Summary Report: Waituna Peak Runoff Control Structure Trial

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Abstract

The loss of sediment and sediment-bound nutrients from land accumulate in waterways and can impact the ecological health of waterbodies. Runoff occurring over the land surface in response to heavy or prolonged rainfall events contributes a significant proportion of these contaminants. These runoff events may occur at any time of the year but tend to be more frequent during the cooler months of the year when soil moisture levels are elevated. Attenuating these losses by intercepting and mechanically slowing soil drainage is one way of reducing contaminant losses during these peak runoff events. Peak Runoff Control Structures (PRC structures) are a potential tool for reducing sediment and contaminant losses in peak runoff events by retaining water behind the structure allowing settling of suspended contaminants and reducing the flow peak.

Two different designs of PRCs (a wooden weir structure and gravel dam) were trialled in the Carran Creek sub catchment on the Eastern edge of the Waituna Lagoon on Foveaux Investments farm. The structures were installed into the upper extent of existing farm drains. Observations from monitoring undertaken over the 18-month trial period indicate:

- The PRC structures trialled all exhibited higher rates of sediment accumulation than observed at the control site. Insufficient data is available to provide a reliable comparison of the sedimentation rates upstream of the two PRC types trialled. Lower sedimentation rates immediately upstream of the structures (compared to further upstream) may suggest that vertical flow/turbulence during high flows may reduce sedimentation rates.
- Assuming sedimentation occurs over a 25-metre reach upstream of the structures, the individual PRC structures are estimated to have retained sediment in the order of 1 to 2 m^3 of suspended sediment compared to the control site over the 18-month trial period (or between 1,100 – 3,200 kg of fine sediment).
- The effect of the PRC structures on discharge during the rising and falling limbs of the flood hydrograph is more equivocal. While Site 1 and Site 4 appeared to slow the rate of flow recession compared to the control site, this effect was less obvious at Site 5 which exhibited a hydrography very similar to the control site (resizing of discharge pipes to reduce over topping may have resulted in greater attenuation). However, the (uncertain) contribution of subsurface flow (from mole tile drains) may also have contributed to variations in the rate of flow recessions observed between individual PRC sites.
- The gravel dam at Site 1 which was reinstated after an initial failure utilising coarse rock ballast appeared to significantly dampen peak discharge following rainfall events. Attenuation of the peak discharge was less evident downstream of the wooden weir structures.
- Delineation of catchment areas can be problematic in areas with limited topographical relief and extensive artificial drainage. Accurate delineation of catchment areas is important to ensure PRC's can be appropriately sized and constructed to accommodate high flow events without adversely affecting structural integrity. Uncertainty regarding contributing catchment area made it difficult to directly compare hydrological effects at the PRC trial sites.

Recommendations for future deployment of PRC Structures include:

- PRC structures of the type included in the Waituna trial are likely best suited to applications where the contributing catchment area is no greater than 10 Hectares.

- Information to characterise discharge should be collected prior to design and construction of PRC structures. This may include physical measurement of stage height/discharge as well as observations from landowners and estimates of high intensity rainfall rates and volumes.
- Dampening of peak flow rates may be less important to the overall performance of the PRC structures than the reduction in upstream flow velocity. Thus, a focus for future applications should be on achieving sufficient residence time in the upstream ponding area to slow flow velocity sufficiently to provide for settlement of suspended sediment.
- Resizing and/or addition of extra discharge pipes to reduce over topping may result in greater attenuation of peak flows downstream of wooden weir PRC structures compared those utilised in the trial.
- Design of PRC structures should require little to no maintenance. While designs such as the floating intake may increase the effectiveness of sediment capture, they require maintenance and have a greater potential for mechanical failure.
- Drain cleaning and rebattering make a significant contribution to mobilisation of sediment. While PRC structures can potentially help to limit contaminant losses from these activities, other mitigations such as excavation and regrassing during low flow periods may also make a meaningful contribution to reducing sediment losses.
- In settings where bed or bank erosion is identified as source of suspended sediment, PRC structures incorporating porous rock ballast may help attenuate peak discharge rates/flow velocity and therefore reduce generation of suspended sediment.

1 Introduction

The loss of sediment and sediment-bound nutrients from land accumulate in waterways and can impact the ecological health of waterbodies, both large and small. In some settings, a significant proportion of these contaminants are lost via runoff over the land surface in response to heavy or prolonged rainfall events. These events may occur at any time of the year but tend to be more frequent during the cooler months of the year when soil moisture levels are elevated. Attenuating these losses by intercepting and mechanically slowing soil drainage is one way of reducing contaminant losses during these peak runoff events.

Prior to agricultural development in the Waituna Lagoon catchment, land cover largely consisted of native forests and wetlands which acted to moderate the rate at which water drained from the catchment following rainfall. Modification of the catchments hydrology to facilitate agricultural production has included vegetation clearance, channel straightening, and extensive artificial drainage, especially in areas where Organic (peat) or hydric soils occur. Artificial drainage lowers the local groundwater table and functions to expedite soil drainage via a network of sub-surface (mole pipe) and open drains to the surface water network. However, during high intensity or prolonged rainfall events, artificial drainage may not be sufficient to prevent runoff occurring over the land surface.

Widespread vegetation clearance, wetland drainage, and intensive modification of soil hydraulic properties have increased the rate and volume of land drainage occurring across the Waituna catchment. These changes to natural hydrological function, increase the magnitude of "peak" flows resulting in the rapid movement of water and increasing the mobilisation of nutrients and sediment via the local stream network to Waituna Lagoon. The increased magnitude of peak discharge may also exacerbate erosion and stream bank instability where streambank materials are loose or friable or where instream works (drain clearing and/or rebattering) have been recently undertaken.

One potential method for mitigating peak water flows is to build small dam structures within the head of ephemeral or intermittent water courses. These structures, referred to as "peak run-off" control (PRC) result in the temporary ponding of drainage water behind the structure, reducing the velocity of the drainage discharge. Sufficient reduction in the velocity of discharge enables entrained sediment and the attendant nutrients and microbes to settle out behind the structures, limiting contaminants reaching the surface water network and ultimately, Waituna Lagoon.

The Whakamana te Waituna Trust (WTW) is seeking to test the deployment of PRC structures within the Waituna catchment to practically reduce the cumulative discharge of contaminants into the lagoon. The objective of the trial was to test whether a limited network of PRC structures can be strategically positioned at key sites to provide meaningful reductions in contaminant losses. If successful, the trial supports the development of a wider PRC network in other strategic locations to maximise contaminant retention.

The Carran Creek' sub-catchment', at the eastern edge of the lagoon was selected for a trial to evaluate alternative PRC designs and assess their performance under real-world conditions. Four PRC structures utilising two alternative designs were installed in May 2021 on the Foveaux Investments property located in the lower reaches of the Carran Creek catchment. Data to characterise the effect of these structures on stream discharge and water quality compared to an un-modified control site was collected over an approximately 18-month period through to October 2022. This report provides an overall evaluation of the performance of the PRC structures trialled in the Waituna Lagoon Catchment.

2 Deliverables

Living Water contracted Land and Water Science (LWS) to provide summary reporting of the "Peak Runoff Control Structure Trial" at Foveaux Investments property in the Waituna Catchment. The overall scope of the reporting is intended to provide:

- An overview of construction, operational and environmental considerations related to the PRC structures trialled.
- A review of monitoring data collected during the field trials.
- An assessment of the function and performance of the PRC options evaluated.
- Recommendations for further deployment.

3 Trial Location and Environmental Conditions

The PRC trial was undertaken on the Foveaux Investments property adjacent to Hansen Road, Kapuka South (Figure 1). The property is situated in the Carran Creek subcatchment on the Eastern edge of the Waituna Lagoon. The susceptibility for runoff to occur and estimated artificial drainage density are shown for the property relative to the Waituna catchment in Figure 1. The sites have a runoff susceptibility between 9 and 12 % of annual rainfall, which is relatively high for a predominantly flat catchment. The sites have a moderate to high density of artificial drainage.

The structures were constructed in existing farm drains. During the trial period, the four PRC structures were monitored along with a single control site[1]. Two designs of PRC structures were trialled, a gravel dam design by RDAgritech and a wooden weir design by Dairy Green. The monitoring sites included:

- Site 1 Gravel Dam Structure - RDAgritech design
- Site 3 Gravel Dam Structure - RDAgritech design
- Site 4 Wooden Weir Structure - Dairy Green Ltd design
- Site 5 Wooden Weir Structure - Dairy Green Ltd design
- Control Site

[1] Site numbers were retained from previous site investigations. Site 2 was not used as a trial site in this study. An additional control site initially selected was not ultimately monitored due to a collapsed culvert upstream.

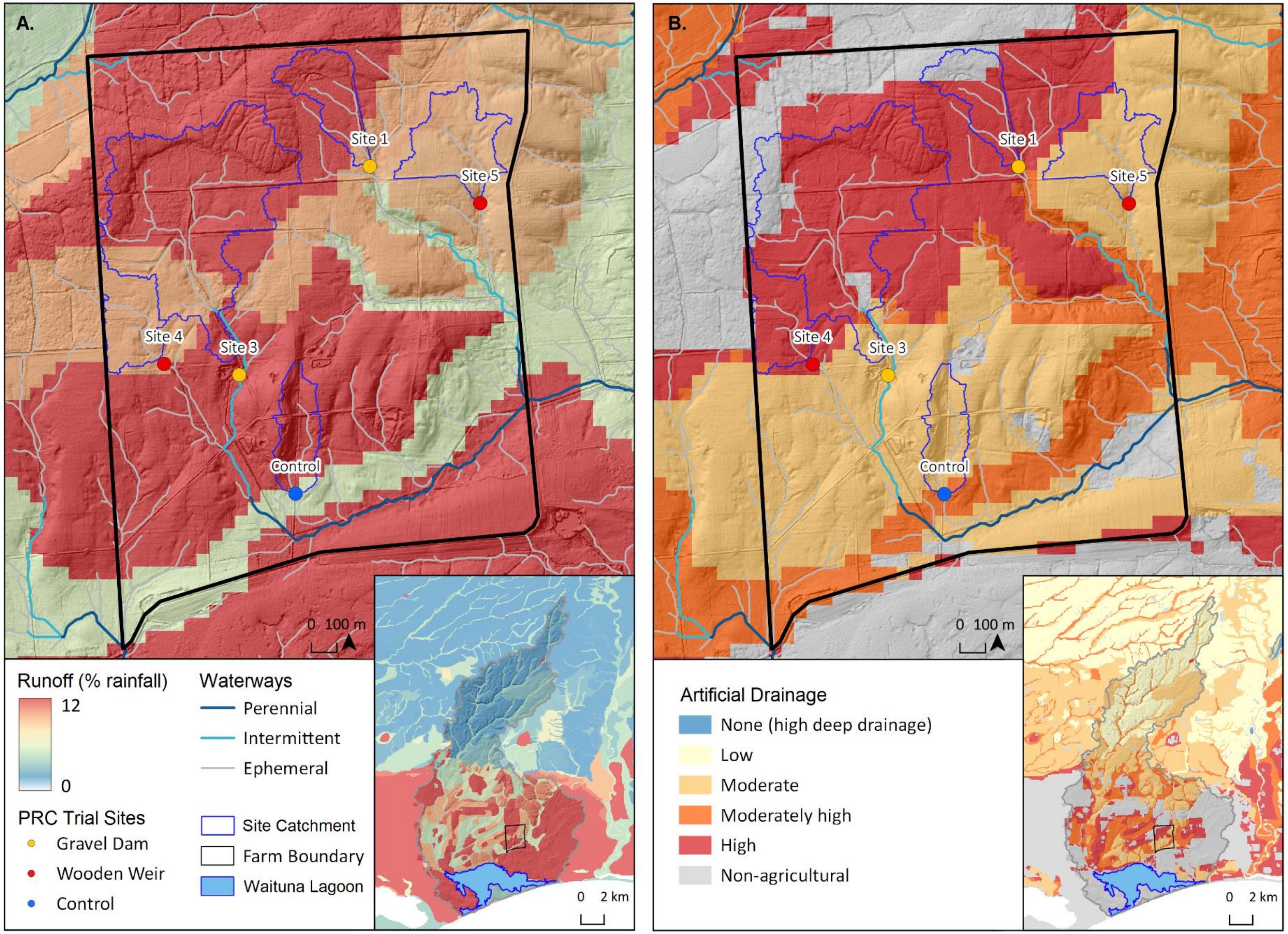

Figure 1: Location of the PRC trial monitoring sites on Foveaux Investments property, Waituna Catchment.

A. Susceptibility of runoff to occur shown as a percentage of annual rainfall, and B. artificial drainage density across the Waituna Catchment and trail property.

3.1 Catchment Sizes and Locations

The estimated catchment sizes for the five monitoring sites based on interpolation using LiDAR imagery is shown in Figure 2 and Table 1. The estimated catchment areas were of relatively uniform area (7 to 11 Ha), except for Site 3 which was estimated to have a substantially larger catchment (approximately 42 Ha).

Table 1. Catchment area of PRC structure sites.

Site	Area (Ha)
Site 1 Gravel Dam Structure	8.04
Site 3 Gravel Dam Structure	41.93
Site 4 Wooden Weir Structure	7.76
Site 5 Wooden Weir Structure	10.60
Control Site	6.80

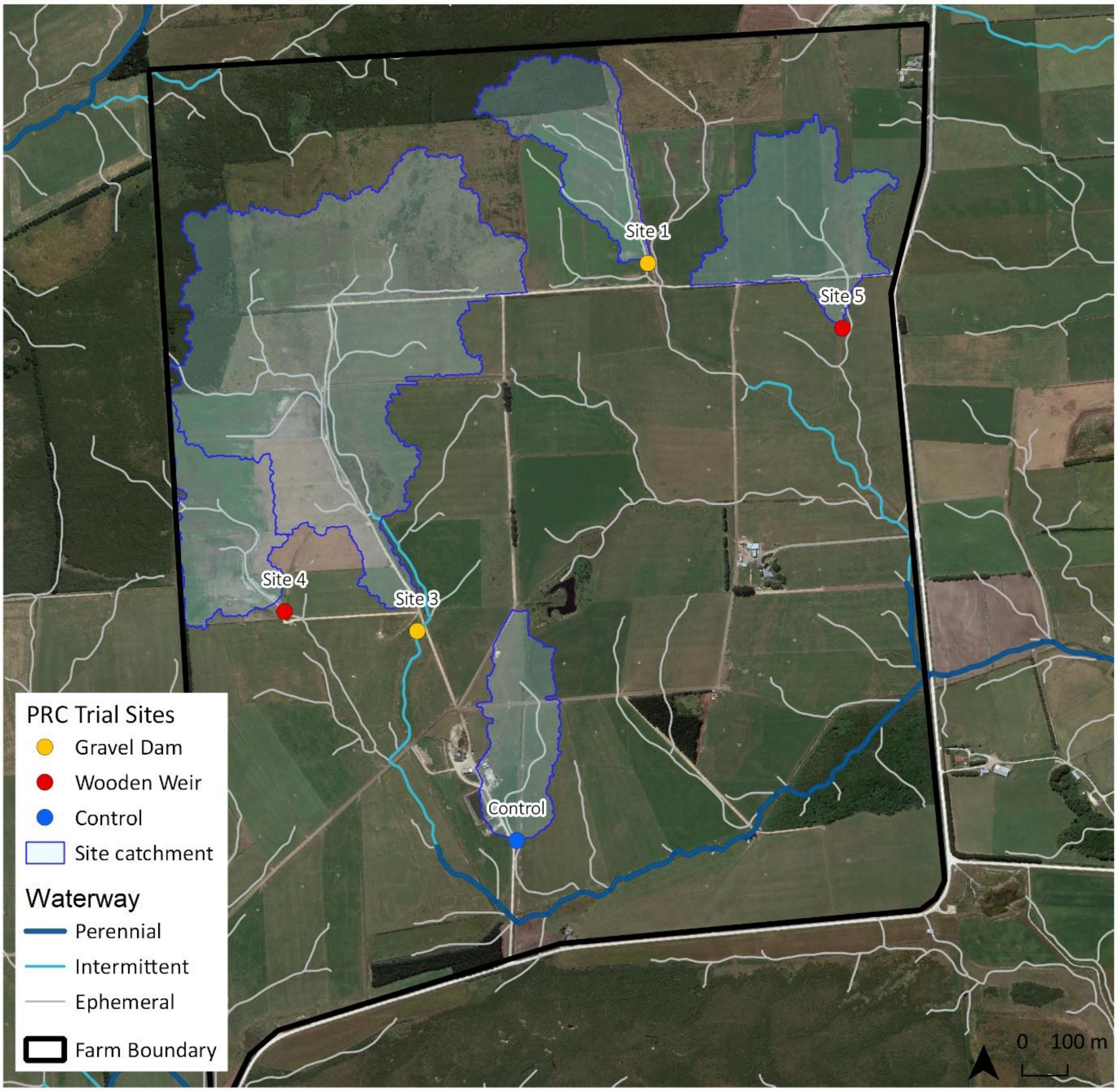

Figure 2. Catchment Sizes and Locations of Peak Runoff Control Structures. Gravel Structures (sites 1 & 3) and Wooden Structures (sites 4 & 5).

It is noted that estimating catchment size in areas where there is an extensive surface and sub-surface drainage network can be problematic (Figure 1). Certainly, as evident by comparison of naturalised flows in Section 4 below, actual catchment areas for the individual PRC sites appear to differ from those listed above. More accurate delineation of catchment areas would require detailed on-ground surveying of topography and the drainage network and, in areas such as the Foveaux Investments property, may remain somewhat uncertain if the historical extent of sub-surface drainage is not accurately documented.

3.2 Environmental Monitoring

All sites were visited fortnightly by Dianne Elliotte from Aquatech. Data from the monitoring sites was downloaded and manual measurements, observations, and photos recorded during each site visit.

At each of the PRC sites, water level, flow (calculated using cross-sectional area data, depth readings, and velocity values) and water temperature were recorded. At the control site, water level, water temperature, and flow were recorded. All sites had three waratah standards installed at 3 metre increments upstream of the PRC structure to provide a baseline reference for monitoring the depth of sediment accumulation over the period of the trial.

3.3 2021-22 Trial Conditions

The Waituna catchment experiences what is best described as a cool temperate climate with regular rainfall. Average annual rainfall along the south coast is generally around 1,080 mm/year. Highest monthly rainfall totals are typically recorded during the summer and autumn, with lowest totals during the winter and spring. Over the long-term (>30 years), annual rainfall totals are relatively consistent, typically varying by less than +/- 20% of the annual total (Rissmann et al, 2012).

Figure 3 shows a plot of daily rainfall recorded at the Environment Southland Lawson Road monitoring site (located approximately 7 kilometres north-west of the Foveaux Investments property) between January 2021 and November 2022. Over this period rainfall was recorded on 360 of 699 days (54 %), with the maximum daily total of 32.5 mm occurring on the 9th September 2021. Rainfall greater than 15 mm was recorded on 7 % of rain days (i.e., 25 days) over this period, with falls of less than 5mm occurring on 66 % of rain days (238 days). These figures indicate that while the Waituna catchment receives regular rainfall, high intensity falls are relatively uncommon.

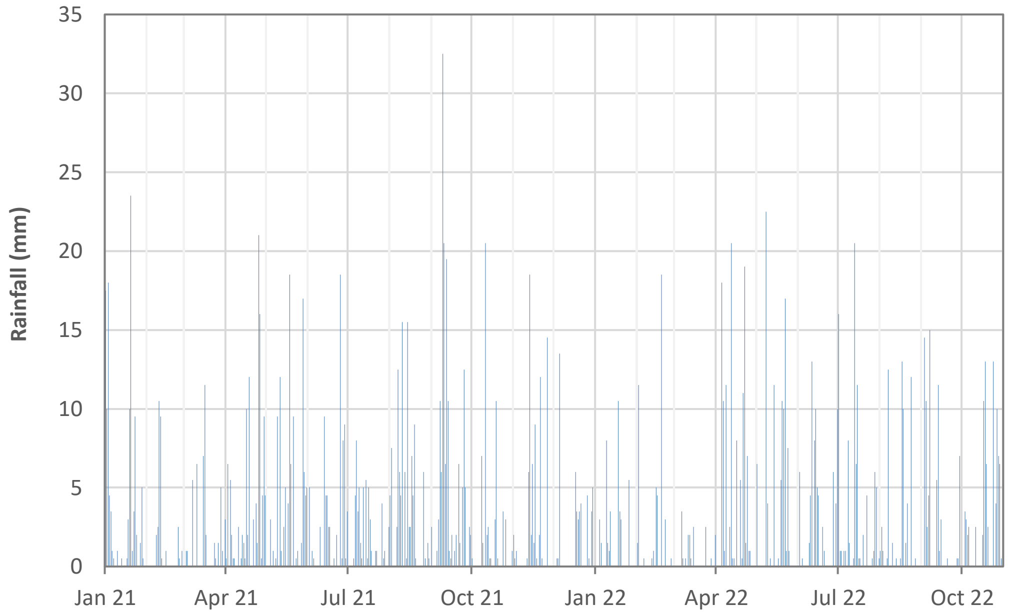

Figure 3: Rainfall recorded at the Environment Southland Lawson Road site, January 2021 to November 2022.

The distribution of monthly rainfall over the 2021-22 year is shown in Figure 4. The figure shows monthly rainfall totals were highest around April/May declining into the late autumn/winter months and were consistently low from October 2021 through to March 2022. Given this period typically receives the highest rainfall, conditions were consistently dryer than normal across the Waituna catchment through late spring and summer 2021-22 due to a La Niña Southern Oscillation. The only month when rainfall was appreciably above average was September 2021 when cumulative rainfall of 106 mm was recorded over a 7-day period between the 7th and 13th September.

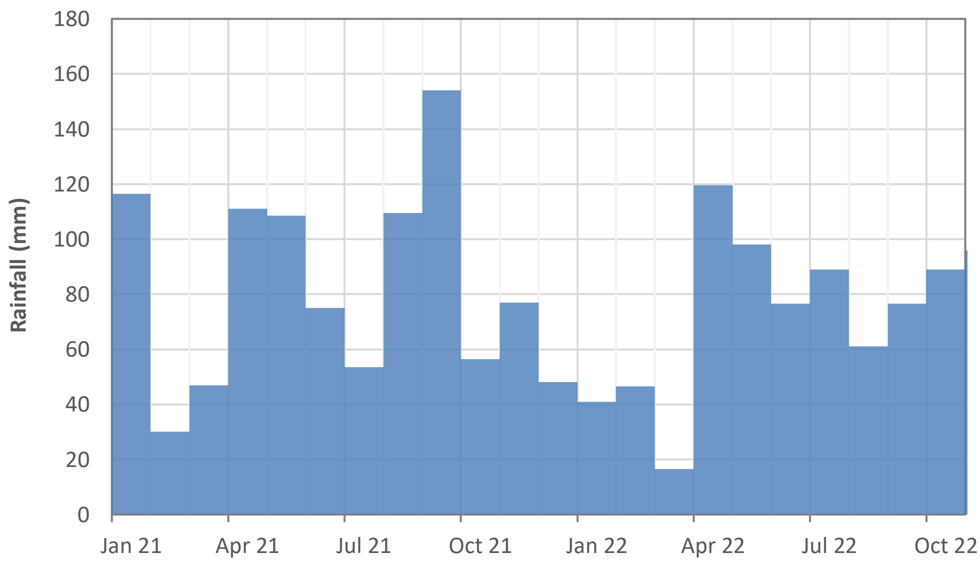

Figure 4: Monthly rainfall totals at the Environment Southland Lawson Road site, Jan 2021 to November 2022.

Figure 5 shows a plot of soil moisture and rainfall recorded at the Environment Southland Lawson Road monitoring site from January 2021 to November 2022. The figure shows an extended period of low soil moisture from mid-January to early April 2022, with soil moisture appreciably lower than that recorded during the preceding (2021) summer.

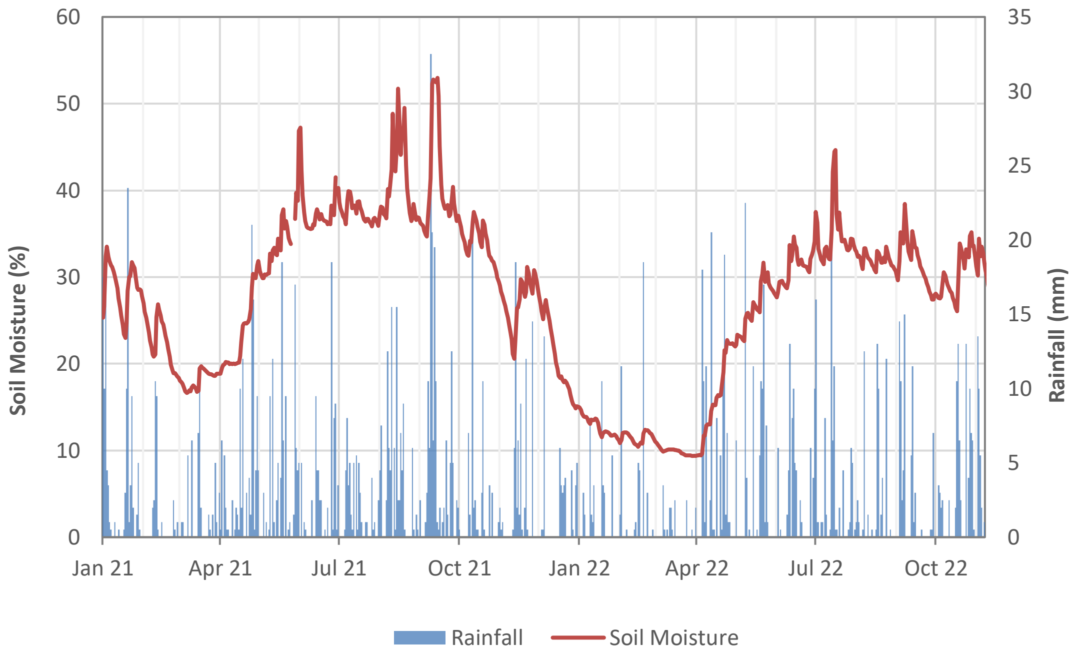

Figure 5: Rainfall and soil moisture at the Environment Southland Lawson Road site, Jan 2021 to November 2022.

The effect of the prolonged period of low rainfall/soil moisture on surface water flows is evident on the hydrograph of discharge in Waituna Creek at Marshall Road shown on Figure 6 below. The figure shows that following a period of high flows (reflecting above average rainfall in early September 2021), flows receded rapidly through October 2021, remaining low and stable through to May 2022. Consequently, flows in the Curran Creek catchment at the Foveaux Investments property during summer 2022 are likely to have been somewhat lower than occurring under normal rainfall and soil moisture conditions.

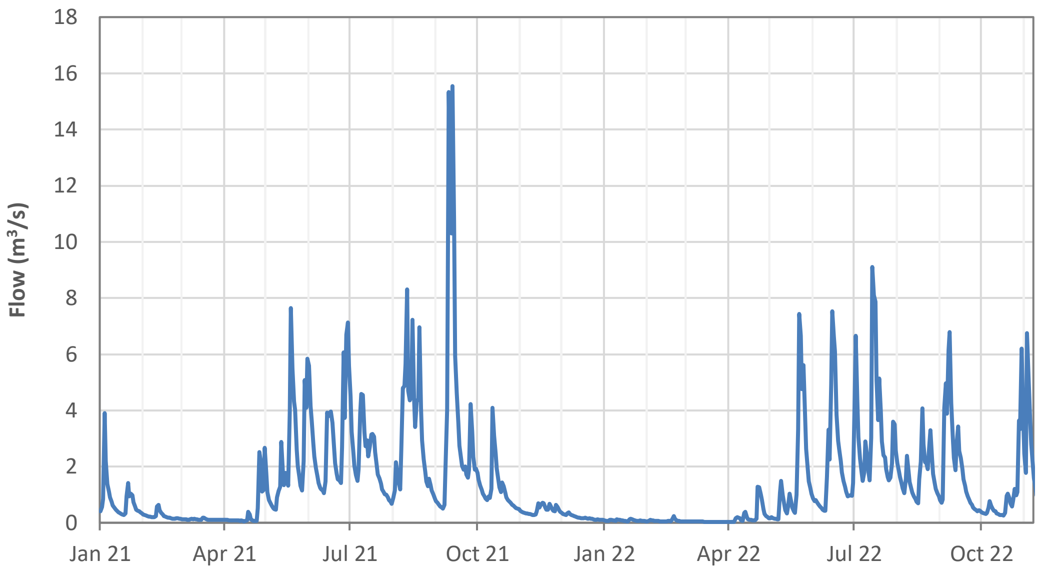

Figure 6: Discharge in Waituna Creek at Marshall Road, January 2021 to November 2022.

As illustrated on Figure 7 below, rainfall intensities in the Waituna catchment tend to be relatively low. As shown, between 7th to 13th September 2021 (a period when two of the five highest daily rainfall totals during 2021/22 were recorded), rainfall intensities were generally less than 3 mm/hour, only exceeding this rate for short periods (1-2 hours).

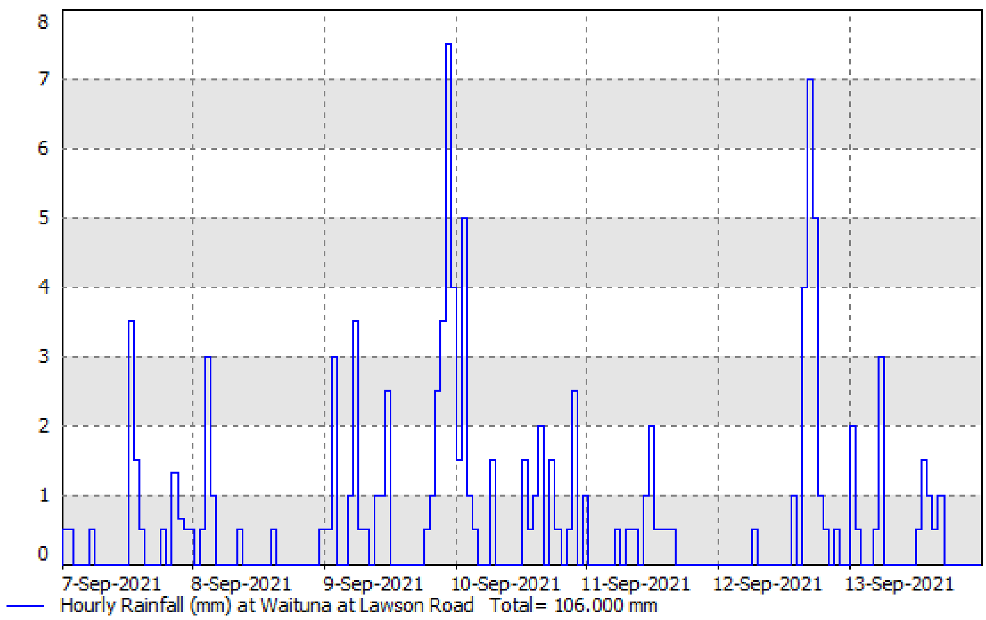

Figure 7: Hourly rainfall intensity recorded at the Environment Southland Lawson Road site, 7-13th September 2021.

Given the nature of rainfall in the Waituna catchment, the land drainage network is typically sized to convey flows associated with frequent, low intensity rainfall. Consequently, during periods of elevated rainfall intensity (particularly when soil moisture is high) peak discharge rates in many smaller artificial drainage channels can result in runoff and relatively high flow velocities, increasing the potential for in-stream erosion and contaminant mobilisation.

4 PRC Structures and Trial Performance

Two PRC design options were included in the PRC trial. These options were:

- Wooden Weir PRC structure
- Gravel PRC structure

The two structures were designed and installed by Dairy Green Ltd (John Scandrett) and RDAgritech (David Ryder) respectively. The wooden weir structures were installed at Sites 4 and 5 shown on Figure 1 above, while gravel structures were installed at sites 1 and 3. It is noted that design modifications were made to all PRC structures during the trial to reinstate structures after high flows and optimise their performance. Details of the design, operation and optimisation of the PRC structures is provided in engineering technical reports prepared for the project (RDAgritech, 2022 and Dairy Green, 2022).

While two control sites were included in the original project design only a single control site was ultimately established due to issues associated with a collapsing culvert at the other location. In addition, due to concerns regarding the representativeness of the initial control site due to bank erosion, the site was relocated mid-way through the trial period in December 2021.

4.1 Wooden Weir Structure

Wooden weir PRC structures were installed at Sites 4 and 5. The structures were constructed from wooden posts installed in the drain bed with tongue and groove timber installed perpendicular to streamflow. The timber was notched into the streambank with concrete placed around the drain bed to prevent scour and potential piping failure (given the loose sandy nature of the bank materials at Site 4). A notch was constructed in the top of the timber to form a weir to direct overtopping flows. Rock backfill was placed behind the timber wall to dissipate the energy from water cresting the weir.

Operational discharge was maintained via a 150mm PVC pipe culvert installed through the timber wall. An orifice plate on the intake was utilised to create ponding upstream of the wall above a pre-set flow. During the trial, the design of the culvert pipe was modified to enable hinging of the inlet section so it could effectively 'float' on the water ponded above the weir. This design modification was intended to ensure inflow to the culvert pipe would occur from the upper part of the water column containing lower concentrations of suspended sediment. Weighting was also required on the downstream section of the culvert to ensure it remained below the water level to maintain fish passage.

Figure 8 below shows an indicative engineering diagram of the post and timber weir structures constructed at Sites 4 and 5. Figures 9 and 10 show the construction and general layout of the timber PRC structures installed at each site.

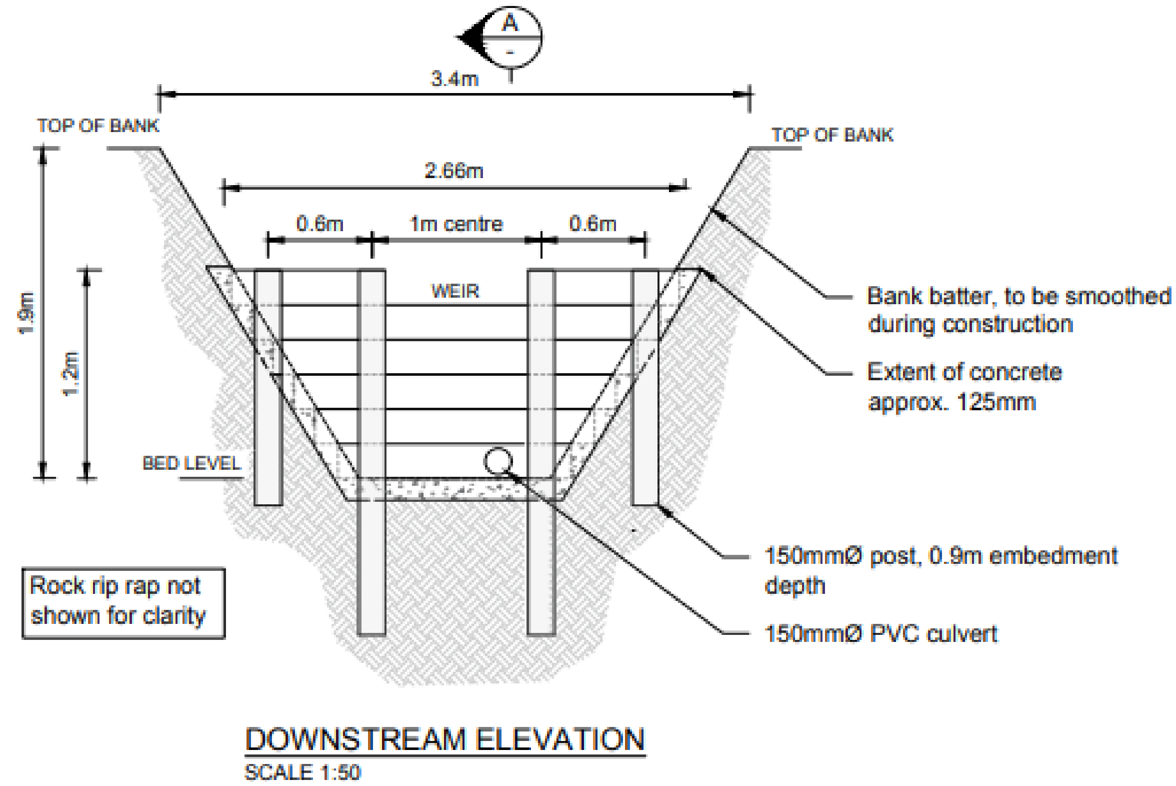

Figure 8: Engineering specifications of wooden peak runoff control structure (Scandrett Rural, 2020).

Figure 9: Site 4 Wooden weir looking downstream (left) and showing rock backfill downstream (right).

Figure 10: Site 5 wooden weir following installation looking downstream (left) and flow monitoring equipment installed downstream of culvert pipe (right).

The wooden weirs operated continuously through the trial period. The only operational issues experienced were:

- Partial blockage of the culvert outlet by a rock dislodged from the rock backfill during the September 2021 high flow event.
- During development and optimisation of the design for the floating intake issues encountered included appropriate floatation and ballasting of the intake and outlet pipes and grass growth in the channel upstream of the weir inhibiting movement of the intake pipe.
- A flexible 'elbow' used to the attached the floating intake at Site 5 became detached during the September 2021 rainfall event.

4.2 Gravel Dam Structure

The gravel dam structures were constructed at Sites 1 and 3. Prior to construction, a 100 to 200 mm deep strip was excavated in the drain bed and banks over a length of approximately 3 metres. Aggregate was then placed in the excavated drain bed up to the invert required for fish passage. A 150 mm PVC pipe was then placed across the gravel footing (with a slight downstream gradient to account for the expected difference in water levels upstream and downstream of the weir). The weir was then completed by placing AP65 to form the dam shape required. Small sediment sumps were formed upstream and downstream of the weir to also double as fish pools.

Shortly following construction, fine sediment was observed to accumulate on the upstream face of the weir forming a low permeability layer, reducing the rate of seepage through the weir. Both structures, ultimately failed during high flow events and required reconstruction during the trial.

The initial gravel weir constructed at Site 1 is shown in Figure 11. As illustrated in Figure 12, progressive erosion of the gravel materials during high flows was observed, with the weir ultimately failing due to scour of the weir crest during a high flow event in late July 2021. Following the July 2021 failure, Site 1 was reinstated using rock ballast as shown in Figure 13 remaining operational for the remainder of the trial period.

Similar structural integrity issues during high flow events were experienced with the gravel weir constructed at Site 3. These issues were associated with the greater fines content of the AP65 gravel utilised at this site (compared to Site 1), as well as the relatively high discharge at this site (due to the larger contributing catchment area compared to the remaining PRC trial sites). After initial reinstatement utilising rock ballast, the structure failed again during the early September 2021 rainfall event. Ultimately the design of Site 3 was modified to incorporate a larger (150 mm) culvert pipe, as well as 3 additional 150mm culvert pipes located higher in the weir structure to accommodate higher flows. Due to initial failure of monitoring equipment, difficulties maintaining structural integrity of the site and the appreciably larger (and therefore not directly comparable with remaining sites) catchment area, monitoring at Site 3 was discontinued early in the trial period.

Figure 11: Site 1 Gravel weir initial installation looking upstream, May 2021.

Figure 12: Site 1 Gravel weir partial erosion (left) and subsequent initial failure (right), July 2021.

Figure 13: Reinstatement of Site 1 utilising rock ballast.

Figure 14: Site 3 initial installation in May 2021 (left) and after initial failure in July 2021 (right).

Figure 15: Site 3 after instatement utilising rock ballast (22 July 2021).

Figure 16: Site 3 after second failure (10 September 2021).

4.3 Control Site

The control site was established in a small catchment towards the southern end of the Foveaux Investments property. However, as illustrated on Figure 17 below, concerns were raised regarding the representativeness of the control site location due to extensive erosion of the stream banks and bed following drain cleaning undertaken during winter 2021. In addition, the initial control site was located on a drain which was observed to be downstream of a small wetland area identified as potentially influencing discharge, particularly during the winter months and/or following heavy rainfall.

To overcome these issues the site was shifted to a more stable stream location where monitoring re-commenced in mid-December 2021. Figure 18 shows a photograph of the final control site.

Figure 17: Bed erosion and bank instability at the initial control site.

Figure 18: Channel section at the final control site.

5 Monitoring Results

Environmental monitoring undertaken during the PRC structure trial included:

- Monitoring of water levels and calculation of stream discharge downstream of the individual PRC structures and at a control site based on an observed stage/discharge relationship. Manual flow measurements were undertaken at regular intervals to validate estimated discharge at each site.
- Sediment accumulation was measured at 3-metre, 6-metre, and 9-metre increments upstream of each PRC structure. Each sediment monitoring site was marked by a waratah to enable consistent measurement.
- Rainfall was measured at Site 4 over the period 22 December 2021 to 7 October 2022.
- Continuous monitoring of electrical conductivity (EC) was undertaken at Sites 1 and 4.

The following section provides an overview of data collected for the Waituna PRC structures trial.

5.1 Rainfall

To provide localised climate data, a rainfall recorder was installed at Site 4 in December 2021. Figures 19 and 20 below provide a comparison of monthly and cumulative rainfall recorded at Site 4 with data from the Environment Southland Waituna at Lawson Road monitoring site (located approximately 7 kilometres north-west of the PRC trial site). The figures show monthly rainfall totals at Site 4 ranged between 20% (September 2022) and 130% (August 2022) higher than those recorded at the Lawson Road site, with cumulative rainfall at Site 4 between 22 December 2021 and 7 October 2022 approximately twice that recorded at Lawson Road.

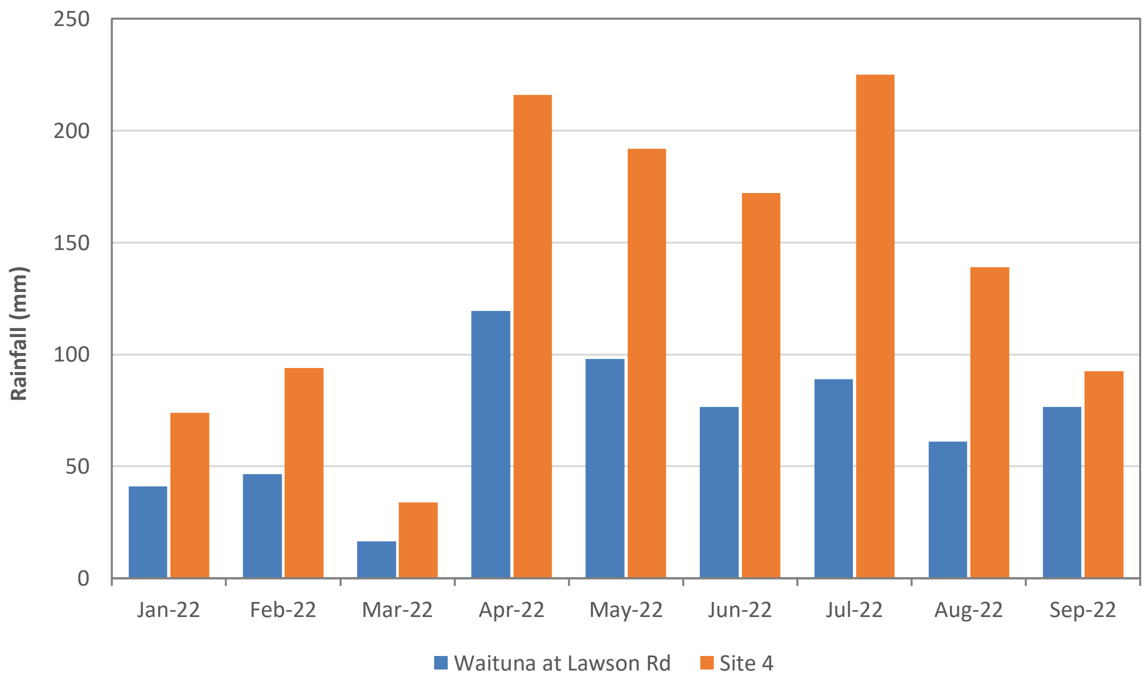

Figure 19: Comparison of monthly rainfall recorded at Site 4 with data from the Environment Southland Waituna at Lawson Road site.

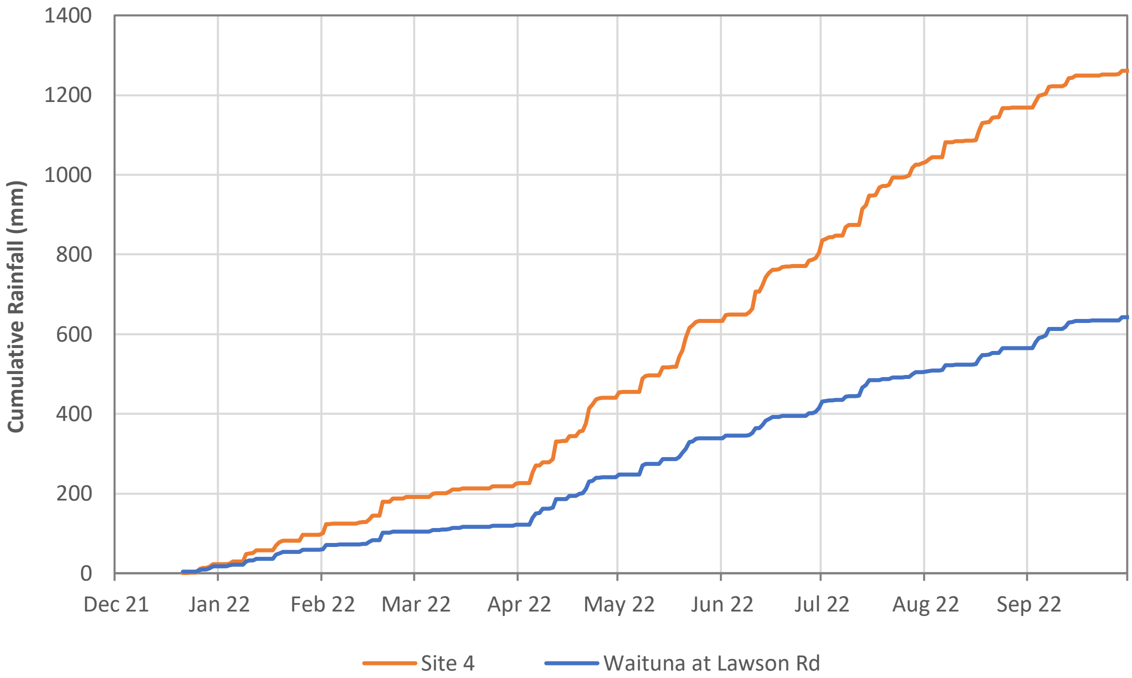

Figure 20: Comparison of cumulative rainfall between December 2021 and October 2022 at Site 4 and the Environment Southland Waituna at Lawson Road site.

Given the relatively uniform spatial and temporal distribution of rainfall typically observed along the south coast, the observed difference in rainfall between the Site 4 and the Lawson Road recorder is somewhat unusual. Given the length of monitoring record available from the respective sites, data from the Lawson Road site is preferred in the following sections as more likely to be representative of the wider Waituna Lagoon catchment.

5.2 Flow Monitoring

Figure 20 shows a plot of measured discharge downstream of the PRC structures and the control site between May 2021 and October 2022.

Prior to September 2021, the data indicates a degree of variation in measured discharge between the individual PRC structures. For example, while highest flows at Site 4 were recorded in response to rainfall during August 2021, no equivalent response was observed during the (larger) early September 2021 rainfall event. Conversely, discharge at Site 1 was relatively minor during August 2021 but exhibited a significant peak following the September rainfall event. At Site 5 discharge was maintained >5 L/s for much of the 2021 winter, while flows only reached this magnitude during peak flows the following (2022) winter. These observed variations in measured discharge are attributed to a combination of factors including the failure of the gravel weir at Site 1 and refinement of monitoring (including placement of water level sensors) at the remaining sites during the initial monitoring period.

Between October 2021 and April 2022 discharge was low to zero reflecting the limited rainfall over this period. The exception was a period of elevated flows at Site 1 from mid-November to early December which appear to reflect backing-up of water downstream of the weir due to a blocked culvert.

From January to September 2022 potential issues with flow measurement appear to have been largely resolved, with the monitoring data providing a more accurate record of discharge at the individual monitoring sites, including the control site which was shifted to a new location in December 2021.

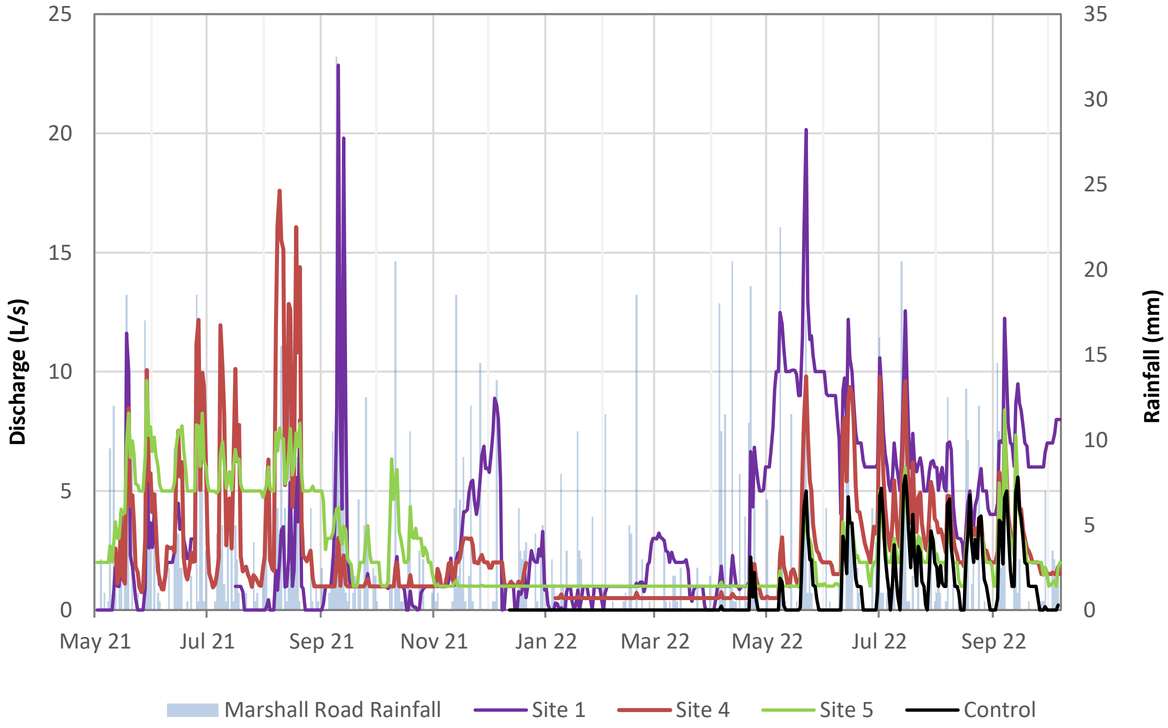

Figure 21: Measured discharge and rainfall at Marshall Road, May 2021 to September 2022.

Naturalising of flows to the catchment areas upstream of the individual PRC sites would typically provide a relative measure of the effect of the individual structures in terms of modifying the natural stream hydrograph. However, due to difficulties reliably delineating catchment areas, specific discharge varies appreciably between the individual catchment area. As illustrated on Figure 22, while normalised discharge at Site 4 and the control site is similar to that calculated for the wider Waituna Creek catchment, the calculated discharge for Site 1 and Site 4 differ appreciably. These observations indicate that catchment areas for these sites listed in Section 3 above under-estimate actual catchment areas.

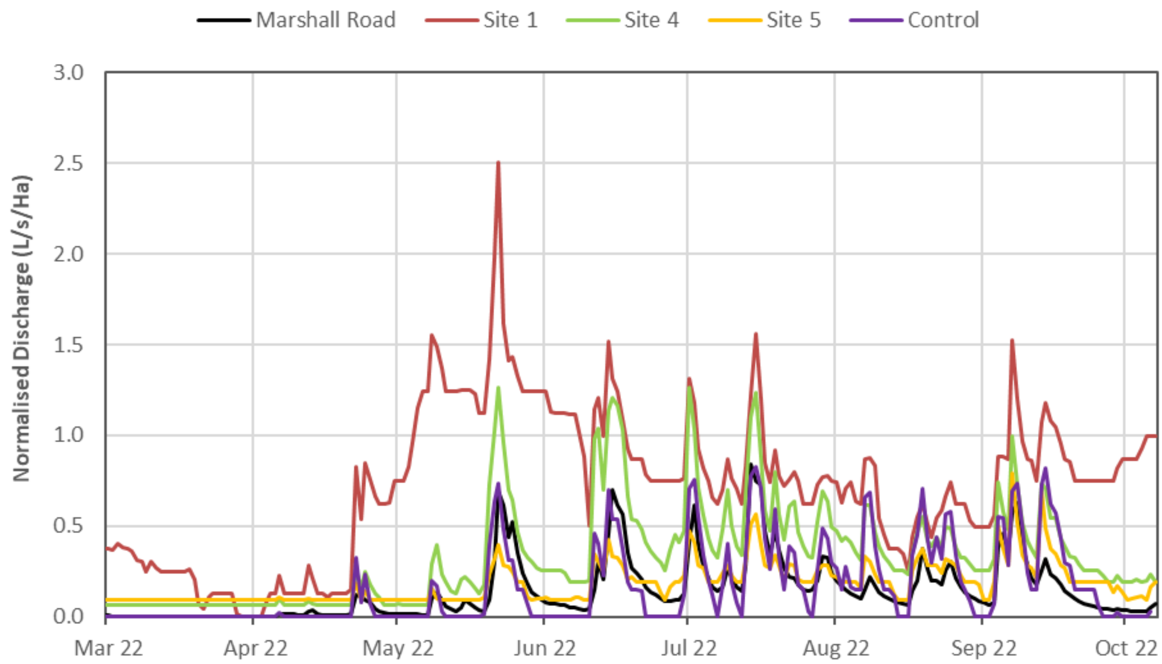

Figure 22: Naturalised discharge calculated for the PRC trial sites compared to Waituna Creek at Marshall Road, May 2021 to September 2022.

Given potential errors in estimated specific discharge, Figures 23 to 25 below provide an individual comparison of measured discharge at each PRC structure and the control site.

Figure 23 shows that despite the larger catchment area, peak flows at Site 1 are of a similar magnitude to those at the control site, with discharge maintained at a relatively high level (compared to peak flow) between individual rainfall events compared to the rapid recession of flow observed at the control site.

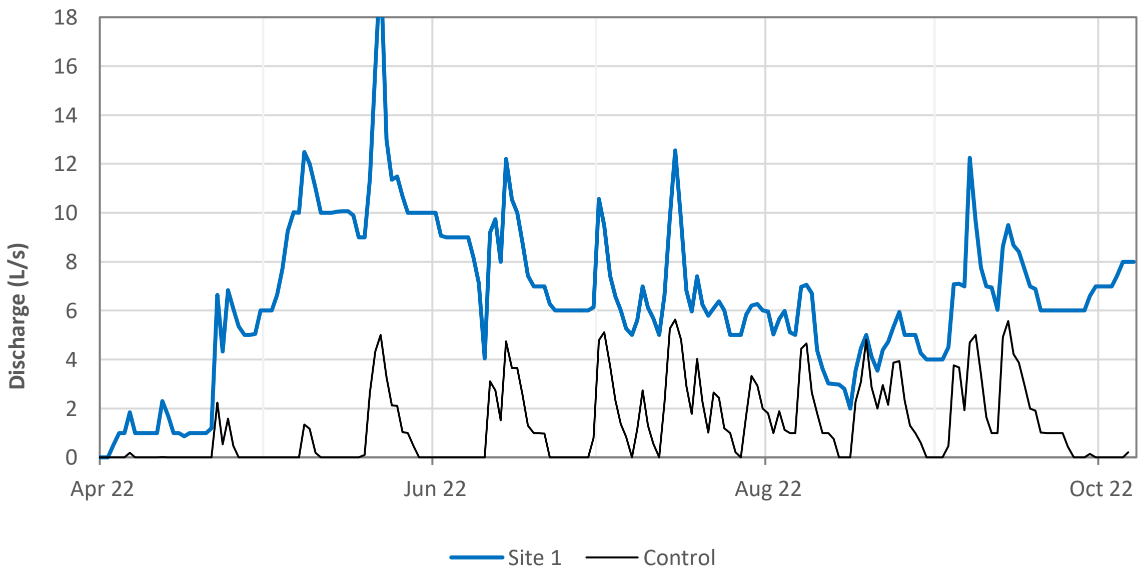

Figure 23: Measured discharge at Site 1 compared to the control site, April to October 2022.

Figure 24 shows that peak discharge at Site 4 during individual high flow events appears to be larger than that observed at the control site from May to mid-July 2022 and similar or slightly lower thereafter. Some attenuation of the rate of flow recession is observed at Site 4 compared to the control site.

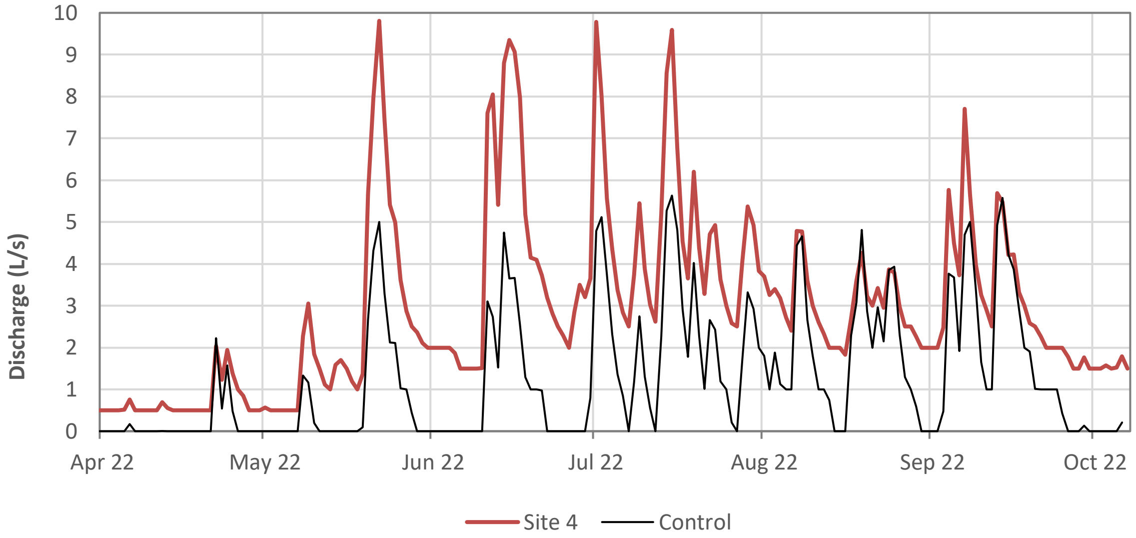

Figure 24: Measured discharge at Site 4 compared to the control site, April to October 2022.

As illustrated on Figure 25 below, peak discharge at Site 5 appears to be of a similar order to that observed at the control site, with minor attenuation of the flow peak apparent during some, but not all, high flow events. Flow recession between individual rainfall events is observed to occur at a similar rate at both sites.

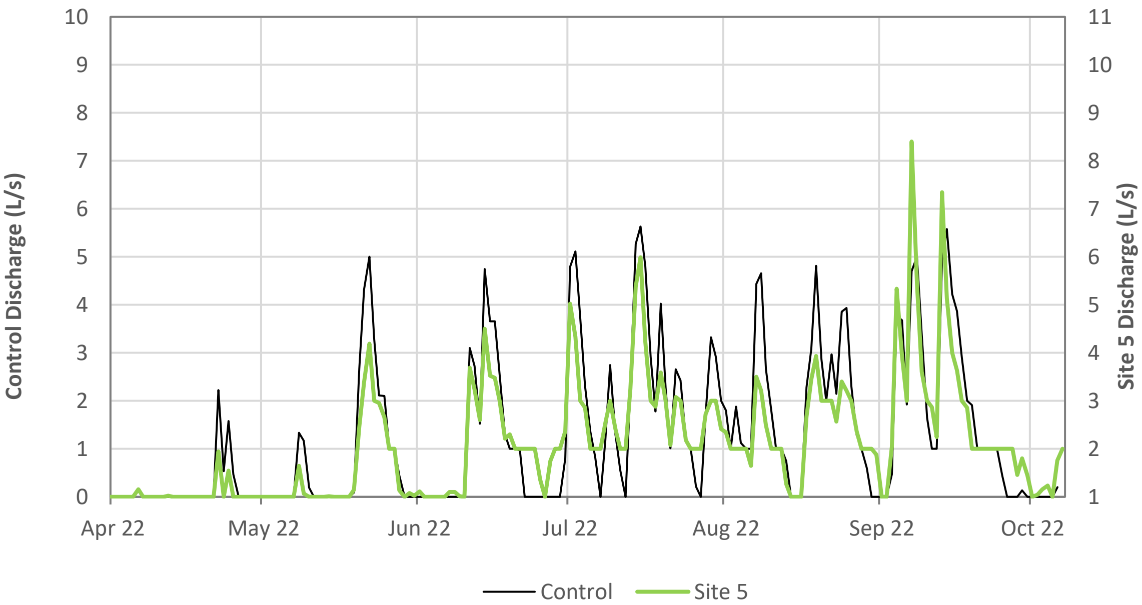

Figure 25: Measured discharge at Site 5 compared to the control site, April to October 2022.

Given the similarity in elevation and catchment characteristics, it is not unreasonable to infer the discharge at the Environment Southland Waituna Creek Marshall Road site should be a reasonable proxy for discharge in the Carran Creek sub-catchment.

As shown on Figure 26, flows in the Waituna Creek catchment recorded on 10 September 2021 (which damaged the gravel weirs at Site 1 and Site 3) were not exceptional in a historical context, with discharge of a similar magnitude (15 to 20 m^3/s) recorded on several occasions over the past 10 years. Table 2 lists hydrogeological statistics for the Waituna Creek at Marshall Road site reported by Environment Southland. These data indicate the peak discharge on the 10th September 2021 (~19.5 m^3/s) is lower than the calculated Mean Annual Flood of 21.7 m^3/s. This indicates flows of the similar (or slightly larger) to those experienced on the 10th September 2021 could be expected to occur, on average, at least once a year over the long-term. It is therefore reasonable to expect that PRC structures should be designed to accommodate discharge of this order without sustaining structural damage.

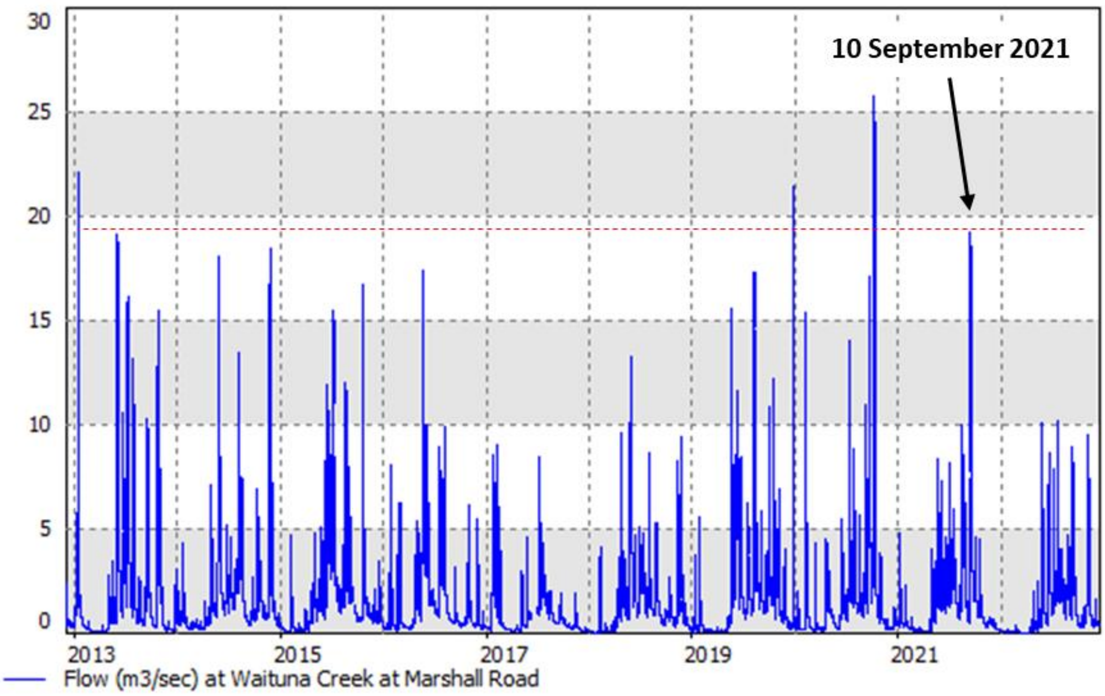

Figure 26: Comparison of the 10 September 2021 flow peak in Waituna Creek at Marshall Road with discharge recorded between 2013 and 2022 (plot from Environment Southland Beacon website).

Table 2. Comparison of peak discharge in Waituna Creek at Marshall Road on 10 September 2021 with annualised flow statistics (Source Environment Southland).

	10 September 2021	Mean Annual Flood	5-year ARI	10-year ARI
Discharge (m^3/s)	19.3	21.7	24.8	26.5

Overall, observations from flow monitoring for the Waituna PRC structure trial include:

- Accurate delineation of effective catchment areas in settings with limited topographic relief where extensive artificial drainage is present can be problematic.

- Significant attenuation of peak discharge appeared to occur downstream of the gravel weir at Site 1. This may be due to the porous nature of the rock utilised to reinstate this structure after the initial failure. Discharge through the rock ballast is likely to enable partial dissipation of storage prior to overtopping of the weir.
- Attenuation of the peak discharge was less evident downstream of the wooden weir structures. This may reflect discharge being limited by the capacity of the culvert pipe until the structure is overtopped, at which time discharge through the structure is effectively equivalent to upstream discharge.
- The effect of the wooden weir structures on discharge during the rising and falling limbs of the flood hydrograph is more equivocal. While Site 4 appeared to slow the rate of flow recession compared to the control site, this effect was less obvious at Site 5 which exhibited a hydrograph very similar to the control site.
- It is however unclear if attenuation of peak discharge is an appropriate metric to evaluate the utility of PRC structures. In some situations, reduction in flow velocity upstream of the structure (allowing suspended sediment to settle) may have greater influence on their performance than the actual magnitude of discharge through the structure. However, at others (particularly where erosion of streambed or bank materials is a major source of suspended sediment), attenuation of peak discharge may be an appropriate measure.
- Discharge during the 10 September 2021 rainfall event is likely to have been close to the Mean Annual Flood. Structures should be designed to ensure their structural integrity is not compromised by discharge of this magnitude.

5.3 Sediment Monitoring

Sediment accumulation at each weir site was measured at waratahs placed in the stream channel 3 metres, 6 metres and 9 metres upstream of the weir structures. Table 3 presents results of monitoring showing the depth of sediment accumulated upstream of each structure between 20th May 2021 and 6 October 2022 (a period of 505 days). The data shows sediment accumulation ranging between 104 and 152 mm immediately upstream of the PRC structures, compared to 66 mm at the control site. This indicates the PRC structures resulted in an additional 38 to 86 mm of sediment accumulation compared to the control site.

Table 3. Summary of sediment accumulation measurements.

Site	Weir Type	Sediment Accumulation (mm)			
		3 m upstream	6 m upstream	9 m upstream	Average
1	Gravel	107	14	190	104
4	Wooden	47	220	125	131
5	Wooden	96	180	180	152
Control		50	87	60	66

As shown on Figure 27 below, sediment accumulation was appreciably higher at distances >3 m upstream of the wooden weir structures. This may reflect the proximity of the floating pipe intakes to this measurement point[2]. The figure also shows that sediment accumulation 6 metres upstream of Site 1 was relatively low compared to the upstream (9 m) and downstream (3 m) monitoring sites.

[2] Refer to Figures 9 and 10 above.

The reason for this anomaly is uncertain but may be related to the extent of grass growth in the channel which may have trapped sediment in the channel upstream of this point (Site 1 recorded the highest sedimentation rate at the 9 m upstream monitoring point).

The wooden weir structures at Sites 4 and 5 were fitted with floating intake pipes compared to the fixed intake at Site 1. Although observed sedimentation rates were highest at the wooden weir sites, sample size is insufficient to determine whether the floating intake design increased the rate of sediment retention.

Assuming pooling and associated reduction in flow velocity extends upstream of the PRC structures for a minimum of 25 metres[3] over a 1m bed width, the measured sediment accumulation equates to retention of between 0.95 and 2.15 m^3 of sediment upstream of the PRC structures.

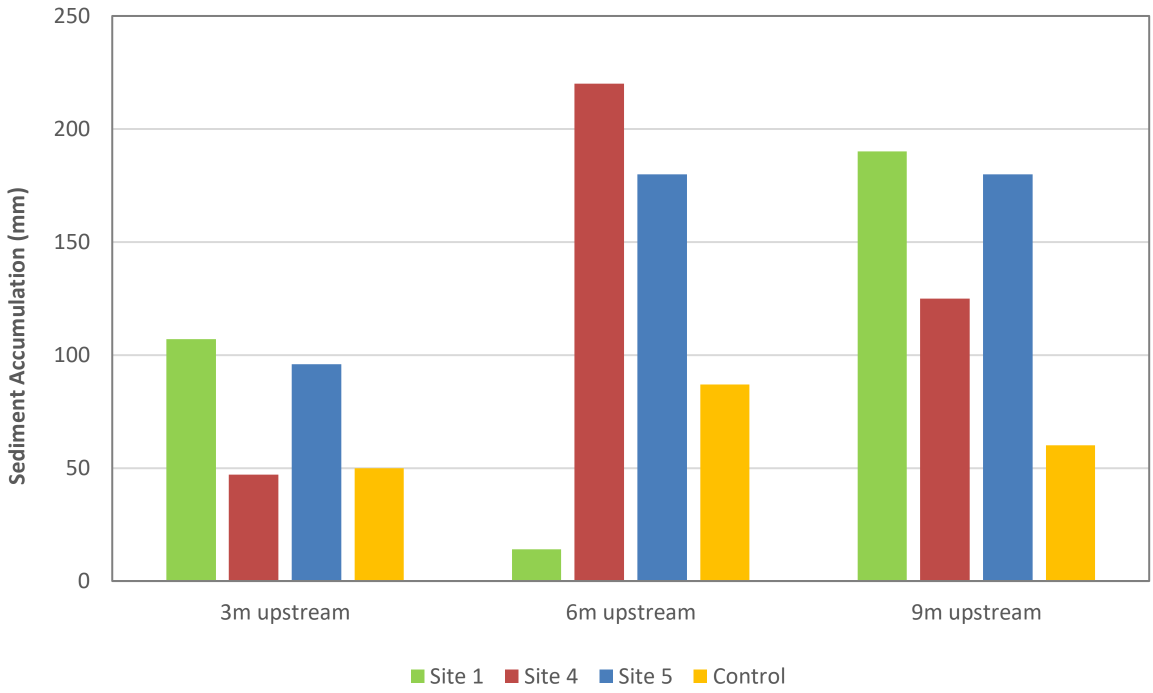

Figure 27: Sediment accumulation measured upstream of the PRC trial sites, 20 May 2021 to 6 October 2022.

Although excluded from the trial, it is noted that the RDA consulting report records accumulation of 150 mm of sediment at the '*upstream pipe waratah*' (presumably ~3 metres upstream of the dam) and 15 mm of sediment on the upstream dam face at Site 3.

Summary of observations from sediment accumulation measurements include:

- Sediment accumulation was observed upstream of the three PRC structures at rates exceeding those recorded at the control site.
- Extrapolating measured sediment accumulation across a nominal 25 metre ponding area upstream of the PRCs, measured sediment accumulation rates indicate retention of between 1 to 2 m^3 of sediment upstream of the PRC structures over an approximately 18-month period. Assuming a conservative dry bulk density of 1.1 to 1.6 g/m^3 for the accumulated fine sediment this equates to c. 1,100 – 1,600 kg per m^3 of retained sediment or 2,200 – 3,200 kg

[3] The Dairy Green summary report indicates the drain 'backed-up' approximately 130 metres from Site 4 and 75 metres from Site 5 so 25 metres is a conservative estimate.

for 2 m^3 of retained fine sediment. The quality, i.e., the N and P content associated with these sediments have not been assessed, although relevant literature points to typically elevated concentrations of P, N, and microbes in sediment derived from farm runoff.

- Measured sediment accumulation rates were lowest at the downstream monitoring point (3 metres upstream of the PRC structure). This may suggest that turbulence or vertical flow in the water column induced immediately upstream of the PRC structures during overtopping may increase sediment entrainment in this area.
- Insufficient data is available to evaluate the effectiveness of floating intake structures as a means to increase sediment capture.
- Significant sediment is generated by drain clean and rebattering and sediment loss can remain high until banks are revegetated. The influence of these activities on trial results is uncertain.

5.4 Electrical Conductivity

Electrical Conductivity (EC) was monitored at Site 1 and Site 4 during the trial period.

Figure 28 shows a plot of the data compared to rainfall measured at Lawson Road. At Site 1 the data show an ongoing reduction in EC through the 2021 winter, with a significant decline recorded following the early September 2021 rainfall event. EC then gradually increased through late spring and early summer before levelling-off in January 2022. From January to October 2022 EC at Site 1 exhibits an ongoing decline, with short duration spikes following individual rainfall events.

Data from Site 4 exhibits a somewhat different temporal pattern to Site 1 with a significant spike in EC observed in early April 2022 followed by an ongoing decline through to October 2022.

The observed variations in EC are inferred to reflect the greater contribution of lower conductivity surface runoff to flows during the winter months with a larger contribution from higher EC soil waters and shallow groundwater during the 2022 summer and autumn. The large spike in EC observed at Site 4 may reflect mobilisation of dissolved contaminants accumulated in the soil zone over the relatively dry spring/summer period via the tile drainage network (which makes a significant contribution to flow at Site 4 (Dairy Green, 2022)).

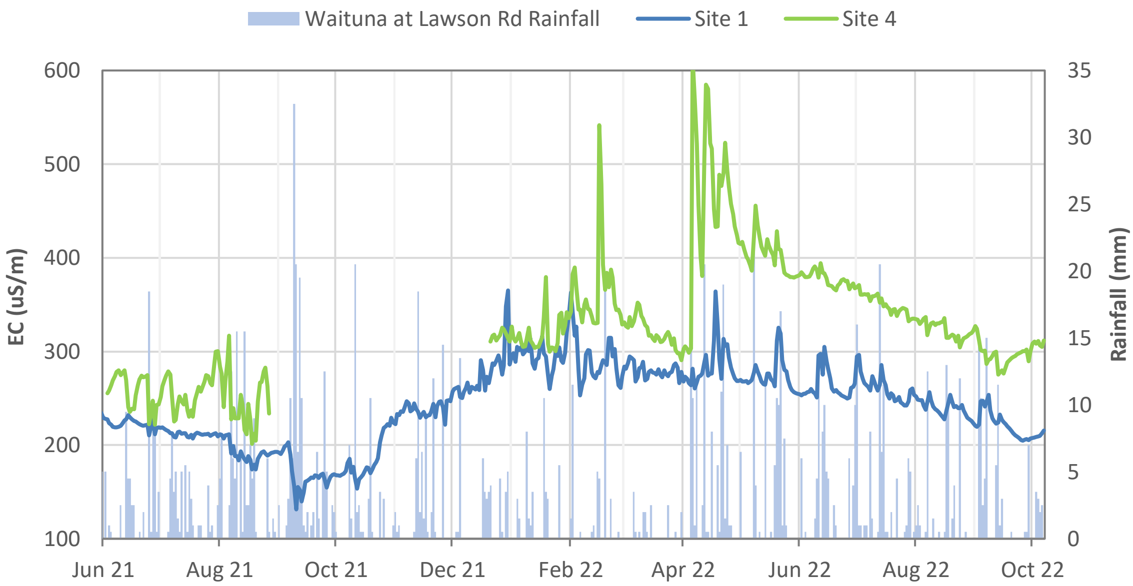

Figure 28. Electrical Conductivity measured at Site 1 and Site 4, June 2021 to September 2022.

5.5 Monitoring Limitations

During the trial, a range of issues were experienced with data collection including:

- Discharge at all sites was very low (zero at several sites) between mid-September 2021 and early-April 2022 due to low rainfall.
- The water level monitoring equipment installed at Site 3 failed shortly following installation in early May 2021. Due to subsequent issues with the availability of hired monitoring equipment as well as the structural integrity of this site, flow monitoring was discontinued for the remainder of the trial period.
- All sites were affected by extensive macrophyte growth. Extensive grass growth was observed in the stream channel at both Site 1 and Site 5. The extent of this growth potentially affected water levels downstream of these structures. In-stream vegetation upstream of Site 4 comprised more Chick Weed-type growth than grass which potentially had less effect on water levels. Extensive in-stream algae growth also restricted flow paths at all sites, particularly at Site 1.
- The partial collapse of a culvert downstream of Site 1 during spring 2021 resulted in water backing up downstream of this site. The culvert was removed/replaced in December 2021.
- Extensive drain clearing was undertaken prior to installation of the Wooden Weir structures at Sites 4 and 5. Drain clearing was also undertaken upstream of the gravel structures and control site during the trial period. The effect of this drain clearing/re-battering on overall sedimentation rates is unknown.
- Due to issues with bank stability and the potential representativeness of the initial control site, this site was relocated in December 2021.
- EC measurements at Site 4 were affected by instrument failure over the period September to December 2021.
- All sites were affected to some degree by discharge from upstream tile drains which potentially increases the contributing catchment area which appeared to increase discharge after drain cleaning.

6 Summary

Key observations from environmental monitoring undertaken for the Waituna PRC structure trial include:

- The PRC structures trialled all exhibited higher rates of sediment accumulation than observed at the control site. Insufficient data is available to provide a reliable comparison of the sedimentation rates upstream of the two PRC types trialled. Although not ultimately reported in the trial, similar (or greater) rates of sedimentation were reported upstream of the gravel weir at Site 3 compared to the remaining sites. Lower sedimentation rates immediately upstream of the weirs (compared to further upstream) may suggest that vertical flow/turbulence during high flows may reduce sedimentation rates.
- Assuming sedimentation occurs over a 25-metre reach upstream of the structures, the individual PRC structures are estimated to have retained of the order of 1 to 2 m^3 of suspended sediment compared to the control site over the 18-month trial period or between 1,100 – 3,200 kg of fine sediment.
- Delineation of catchment areas can be problematic in areas with limited topographical relief and extensive artificial drainage. Accurate delineation of catchment areas is important to ensure PRC can be appropriately sized and constructed to accommodate high flow events without adversely affecting structural integrity. Uncertainty regarding contributing catchment area made it difficult to directly compare hydrological effects at the three PRC trial sites.
- The effect of the PRC structures on discharge during the rising and falling limbs of the flood hydrograph is more equivocal. While Site 1 and Site 4 appeared to slow the rate of flow recession compared to the control site, this effect was less obvious at Site 5 which exhibited a hydrography very similar to the control site (resizing of discharge pipes to reduce over topping may have resulted in greater attenuation). However, the (uncertain) contribution of subsurface flow (from mole tile drains) may also have contributed to variations in the rate of flow recessions observed between individual PRC sites.
- The gravel weir at Site 1 which was reinstated after initial failure utilising coarse rock ballast appeared to significantly dampen peak discharge following rainfall events. This may be due to the porous nature of the rock ballast which enabled partial dissipation of storage prior to overtopping of the weir. Attenuation of the peak discharge was less evident downstream of the wooden weir structures. This may reflect discharge being limited by the capacity of the culvert pipe until the structure is overtopped, at which time discharge through the structure is effectively equivalent to upstream discharge. Resizing of discharge pipes to reduce over topping may have resulted in greater attenuation. The design of an adjustable outflow aperture is worth considering.
- Although appearing to make logical sense, insufficient data is available to evaluate any additional sediment retention associated with floating vs fixed culvert intakes.

7 Recommendations for Future Deployment of PRC structures

- The PRC structures included in the Waituna trial are likely best suited to applications where the contributing catchment area is no greater than 10 Hectares. This is likely to be in smaller catchments or headwater areas of larger streams. Ideally information to accurately define the catchment area should be available for incorporation into the design of PRC structures, including the extent of artificial (mole tile) drains.

- Information to characterise discharge should be collected prior to design and construction of PRC structures. Ideally this would include measurement of discharge over a representative period prior to construction but could also include physical inspection during rainfall events, recording of water depth (for example based on debris marks) and observations from landowners. Land users with long standing knowledge of where, how often, and how much runoff is generated are a valuable source of relevant information for site selection and design. NIWA's High Intensity Rainfall Design System (HIRDS) could also be utilised to ensure the design is appropriate for a given annual return interval.
- Dampening of peak flow rates may be less important to the overall performance of the PRC structures than the reduction in upstream flow velocity. Thus, a focus for future applications should be on achieving sufficient residence time in the upstream ponding area to slow flow velocity sufficiently to provide for settlement of suspended sediment. This raises the possibility of situating PRC structures upgradient of a drain, across an area identified as a major runoff pathway (critical source area). Detainment bunds, or weeping wall structures have been employed in such situations to slow down the velocity runoff waters. Such an approach would have the benefit of mitigating issues around fish passage and possible modification of a natural waterway.
- Resizing and/or addition of extra discharge pipes to reduce over topping may have result in greater attenuation of peak flows downstream of wooden weir PRC structures compared to those utilised in the trial.
- Design of PRC structures should require little to no maintenance. While designs such as the floating intake may increase the effectiveness of sediment capture, they require maintenance and have a greater potential for mechanical failure.
- Drain cleaning and rebattering make a significant contribution to mobilisation of sediment. While PRC structures can potentially help to limit contaminant losses from these activities, other mitigations such as excavation and regrassing during low flow periods may also make a meaningful contribution to reducing sediment losses.
- In settings where bed or bank erosion is identified as source of suspended sediment, PRC structures incorporating porous rock ballast may attenuate peak discharge rates/flow velocity and therefore help reduce erosion. However, the design specifications for such structures need to be carefully engineered or even over-engineered to ensure they are sufficient to maintain structural integrity during high flow events.

References

Dairy Green Limited, 2023; Wooden Weir Peak Runoff Control Structures Final Report. Report prepared for Whakamana te Waituna Trust, December 2022.

RDAgritech, 2022; Final Field Report - Check Dam. 51396 WTW Foveaux PRCS Trial. Report prepared for Whakamana te Waituna Trust, July 2022.

Rissmann, C., Wilson, K., Hughes, B., 2012; Waituna Catchment Groundwater Resource. Environment Southland Technical Report, May 2012.