culvert	SwPipe 76008	F4	Historic records of banded kokopu, but no recent records. Downstream there is another perched culvert of unknown ownership that would need to be addressed at the same time. Local residents report that the stream goes dry at times.	

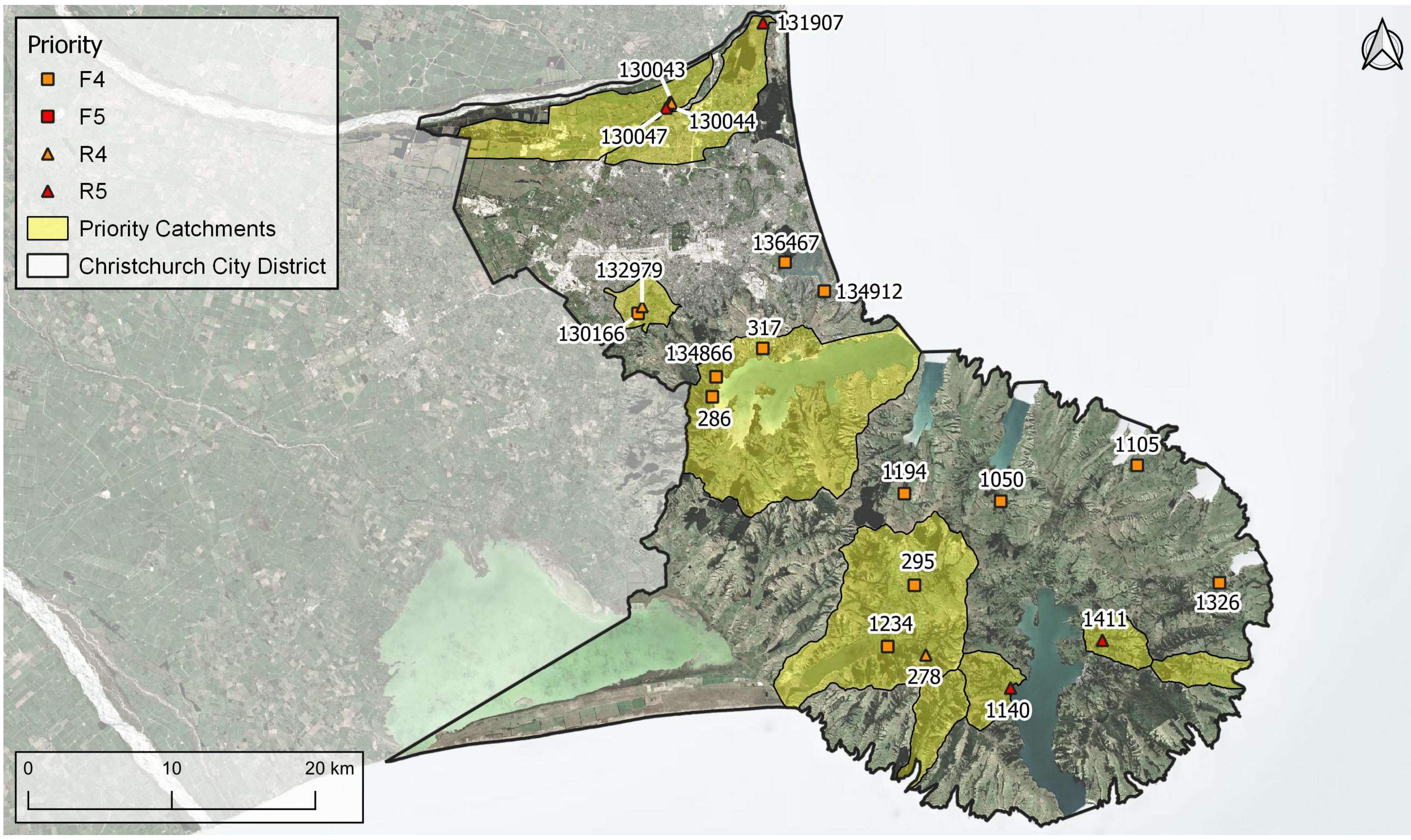

Figure 6: All CCC owned assets that are a high priority for fish surveys (F4, F5) or remediation (R4, R5). Structures labelled with their FPAT record ID.

Culverts were the most common CCC asset to be assigned a high priority in the remediation and fishing categories, accounting for 10 out of 20 (50%) structures in these categories (Table 5). Weirs, dams, and flow restrictions also appeared in these categories, representing a further 6 (29%) of high priority structures. While this appears to go against the assumption that weirs, dams, and flow restrictions are of higher risk to fish passage relative to culverts, this is likely an artifact of the number of structures in each of these categories. A total of 47 CCC owned weirs, dams or flow restrictions were included in the database, of which 39 have been FPAT assessed. For comparison, there were 820 CCC owned culverts included in the database, of which 195 have been assessed. Therefore, weirs, dams, and flow restrictions contribute a disproportionately high number of structures to the high priority categories, relative to other structure types. Weirs and flow restrictions are often associated with stormwater treatment and attenuation systems. Thus, these systems create high-risk environments for fish passage. However, as structures in such systems are often bespoke, determining their impacts on fish passage is difficult. Targeted surveys are therefore required to identify to what level fish are utilising stormwater treatment facilities, to identify potential fish passage issues, and to determine if providing passage into such facilities is appropriate.

Table 5: The number of structures per priority category, separated by structure type, for CCC owned assets.

Priority	Culvert	Bridge	Weir, Dam or Flow Restriction	Gate or Valve	Pump	Other	Ford with Culvert	Ford without Culvert	Total
Remediation									
R5			3	1					**4**
R4	2		1		1				**4**
R3	9		7	8	1		1	1	**27**
R2	10	2		2					**14**
R1	33	30	8	6		1	1		**79**
Fishing									
F5									**0**
F4	8		2	2		1			**13**
F3	29		3	7	2				**41**
F2	40	2	6						**48**
F1	64	30	9	3	1	1	1		**109**
FPAT Assessment									
A5			1	1	5				**7**
A4	35	1	7	11	3				**57**
A3	590								**590**
A2		58							**58**
A1		234							**234**
Total:	**820**	**357**	**47**	**41**	**13**	**3**	**3**	**1**	**1,285**

The distribution of high priority structures was not even over the Christchurch district. High priority structures were far more numerous on Banks Peninsula than they were in Christchurch city, with 29 of the 38 (76%) high priority structures identified being located on the peninsula

(Appendix 3). This pattern remained when this list was reduced to CCC owned assets, with 13 of the 20 (65%) high priority structures being located on the peninsula (Figure 6). A combination of factors may contribute to the high number of priority structures on the peninsula. These factors include the presence of large priority catchments (i.e., Whakaraupō and Wairewa), as well as the local topography and geology. The steep topography and highly erodible loess soils on the peninsula create an environment where culverts may become perched over time, due to erosion. Furthermore, culverts have typically been installed on a gradient closer to that of the road than the surrounding hillslope. The result of this is a perched culvert on the downhill side of the road. Culvert perching was associated with 13 of the 19 (68%) high priority structures on the peninsula, compared with three of the nine structures (33%) in the city.

Within the city there was a more even spread of CCC owned high priority structure types. These included three culverts, three gates or valves, a historic pump station, and a weir. While these structures were spread among various catchments, the Ōtūkaikino catchment stood out as being highly impacted by fish barriers, containing three of the six high priority remediation structures. These structures were all identified as having a 'Very High' risk to fish passage by the FPAT application. These barriers may reduce access or exclude migratory fish from up to 35 km of upstream waterway (measured from the CCC waterways layer; Figure 7). This estimate assumes there are no further upstream barriers and does not make any assumptions around suitable fish habitat, or intermittently dry reaches. The impact on inanga distributions within the catchment can be clearly demonstrated by mapping recent NZFFD records for this species (Figure 7).

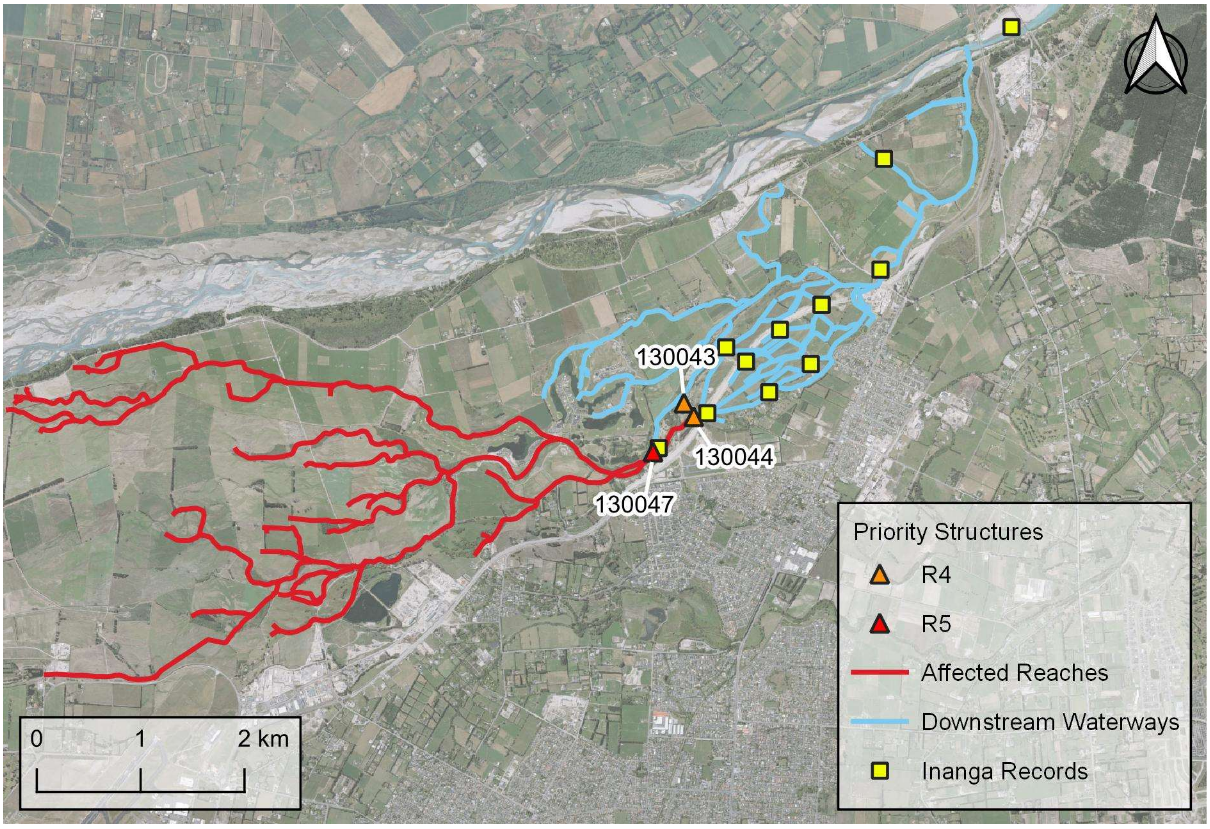

Figure 7: The locations of the three high remediation priority CCC structures in the Ōtūkaikino catchment, labelled with FPAT IDs. Inanga NZFFD records in the catchment (since 2000) are also included. The catchment upstream of the barriers is symbolised as 'Affected Reaches' in red, totalling 35 km.

Inanga records in the Ōtūkaikino are limited exclusively to reaches downstream of the identified structures. Other potentially affected migratory species in the catchment, some of which are of conservation interest, includes: 'Threatened – Nationally Vulnerable' lamprey (*Geotria australis*; Dunn *et al.* 2018); 'At Risk – Declining' bluegill bully (*Gobiomorphus hubbsi*) and longfin eel (*Anguilla dieffenbachii*); 'At Risk – Naturally Uncommon' giant bully (*Gobiomorphus gobioides*); as well as shortfin eel (*Anguilla australis*). Due to the substantial ecological values identified, and the considerable upstream habitat that can made accessible through remediation, these structures represent some of the highest priority structures in the Christchurch district.

3.2. Other Notable Barriers

The current design of the prioritisation model places a strong weighting on priority catchments, with structures outside these catchments receiving a maximum remediation priority of 'R3' (Figure 2). While this approach achieves its purpose, prioritising structures in catchments of high ecological and stakeholder interest, it does exclude significant barriers in non-priority catchments. One way of identifying such barriers is to organise the structures by the FPAT "risk to fish passage" category. This is a qualitative measure of risk made by the assessor during FPAT assessments. The risk category is selected following advice provide in the FPAT user guide (Franklin 2018), as summarised in Table 6. Risk to fish passage also has a quantitative counterpart that is calculated by the FPAT application. However, the quantitative risk assessment does not assess risk in the context of the local fish community and the gradient of the stream, and has a tendency for 'Very High' risk to be calculated when there is little or no water. Therefore, the qualitative assessment made by the assessor reduces the number of false positives when discussing the high-risk categories.

Table 6: Qualitative FPAT risk assessment categories that guide the FPAT assessors. From Franklin (2018).

Risk Category	Description
Very high	Very high chance that most fish species will be blocked most or all the time.
High	High chance that the movements of many fish species and life stages will be restricted for much of the time.
Moderate	Moderate chance that movements of some fish species and life stages are commonly restricted.
Low	Some chance that movements of weaker swimming species are restricted some of the time.
Very low	Movements are unimpeded for most or all fish species and life stages for most or all the time.
Not assessed	Select this if you are not confident or do not have the knowledge to determine the likely risk.

The division of high-risk structures (the combination of 'High' and 'Very High' risk categories) was relatively even between priority and non-priority catchments, with a total of 63 high risk structures in priority catchments and 80 in non-priority catchments (Figure 8). This indicates that there are 80 structures that are very likely to be impeding fish passage, that have been limited to a maximum 'R3' prioritisation in the current study. One notable example from this category is the Mona Vale weir in the Avon River, which was identified as a ‘Very High risk’ to fish passage by the assessor (FPAT ID: 1630). This weir has been previously identified as a major fish barrier, restricting fish distributions in the Avon River (Instream Consulting 2019a). It is the most downstream barrier in the Avon River mainstem, with a sizeable upstream catchment including 34 km of open waterway (based on the CCC watercourse GIS layer, without considering other barriers). This structure is discussed in further detail as a remediation case study in Section 3.3.2.

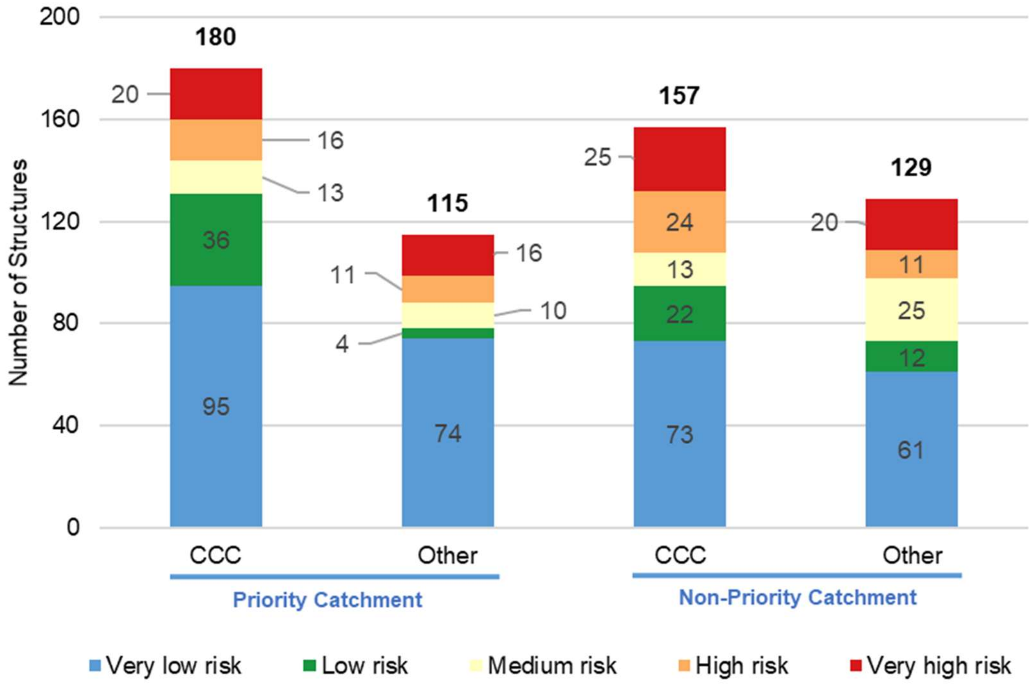

Figure 8: The number of structures per risk level in priority and non-priority catchments, separated by ownership status. ‘Other’ includes structures of unknown ownership. Risk level assessed qualitatively by FPAT assessors. Structures without risk assessments (3) excluded.

Pump stations and flap gates can also pose considerable risk to fish passage, however, most of these structures in the prioritisation database (48 out of 70; 69%) occurred outside of priority catchments. Examples of these structures include the pumpstation and associated tide gates at the Waikākāriki / Horseshoe Lake outlet (PS205; FPAT ID: 136500). The ecological values of the upstream catchment and the potential effects of this structure were discussed in a report prepared by Instream Consulting (2021) for CCC. Ecological values of the catchment included a diverse migratory fish community, including: ‘At Risk – Declining’ inanga, longfin eel, and bluegill bully; ‘At Risk – Naturally Uncommon’ giant bully; as well as shortfin eel and common bully (*Gobiomorphus cotidianus*). Upstream movements of juveniles of these species are likely impeded by the tide gates, which close on an incoming tide, coinciding with peak upstream fish movement. While one of the five gates is a “fish-friendly” design, CCC engineers observed negligible difference in opening duration between the standard and fish-friendly gates (Instream Consulting 2021b). Downstream migration of adult eels is also likely affected by this structure, with fish entrained into the pump screws potentially suffering injury or mortality.

While the structure was assigned a remediation priority in the current study, further investigation into the periodicity of the gate openings and closings, and the impact of the pumpstation on downstream fish movements is recommended to inform remediation design.

The risk of pumpstations on fish passage is context dependent. While the above example describes a pumpstation that is likely to have a high impact on fish passage, this is not true of all pumpstations. A key consideration when determining the potential impact of a pumpstation, and thus its priority for remediation, is the amount of pipe network both upstream and downstream of the structure. The relative amount of pipe network to open waterway upstream should be considered as it reflects the amount of potential fish habitat upstream. Pumpstations downstream of catchments with a large proportion of open waterway should be considered a priority for further investigation, as these pumps are likely to have a greater number of fish migrating past them in a downstream direction. Pumps with large amounts of inline pipe downstream can be considered to have a lower risk to fish passage. This is due to long lengths of pipe creating partial barriers to fish passage, reducing the number of fish upstream, and thus the risk of the pump to fish passage. Examples of these exist in the Dudley Creek Diversion (SwPump 40 and SwPump 6). In a survey of the open reaches upstream of these pumps (immediately downstream of Paparoa Street), Brown *et al.* (2021) caught only non-migratory upland bullies, with one eel seen but not caught. Low fish diversity and eel abundance was attributed to the long continuous lengths of downstream pipe acting as a partial barrier. Given the low abundance of migratory fish upstream, the inline pumps in Dudley Creek diversion pose lower risk to fish passage and are not a high priority for remediation.

While the Dudley Creek Diversion example demonstrates that pipe networks can present substantial risk to upstream fish passage, these networks are not represented in the current study, or explicitly considered by the FPAT application. We intentionally excluded pipe systems via GIS routines, described in Appendix 2. Pipe networks were not included to reduce noise in the dataset, with a focus on improving passage to open waterways. However, the process of “daylighting”, restoring piped networks to natural open states, is becoming increasingly common both overseas and in New Zealand. Daylighting may provide direct benefits, through the creation of more open water habitat, and indirect benefits, by allowing greater access to open upstream reaches. When compared to individual barrier remediation, daylighting is very costly, with the relative ecological merit depending largely on factors relating to the amount of open upstream habitat, the length of downstream piped sections, the species present in downstream reaches, and a range of social factors. A prioritisation process involving these principals could be used to determine which piped reaches are the strongest candidates for daylighting locally. However, we suggest that CCC focuses on remediating other fish passage barriers before daylighting parts of the pipe network, due to the lower associated costs and clearer benefits of barrier remediation.

3.3. Fish Barrier Remediation Case Studies

3.3.1. Antigua Boat Sheds Weir

Waterway: Avon River

Location: Antigua Boatsheds

FPAT ID: 136460

CCC Asset ID: WcWeirs 151

Fish passage issue: The older rock weir created a vertical drop in the order of 0.5 m and fast velocities that would have reduced fish passage for poor climbers (Figure 9). The weir was unstable, with rocks rolling away from the weir causing upstream water levels to drop. Weir removal was impractical, due to the historical significance of the upstream reach for boating.

Potential upstream habitat: Up to 48 km, excluding pipes. Potential habitat calculated from CCC watercourse and stormwater GIS layers. The distance is likely an overestimate, as this assumes that all reaches are habitable by fish and have permanent flow. Access to much of the upstream habitat is limited by the Mona Vale Weir, located 5.3 km upstream.

Fish community: There are NZFFD records of numerous migratory species in the vicinity, some of which are of conservation interest. This includes Threatened lamprey and At Risk inanga, bluegill bully, and longfin eel (Dunn *et al.* 2018). Additionally, shortfin eel, common bully, and brown trout (*Salmo trutta*) have also been recorded.

Solution: Proposed solutions included upgrading the current weir by adding more rocks, a formal concrete weir, and a rock riffle, with the latter ultimately being selected (Figure 9). Construction of the rock riffle was completed in 2008.

Figure 9: The unstable rock weir (left) and the replacement rock riffle weir (right).

Costs: Total renewal cost of $216,000. As there was no additional structure added to provide fish passage, and renewal of the weir was to occur anyway, there were no additional costs for fish passage enhancements beyond the design and construction costs for the weir.

Remediation effectiveness: Remediation of the structure was highly successful. The riffle section was a suitable length as to not create a significant velocity barrier. From a fish passage perspective, the selected riffle design was far superior to the alternative design suggestions and did not require any additional structures for fish passage. Many migratory species, including inanga, have been recorded upstream of the structure since the riffle was installed. Additionally, NZFFD records show bluegill bullies (riffle habitat specialists) are abundant through the riffle section.

Lessons learnt:

- The structure was due for renewal, creating an opportunity for “cost-neutral” fish passage enhancement. Greatest efficiency is likely to be achieved when fish passage enhancements can coincide with structure renewals.
- By creating a raised platform constructed on top of concrete blocks, the excavator was able to remain out of the water, minimising some associated construction impacts.
- Coffer dams were installed across the river, one half at a time, allowing for sediments disturbed in the construction zone to settle out of the main flow.
- The water level drop over the riffle length is quite small (c. 0.5 m) and the channel is narrow downstream, resulting in the riffle being fully submerged during even small floods. Thus, the experience from this remediation may not be readily transferable to higher weirs, such as Mona Vale (John Walter, 2021, Pers. Comm.).

3.3.2. Mona Vale Weir

Waterway: Avon River

Location: Mona Vale

FPAT ID: 1630

CCC Asset ID: WcWeirs 108

Fish passage issue: A large, stepped weir with drop heights of up to 0.6 m (Figure 10). Fish ladders are present, but they do not provide passage for smaller non-jumping native fish and they do not appear to be used by the original target species, brown trout, which have been seen trying to jump over the weir (personal observation).

Figure 10: Photographs of the weir in the Avon River at Mona Vale.

Upstream habitat potential: Up to 34 km, excluding piped sections (CCC watercourse GIS layer). This number is indicative only, as discussed in Section 3.3.1 above.

Fish community: NZFFD records show numerous migratory species immediately downstream of the weir, many of conservation interest. Fish records include a single lamprey (Threatened), and longfin eels, inanga, bluegill bully, and giant bully (all At Risk species, Dunn *et al.* 2018). Additionally, shortfin eels, common bully and brown trout have also been recorded. All species except for inanga and lamprey have been recorded above the weir.

Priority and values: This structure was assigned a medium priority for remediation (**R3**). This is the maximum priority for a structure in a non-priority catchment. The structure fulfils many of the suggested ecological prioritisation criteria (Table 1). While the structure is a long distance from the coast (c. 20 km), this is the first structure in the mainstem of the Avon River that is a substantial barrier to fish passage. The upstream catchment is large, including access to numerous tributaries. The local fish community includes migratory species that would benefit from enhanced passage, including many of conservation interest. This structure was previously identified as a significant fish passage barrier and a top priority for remediation in the Avon River catchment (Instream Consulting 2020b).

Potential remediation and cost: Discussions are currently underway regarding remediation of this structure with the addition of a rock riffle downstream. Construction of a rock riffle at Mona Vale is estimated to cost in the order of $750,000 (Mark Mullaney, 2021, Pers. Comm.). From a fish passage perspective, the design should focus on achieving low marginal velocities and rest zones. Slopes of 1:30 are recommend to achieve passage of weakly swimming species such as inanga (Franklin *et al.* 2018).

3.3.3. Kaituna Valley Culvert

Waterway: Kaituna River Branch No 6

Location: Kaituna Valley Road

FPAT ID: 130205

CCC Asset ID: SwPipe 58799

Fish passage issue: A perched culvert with a drop height of 0.9 m below the culvert and shallow swift flow through the culvert (Figure 11).

Upstream habitat potential: 1.8 km (CCC watercourse GIS layer), however a high-risk private ford is located 50 m upstream that limits the value of remediating the culvert.

Fish community: Electric fishing and spotlighting upstream and downstream of the culvert prior to remediation identified a small number of At Risk longfin eels (Dunn *et al.* 2018), both upstream and downstream of the culvert. Longfin eels are strong climbers and no weak swimmers or climbers (e.g., inanga) were identified upstream or downstream of the culvert (Instream Consulting 2020a).

Solution: The structure was considered a low priority for remediation, given the fish community present, and surrounding natural and artificial barriers (Instream Consulting 2020a). However, culvert repairs were being undertaken, so fish passage remediation was included in the repairs. This entailed the addition of a fish ramp (slope: 1:2.8) constructed of rocks embedded in concrete, and the addition of baffles through the culvert (Figure 11). Construction was completed in 2020.

Figure 11: The perched culvert in Kaituna Valley before (left) and after (right) remediation.

Costs: Construction cost of $25,500, including labour and materials, but excluding professional services, monitoring, and fish salvage (which would be an additional c. $7,000). Of the construction cost, $12,400 related to the downstream ramp and back filling, and $1,000 related to the baffles. It should be noted that this project was competitively priced by the contractor, and relatively local to Christchurch for a Banks Peninsula site, which also reduced costs (Neil Andrews, 2021, Pers. Comm.).

Remediation effectiveness: Electric fishing after remediation revealed similarly low numbers of fish with only longfin eels caught, all of which were downstream of the culvert. Given the low density of this species prior to remediation, it is difficult to quantitatively demonstrate effectiveness of the installed fish passage enhancements. The slope of the fish ramp was much steeper than the 1:30 slope recommended by the Fish Passage Guidelines to allow passage of small bodied fish (Franklin *et al.* 2018), however, it was appropriate for the target species (longfin eels). Given the natural barriers (cascades) downstream, weak climbing species such as inanga are very unlikely to gain access to the culvert. Individuals that may be able to pass through the remediated culvert would be introduced to limited upstream habitat, as there was a high-risk ford 50 m upstream.

Lessons learnt:

- The structure was a lower priority for remediation, given the limited number of species present, low fish numbers, high position in the catchment, and presence of an additional barrier upstream. However, remediation was legally required because the structure was being repaired.
- The rock ramp and baffles did enhance <u>potential</u> fish passage, by removing the fall height and reducing culvert velocities.
- The remediation design was appropriate for the fish species present.
- Quantifying <u>actual</u> fish passage enhancement was not possible, due to low fish abundance.

- Faced with similar circumstances in the future, where fish abundances are very low, follow-up fish monitoring is of limited value because it will be difficult to detect a change in fish populations.
- Feedback from the CCC project manager Neil Andrews:
    - Contractors in the area are relatively inexperienced with fish passage designs, requiring a lot of guidance on site.
    - Results of follow up ecological monitoring should be passed on to project managers, so they know what has worked in the past.
    - Important to implement fish passage enhancements in a way that does not impede the hydrological function of the structure.

3.3.4. Hukahuka Turoa Stream Culvert

Waterway: Hukahuka Turoa Stream

Location: Bachelors Road

FPAT ID: 1377

CCC Asset ID: SwPipe 59083

Fish passage issue: Culvert perched with high velocity flow through (Figure 12).

Upstream habitat potential: 4.8 km (CCC watercourse GIS layer).

Fish community: Electric fishing upstream and downstream prior to remediation found high numbers of juvenile brown trout (both upstream and downstream), and low numbers of longfin eel (At Risk) and upland bully (Not Threatened; Dunn *et al.* 2018), which were only caught at downstream of the culvert (Instream Consulting 2020a). The only migratory species recorded, the longfin eel, is a strong climber, and adults are moderate swimmers.

Figure 12: The perched culvert in Hukahuka Turoa Stream before (left) and after remediation (right).

Solution: Due to the absence of weak swimmers, and the only migratory species in the vicinity being longfin eel, the solution was tailored towards providing passage for this species. This included the installation of a rock ramp and mussel spat rope running through the culvert.

Costs: Total construction cost of $24,000 excluding monitoring, professional services, and fish salvage. Of this, $3,400 directly relates to the installation of the mussel spat ropes. The cost of the downstream fish ramp is unknown. It should be noted that this project was competitively priced by the contractor, and relatively local to Christchurch for a Banks Peninsula site, which also reduced costs (Neil Andrews, 2021, Pers. Comm.).

Remediation effectiveness: Follow-up monitoring has not been carried out at this location, due to the large number of natural barriers downstream and low densities of migratory fish encountered downstream during the fish survey. However, the remediation is likely to enhance passage for the target species, longfin eels. The installed ramp is perpendicular with the main flow (Figure 12), creating a low velocity environment for climbing fish. The mussel spat ropes provide a rough surface with low velocity zones for climbing species ascending the ramp and through the culvert. The spat ropes were, however, loose at the downstream end (Jeff Bellamore, 2021, Pers. Comm.), which may result in rope clumping (removing swimming lanes between ropes) and increasing risk of debris snags. As a result, the ropes needed to be tightened. Effective installation of spat ropes, including the requirement for tight ropes, is outlined in Franklin *et al.* (2018). Regardless of installation, regular maintenance of fish pass additions is required to preserve hydraulic and ecological functions (Franklin *et al.* 2018).

Lessons learnt:

- Correct installation of fish passage enhancing structures, following relevant guidelines, is necessary to achieve the maximum benefit to fish passage, reduce risks to blocking culverts, and prevent additional follow-up work.
- Low velocity ramps may be able to be constructed out of the main flow, allowing for enhanced passage while minimising the effects on water conveyance.

3.3.5. Steamwharf Stream Fish-Friendly Tide Gate

Waterway: Steamwharf Stream

Location: Ferry Road

FPAT ID: 134110

CCC Asset ID: SwValve 492

Fish passage issue: Tide gate that was a high risk for upstream migrating fish. It had previously been manually propped open to enhance fish passage, but the tide gate was in a poor state of repair and needed replacement.

Upstream habitat potential: Up to 1.4 km, excluding pipes (CCC watercourse GIS layer).

Fish community: Several migratory fish have been recorded upstream of the structure, including, inanga, longfin eel, and giant bully (all At Risk species), as well as common bully, redfin bully, and shortfin eels (all Not Threatened species; Dunn *et al.* 2018). Inanga spawning habitat is present upstream.

Solution: Fish-friendly tide gate installed. This type of tide gate includes a counterbalance to delay gate closure on the incoming tide (Figure 13).

Figure 13: Steamwharf Stream tide gate before (left) and after (right) remediation. The right-side photograph shows the structure on an incoming tide, with the counterweight delaying gate closure.

Costs: Estimated to cost approximately $50,000 (Grant Stowell, 2021, Pers. Comm.)

Remediation effectiveness: Effectiveness of this remediation was discussed in a report prepared by Instream Consulting (2018) for CCC, regarding fish-friendly tide gates in the city. The fish-friendly tide gate was determined to be effective at delaying the closure of the gate, allowing for the gate to be open for a longer period on an incoming tide (as shown in Figure 13). The presence of many migratory species and abundant inanga (including juveniles) upstream of the structure was also viewed as a strong indicator that the fish-friendly gate was allowing fish passage.

3.3.6. Avoca Valley Fish-Friendly Tide Gates

Waterway: Avoca Valley Stream

Location: Ferrymead Golf Club

FPAT ID: 134911

CCC Asset ID: SwValve 170

Fish passage issue: Tide gates that were in a poor state of repair needed replacing. Standard tide gates would present a high risk to passage for upstream migrating fish.

Potential upstream habitat: Up to 14.6 km, excluding pipes (CCC watercourse GIS layer). Note that the upper reaches of this catchment are likely ephemeral, therefore the actual length of aquatic habitat is probably somewhat lower.

Fish community: A survey of fish passage through fish-friendly tide gates for CCC (Instream Consulting 2018) recorded a community dominated by migratory and estuarine species, including inanga, longfin eel, and giant bully (all At Risk species), as well as common bully, shortfin eel, yellow-eye mullet, and black flounder (all Not Threatened species; Dunn *et al.* 2018).

Solution: The old tide gates were replaced with two fish-friendly gates (Figure 14). These gates were much larger than the standard fish-friendly design, requiring two counterbalance arms on each gate.

Figure 14: The old tide gates (left) and new fish friendly tide gates (right) in Avoca Valley Stream near the Ferrymead golf course.

Costs: $140,000

Remediation effectiveness: Effectiveness of this remediation was discussed in a report prepared for CCC (Instream Consulting 2018) regarding fish-friendly tide gates in the city. The gates were determined to be effective at allowing fish passage, indicated by the strong dominance of migratory and estuarine species upstream (including abundant yellow-eye mullet). At the time of writing the assessment report, there was concern that the gates did not remain open long enough to inundate salt marsh habitat upstream, which includes the threatened New Zealand musk, *Thyridia repens* (McCombs 2018). Subsequent observations by CCC ecologists indicates that there has been a reduction in the extent of salt marsh upstream.

Lessons learnt:

- Fish-friendly tide gates may allow passage for a range of migratory and estuarine species.
- When altering tide gates, careful consideration must be made of the potential ecological effects of altering tidal regimes upstream, including saltwater penetration.

3.3.7. Takamātua V-notch Weir

Waterway: Takamātua Stream Branch No 7

Location: Old Le Bons Track, near Coombe Farm

FPAT ID: 1411

CCC Asset ID: Unknown, upstream of bridge A33.

Fish passage issue: High water velocities and drop height through v-notch flow gauging weir (Figure 15).

Potential upstream habitat: Up to 6.5 km

Fish community: A fishing investigation identified an abundant fish community downstream of the structure (Instream 2020, unpublished). This community included bluegill bullies and longfin eels (both At Risk species), as well as redfin bullies (Not Threatened; Dunn *et al.* 2018), and a single whitebait. It is highly likely that banded kokopu or koaro are also present in the catchment, based on their presence in similar nearby streams. Upstream of the weir no fish were caught, indicating that the weir is a significant fish barrier.

Priority and values: This structure was considered a high priority (R5) for remediation in the current study. It fulfils many of the suggested ecological prioritisation criteria (Table 1). It is proximate to the coast (1.4 km), with a relatively large upstream catchment (6.5 km), that includes divers flow habitats and native riparian vegetation (Figure 15). There are no known barriers upstream of the weir. Numerous species downstream are likely to benefit from the remediation of this structure, including two At Risk species.

Figure 15: The Takamātua v-notch weir (left) and upstream habitat (right).

Potential remediation and cost:

In order of ecological benefit:

1. Removal: If the flow gauging at this location is no longer required, complete removal would provide the greatest ecological benefits.

2. Addition of a downstream rock ramp: If flow gauging at this location is still required, a downstream ramp could be installed to assist fish passage. Given the high-energy stream environment, the best ramp option would likely be a concrete ramp embedded with numerous angular rocks. In a study on redfin bully passage, successful passage was found to significantly reduce from 15–30 degree slope, however, wetted margins allowed this species to climb on greater slopes (Baker and Boubée 2006). Therefore, important design features to incorporate in this rock ramp would be a low gradient slope, wetted margins, and resting pools.

This would be an excellent site to monitor remediation success, given the abundant and relatively diverse fish fauna found immediately downstream and the lack of fish found upstream.

Costs: Installation of a rock ramp is estimated to cost in the order $15,000 (Grant Stowell, 2021, Pers. Comm.). There would be additional costs for fish salvage and post-enhancement monitoring.

3.3.8. Knights Stream Weir

Waterway: Knights Stream

Location: Sabys Road

FPAT ID: Not FPAT assessed

CCC Asset ID: Not in WcWeirs GIS layer

Fish passage issue: A water level recorder needed to be installed, but standard gauging weirs can present a significant barrier to fish passage.

Potential upstream habitat: Up to 6.9 km (excluding McCarthys Drain, which is often dry), of which approximately 4.8 km has perennial flow.

Fish community: The fish community near this location was recently surveyed during the 2021 round of the CCC five-yearly monitoring of the Halswell River catchment (Instream Consulting 2021a). A single longfin eel (At Risk), as well as non-migratory upland bullies (Not Threatened; Dunn *et al.* 2018), were recorded immediately downstream. While no weak swimmers were recorded at this location, a single inanga was recorded at Tai Tapu Road (c. 3 km downstream) and in Creamery Stream, which joins Knights Stream c. 1 km downstream. Additionally, there are NZFFD records of low abundances of inanga in Creamery Stream and the inline pond system. During the 2021 round of the CCC five-yearly monitoring, three migratory species were recorded at locations upstream, including common bully and shortfin eels (both Not Threatened species), as well as longfin eel (At Risk; Dunn *et al.* 2018), indicating that the structure is not a barrier to fish passage.

Solution: A rock riffle was installed in 2015 to provide the necessary hydraulic requirements for the water level recorder station, while allowing for fish passage.

Figure 16: The weir just after construction in 2015 (left) and in 2021 (right).

Costs: $44,000 of which approximately half could be considered to relate to fish passage (Paul Dickson, 2021, Pers. Comm.).

Effect on fish passage: With regards to fish passage, the selected rock riffle weir design is superior to other alternative flow gauging designs, such as v-notch or crump style. Consideration of fish passage was given during the design of this structure. This included design criteria of c. <0.3 m/s velocity, with a riffle gradient of 1:20. This is steeper than the 1:30 slope required on all new weir structures by the NESF (Parliamentary Counsel Office 2020), but the structure pre-dates the guidance in the NESF. Velocity measurements made by Instream in March 2021 revealed that velocities <0.3 m/s were generally achieved on the margins of the riffle, with marginal velocities being comparable to downstream run habitat (Figure 17). While the low marginal velocities and abundant rest areas among cobbles and marginal vegetation is likely to allow passage for many species, the high velocities through most of the channel may deter a proportion of inanga swimming upstream, especially smaller individuals. Stronger swimming species are unlikely to be deterred by these velocities. The presence of eels upstream, including a juvenile that must have passed this location since construction of the riffle, indicates that it is indeed passible by these species.

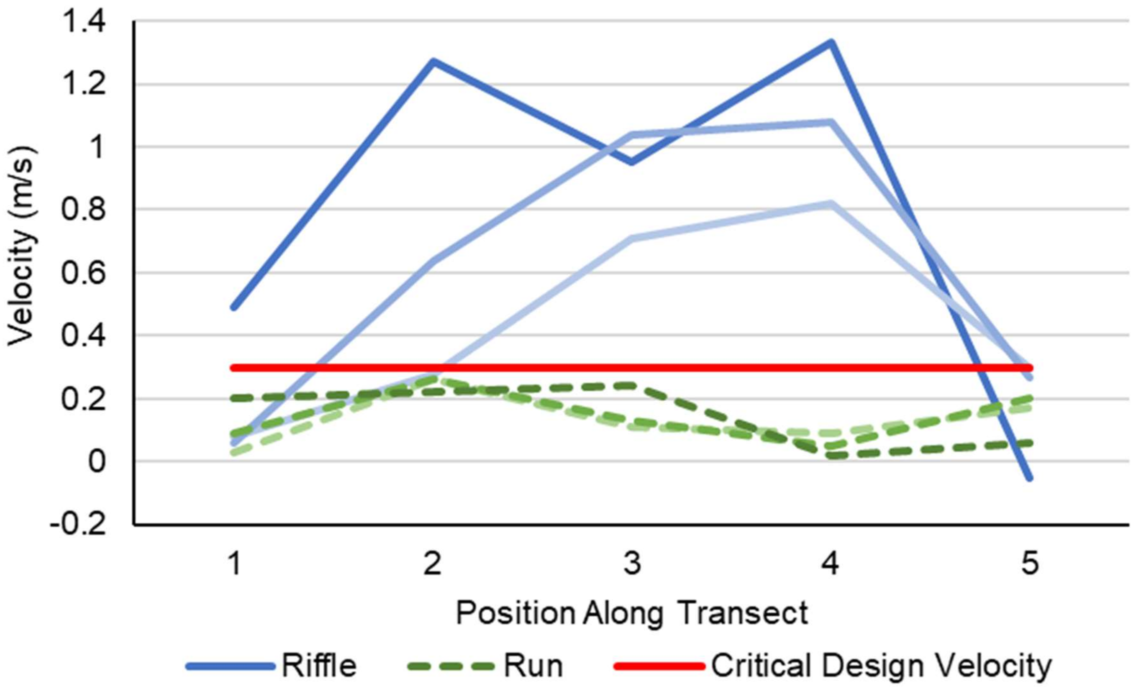

Figure 17: Velocity profile through the riffle section of the weir compared to downstream run habitat. Critical design velocity (<0.3) included.

Lessons learnt:

- If rock riffle weirs meet the requirements for flow gauging, they are a superior design choice compared to alternatives, from a fish passage perspective.
- Latest fish passage guidelines and ecology advice should be considered when designing similar future structures.

4. CONCLUSIONS AND RECOMMENDATIONS

A total of 38 structures in the Christchurch district were determined to be a high priority for remediation projects or fish surveys. Of these high priority structures, 20 were associated with CCC assets. Of the assessed CCC assets, culverts were the most common high priority structure type. Culvert perching was identified as a particularly common feature on Banks Peninsula. Weirs, dams, and flow restrictions were the second most common CCC assets to appear in the high priority categories. These structures are often associated with stormwater treatment facilities. Targeted monitoring is required to determine to what level fish are using stormwater facilities, and any fish passage issues.

The priority catchment most significantly impacted by fish passage barriers was the Ōtūkaikino, with inanga demonstrated to be excluded from up to 35 km of habitat by artificial instream barriers. The current prioritisation model included a strong weighting on such priority catchments. However, many high-risk structures were identified outside of these catchments, some with potentially substantial impacts on fish passage. Notable examples include the Mona Vale weir in the Avon River and the Waikākāriki / Horseshoe Lake pumpstation and flap gates.

Such structures should not be excluded from further investigation and remediation discussions, especially once the key structures in priority catchments have been addressed. Similarly, the current prioritisation model does not include pipe networks.

Lessons learnt from fish passage remediation projects already completed in the district include:

- New structures and repairs to existing structures should be designed in consultation with an ecologist and with reference to New Zealand fish passage guidelines.
- Hands-on guidance is required during construction of fish passage enhancements, because many contractors lack experience in building structures for fish passage.
- Well-designed rock riffles and concrete ramps with rocks embedded can provide good fish passage and are much better alternative to traditional weirs that are often significant fish barriers.
- Fish-friendly tide gates have varying degrees of ecological success. It is important to consider impacts beyond fish passage, such as salt marsh vegetation upstream.
- When choosing sites for follow-up fish monitoring after remediation, choose locations with good numbers of fish downstream. If downstream densities are low, it will be difficult to detect an impact of fish passage improvement.
- It is important to pass on results of any follow-up monitoring to designers, to help with future designs.

Based on the results of this prioritisation project, we recommend the following:

- Discussions with CCC engineers should take place around design solutions for the eight high remediation priority CCC assets.
    - Ōtūkaikino should be a focus catchment.
- Discussions with ECan should take place for high priority, non-CCC assets.
- Fish surveys should be carried out for high priority fishing structures, including:
    - Brief habitat surveys to determine habitat quality.
    - Stream walks to validate upstream potential and identify barriers.
- Once remediation plans for high priority structures in priority catchments are underway, structures in non-priority catchments with R3 priorities should be further examined as many represent major fish passage barriers.
- Targeted fishing and ecological surveys should be carried out in stormwater treatment facilities.
    - Stormwater facilities include numerous structures that are potential fish barriers, but their impact on fish passage is often not investigated, however:
    - Further investigation is also required to determine if it is appropriate to provide passage into such facilities.
- Where possible, fish passage enhancements should aim to coincide with renewals to increase construction efficiency.
    - Especially beneficial at locations with high transport costs.
- Follow-up fish surveys should be carried out on remediated structures, unless low fish abundances are recorded downstream during pre-remediation fish surveys.

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APPENDIX 1: SUMMER 2020–21 FPAT ASSESSMENTS

Preliminary analysis of the prioritisation database in 2020 identified 573 high priority assessment structures (i.e., A5 and A4) owned by CCC. These structures included any pump stations, flap gates, weirs, and dams (in all catchments), as well as culverts and fords (in priority catchments). With funding from CCC and supervision by Instream, a summer student was commissioned to complete FPAT assessments of as many of these structures as possible, over the summer period. The following sections describe these assessments, and how it has affected the prioritisation database.

Through GIS processes aimed at removing pipe network structures and records not relevant to fish passage (described in Appendix 2), the number of high priority CCC assessment structures was reduced to 288. Over the summer 2020–21 period, the assessor visited 280 of these structures, of which, 175 (61%) resulted in complete FPAT assessments that were included in the prioritisation database. For the 105 visited structures that did not result in an FPAT survey, the assessor recorded the reason for not assessing and took photographs when appropriate. Most commonly this reason was either that the waterway was dry (26% of non-assessments) or the structure could not be located (21% of non-assessments). Other common reasons for not assessing structures included: structure inaccessible to public, structure physically inaccessible, or structure associated with a pipe network (12%, 8%, and 14% of non-assessed structures, respectively). Visited structures that were recorded as being dry were removed from the prioritisation database as they pose no risk to fish passage, while all other visited structures were kept in the database.

A low number of structures from the summer assessments were identified as high priorities for further action. Only a single structure was identified as a high priority for remediation (R4) while 3 were identified as high priorities for fishing (R4; Table 1). All these structures are discussed in the body of this report in Section 3.1. Most assessed structures were determined to be low priority for further action, with 77% of assessed structures receiving R2, R1, F2, or F1 priorities. However, there were a total of 37 structures in the R3 and F3 categories, 18 of which were located outside of priority catchments. While some of these structures may be significant barriers to fish passage, there priorities are limited in the current model by the priority catchment filter. Of these 18 structures, 14 (78%) were determined by the assessor to be of High or Very High risk to fish passage, indicating that they would likely be priorities for further action, if the priority catchment filter was removed.

Through the completion of the summer FPAT assessments, and the GIS routines described in Appendix 2, the number of CCC structures in the high priority for assessment categories has reduced from 573 to 64. Of these remaining structures, 40 were visited during the summer FPAT assessments, but were unable to be assessed. The 175 FPAT assessed CCC structures represents a substantial contribution to the coverage of the FPAT database in the Christchurch district, with the database now containing complete records of 480 structures, at the time of writing.

Table 1: The number of CCC structures in each prioritisation category that were assessed over the summer.

Priority	Structures
R5	–
R4	1
R3	17
R2	8
R1	38
F5	–
F4	3
F3	20
F2	34
F1	54
Total:	**175**

APPENDIX 2: TECHNICAL GIS ROUTINES

The following paragraphs describe the various GIS routines that were used to create the final prioritisation database. These processes were designed to enable the joining of the CCC asset data with the FPAT database, while focusing on the inclusion of CCC assets relevant to fish passage.

Joining CCC assets and FPAT records

Bridge locations were downloaded from the online RAMM database (https://go.ramm.com), with access provided by CCC. All other CCC asset data was accessed via the publicly available Web Feature Services (WFS; https://opendata.ccc.govt.nz/StormWater and https://opendata.ccc.govt.nz/WaterCourse). From these services, layers containing features that may be barriers to fish passage were selected (Table 1). Each layer was reduced to structure types that were relevant to fish passage and associated with open watercourses (i.e., not piped networks). For example, only structures of the types 'Flap' and 'Tide Gate' were included from the SwValve layers, as other structure types from this layer were largely associated with stormwater pipe outfalls and were outside the scope of the current project.

Table 1: The CCC asset layers included in the study. Included assets represents the number of structures included in the final database, after processing.

CCC GIS Layers	Included Structure Types	Included Assets
SwPipe	Arch Culvert, Box Culvert, Brick Barrel, Bridge, Culvert, Field Tile, Gravity[1]	914
RAMM	All bridges	357
WcWeirs	Circular, Rectangular, Slot, V Notch, Unknown, Not Applicable	145
SwValve	Flap, Tide Gate	46
SwPump	Pump	12
SwFlowRestriction	Weir	10
WcValve	Flap, Penstock, Unknown	9
	Total:	**1,493**

[1]Note that this structure type was only included for Banks Peninsula waterways, as it is often associated with pipe networks in the city.

To further reduce the number of features in the prioritisation database that were associated with pipe networks, features that were not located on the CCC GIS WaterCourse lines were excluded. For features in the SwPipe layer this was a two-step process. Culverts in the CCC SwPipe database may consist of multiple assets (i.e., multiple pipe sections, each with a unique ID). To create a single point asset for each culvert, features from the SwPipe layer were selected that intersected NZTA road centreline layer (Figure 1). Points were then created for all selected SwPipe features. Finally, SwPipe features not on CCC watercourse lines were excluded, creating a dataset of culverts that were not associated with pipe networks. Note that this method does not capture piped sections that do not intersect roads, as demonstrated in Figure 1.

Figure 1: The selection of a single culvert asset by intersecting the layer with road centrelines, for which points were created (top). Pipes that were not on CCC watercourse lines (bottom left) were excluded (bottom right), reducing noise in the dataset. Note that this method does not capture pipes that do not intersect roads, as highlighted by the white circle on the bottom right map.

The CCC asset database was then joined with the FPAT database. This join was carried out spatially, with FPAT records within 20 m of a CCC asset assumed to relate to that structure. In instances where multiple CCC assets fell within 20 m of an FPAT record, the asset with the highest perceived risk to fish passage was assigned to the record (as per a modified version of rule based risk assessments of Franklin (2018). For example, an FPAT record in the vicinity of a culvert that ends in a flap gate would be assigned the flap gate CCC asset ID. When multiple assets of the same risk were in the vicinity (e.g., multiple parallel culverts), the closest asset to the FPAT record was selected. This spatial join allowed for the identification of FPAT assessments of CCC assets, as well as preventing the inclusion of double-ups between FPAT records and CCC assets. The remaining unpaired records from both databases were then also included.

For the purposes fitting data to the decision tree model, all records in the database required a single structure type. However, sometimes the FPAT records and the CCC records did not agree on the structure present at a location. To create a consistent unified structure type between the FPAT and CCC databases, a hierarchical approach was used, where the structure type from what was decided to be the most accurate data source was used. The structure of this hierarchy was: Complete data (i.e., ground truthed with photographs) > CCC asset data > incomplete FPAT records (i.e., historic datasets and river-road intersections)

Additional manual edits

The database was further refined through a series of mostly manual processes, aimed at reducing noise (i.e., irrelevant or inaccurate records) in the database. Double-ups in the FPAT database were removed by inspecting all records within 20 m of another FPAT record and selecting the most complete of the two. Double-ups that were more than 20 m apart were removed opportunistically if they were detected. Despite the processes to remove structures associated with pipe networks detailed above, further records required manual removal. This additional process was entirely manual, involving a visual scan of the GIS database and removal of structures associated with the pipe network. This process was carried out prior to the summer FPAT assessments to prevent assessors losing time looking for underground structures in the field.

Further records were removed over the summer FPAT assessment period. These included structures at locations where surveyors recorded the waterway as dry (i.e., having no fish habitat). In such instances, the structures were decided to have no implications for fish passage, thus the records were removed. Records from the WcWeirs database were also refined manually. Initially this layer contained a variety of structures ranging from permanent to temporary, with varying levels of significance regarding fish passage. By examining photographs in the internal CCC database, temporary structures and those decided to have little impact on fish passage were excluded from the prioritisation database.

Through a combination of the above processes, 502 records were manually removed from the prioritisation database.

APPENDIX 3: ALL HIGH PRIORITY STRUCTURES

Table 1: All high remediation and fishing priority (R5, R4, F5, & F4) structures of all ownerships.

FPAT ID	CCC Asset ID	Ownership	Structure type	Priority	East (NZTM)	North (NZTM)
278	RAMM W11	CCC	Weir dam or flow restriction	R4	1586352	5150936
286	SwPipe 76008	CCC	Culvert or pipe	F4	1571477	5168934
295	SwPipe 58366	CCC	Culvert or pipe	F4	1585556	5155791
317	SwPipe 96452	CCC	Weir dam or flow restriction	F4	1574993	5172307
1050	SwPipe 60168	CCC	Culvert or pipe	F4	1591569	5161650
1105	SwPipe 60656	CCC	Culvert or pipe	F4	1601082	5164156
1140	WcWeirs 242	CCC	Weir dam or flow restriction	R5	1592254	5148617
1194	SwPipe 59843	CCC	Culvert or pipe	F4	1584853	5162183
1234	RAMM W17	CCC	Culvert or pipe	F4	1583692	5151522
1326	SwPipe 61976	CCC	Culvert or pipe	F4	1606808	5155964
1411	RAMM A33	CCC	Weir dam or flow restriction	R5	1598653	5151961
130043	SwPipe 46740	CCC	Culvert or pipe	R4	1568544	5189564
130044	WcWeirs 200	CCC	Pump	R4	1568639	5189432
130047	WcWeirs 199	CCC	Weir dam or flow restriction	R5	1568247	5189093
130166	SwPipe 87535	CCC	Other	F4	1566304	5174775
131907	WcValve 27	CCC	Gate or valve	R5	1575012	5195032
132979	SwPipe 45899	CCC	Culvert or pipe	R4	1566586	5175255
134866	SwPipe 76048	CCC	Culvert or pipe	F4	1571742	5170327
134912	SwValve 306	CCC	Gate or valve	F4	1579282	5176321
136467	SwValve 501	CCC	Gate or valve	F4	1576544	5178346
1233	SwPipe 63381	NZTA	Culvert or pipe	F5	1585022	5155029
136473	SwPipe 46635	Private	Culvert or pipe	R4	1571322	5187116
276		Unknown	Weir dam or flow restriction	R4	1586377	5150922
1107		Unknown	Ford with culvert	F4	1600148	5158584
1174		Unknown	Ford with culvert	R4	1576306	5166132
1177		Unknown	Ford with culvert	F5	1576552	5165478
1184		Unknown	Ford with culvert	F4	1571534	5167559
1196		Unknown	Weir dam or flow restriction	F4	1571532	5167612
1228		Unknown	Weir dam or flow restriction	F4	1598641	5148926
1229		Unknown	Weir dam or flow restriction	F4	1599409	5149736
1241		Unknown	Ford with culvert	F4	1598640	5163935
1412		Unknown	Ford with culvert	F4	1594698	5157143
1413		Unknown	Weir dam or flow restriction	F5	1599237	5151349
1414		Unknown	Weir dam or flow restriction	F5	1599286	5151337
1439		Unknown	Ford with culvert	F4	1595728	5155802
28208		Unknown	Weir dam or flow restriction	F5	1571520	5167657
109234		Unknown	Culvert or pipe	F5	1571546	5168817
133560		Unknown	Ford with culvert	F4	1583594	5155952