Monitoring of Fish-Friendly Tide Gates, Fish, and Salt Marsh Communities

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EXECUTIVE SUMMARY

This report describes the results of monitoring “fish-friendly” tide gates, fish communities, and salt marsh ecosystems around Christchurch’s Avon-Heathcote Estuary / Ihutai. The report aim is to help inform future management of tide gates in general and the Avoca Valley Stream tide gates in particular.

Use of time-lapse photography in Steamwharf Stream proved useful for showing general patterns in tide gate opening in relation to tide height. However, observations were limited to daylight and converting the photographs into data on gate opening width and duration was labour-intensive. Accelerometers mounted on both the Steamwharf Stream and Avoca Valley Stream tide gates provided very useful data on gate opening duration and angle. The addition of telemetered water level monitoring upstream and downstream of the Avoca Valley Stream tide gate also proved very useful.

Disengaging the counterweight on the Steamwharf Stream tide gate reduced the mean gate opening width by 256 mm and gate opening duration by 33 minutes over a 24 hour period. This indicates that the fish-friendly tide gate at Steamwharf Stream provides substantially greater opportunity for migratory fish to pass upstream than would be provided by a conventional tide gate.

A total of seven fish species were recorded upstream of tide gates in Steamwharf Stream, Avoca Valley Stream, and Truscotts Stream Branch. Six of the species caught upstream of the tide gates migrate between freshwaters and the sea to complete their life history, and one species (yelloweye mullet) is primarily a marine species. All fish species that were relatively abundant included a range of smaller juveniles and larger adult fish, indicating that the fish-friendly tide gates were not impeding fish recruitment.

Overlying salt marsh survey data with topographic data indicated that tides need to reach a relative level (RL) of 10.3 m (Christchurch Drainage Datum) to inundate the Avoca Salt Marsh. This was validated by observations of tidal waters entering salt marsh pond complexes when the tide reached RL 10.3 m during a period when the tide gates were propped open.

Monitoring of the Avoca Valley Stream tide gates indicated that under normal operation, water levels immediately upstream of the gates were typically 900 mm lower than downstream of the gates at high tide. High tide water levels typically varied from RL 9.9 to 10.6 m downstream of the tide gates but varied over a narrower range of RL 9.4 to 9.6 m upstream of the tide gates.

Water conductivity was higher and more variable at most monitoring sites during a period when the tide gates were propped open, reflecting the greater tidal range. A complex of shallow ponds and salt marsh vegetation showed large swings in conductivity when the tide gates were propped open. Observations over several tides revealed that the ponds were intermittently inundated by spring tides that pushed saline water up Avoca Valley Stream and its tributaries. This did not occur when the tide gates were operating normally.

We recommend that before installing, repairing or replacing any tide gates, CCC staff check what natural values may be affected by altering the tide gate management regime. We also recommend adjusting the Avoca Valley Stream tide gates so that they only close after reaching an RL of 10.3 m, to protect the salt marsh community upstream. Further recommendations are provided in the report.

1. INTRODUCTION

Tide gates have historically been installed at the mouth of coastal waterways to protect upstream property from inundation caused by large tides and heavy rain. At their simplest, tide gates comprise a flap at the end of a pipe culvert that allow water to drain out and prevent the ingress of tidal waters upstream. In practice, many tide gates leak to some extent, but they all dampen the tidal range upstream.

Several tide gates around the Estuary of the Avon-Heathcote Estuary / Ihutai were damaged following the Canterbury earthquake series of 2010 and 2011. Damaged tide gates at the mouths of Avoca Valley Stream, Truscotts Branch Stream, and Steamwharf Stream were all replaced with “fish-friendly” tide gates (FFGs). The FFGs are made by ATS Environmental and incorporate a counterweight and double hinge design to delay gate closure on an incoming tide, which provides a longer window of opportunity for fish to migrate upstream. See Table 1 for details of when the tide gates were replaced.

In early 2018, Christchurch City Council (CCC) commissioned a study to investigate the effectiveness of the new FFGs at delaying tide gate closure and improving fish passage. After the gate monitoring project had commenced, concerns were raised by CCC Parks Rangers regarding impacts of the newly installed Avoca Valley Stream FFG on salt marsh vegetation. The Avoca Salt Marsh had grown in extent following the earthquakes, due to the damaged tide gate allowing for an increased tidal range, and possibly also due to land subsidence. The concern was that reinstating the gates would result in negative impacts on the newly-extended salt marsh habitat. This resulted in an extension of the FFG monitoring study to investigate impacts of the Avoca FFG on the salt marsh upstream.

This report summarises results of investigations into the effectiveness of the new FFGs at providing fish passage and also summarises impacts of the Avoca FFG on upstream water levels and salt marsh. The purpose of this report is to help inform future management of tide gates in general and the Avoca Salt Marsh in particular.

2. METHODS

2.1. Site Descriptions

Avoca Valley Stream, Truscotts Stream Branch, and Steamwharf Stream all drain into the Estuary of the Avon-Heathcote Estuary / Ihutai near Tunnel Road in Ferrymead (Figure 1). The three streams drain urban catchments and range in size from 1.45 to 4.43 m wide and 4 to 21 cm deep at low tide (Table 1).

Truscotts Stream Branch is timber-lined, runs alongside Ferrymead Park Drive, and is the smallest of the three waterways studied (Figure 2). Most of the freshwater inflow into Truscotts Stream Branch has been diverted into a series of stormwater ponds to the east, markedly reducing freshwater flows downstream. The FFG at the mouth of Truscotts Stream Branch is a standard design, with a single cantilever arm and weight attached to a single gate that closes on a pipe culvert (Figure 2).

Steamwharf Stream flows through a CCC reserve upstream of the FFG, and it has natural banks that are heavily vegetated with native plants (Figure 3). Freshwater flows in Steamwharf

Stream are sourced from headwater springs. The Steamwharf Stream FFG is of a similar standard design to that at Truscotts Stream Branch (Figure 3).

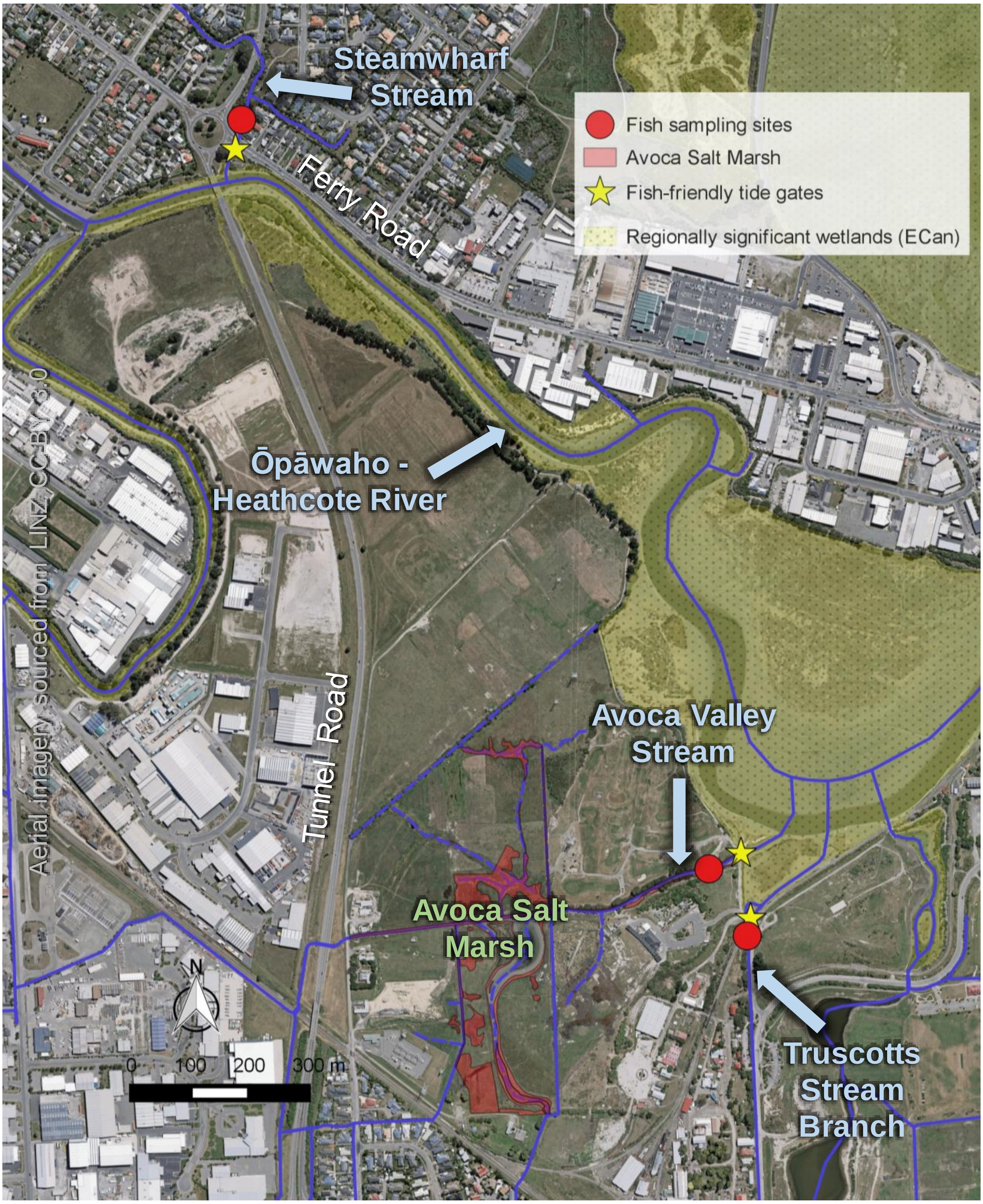

Figure 1: Location of the Avoca Salt Marsh and fish-friendly tide gates.

Table 1: Fish sampling site locations, their mean depth and width at low tide, and dates for completion of each new tide gate.

Site	Easting	Northing	Depth (cm)	Width (m)	Completion date for new tide gate
Avoca Valley Stream	1575916	5176398	21	4.43	19 January 2018
Steamwharf Stream	1575121	5177683	17	3.26	14 June 2017
Truscotts Stream Branch	1575970	5176284	4	1.45	7 July 2017

Note: Eastings and northings were taken at the downstream end of each sampling site and the map projection is New Zealand Transverse Mercator. Mean depths and widths were taken from four transects, each with three depth measurements.

Figure 2: Truscotts Stream Branch (left) and its fish-friendly tide gate (right).

Figure 3: Steamwharf Stream (left) and its fish-fiendly tide gate (right).

Avoca Valley Stream is the largest of the three streams studied, with mean water depths upstream of the tide gates of 21 cm at low tide. After draining through a mix of industrial and residential land, Avoca Valley Stream enters the Avoca Salt Marsh area, which comprises a mix of horse paddocks and stormwater detention basins. After leaving the Avoca Salt Marsh, the stream flows through into the estuary via two large rectangular culverts, each with a rectangular FFG with two cantilever arms and counterweights (Figure 4).

Figure 4: Avoca Valley Stream (left) and its fish-friendly tide gates (right).

2.2. Fish Sampling

Fish sampling was undertaken on 1 and 2 March 2018 upstream of each of the three FFGs, to determine what fish species and life stages were present. Six fine-mesh fyke nets and 12 Gee minnow traps (per Joy et al. 2016) were placed at each site and left overnight. The next day all fish were identified and counted, and their lengths measured. The exception was at Avoca Valley Stream, where only a subset of all fish caught had their lengths measured, due to the large numbers of fish caught and the desire to return them quickly back to the stream to minimise stress.

The nets and traps were not baited, so that they passively sampled fish swimming past. Fyke nets were placed densely in a herringbone fashion, with the leader facing downstream on alternating banks (Figure 5). This was done to maximise the likelihood of catching fish swimming upstream past the gates, as well as downstream migrants.

2.3. Salt Marsh Vegetation Sampling

A botanical survey of the Avoca Salt Marsh was undertaken on CCC-owned land by Kate McCombs in May and June 2018. Methods and results of the survey are detailed in McCombs (2018), and the results are briefly summarised in Section 3.2 of this report.

GIS shapefiles of the vegetation survey were provided to the CCC land drainage team, who overlaid the vegetation outline with recent levels obtained from LiDAR (Light Detection and Ranging). The LiDAR data were used to assess the level at which the surveyed vegetation would be inundated at high tide. It was also used to estimate whether allowing the vegetation to be inundated at high tide would appreciably affect flood storage capacity.

Figure 5: Fyke nets and minnow traps arranged to maximise fish capture rates in Truscotts Stream Branch.

2.4. Gate and Water Level Monitoring

Two different methods were trialled at Steamwharf Stream to monitor FFG opening and water levels. Steamwharf Stream was chosen for the initial trial because inanga spawning occurs upstream and the stream has been the focus of considerable restoration efforts in the past. The first monitoring method involved temporary installation of a weather-proof time-lapse camera to determine gate opening duration, following the general method described by Bocker (2015). A temporary staff gauge was installed beside the FFG, so that the water level could be recorded when each time lapse photograph was taken (Figure 6). The second method involved measuring gate angle with a MPU6050 tri-axial accelerometer, aligned parallel to the gate and mounted to the web of the gate. Accelerometer data were recorded at 5 minute intervals on a standalone data logger. The accelerometer installation and monitoring was undertaken by Altissimo Consulting.

Following the initial trial at Steamwharf Stream, monitoring focussed on Avoca Valley Stream. Altissimo Consulting attached two accelerometers to the Avoca Valley Stream FFGs, with one on each gate (Figure 7). At this site, the accelerometers recorded gate angle every 15 minutes, and data were telemetered. In addition, water levels were monitored at three locations: immediately downstream of the gates, immediately upstream, and approximately 230 m upstream of the gates. Water levels were determined using a Maxbotix MB7389 ultrasonic range finder, referenced to a surveyed location (Figure 7). The relative level (RL) of the water is presented in terms of the Christchurch Drainage Datum. The distance to the surface was averaged over a 10 second period, with samples taken every 15 minutes and telemetered. Anomalous data (caused by floating debris or other obstructions) were removed by Altissimo Consulting in post processing.

Figure 6: Time-lapse camera and temporary staff gauge setup at Steamwharf Stream.

Figure 7: Gate monitoring accelerometer (left) and water level recording (right) at Avoca Valley Stream tide gates.

The counterweight on the Steamwharf Stream FFG was temporarily disengaged for several days to assess the relative impact of the FFG on gate opening width and duration. The Avoca Valley Stream FFGs were held open for one week, to determine the extent to which the culverts themselves were constraining tidal range upstream.

2.5. Conductivity Monitoring

Water conductivity and salinity was measured at multiple points along Avoca Valley Stream and its tributaries, using calibrated YSI handheld meters. Monitoring was undertaken over a range of lower and higher tides, both when the gates were operating normally and when they were held open for approximately two weeks. Some additional spot-measurements were made of conductivity and salinity, in relation to spring high tides and inundation of side ponds.

3. RESULTS AND DISCUSSION

3.1. Fish Communities

A total of seven fish species were caught upstream of the three FFGs (Table 2). The total number of fish caught at each site ranged from 134 fish at Truscotts Stream Branch to 595 fish at Avoca Valley Stream (Figure 8). The number of fish species caught per site ranged from four at Truscotts Stream Branch to seven at Avoca Valley Stream. Common bully, giant bully, longfin eel, and shortfin eel were found at all three sites, while inanga were only caught at Avoca Valley Stream and Steamwharf Stream. Yelloweye mullet and black flounder were only caught from Avoca Valley Stream (Table 2).

Inanga, longfin eel, and giant bully are all of conservation interest, because they have an “At Risk” threat status (Dunn et al. 2018). In addition, inanga, both eel species, black flounder, and yelloweye mullet are also valued mahinga kai and support recreational fisheries. Juvenile inanga comprise the majority of the highly-valued whitebait catch that migrates into estuaries and rivers every spring.

All fish caught are native species that spend varying amounts of time in both freshwater and the marine environment. Common bully, giant bully, inanga, longfin eel, shortfin eel and black flounder spend most of their life history in freshwater and migrate to sea to complete part of their life cycle. In contrast, yelloweye mullet spend their entire life history in the marine environment, only venturing upstream into estuaries on high tides, and they cannot live permanently in freshwater (McDowall 2000).

Common bully, giant bully, and inanga all spawn in rivers, with juveniles developing in the ocean, before migrating upstream to mature. Longfin and shortfin eel spawn in the ocean and transparent juvenile glass eels migrate into estuaries, then quickly darken to become elvers (colloquially known as “bootlace eels”), which migrate upstream. Black flounder also spawn at sea, although their life history is not well known (McDowall 2000).

Indicators that all three FFGs were passing fish include the complete dominance of migratory species upstream of the gates and also the number of juvenile fish recorded. Eel elvers were recorded from all three sites and they were particularly abundant at Avoca Valley Stream, where 65 individuals were caught (compared to a combined total of 74 larger longfin and shortfin eels). While elvers were uncommon at Steamwharf Stream (only one elver was caught), inanga were most abundant at this known spawning waterway, with a total of 40 caught across a broad size range (56 to 113 mm long). Yelloweye mullet were only caught from Avoca Valley Stream, where a total of 185 fish were caught, ranging in size from 81 to 282 mm (Table 2).

Table 2: Abundance of fish at each site with size range (mm) in brackets.

Site	Common bully	Giant bully	Inanga	Longfin eel	Shortfin eel	Elver	Yellow-eye Mullet	Black Flounder
Avoca	**221** (43 - 100)	**47** (94 - 149)	**2**	**13** (530 - 850)	**61** (131 - 1002)	**65** (76 - 144)	**185** (81 - 282)	**1** (106)
Steamwharf	**80** (44 - 109)	**51** (64 - 198)	**40** (56 - 113)	**3** (330 - 570)	**16** (160 - 994)	**1** (126 - 126)		
Truscotts	**85** (42 - 99)	**16** (88 - 139)		**1** (392 - 392)	**28** (132 - 910)	**4** (95 - 172)		

Note: Abundance is the total from six fyke nets and 12 minnow traps.

The FFGs at Steamwharf Stream and Truscotts Stream Branch were completed in June 2017 and July 2017, respectively (Table 1). Based on their small size, many of the smaller common bullies caught at both streams would have passed upstream through the tide gates after the FFGs were completed. Similarly, juvenile inanga at Steamwharf Stream and small elvers at Truscotts Stream Branch would most likely have entered these waterways after the FFGs were completed. The Avoca Valley Stream FFG was not completed until mid-January 2018 and the fish sampling occurred in early March 2018. It is therefore possible that the juvenile bullies and eels caught in Avoca Valley Stream had entered the waterway prior to the FFG being built. However, the yelloweye mullet caught upstream of Avoca Valley Stream FFG would almost certainly have ventured upstream after the FFG was completed, given the transitory nature of mullet in freshwater.

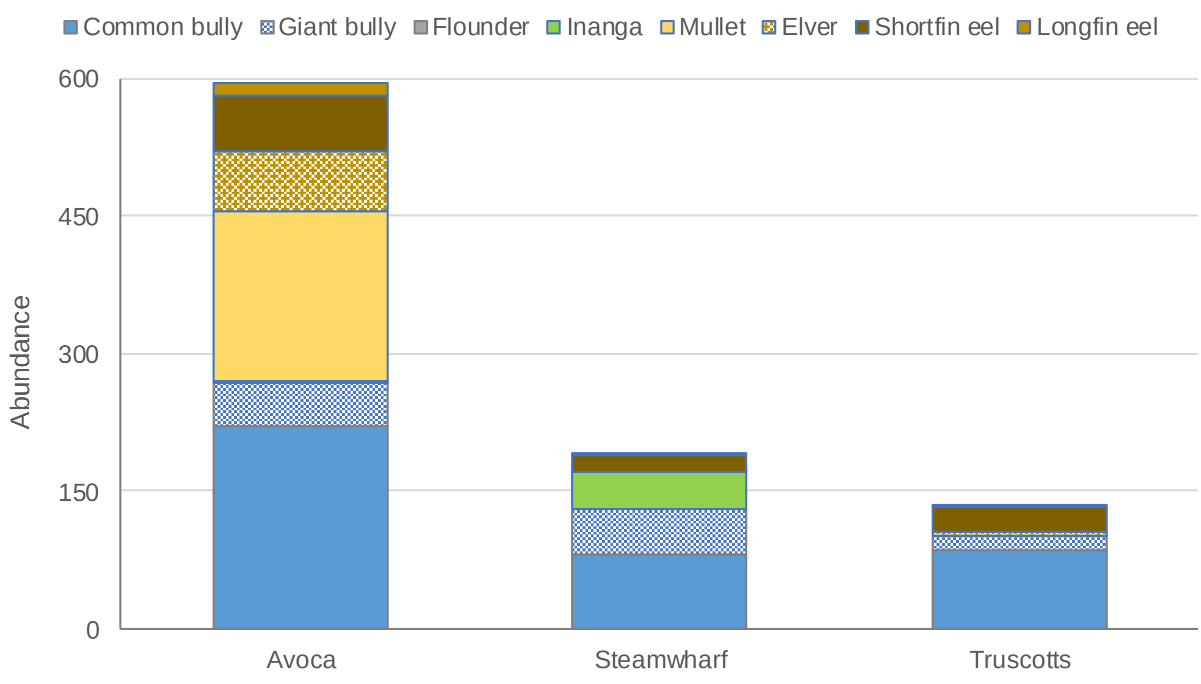

Figure 8: Fish abundance at each site (total of six fyke nets and 12 minnow traps).

Overall, the fish monitoring results indicate that fish can swim upstream past all three FFGs. Where fish species were abundant, they were also represented by a broad range of sizes, which indicates that the FFGs are not preventing recruitment. The large numbers of yelloweye mullet in Avoca Valley Stream indicates a relatively high degree of tidal flushing in the lower reaches of this waterway, because yelloweye mullet are a predominantly marine and estuarine species.

3.2. Salt Marsh Vegetation

McCombs (2018) identified a total of 23,853 m² of various vegetation types within an approximately 95,000 m² area of Avoca Salt Marsh (Figure 9). McCombs (2018) noted that plant species composition varied markedly with small changes in topography, reflecting species' tolerance to salinity and inundation frequency. Glasswort (*Sarcocornia quinqueflora*) dominated low-lying areas alongside ponds and watercourses, covering a total area of 15,743 m² (Figure 10), while threatened New Zealand musk (*Thyridia repens*) was widespread in the upper reaches of Butts Valley Waterway, covering an area of 1,557 m². (Figure 10).

McCombs (2018) concluded that there is some evidence that reinstatement of the Avoca Valley Stream tide gates may have impacted the salt marsh vegetation. This was based on the observation of some tall fescue plants amongst the New Zealand musk plants, and the presence of some seedlings of salt-sensitive amongst the salt marsh species. However, McCombs (2018) pointed out that it is also possible for rainfall to dilute the salt concentration in upper soil layers to allow salt-sensitive seedlings to germinate and that they may not persist. Overall, there was no strong evidence for a major reduction in the extent and health of the salt marsh community, but McCombs (2018) noted that such changes may take several years to become apparent.

Overlaying LiDAR data on top of the vegetation survey data indicated that at an RL of 10.3 m, the majority of the salt marsh vegetation would be inundated (see Appendix 1). CCC land drainage engineers indicated that at an RL of 10.3 m, there would be negligible impact on flood storage capacity, as the volume stored up to RL10.3 m in this area of the flood plain is negligible.

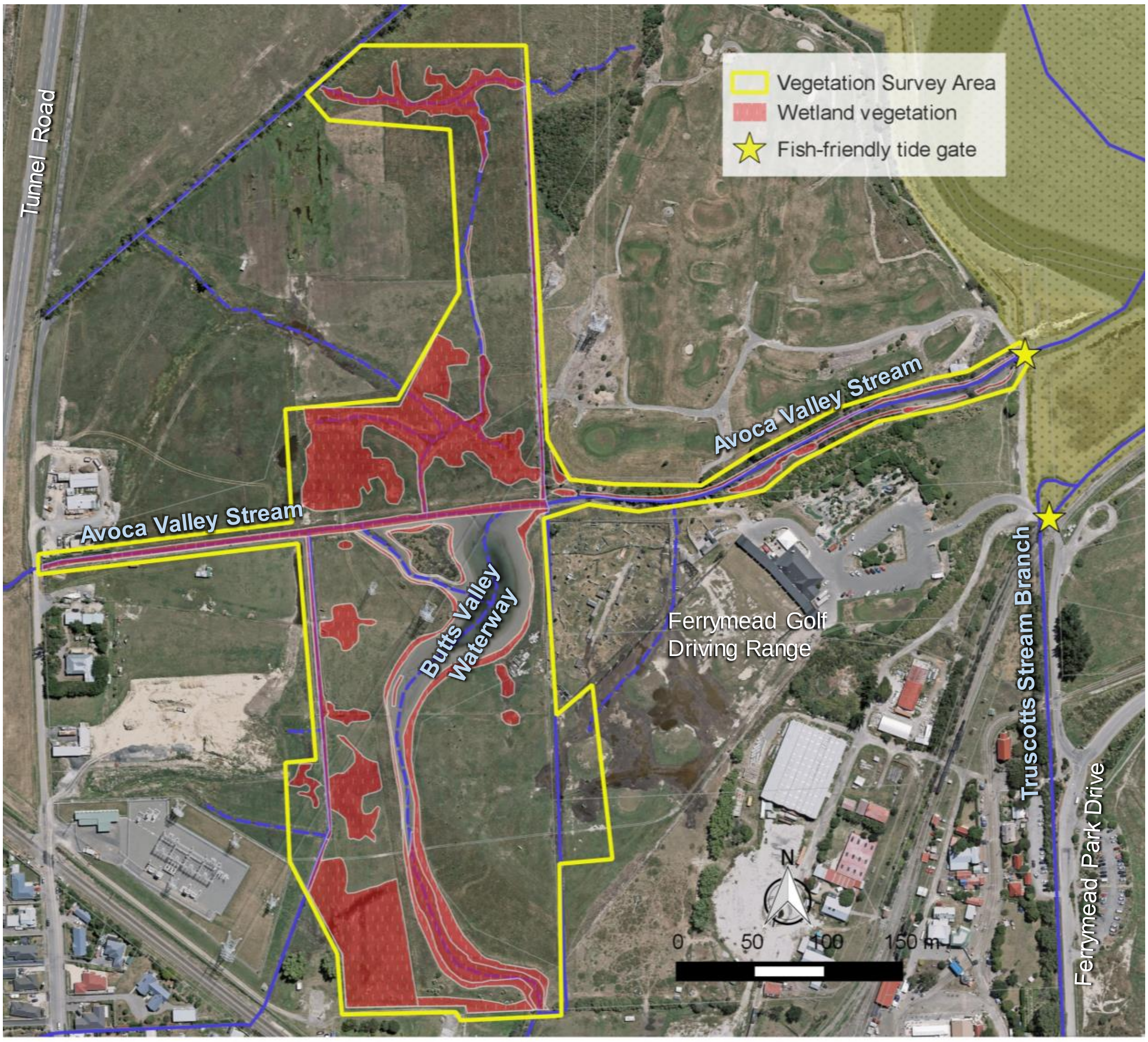

Figure 9: Avoca Salt Marsh survey area (raw data from McCombs 2018).

Figure 10: Glasswort lining a tributary drain (left) and threatened New Zealand musk (right)

3.3. Gate Opening and Water Levels

3.3.1. Steamwharf Stream

Time-lapse photographs showed that the Steamwharf Stream FFG remained open throughout much of the tidal cycle, only closing at well above mid-tide (Figure 11). Under normal operating conditions with the counterweight engaged, the gate opening at low tide was 450 mm (measured from the bottom of the gate to the culvert face). Disengaging the counterweight resulted in a low tide gate opening width of only 62 mm and the gate closed completely prior to reaching mid-tide (Figure 12).

The time-lapse photography provided a useful illustration of FFG performance. However, deriving data on gate opening duration proved time-consuming, plus it was limited to images taken during daylight hours, when the gate and staff gauge could be seen adequately. Therefore, the time-lapse photography approach was abandoned in favour of electronic monitoring using an accelerometer.

Accelerometer data clearly showed the Steamwharf Stream tide gate remaining wide open throughout most of the tidal cycle, along with the impact of removing the counterweight on reducing gate opening width (Figure 13). Disengaging the counterweight resulted in an average reduction in gate opening duration of 33 minutes over a 24 hour period, but mean gate opening width was reduced by 256 mm over the same time period[1]. Thus, the main effect of the fully-operative FFG was to maintain the gate wide open for much longer than would be achieved without the counterweight engaged. This suggests that the Steamwharf Stream FFG provides substantially greater opportunity for migratory fish to pass upstream and downstream than would be provided by a conventional tide gate.

[1] Determined by correlating gate angle with opening width and taking the average gate width over three days, with and without the counterweight engaged.

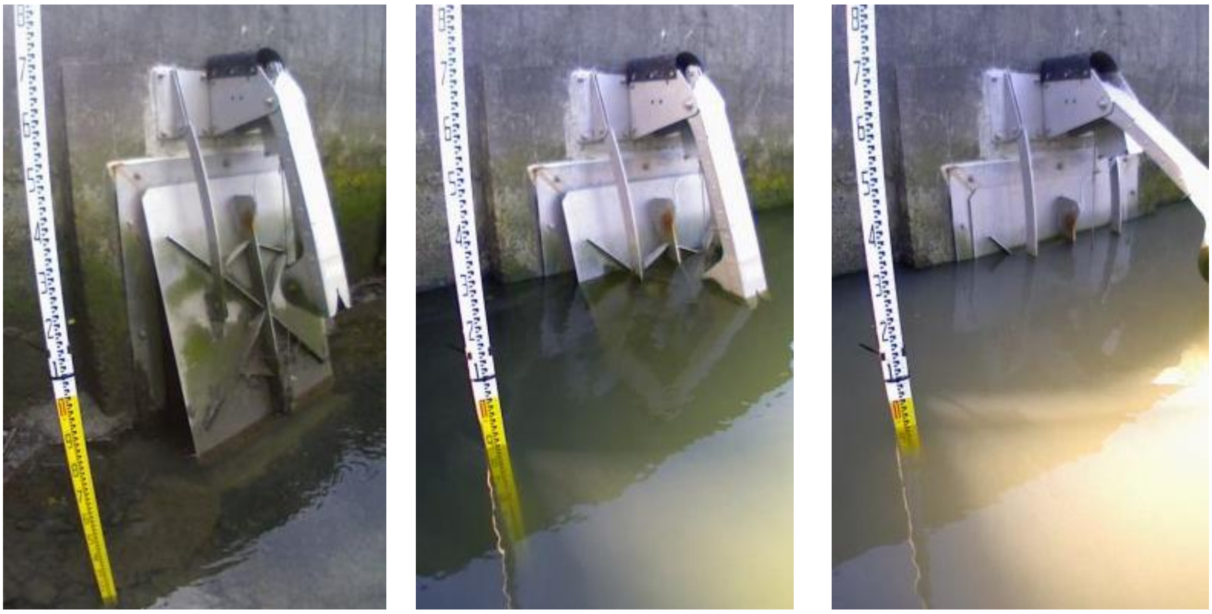

Figure 11: Time-lapse photographs of the Steamwharf Stream tide gate and temporary staff gauge, taken on an incoming tide. The tide gate counterweight was engaged, resulting in a delay of gate closure with the rising tide.

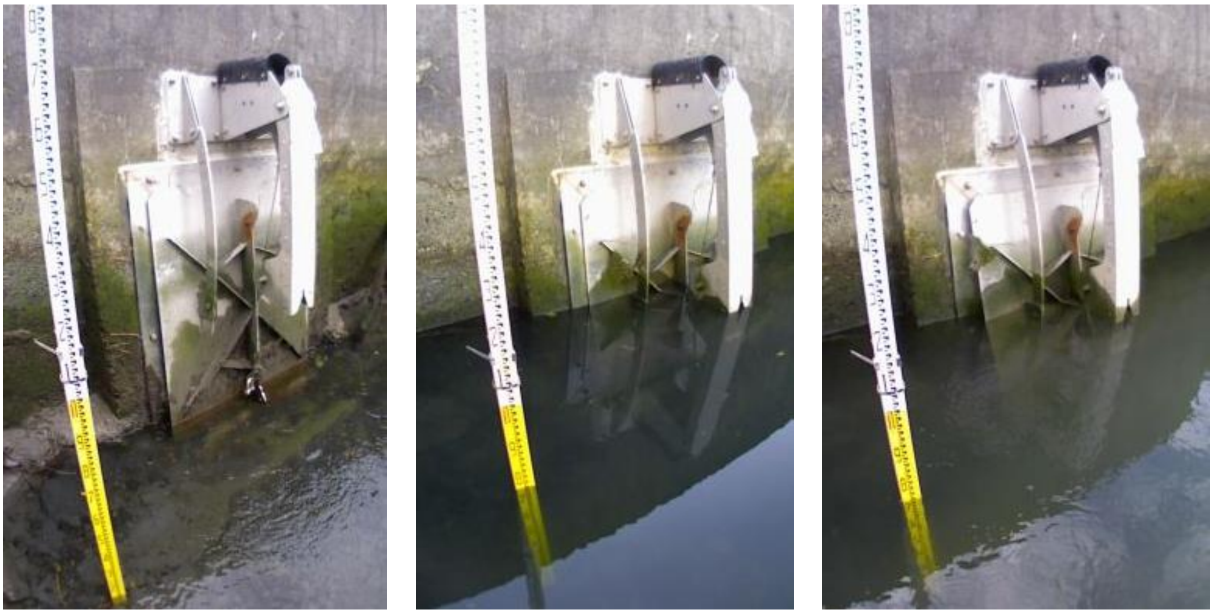

Figure 12: Steamwharf Stream tide gate with the counterweight temporarily disengaged. The left and middle photographs are on an incoming tide, while the right photograph is on an outgoing tide.

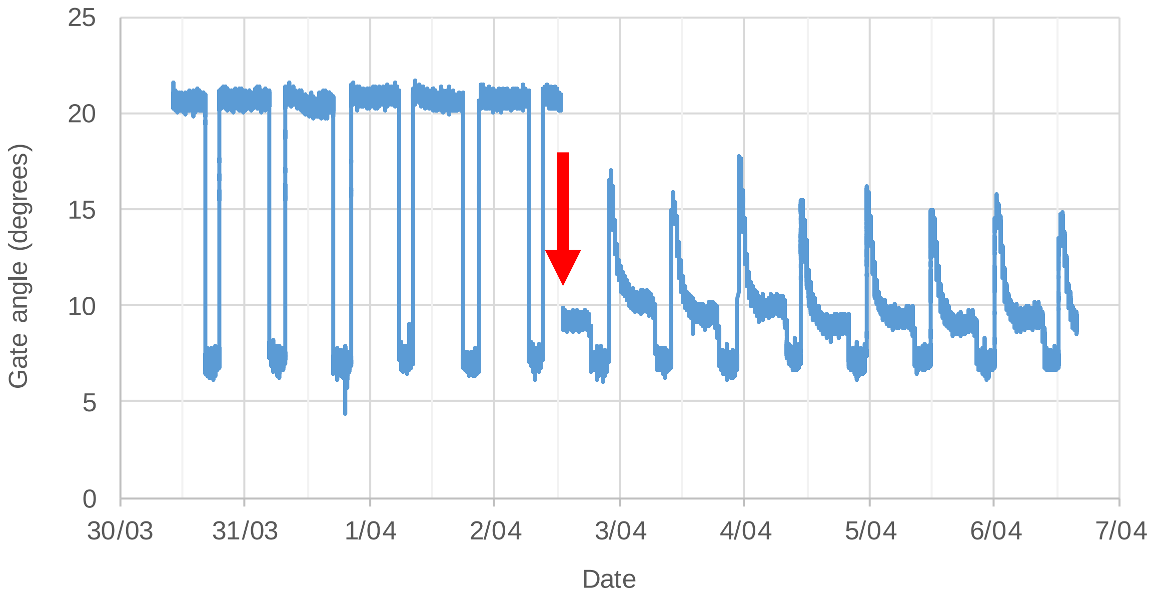

Figure 13: Steamwharf Stream tide gate angle. Data to the left of the red arrow are with the counterweight engaged and show the gate open wide most of the time. Data to the right of the red arrow are with the counterweight disengaged and show the gate opening widest on the outgoing tide, and then gradually closing on the incoming tide.

3.3.2. Avoca Valley Stream

The maximum gate opening angle for the Avoca Valley Stream FFGs was around 12 to 18 degrees for the two gates, but this only occurred for a short period on the outgoing tide (Figure 14). The Avoca Valley Stream FFGs followed a similar pattern to the Steamwharf Stream FFG with the counterweight disengaged. Thus, the Avoca Valley Stream gates maintained a small opening throughout much of the tidal cycle, with the gates opening rapidly on an outgoing tide, as the head pressure became greater on the upstream side (Figure 13 and Figure 14). Both Avoca Valley Stream gates that were monitored showed similar patterns in gate opening angle, so results from only one gate are presented here.

The primary effect of the Avoca Valley Stream tide gate opening regime was to reduce the rate at which the incoming tide could pass through the gates. This resulted in a marked difference in water level between sites downstream and upstream of the Avoca Valley Stream tide gate (Figure 14). Water levels immediately upstream of the gates were typically around 900 mm lower than downstream (on the estuary side) of the gates at high tide. Water levels at the monitoring site further upstream were identical to those immediately upstream of the gates, so are not discussed further here.

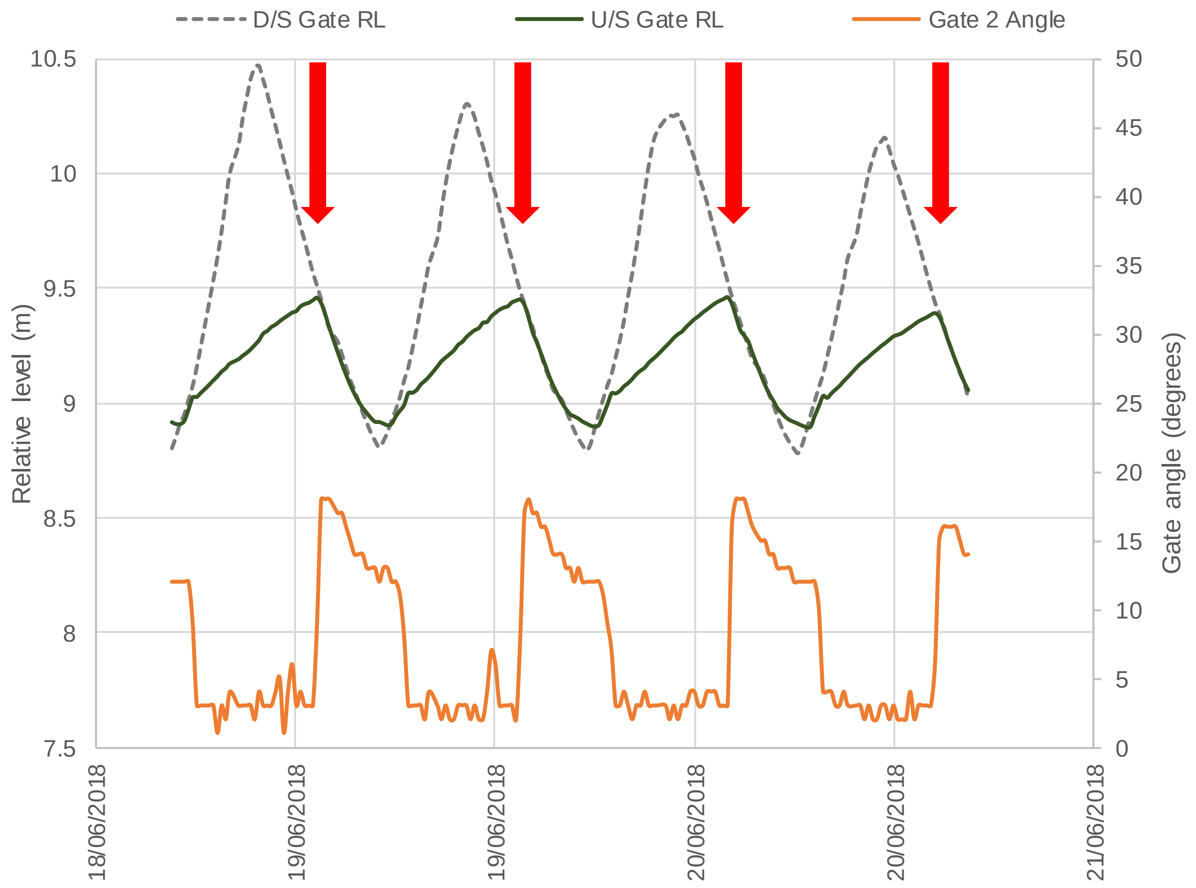

Figure 14: Avoca Valley Stream gate opening angle (orange line) and water levels downstream (dashed line) and upstream (solid dark line) of the tide gates with the counterweights engaged. Red arrows show when upstream water levels match those downstream on the outgoing tide, resulting in the tide gates opening.

High tide water levels typically varied from RL 9.9 to 10.6 m downstream of the tide gates, but varied over a narrower range of RL 9.4 to 9.6 m upstream of the tide gates (Figure 15). However, upstream and downstream water levels closely followed each when the tide gates were temporarily held up (Figure 15). This indicates that reduced tidal height upstream of the gates was caused by the gate opening regime, rather than any choking effect caused by the culvert constriction. Figure 15 also shows that water levels exceeding the 10.3 m RL appear to be associated with monthly spring tides, rather than occurring on every high tide. As noted in Section 3.2, LiDAR data indicate that the majority of the salt marsh vegetation would be inundated at 10.3 m RL. Hence, the water level monitoring data in Figure 15 indicates that the upstream salt marsh would only be completely inundated on spring tides.

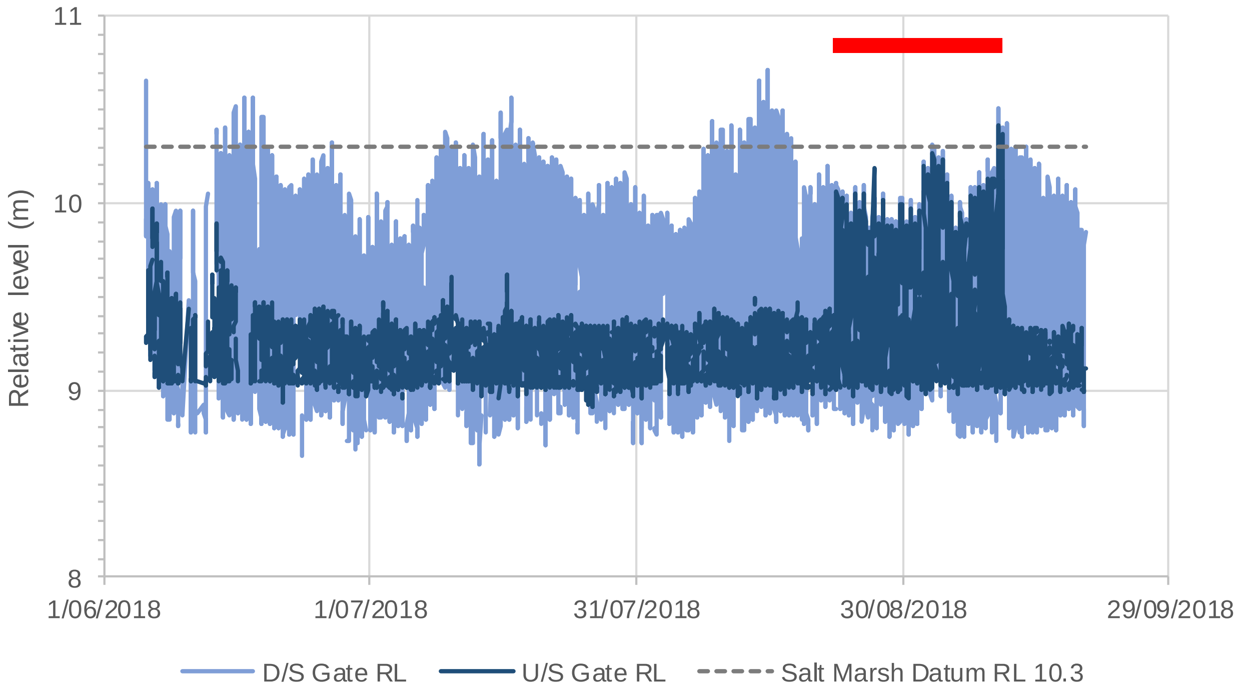

Figure 15: Water levels upstream (U/S) and downstream (D/S) of the Avoca Valley Stream tide gates. The red horizontal bar indicates the period when the tide gates were held open. Note that minimum water levels for the upstream site are inaccurate, due to the sensor reading the bed level, rather than the water level at low tide.

3.4. Conductivity Monitoring Results

Conductivity varied greatly amongst the salt marsh monitoring sites, reflecting the relative influence of freshwater sources and tidal flushing (Figure 16). Under typical gate operating conditions (i.e., prior to the gates being propped open), conductivity was highest (10 to 32 mS/cm) along the mainstem of Avoca Valley Stream and its tributary Butts Valley Waterway, and lowest along an unnamed northern tributary inflow (ranging from <0.5 to 5 mS/cm; Figure 16). Conductivity was intermediate (1 to 5 mS/cm) in small ponded areas, disconnected from the tributary waterways during typical gate operation.

Conductivity was higher at most sites during the period when the gates were held open (Figure 17), indicating a greater influx of saline water compared to typical gate operation. The conductivity increase was particularly large for Sites 7 to 10 and Sites 17 to 21. Conductivity was also more variable over time when the gates were held open (indicated by wider error bars on Figure 17), reflecting a greater tidal range than occurs during typical gate operation.

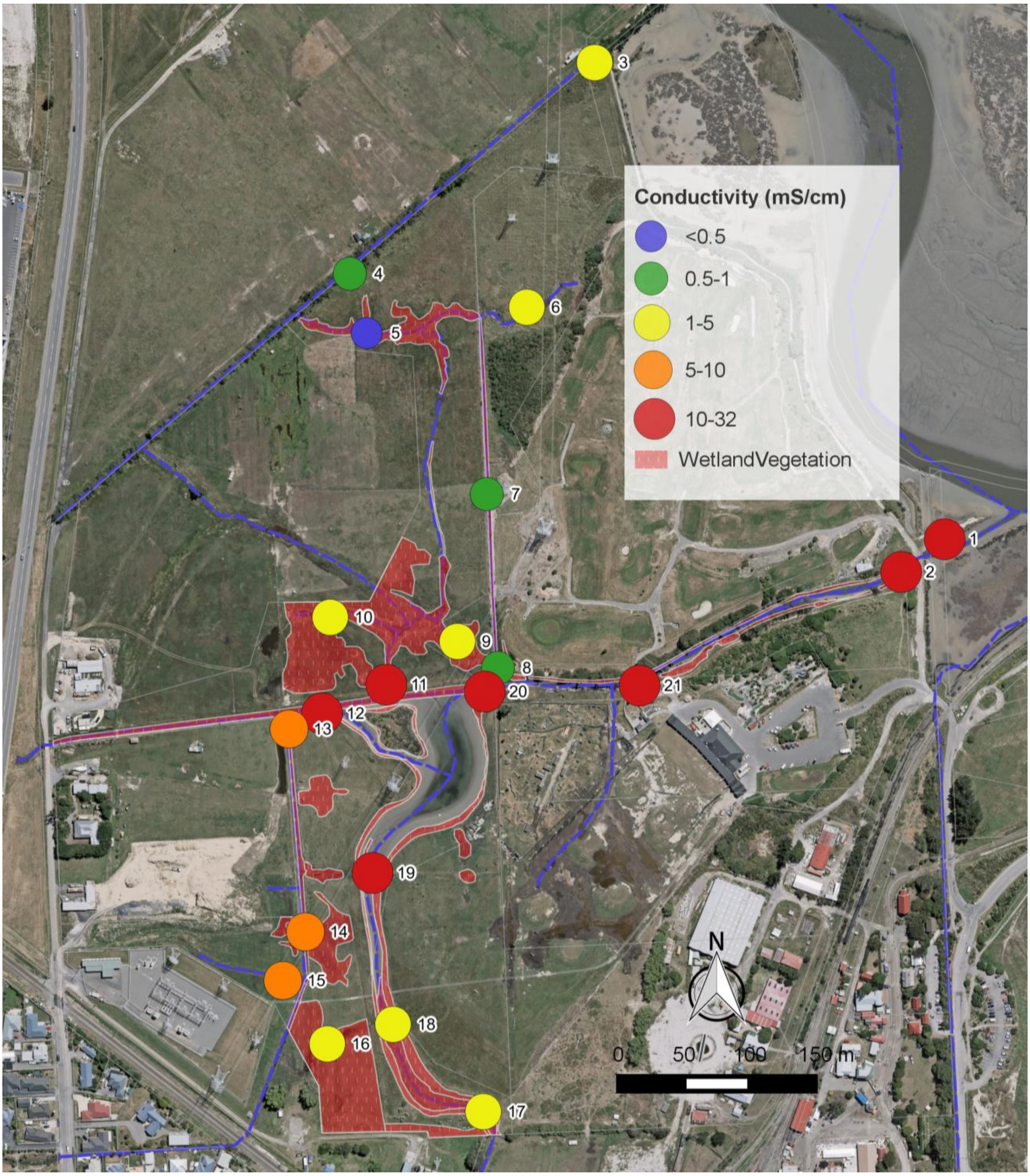

Figure 16: Mean conductivity measured at Avoca Salt Marsh sites during typical tide gate operation, without the gates being held open.

A complex of shallow ponds and salt marsh vegetation at Sites 9 and 19 showed large swings in conductivity when the tide gates were propped open. Observations over several tides revealed that the ponds were intermittently inundated by spring tides that pushed saline water up Avoca Valley Stream and its tributaries (Figure 18). For example, at Site 9 conductivity was 3.6 mS/cm on 28 August 2018 and 26.3 mS/cm five days later, immediately after a spring tide

(Figure 18). The high tide on 2 September 2018 reached an RL of 10.3 m, at which point tidal water was observed to back up a tributary drain and tip into the pond at Site 9. A high tide on 5 September 2018 reached an RL of 9.9 m, which was sufficient to push tidal water up the side drain at Site 11 and into the pond at Site 10, but the tide was of insufficient height to enter the pond at Site 9.

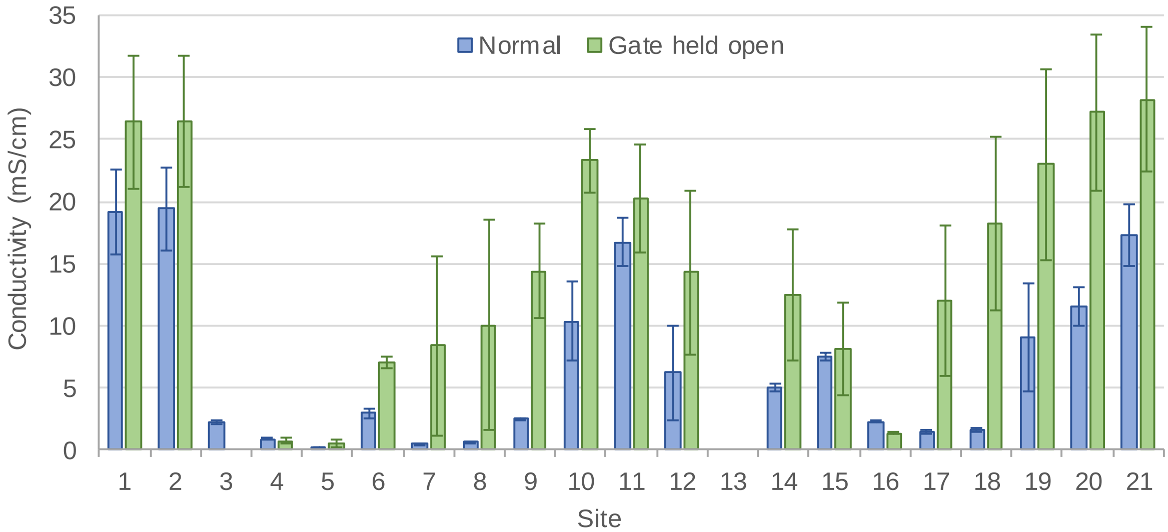

Figure 17: Mean (±1 SE) conductivity at Avoca Salt Marsh monitoring sites, measured during normal tide gate operation and when the gates were held open.

Overall, these monitoring data highlight the influence of small changes in topography on tidal inundation, and the effect of the tide gates on tidal range and salinity. Observations made when the gates were propped open indicate that water levels need to reach an RL of 10.3 m to inundate salt marsh pond complexes.

Figure 18: Site 9 on 28 August 2018 (left) and following inundation by a spring tide on 2 September 2018 (right).

4. CONCLUSIONS

Key conclusions from this study are as follows:

- Time-lapse photography proved useful for illustrating general tide gate performance. However, a combination of gate-mounted accelerometers and water level recorders provided data that was more readily analysed. Also use of telemetry enabled near-real time monitoring of changes.
- Disengaging the FFG counterweight at Steamwharf Stream greatly reduced the width of gate opening and slightly reduced the overall duration of gate opening. This indicates that the counterweight design provides considerable benefit for migratory fish.
- Fish sampling results indicate that all three FFGs were successfully providing passage to a range of native migratory species.
- Sampling of the Avoca Salt Marsh confirmed that the salt marsh extent increased after the tide gates ceased operating effectively following the Canterbury earthquakes of 2010/2011.
- Evidence for any impacts of the repaired tide gates on the Avoca Salt Marsh was equivocal, likely due to the small amount of time elapsed between the repair and vegetation sampling.
- Monitoring of the Avoca Valley Stream tide gate angles and water levels showed that the installed gates reduce the upstream tidal maximum by approximately 900 mm.
- Conductivity measurements and water level observations with the tide gates propped open revealed that tide levels need to reach RL 10.3 m to inundate salt marsh pond complexes.
- The tide was unable to reach RL 10.3 m upstream of the tide gates with the tide gates operating normally.

5. RECOMMENDATIONS

5.1. General Recommendations

Based on the results of this tide gate monitoring study, we make the following general recommendations.

- Before installing, repairing or replacing tide gates, check what values beyond flood protection may be affected by altering the existing tide gate management regime.
  - As a minimum, this should involve contacting a range of stakeholders with local expertise, including ecologists.
  - It may also entail collecting field data to better understand the values present.
- Consider installing equipment to monitor tide gate opening and water levels prior to making any changes to the gate opening regime, to establish a baseline.
- CCC asset managers should work with ecology staff and Park Rangers to identify waterways that may benefit from altered tide gate operating regimes.

- This will likely require a stocktake of existing tide gate structures and their condition, along with a high-level summary of the natural values upstream.
- Tide gates could be prioritised for remedial work based on the current state of the gate structure as well as the current and *potential* future state of natural ecosystems after changing the gate opening regime.

5.2. Avoca Valley Stream Tide Gates Recommendations

Based on the results of the Avoca Valley Stream investigations reported here, we recommend the following:

- Adjust the gates so that they remain open until reaching RL 10.3 m.
  - This will allow tidal waters to replenish upstream salt marsh communities, while having negligible impact on flood storage volume (pers comm. Peter Christensen, CCC Land Drainage Team).
  - At the time of writing, the CCC Land Drainage team were working with ATS Environmental to adjust the gates to remain open until RL 10.3 m.
- Investigate alternative options if the gate adjustment does not achieve the desired outcome of maintaining salt marsh extent and health.
  - It is beyond the scope of this report to explore alternative options, but various engineering and management options may exist.
- Continue water level monitoring upstream and downstream of the gates following any tide gate adjustments, to confirm whether water levels have increased upstream.
- Monitor the Avoca Salt Marsh plant community after altering the tide gate opening regime, to assess salt marsh extent and condition.

6. REFERENCES

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APPENDIX 1: AVOCA VALLEY STREAM INUNDATION MAP

Avoca Gate LiDAR