Opuha River periphyton management investigations 2013-2014

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Executive summary

Over the 2013-2014 summer a series of investigations into causes and mitigation of nuisance periphyton in the Opuha River have been undertaken by NIWA in collaboration with Opuha Water Ltd and Environment Canterbury. Data collection included: regular visual estimates of periphyton coverage made at 20 consistent marked and surveyed view locations at each of three sites (Dam, Skipton and Confluence) in the Lower Opuha; measurement of velocity and depth at the viewer locations for a range of flows; and installation and maintenance of temperature loggers on the North and South Opuha and the three monitoring sites in the Lower Opuha.

On 27 February 2014 an artificial flushing flow was released down the Lower Opuha. Periphyton coverage was monitored on days before and after the flush, and velocities and depths were measured during the flush peak. The flushing flow was larger and of longer duration than all previous artificial flushing flows. With the current dam infrastructure there is little more that can be done to increase the flow rate or duration of flushes released from the dam. The flush successfully mitigated the problem of detached nuisance periphyton clogging irrigation takes and deposited much less organic material along the banks of the Opihi River and the river mouth lagoon/hapua than previous monitored flushes. Reduced deposition was likely a result of: (1) the longer duration flush, (2) the river mouth being opened mechanically immediately prior to the flush, and (3) the timing of the rising limb of the flush hydrograph coinciding with low tide. It is recommended that future flushes are timed to coincide with low tide and that they are of similar long duration (provided there is sufficient water available).

Monitoring showed the flush was significantly more effective at removing periphyton at all three monitoring sites than previous monitored flushes and although periphyton coverage did increase rapidly after the flush it took significantly longer to return to pre-flush levels than after previous trial flushes (longer than 1 month at Skipton and Confluence sites). Trends in periphyton type and abundance at the Dam site differed from other sites. This was similar to patterns observed in 2013. In early February, prior to the flush, didymo cover started declining at this site and never recovered. The causes of the changes at the dam site are unknown but may relate to water temperature or water chemistry.

Relationships between periphyton cover / changes in cover and hydraulic conditions at the individual periphyton monitoring locations were investigated to better understand the effect of different flows on periphyton growth and removal. Bed shear stresses exceeding 45 N/m^2 during the flush were found to result in greater than 50% reduction in cover while shear stresses less than 35 N/m^2 show very variable reduction in cover. This supports and adds certainty to shear stress thresholds used during analysis in Measures and Bind (2012) which identified 40 m^3/s as a required flow for effective flushing. Areas of bed that are exposed to higher shear stresses during normal flows were found to recover more slowly to the effect of the flush, and showed lower periphyton cover on average over the whole monitoring period.

Monthly water temperature measurements collected since 1989 as part of the National River Water Quality Network indicate that minimum daily water temperature in the Opuha River at Skipton may have increased by as much as 3°C in late summer and autumn following installation of the dam. This effect of the dam on temperatures is confirmed by data from the temperature loggers which show temperatures in the Opuha downstream of the lake are consistently 2-3°C higher than temperatures upstream. This temperature difference is likely to have a significant effect on periphyton, with previous research demonstrating small temperature differences can cause significantly increased biomass. Previous research also highlights 15°C as an important threshold above which high cover of *Phormidium* becomes more likely. The dam effect on the Opuha does increase the proportion of time water temperature is above this threshold.

Experiments into the effects of exposure of periphyton to air were undertaken to investigate the possibility of using temporarily lowered water levels as a means of helping mitigate nuisance periphyton. The experiments involved placing an array of artificial substrates (paving tiles) and natural substrates (large river cobbles) in the Opuha River. The substrates were grouped and the groups were exposed to different treatments including short duration (a few hours) and longer duration (one day) exposures by removing them from the river to the bank, while a control group of substrates remained in the river. Some groups of substrates were also exposed to high flows by placing them in a different area of river to replicate the effects of a flush. Conclusions from the experiment were: (1) any exposure to air (short or long, even on overcast days) sets back biomass development, and (2) overnight exposure of a well-developed didymo mat prior to flushing may increase the effectiveness of the flush, although more replication would be required to confirm this.

The observed effect of shear stress reducing periphyton regrowth and mean cover, and the effect of exposure to air reducing biomass suggest that increasing short term (hours-days) flow variability may be a useful technique to help mitigate nuisance periphyton. Increased flow variability could be implemented with minimal operational impact during any periods when average flow is raised above minimum flow requirements. Increased flow variability could help complement flushing flows by improving flush effectiveness and slowing regrowth after flushing.

1 Introduction

1.1 Background

Nuisance growths of periphyton have been reported regularly in the Opuha River downstream of the Opuha dam, and in the Opihi River farther downstream, since the dam was commissioned in 1999. Between 1999 and 2008, the main nuisance alga in the river was the potentially toxic cyanobacterium *Phormidium*. Green filamentous algae were also prominent. In early 2008 the bloom-forming diatom *Didymosphenia geminata* (didymo) was discovered in the Opuha River, and has been a major component of the periphyton since then, sometimes forming large blooms. However, *Phormidium* is still common in the river and in suitable conditions co-exists with didymo and can form high cover, overgrowing didymo mats.

There is little doubt that the presence of the dam is associated with the increase in periphyton (Lessard et al. 2012), and the pattern is a well-known consequence of river impoundment. The main driver of increased periphyton is thought to be a reduction in bed clearing high flows and an accompanying stabilisation (armouring) of the river bed, which allows periphyton to resist changes in water velocity.

Restoring flow variability as a part of dam operation could potentially mitigate nuisance periphyton and this approach has been investigated in the Opuha River since 2005. Flushing flow trials were conducted between 2005 and 2007, and generally produced inconsistent and only marginally effective results in terms of removing periphyton biomass (Lessard et al. 2012). In 2012 a study was undertaken to investigate the hydraulics of flushing flows released from the Opuha Dam. Hydrological records of the previous flushing trials were analysed and a 1-dimensional hydrodynamic model of the Opuha River was developed (Measures and Bind 2012). That report made several recommendations for (a) management of the dam infrastructure to maximise the effectiveness of flushing releases, and (b) monitoring future releases to better understand their effectiveness.

A monitored trial flushing flow was released on 13 February 2013. Monitoring included surveys immediately before and after the flush, but also 2 weeks before and after to determine prior growth and re-growth. Technical problems meant that the flush size could not be fully optimised. In terms of periphyton removal the flush was moderately successful, but regrowth was rapid (Measures and Kilroy 2013).

Although flow alteration is thought to be the primary cause of nuisance algae in the Opuha, other factors have also been considered. The Opuha Dam has a hypolimnetic release (i.e. water from the bottom of the lake is discharged to the river). Especially in summer, thermal stratification of the lake can causes the bottom water to become deoxygenated. This triggers chemical reactions leading to solubilisation of metals including iron and manganese, which then enter the river (Martynova 2010, 2012). Re-oxygenation in the turbulent river water leads to precipitation of these metals (seen as a black coating on rocks immediately below the dam). A potential change in water quality as a result of these processes has been suggested as contributing to the periphyton problems, especially *Phormidium*. Opuha Water Limited is already taking measures to minimise water quality changes by mechanical mixing of the deep lake waters at appropriate times to limit deoxygenation. In addition, Environment

Canterbury initiated a monitoring programme in summer 2012-13 to investigate water chemistry in relation to periphyton cover at several sites in the Opuha – Opihi catchment, including upstream of Lake Opuha.

Another factor that could be increasing periphyton is increased water temperature. Increased temperature has been shown to influence both periphyton biomass and community composition in streams (e.g. Piggott et al. 2012). Monthly spot temperature data from NIWA's National Water Quality Monitoring Network (NRWQN) indicate that temperature increased in the Opuha River following construction and commissioning of the Opuha Dam. Improved understanding of the link between water temperature and periphyton growth in the Opuha will help address the question of whether the effects of the dam on water temperature have influenced periphyton abundance downstream.

1.2 Study aims

In this report we describe studies in 2013 -14 that follow up and expand on the flushing flow trial in February 2013. The work included coordinating with Environment Canterbury staff to add value to the data they are planning to collect in their water chemistry – periphyton investigation. The tasks required were outlined in a proposal to Opuha Water Company on 1 November 2013. The outcome of the summer fieldwork and subsequent analyses are presented as three studies.

Study 1: Periphyton surveys, summer 2013-14. Visual assessments of periphyton cover carried out by both NIWA and Environment Canterbury were combined into a time series from December 2013 to April 2014. The surveys included those around a flushing flow carried out on 27 February 2014. The effects of the 2013 and 2014 flushing flows are compared.

Study 2: Effects of hydrology and hydraulics on periphyton cover. The aim of this study was to analyse more precise data on periphyton cover and associated hydraulic conditions, to improve understanding the effects of changes in water velocity and bed shear stresses (i.e., flows) on periphyton in different parts of the river.

Study 3: Water temperature. In this study we compared water temperature across the sites in summer 2013-14 and discuss results in relation to the NRWQN data.

In addition, we carried out pilot trials to assess the effects of exposing periphyton to air on (a) subsequent periphyton development, and (b) the effectiveness of flushing flows. Flushing flows are not the only option for introducing flow variability into a controlled river. The trials investigated the potential for controlling periphyton development by periodically lowering flows. They were conducted as part of NIWA's research programme "Sustainable Water Allocation", and are reported here as **Study 4** because they are highly relevant to the Opuha River case.

The report is structured as a series of stand-alone sections. The first section describes the 27 February 2014 flushing flow and compares it to previous flushes, the following sections each report on one of the four studies defined above.

2 February 2014 flushing flow

2.1 Flushing release

On 27 February 2014 a flushing flow designed to remove nuisance periphyton was released from the downstream weir. The flush was similar in design to the one released on 13 February 2013 (described in Measures and Kilroy 2013) except for a two key differences:

- The flush duration was significantly extended to almost 24 hours, albeit at reducing flow rates due to the twin limitations of the maximum release rate from the main dam (approximately 16 m^3/s) and the storage capacity of the re-regulation pond (Measures and Bind 2012). The aims of extending the flushing duration were twofold, to improve flush effectiveness at removing periphyton and to wash as much of the detached periphyton all the way through the lower Opihi and lagoon/hapua to the coast, avoiding the deposition experienced in 2013.
- The initial flush release had a more sharply increasing flow rate and higher peak flow (39 m^3/s) due to more rapid opening of the gate on the downstream weir.

These differences are shown in Figure 2-1.

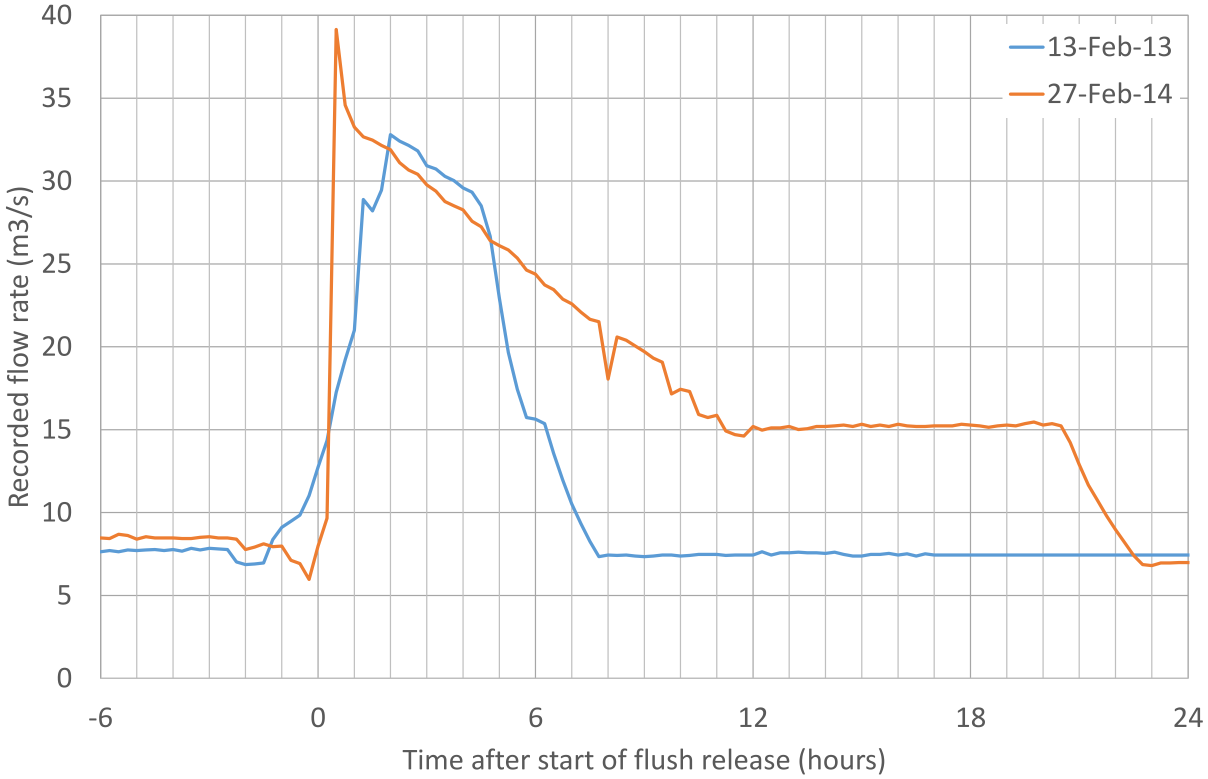

Figure 2-1: Comparison of flushing releases in 2013 and 2014. Flow rates recorded at downstream weir gauging station.

The 2014 flushing release was optimised by overfilling the re-regulation pond prior to release, running the power station during the release, opening the gate fully and rapidly, and leaving the gate open for almost 24 hours, well beyond the time at which the re-regulation pond fully emptied. The flushing release achieved greater peak flow and longer duration than all previous artificial flushing flows released down the Lower Opuha. With the current dam infrastructure there is little more that can be done to increase the flow rate or duration of flushes released from the dam unless there is the opportunity to combine a flush with naturally higher flows in the tributaries downstream of the dam or overtop the main dam spillway.

2.2 Flush propagation/attenuation

The propagation of the flush downstream past the various flow recorders is shown in Figure 2-2 and Table 2-1. The propagation and attenuation of the flush was similar to 2013 except the longer duration of the flush helped achieve higher peak flows into the Lower Opihi and the longer duration of the release meant flows stayed higher for longer.

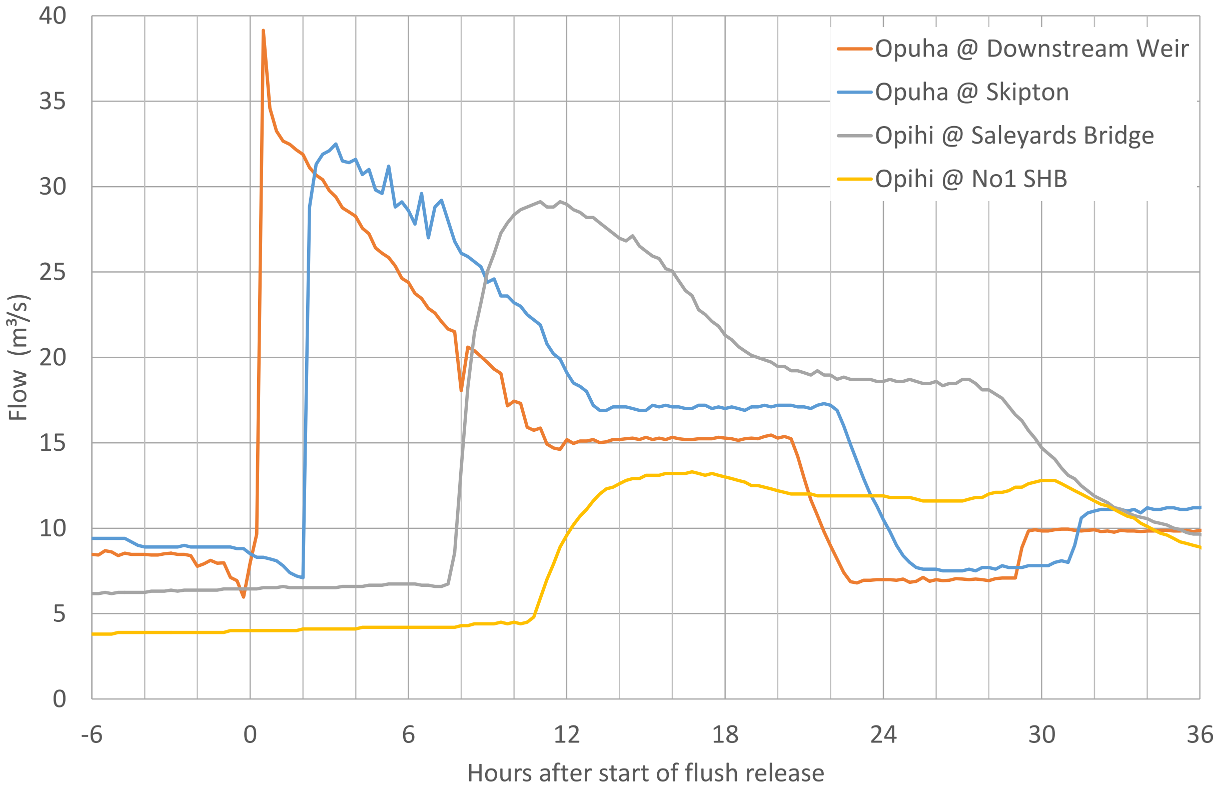

Figure 2-2: Propagation of flushing wave through lower Opuha and Opihi. Flow data provided by ECS Ltd and Environment Canterbury.

Table 2-1: Propagation and attenuation of 2013 and 2014 flushing flows. (Timings based on 2014 flush).

Site	Distance from downstream weir (km)	Time from flush release starting (hours and minutes)		Feb 2014 peak flow (m^3/s)	Feb 2013 peak flow (m^3/s)
		Flush arrival	Flow peak		
Opuha @ Downstream weir	0.1	0:00	0:30	39.1	32.8
Opuha @ Skipton	12.7	2:00	3:25	32.5	32.1
Opihi @ Saleyards	41.6	7:30	11:00	29.1	25.9
Opihi @ No.1 SHB	52.0	10:45	16:45*	13.3	11.5

* Although the 2014 flush took 6 hours to peak at SH1 it had reached 90% of peak flow by 13:15 after the start of the release, after which the rate of rise was very gradual.

It is notable that the observed peak flow (and flush volume) is significantly lower at the Opihi @ No.1 SHB flow recorder compared to the recorders upstream. The accuracy of the rating equation at this site was confirmed by two gaugings (of 11.68 m^3/s and 12.37 m^3/s) undertaken by Environment Canterbury on 28 February, during the flush recession. The flow reduction observed between Saleyards Bridge and No.1 SHB flow recorders is most likely due to infiltration of water into the river gravels.

2.3 Additional commentary

The effectiveness of the flush at removal of periphyton in the Lower Opuha is analysed in Sections 3.4.2 and 4.3.1 using data from the periphyton monitoring surveys. In addition to the detailed analysis presented in these sections, there are several features of the February 2014 flush which are particularly noteworthy.

2.3.1 Pre-flush conditions

In early February the flow in the Opuha River had been gradually ramped up following a period of low flows. This resulted in significant quantities of didymo being dislodged from the bed and floating downstream. This dislodged didymo rapidly clogged irrigation takes by wrapping around screens causing a significant operational problem.

Figure 2-3: Didymo clogging log protector screen at Skipton Irrigation take. Photo Steven Pagan 2 February 2014.

Whilst this problem had reduced somewhat prior to the flush it was still a concern operationally as further flow increases were required in order to meet seasonal environmental flows and irrigation demands. Following the flushing flow this problem was eliminated. This highlights that flushing flows are useful from an operational as well as environmental viewpoint.

2.3.2 Opihi mouth considerations

The 13 February 2013 flush caused a number of concerns at the Opihi river mouth lagoon/hapua. In particular the flush deposited significant quantities of organic material suspended by the flush on river margins in the lower Opihi. In contrast the 27 February 2014 flush deposited much less and was perceived by residents and fishermen to be much more successful. The reduced deposition was most likely a result of a combination of factors:

1. The 2014 flush had much longer duration and more gradual recession than the 2013 flush. This is likely to have helped carry suspended material right the way through the river system.
2. Environment Canterbury mechanically opened the river mouth directly in front of the main Opihi River channel immediately prior to the flush.
3. The arrival of the rising limb of the flushing hydrograph at the river mouth coincided with low tide.

The mouth closure and tide timing are discussed further below.

During the week leading up to the flushing release the Opihi mouth naturally closed as a result of wave action. Environment Canterbury undertook earthworks to re-open the mouth directly in line with the Opihi river channel immediately prior to the flush release. The timing of the mouth closure, reopening and flushing flow is shown in Figure 2-4.

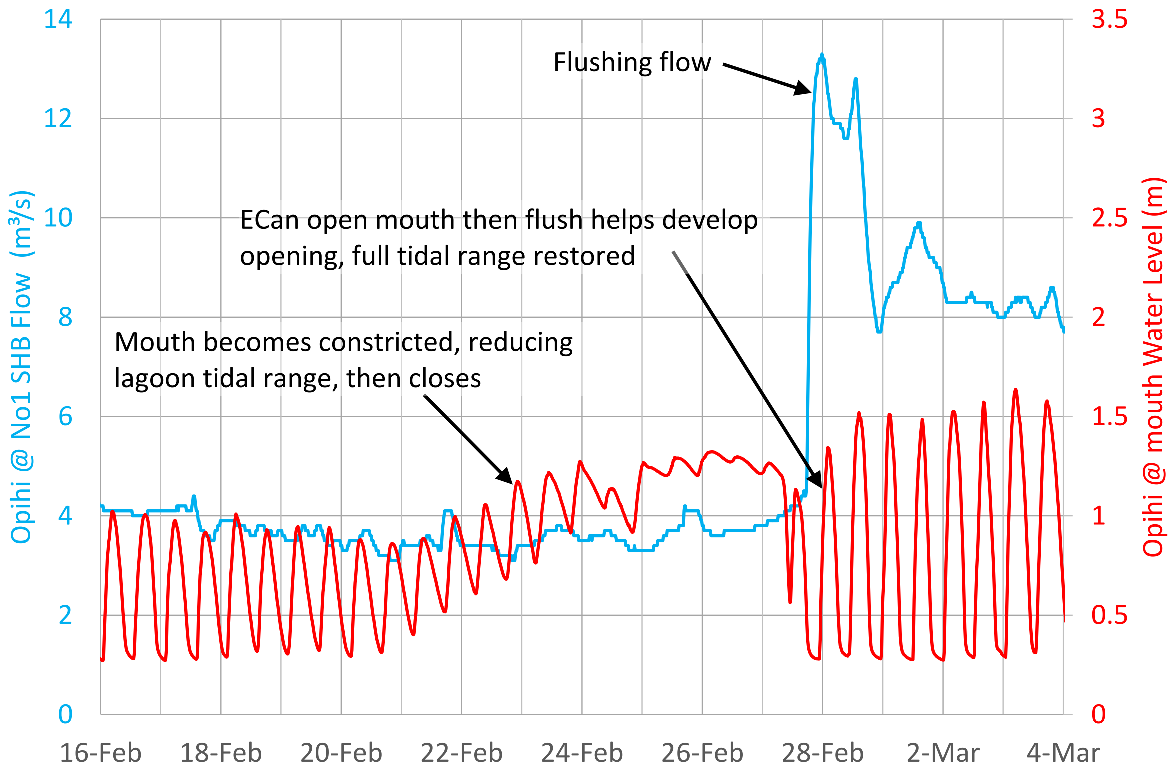

Figure 2-4: Flows and water levels at the Opuha Mouth before, during and after the February 2014 flushing flow.

The timing of the mouth opening immediately prior to the flushing flow had two benefits:

- Opening the river mouth prior to the flush helped reduce deposition of suspended organic material within the lagoon/hapua.
- Releasing the flushing flow through the new cut helped enlarge and develop the cut making it less likely to be closed.

The arrival of the February 2014 flushing flow at the mouth of the Opihi coincided with low tide unlike the February 2013 flushing flow which arrived several hours before low tide (Table 2-2). Measurements of the concentration of suspended organic matter during the February 2013 flush showed that the rising limb of the flush hydrograph transports most of the suspended material (Measures and Kilroy 2013). This suggests that timing the start of the flush to coincide with low tide helps transport the majority of suspended organic material directly out to sea with minimal deposition. As the tide comes in during the flush peak and later stages of a flush, rising water levels in the hapua encourage the removal of any material which did get deposited during passage of the high concentration rising limb of the flush hydrograph.

Table 2-2: Timings of tide and flushing flow at mouth of Opihi during February 2014 flushing flow.

Event	Time (NZDT)	
	2013	2014
Flush arrives at SH1 (~7.5 km from mouth)	20:00	18:45
Flush peaks at SH1	21:30	00:45*
Low tide (Timaru)	00:46	20:26

* Although the 2014 flush took 6 hours to peak at SH1 it had reached 90% of peak flow by 21:15 after which the rate of rise was very gradual.

It is likely that the timing of the February 2014 flush relative to the low tide (flush release started 12 hours 30 minutes before low tide at Timaru) contributed to reduced deposition of organic matter in the Opihi lagoon/hapua compared to the 2013 flush.

3 Study 1: Periphyton surveys, Opuha River, summer 2013-14

Monitoring around the flushing flow on 13 February 2013 comprised two surveys before and two surveys after the flush, over a period of 4 weeks. This was adequate to determine the effects of the flush and compare periphyton accrual leading up to and following the flush. However, it was considered that a longer time series could provide useful information about periphyton dynamics over extended periods, especially if natural freshes occurred. Therefore, in 2014, we took advantage of a programme of visual assessments of periphyton in the Opuha River that had already been planned by Environment Canterbury. A combined programme with Environment Canterbury staff allowed us to extend the monitoring period and to include more surveys. In addition, we worked with Environment Canterbury to set up fixed transects to ensure that the visual estimates would be made on the same areas of river bed in each survey. This served two purposes:

1. Fixed viewing areas allowed investigation of hydraulic effects at different flows (including the flushing flow) on defined areas of river bed (see Section 4);

2. Using defined areas meant that inter-operator variability in visual assessments would not include variation caused by viewing different parts of the river bed. This was expected to improve consistency among surveys carried out by the different teams.

3.1 Sites and transect set up

The programme included three sites on the Opuha River: about 500 m below the downstream weir at the Opuha Dam (Dam site), just downstream of Skipton Bridge (Skipton site), and about 500 m upstream of the confluence with the Opihi River (Confluence site).

On 19 December 2013, Environment Canterbury and NIWA staff set up fixed transects at each site to define the survey points. At each site, transects were defined by driving posts into a stable location on each bank. Using a tagline stretched between the posts, the locations of viewing points on the river bed were marked at specified distances across the transect from the post on the true left bank. A brightly painted rock was placed on the river bed to mark a point at the middle of the left-hand side of the viewing circle (view are always taken looking upstream). All the distances were recorded and were subsequently included on the field sheets for each site. This meant that the positions of the rocks could be checked, and they could be moved back into position if they shifted.

Twenty viewing points were marked at each site. Four part-transects each with five viewing points were defined at the Dam and Confluence, and two transects each with 10 viewing points (spanning the whole river width) were defined at Skipton. All viewing points were in wadeable areas (up to about 0.7 m deep and water velocity up to 1.2 m/s).

The first survey in the programme was conducted on 19 December 2013.

3.2 Methods

Surveys were conducted at approximately weekly intervals, with a 3-week break between 23 December and 14 January. Visual estimates were conducted through an underwater viewer (Nuova Rade, Genova, Italy) with a diameter of 350 mm. All views were located so that the coloured marker rock was just out of view at the middle left-hand side of the area assessed.

Algal cover within each view was assessed by estimating percentage cover, usually to the nearest 5%, in nine categories. These were:

- No algae – rocks have no green/brown algae colour and are not slimy/slippery to touch;
- Film – rocks are slimy/slippery to touch and have a visible coating of algae, less than about 1 mm thick, on average;
- Sludge –loose, unconsolidated, non-filamentous algae often found in slower flowing areas (mostly mucilaginous diatoms)
- Mats – more consolidated layers of algae from about 2 mm thick; mostly diatoms but also includes red algae;
- *Phormidium* – distinctive black, dark brown or greenish shiny or mottled mats;
- Didymo – characteristic thin to very thick, wool-like mats with whitish stalks underneath and brown cells at the surface;
- Fils_green – bright green filamentous algae, short or long filaments, sometimes overgrowing other algae;
- Fils_other – other filamentous algae, generally brown; includes filamentous diatoms and green algae with diatom epiphytes
- Macrophytes – vascular plants rooted in the river bed.

We also estimated the mean thickness of didymo mats (in millimetres), by measuring thickness at several points in the mats using a graduated pointer. The datasheet used is shown in Appendix A. The glass viewing circle was marked into quarters to aid in estimates of percentage cover.

The raw data from 20 views were averaged to obtain mean percentage cover of each periphyton category on each survey. In addition, we calculated a "standing crop index" (SCI) of didymo calculated as percentage cover multiplied by mat thickness (mm). For example, coverage of 50% by mats 6 mm thick would have an SCI of 300. Percentage cover of the different algal categories, were plotted and results compared across site by eye.

3.3 Results

3.3.1 Periphyton Surveys

Twelve surveys were completed by NIWA and Environment Canterbury teams, between 19 December and 14 April (Figure 3-1). During that time flows remained low and stable except for a period of high flows between 29 December and 7 January, and the flushing flow on 27 February (flushing flow described in Section 2). The high flows in January averaged about 18 m^3/s but were prolonged.

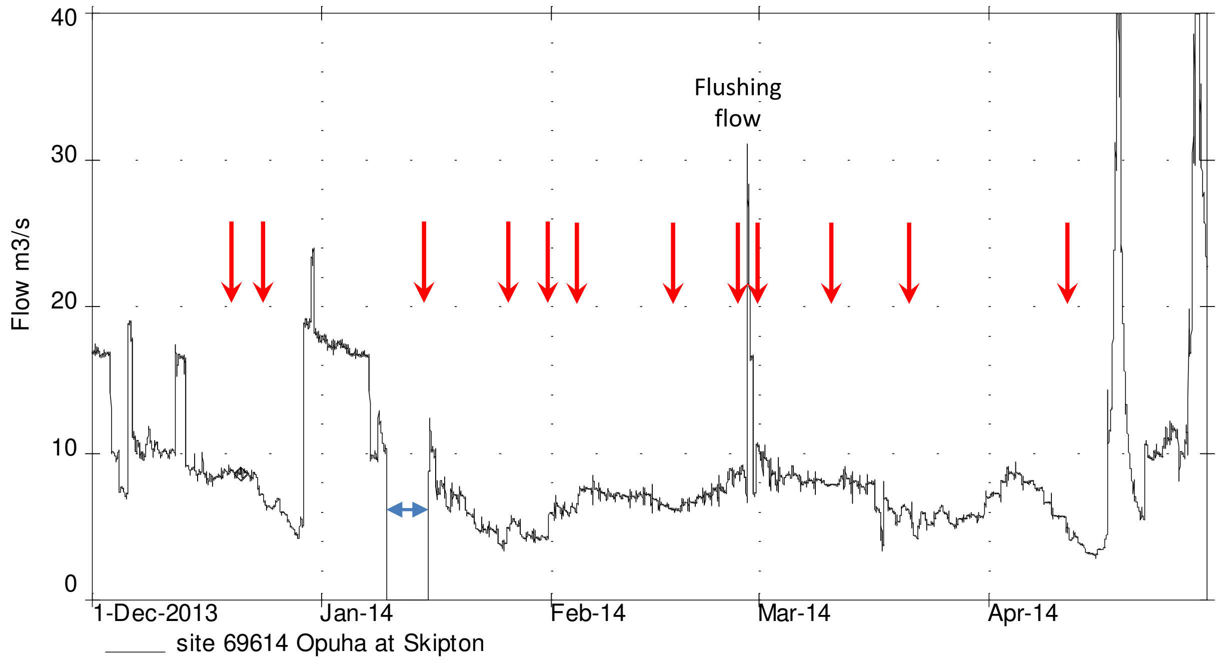

Figure 3-1: Hourly flow recorded at Skipton, December 2013 to April 2014. Red arrows indicate survey dates, blue arrow indicates data gap in Skipton flow recorder record.

3.3.2 Periphyton in the Opuha River in summer 2013-14

Periphyton cover

On the first survey (19 December 2013), periphyton at all three sites was dominated by didymo mats, which formed extremely high cover at the Dam site, medium cover at Skipton and low cover at the Confluence. This cover was maintained at all sites until about the end of January (Figure 3-2). Cover increased at Skipton and the Confluence at the end of January then stabilised at a new higher level until the flushing flow on 27 February. *Phormidium* was recorded at both these sites, with most at the Confluence, but cover never exceeded 10%.

The pattern of periphyton cover at the Dam site was different. Didymo coverage started declining in early February, after the survey on 30 January. By 17 February, didymo was generally visible only in the centre of the channel. Shallower areas at the edge were dominated by other algal mats and filaments.

Cover at all three sites was strongly affected by the flushing flow. Total cover (excluding thin films) declined from 76% to 31% at the Dam, 72% to 23% at Skipton and 56% to 12% at the Confluence.

Following the flushing flow, cover at Skipton and Confluence followed a similar recovery trajectory. *Phormidium* and green filaments reappeared in low cover after about 3 weeks. Didymo cover increased steadily, reaching pre-flush levels after about 4 weeks (Figure 3-2). At the Dam site, didymo cover remained at very low levels after the flushing flow. Overall periphyton cover also remained low until the end of the survey period. Cover comprised mainly “sludge” material in the shallow river margin, and thin film elsewhere. Low cover by macrophytes was recorded from late January and remained until April.

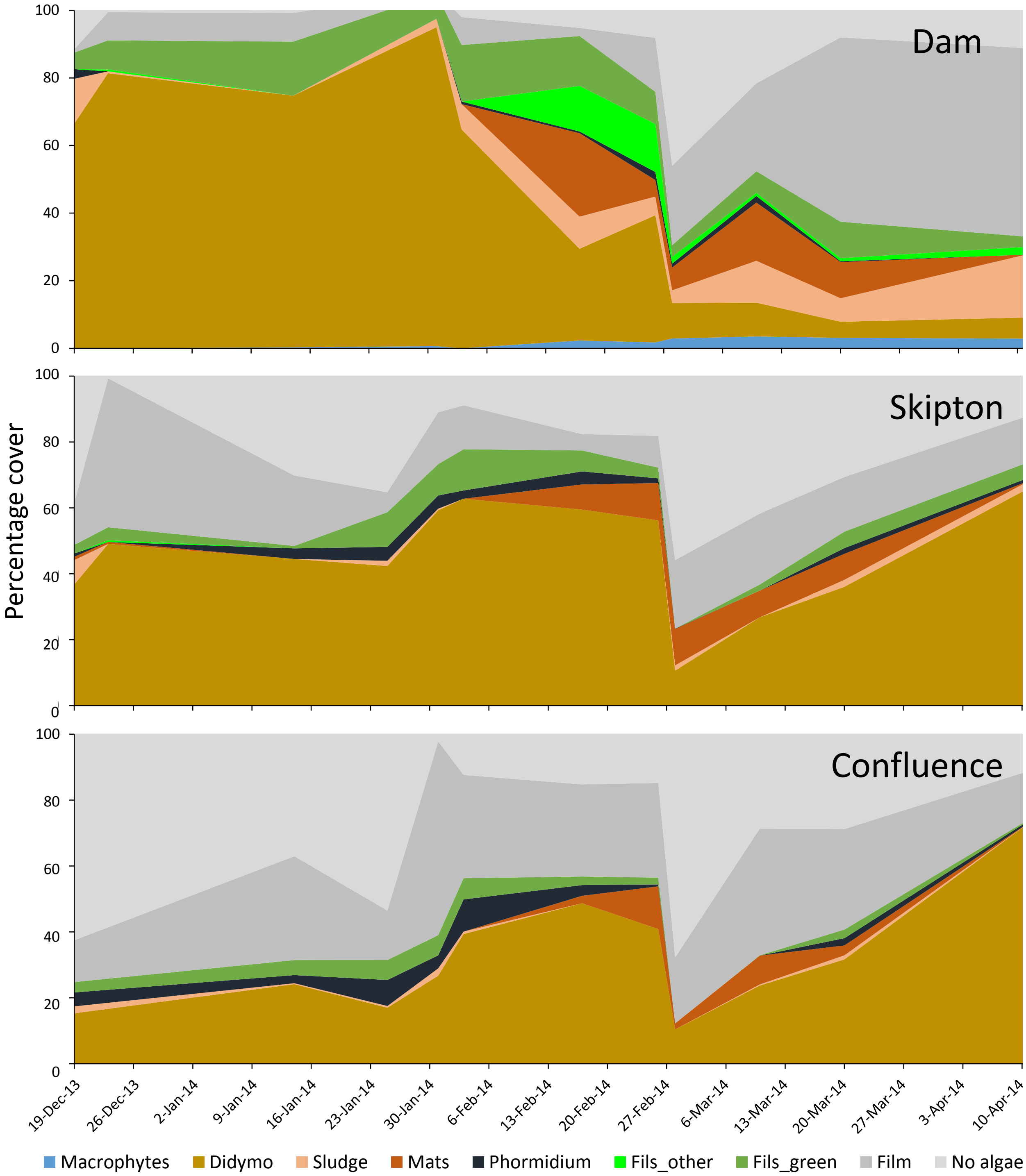

Figure 3-2: Percentage cover by eight categories of periphyton, and macrophytes, at three Opuha River sites from December 2013 to April 2014. Refer to section 2.2 for explanations of each cover category.

Standing crop index

The high flows in January (see Figure 3-1) did not affect cover, but did affect SCI, especially at Skipton (Figure 3-3), but also at the Dam. SCI reached levels close to those before the January high flows by the end of the month. Low cover at the Confluence remained low following the high flow. After mid-January, changes in SCI at Skipton and the Confluence were consistent with the changes in cover. The flushing flow reduced SCI to less than 100 at Skipton, a reduction of 85%. The proportional reduction at the Confluence was even higher (90%) but from a lower starting point. Following the flush, both cover and SCI increased at the same rate at both sites, indicating recovery to a higher level at the Confluence than before the flush.

SCI at the Dam site also tracked changes in cover. The flushing flow reduced SCI by almost 80% (from just over 250). By April SCI was only 14, compared to the peak of over 1000 in late December.

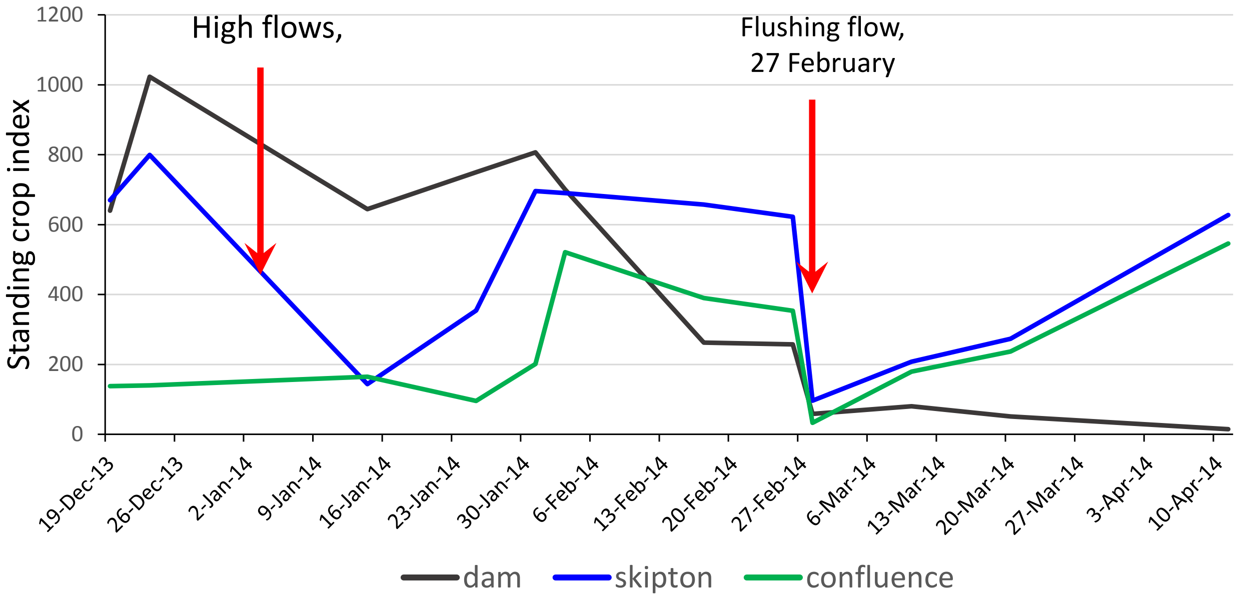

Figure 3-3: Mean didymo standing crop index at three sites in the Opuha River from December 2013 to April 2014. Red arrows indicate high flows during the monitoring period, which reduced SCI at some sites. Flows were low and stable at all other times.

3.4 Discussion

The strategy in 2013-14 of pre-marking all the surveys points so that the same areas were viewed on each occasion worked extremely well. This was done primarily for the hydraulics study (Study 2, described in Section 4), but clearly has advantages for repeated monitoring at the same sites. Variability between surveys is reduced; variability between observers is also reduced: successive surveys carried out by the Environment Canterbury and NIWA teams were always consistent with each other. There were some discrepancies over assigned categories. For example, the categories of "sludge" and "fils_other" may have been used interchangeably at the Dam site. This did not alter the overall pattern of changing cover at that site.

3.4.1 Effect of the January high flow

The period of high flows in January did not reach flood proportions but was prolonged, lasting over 9 days (29 December to 7 January). The effects of this event were seen in the cover estimates because cover did not increase (or increased only slightly) between 23 December and the first survey after the New Year, on 14 January. The sharp drop in SCI at the Dam and Skipton suggests that the January high flows were effective in removing cover, but by the time of the survey, 7 days after the end of the event, thin mats were already starting to develop.

3.4.2 Effect of the flushing flow

The flushing flow on 27 February was very effective in removing cover, particularly compared to the 2013 trial. For comparison, Figure 3-4 shows cover data from 2013 plotted in the same way as the 2014 data in Figure 3-3. This illustrates the relatively minor effect of the 2013 flush on cover. The effect on SCI was similarly small: 41%, 11.5% and 40% removal at the Dam, Skipton and Confluence sites respectively, compared to 77%, 85% and 90% in 2014.

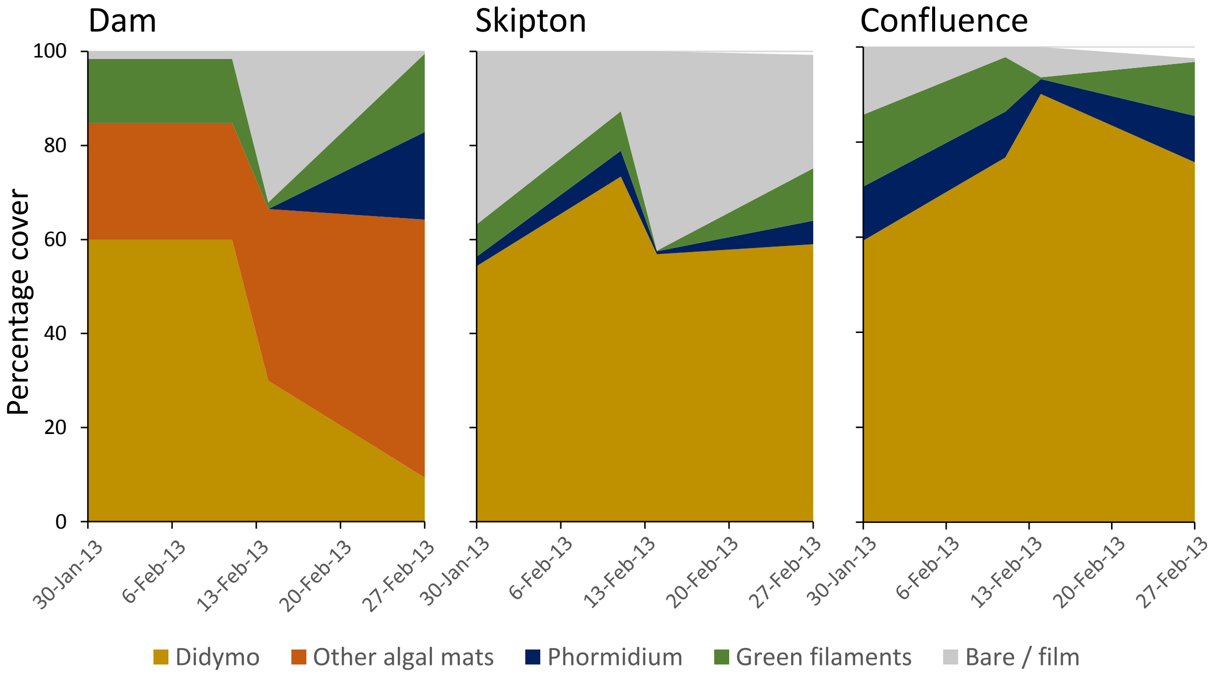

Figure 3-4: Periphyton cover at three sites in the Opuha Rive recorded before and after a flushing flow on 13 February 2013. Note that periphyton was recorded in fewer categories in 2013. "Other algal mats" includes mats, sludge and possibly fils_other, recorded in 2014.

3.4.3 Conditions at the Dam site

As in 2013, periphyton at the Dam site differed from that farther downstream in the Opuha. In 2013, we observed high cover of *Phormidium* developing by 2 weeks after the flushing flow. This was not observed in 2014. However, the pattern of a continuing decline in didymo after the flushing flow was the same in both years. In 2014, the decline started well before 27 February: some time between the end of January and mid-February. The water temperature record shows a few days in late January with unusually high maximum daily temperatures of well over 19 °C. Whether this would be sufficient to cause a turnover of algal species is not known. It is possible that the high temperatures coincided with a change in water chemistry, and this may be revealed in the parallel study being carried out by Environment Canterbury.

4 Study 2: Flow effects on periphyton

Monitoring periphyton and flow conditions at consistent defined locations on the riverbed allowed investigation of linkages between periphyton growth/removal and local hydraulic conditions. Better understanding of the way nuisance periphyton growth and removal is influenced by flow will allow improved management of the flow regime to help mitigate nuisance periphyton.

4.1 Data collection

For this study 20 fixed survey points were defined at each of the three monitoring sites on the Lower Opuha. At each survey point data collection involved: monitoring periphyton coverage regularly, surveying bed elevations; measuring water velocities and depths at different flows; and assessing bed surface substrate composition.

The location/setup of the survey points and the periphyton monitoring are described in Sections 3.1 and 3.2 respectively.

On 3 February the monitoring transects were surveyed using a Trimble R10 RTK GPS. Confluence and Skipton sites were measured from a single base station setup on Gudex Road and Dam site was surveyed with a separate base setup at the downstream weir. Both surveys used a single point calibration against points surveyed during the 2012 RTK GPS survey (Measures and Bind, 2012). As well as surveying the monitoring transects, water surface elevation upstream and downstream of each site was measured to enable calculation of water surface slope.

Water velocities and depth were recorded at each survey point on 23 December, 3 February, 17 February and 27 February during the flush peak. The first three velocity measurements were made at 0.6 depth (representative of depth averaged velocity) using a Marsh-McBirney Flo-Mate. The velocities were consistently measured just downstream and to the right of the marker rock (i.e., at the downstream end of the viewed area, in the middle). During the flush, the depths and velocities were measured using a Teledyne RD Instruments Stream Pro ADCP mounted in a remote controlled boat with a high resolution GPS (Figure 4-1). In order to capture the flood peak at all three locations the measurements were first taken at the Dam monitoring site then Skipton and finally Confluence. Due to the ease of launching and retrieving the remote control boat it was possible for a single team to follow the flush downstream and capture the flood peak at all three locations. The remote controlled boat performed well at the Dam site and Skipton but at Confluence tended to lose power due to didymo clogging the propeller before each transect could be completed resulting in the boat being unable to maintain position on the transect. This limitation meant data was only collected successfully at five of the twenty Confluence survey points.

Figure 4-1: Remote controlled boat gauging velocities and depths during the flush. Photo shows gauging at the dam periphyton monitoring site, just downstream of the downstream weir.

Bed substrate composition was also assessed on two occasions at the Confluence and Skipton sites (30 January and 28 February). The assessment was made only once at the Dam (28 February) because high cover by periphyton precluded substrate assessments until after the flush. At each periphyton viewing circle, the proportion of bed material was assessed in six categories: boulders (> 256 mm across), large cobbles (128-256 mm), small cobbles (64-128 mm), gravel (2-64 mm), sand (0.25-2 mm) and silt (<0.25 mm).

4.2 Analysis

The velocity and depth data collected at each survey point were analysed over the range of flows experienced during the monitoring period. For each survey point a rating equation to predict velocity and depth from flow was fitted to the observed data. The rating equations were in the format:

$$H = a\ln(Q - b) + c$$

$$U = d\ln(Q - e) + f$$

Where: H = depth at the location of the view

U = depth averaged velocity at the location of the view

Q = flow through the cross-section

a, b, c, d, e and f are coefficients fitted to the data at each site

Example rating curves for velocity and depth are shown in Figure 4-2.

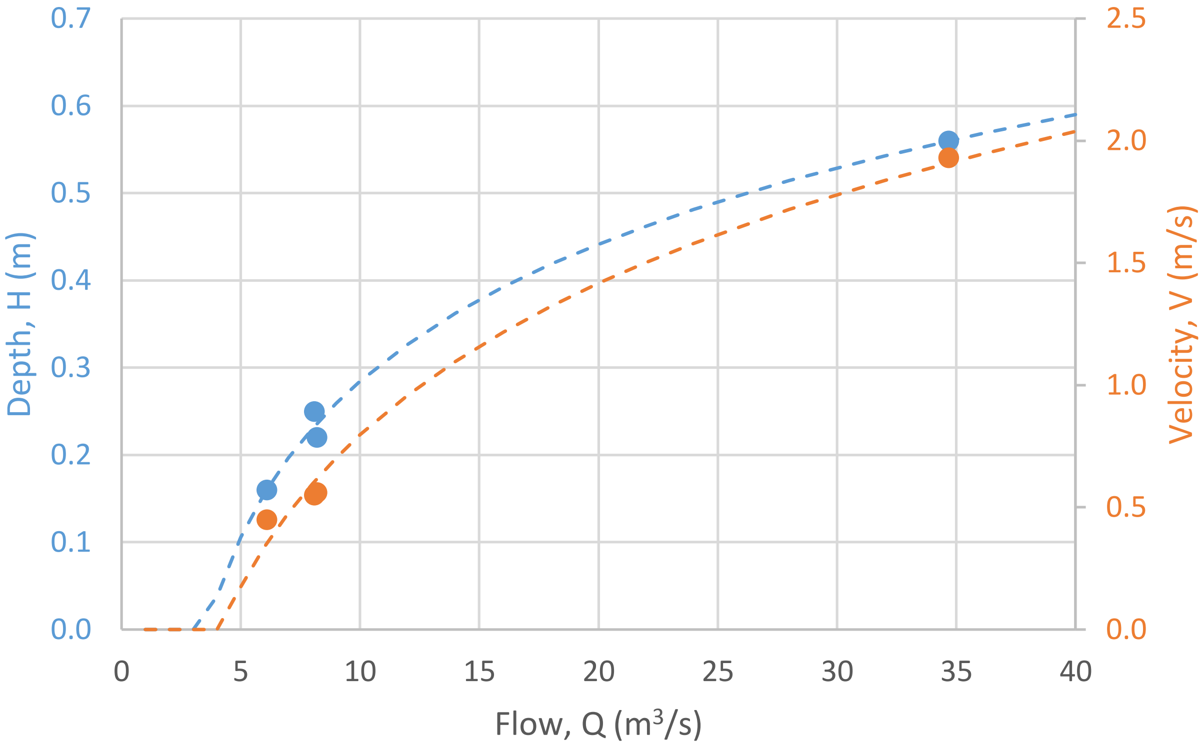

Figure 4-2: Velocity and depth rating for Skipton view 3 (S3).

Many of the survey points at Confluence site were lacking a high flow measurement of velocity and depth due to the suspended didymo restricting operation of the remote controlled gauging boat. For these points a NIWA in-house hydraulic model was used to predict depths and velocities. The model calculates the water depth and velocity distribution across the width of a cross section by assuming normal flow conditions in a streamwise sense, and using the lateral transfer of momentum and an iterative solver to determine depth-averaged velocity at each point across the cross section. The input data required is cross-section topography, water surface slope, a Manning's n roughness coefficient, and a horizontal eddy viscosity coefficient. The topography and slope were taken from the RTK GPS survey, roughness from the calibrated 1D model of the Opuha (Measures and Bind, 2012), and eddy viscosity was assumed to be 0.01 kg/m/s, based on detailed studies in other rivers. The model outputs were validated against measured velocities and depths at low flows before using the model to predict flushing flow velocities and depths. Figure 4-3 shows an example of the hydraulic model outputs for a flow of 30m^3/s at Confluence transect 1 (sites C1 to C5).

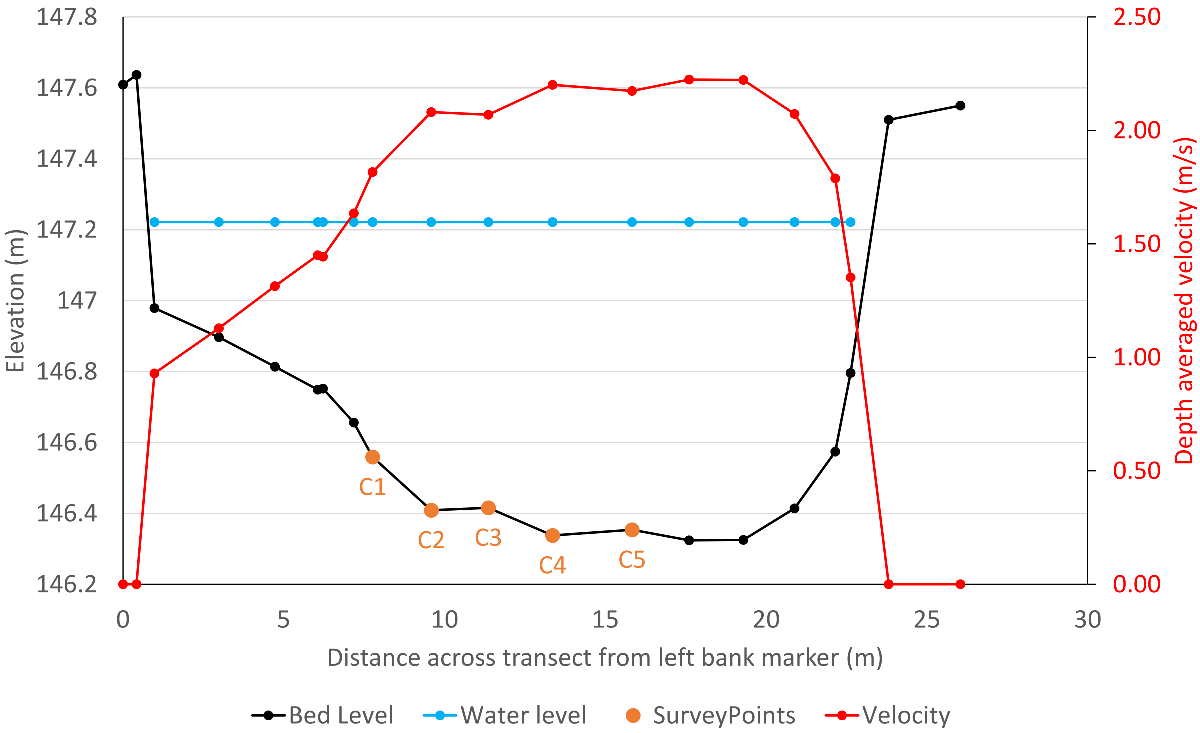

Figure 4-3: Modelled velocity and depth for confluence transect 1 at 30m³/s.

Using the rating curves it was possible to predict velocity and depth for each view location for all flows experienced during the monitoring period from 19 December to 14 April (Figure 3-1).

The substrate data collected at each view location was analysed to estimate median (D_{50}) and 90th percentile (D_{90}) grain size at each view location. Using the assumption that bed roughness height (*Ks*) equals twice the D_{90}, local bed shear stress at each view location was then calculated from depth and velocity using a power law approximation to the Law of the Wall:

$$\frac{U}{u_*} \cong 8.1 \left(\frac{H}{k_s}\right)^{1/6}$$

Where: u_*= shear velocity, related to bed shear stress (τ) and water density (ρ) by:

$$u_* = \sqrt{\frac{\tau}{\rho}}$$

Using the derived relationships between flow, depth velocity and shear stress at each view location it was possible to investigate relationships between these drivers and the observed changes (growth and removal) of periphyton.

4.3 Results

4.3.1 Periphyton removal

Significant periphyton removal occurred twice during the monitoring period, during high flows from late December to early January and during the flushing flow on 27 February. Figure 4-4 plots the shear stress experienced during the high flow event against the % reduction in total pre flush periphyton cover (cover of all categories of periphyton excluding film). There is a lot of noise in the data but it is notable that all sites experiencing bed shear stresses exceeding 45 N/m^2 show greater than 50% reduction in periphyton cover and that sites experiencing less than 35 N/m^2 show very variable reduction in cover.

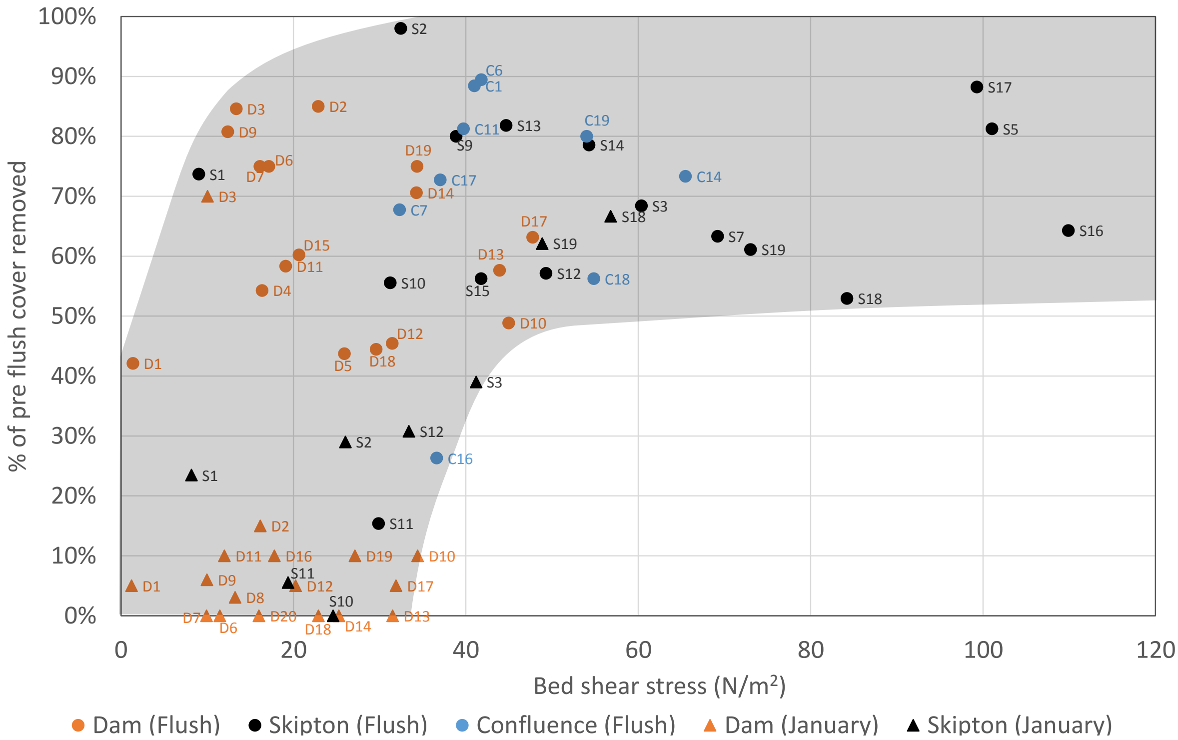

Figure 4-4: Percentage reduction in periphyton coverage vs shear stress experienced during January and February 2014 high flow events. No data for effects of January high flows on Confluence site are available as there was no periphyton survey of this site on 14 January. Sites/dates where preceding cover was < 50% have been excluded (22 data points).

The 2012 analysis and modelling of flushing flows on the Opuha (Measures and Bind 2012) identified required shear stresses for removal of periphyton from 28 to 50 N/m^2. This is consistent with the 35-45 N/m^2 thresholds identified above suggesting that the flow requirement of approximately 40 m^3/s for effective flushing identified in the 2012 study is reasonably accurate.

4.3.2 Periphyton recovery

Following the February flushing flow periphyton coverage at the different sites increased at varying rates. Periphyton was monitored at all sites the day after the flush and again 10 days later, during this period the flows were stable at around 8 m^3/s. Figure 4-5 shows the relationship between regrowth in the 10 days following the flush and the bed shear stress associated with a flow of 8 m^3/s. Re-growth at the Dam site was very different to the other sites so has been excluded from the plot (see Section 3.4.3 for a discussion of the differences experienced at the Dam site). Sites where post-flush coverage was greater than 50% have also been excluded because sites are not a good measure of re-growth if they already have high coverage. The figure shows that sites with higher shear stress generally showed smaller increases in periphyton coverage in the 10 days following the flush, suggesting that periphyton were slower to recolonize/grow in high shear stress environments.

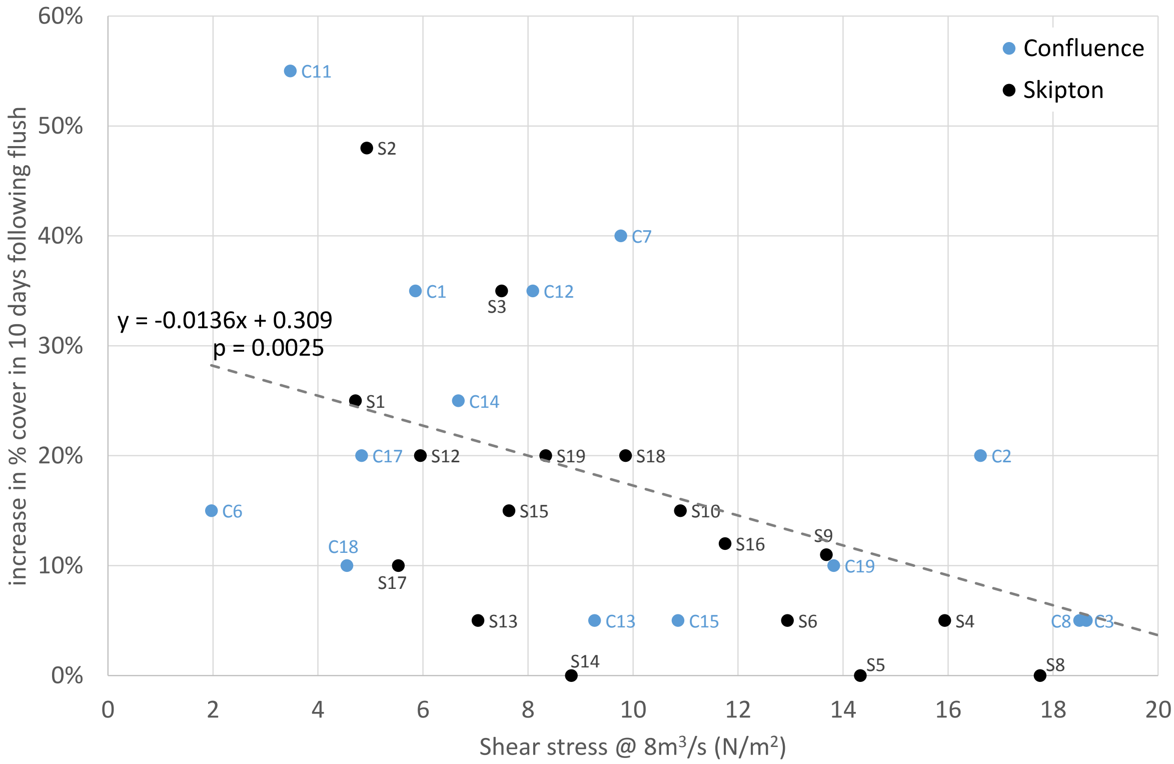

Figure 4-5: Relationship between shear stress and regrowth of periphyton following flush. Sites with >50% coverage after the flush excluded. The p value indicates the likelihood of achieving this correlation if the relationship between cover and shear stress was random i.e. a low p value indicates a high degree of certainty in the relationship.

4.3.3 Average and maximum cover

Average and maximum periphyton coverage at each site also show linkages to flow parameters. Figure 4-6 shows the relationship between average percent periphyton cover and local shear stress at 7 m^3/s (a typical flow rate experienced during the monitoring). At Confluence site the different view locations experienced a wide range of shear stresses and there was a strong relationship with shear stress – sites with high shear stress generally having lower periphyton coverage. At Skipton there was a similar but less clearly defined relationship, but at the Dam site there was little correlation between shear stress and average periphyton coverage.

Phormidium coverage did not show an obvious correlation with shear stress but at Confluence and Skipton maximum *Phormidium* coverage did show a weak correlation with depth, with greater *Phormidium* coverage likely at deeper sites (Figure 4-7). The reasons for this possible relationship are unknown and further monitoring would be required to confirm it. There was little correlation at the Dam site.

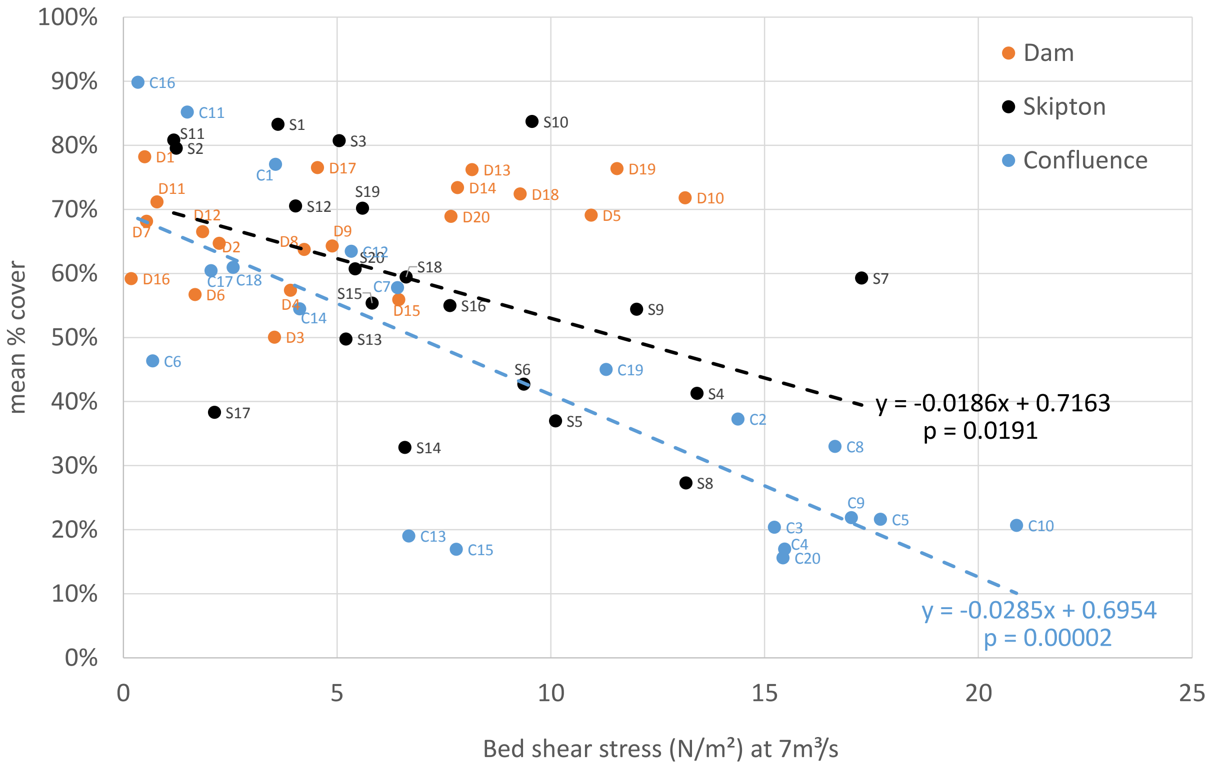

Figure 4-6: Relationship between average percent cover at a site and the typical shear stress it experiences.

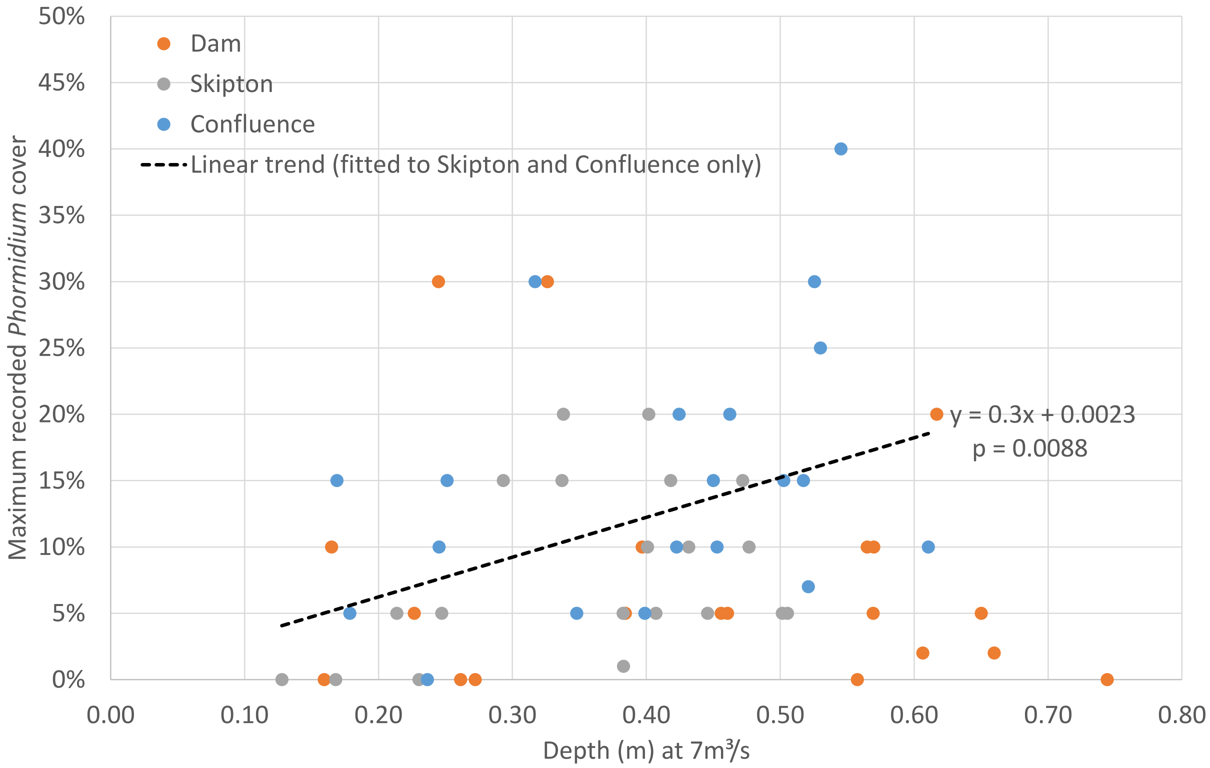

Figure 4-7: Relationship between maximum *Phormidium* cover and typical water depth.

5 Study 3: Water temperature

Data from Opuha at Skipton Bridge, collected in National River Water Quality Monitoring Network (NRWQN) surveys indicates that water temperature at that site has increased since the dam was commissioned (Lessard et al. 2011). Elevated water temperature increases metabolic rates in streams (Demars et al. 2011) and may influence stream ecosystems at least as much as hydraulic changes (Friberg et al. 2013). Higher water temperature has also been linked to greater *Phormidium* coverage in a North Island river (Heath et al. 2011). If water temperature has increased in the Opuha River, this may partly explain the observed changes in periphyton in the Opuha River downstream of the dam, and in the Opihi River farther downstream.

We investigated water temperature in the Opuha – Opihi catchment by (a) examining the NRWQN data more closely and (b) collecting new data on water temperature during the summer of 2013-14.

5.1 Methods

5.1.1 NRWQN data

The NRWQN includes three sites in the Opihi catchment: the Opihi at Rockwood (upstream of the confluence with the Opuha), Opihi at SH1 (downstream of the confluence) and the Opuha at Skipton Bridge. Water temperature has been measured monthly at all three sites since 1989. Such spot temperature data have limited usefulness because river water temperature has strong diurnal variations, which depend on local weather conditions as well as time of day. However, the time of each measurement is included in the dataset, which allows checking and/or filtering of the data to ensure that the times are consistent. Different measurement times mean that the temperatures cannot be compared between sites. However, if all measurements within a site are collected at the same time of day (on average), then we can compare data within each site, over time.

We compared water temperature in two periods: pre-dam (1989 to 1996, before dam construction started) and post-dam (2003 to 2013). Although the dam was commissioned in 1999, effects of a change from a hill-fed to a lake-fed river can extend over some years. We assumed that this process had “settled down” by 2003. The dataset was first checked to see whether the mean time of data collection was consistent between the two periods. We then divided the data into months and plotted pre-dam and post-dam data against month. This allowed an assessment of the relative temperatures (between the two periods) at different times of year.

5.1.2 Temperature loggers

Waterproof temperature loggers (HOBO Tidbit V2, Onset Corporation, Cape Cod, MA, USA) were deployed at five sites in the Opuha catchment from December 2013. The sites were:

- North Opuha at Clayton Settlement Road Bridge (at the Environment Canterbury WQ monitoring site);
- South Opuha at Monument Bridge (at the Environment Canterbury WQ monitoring site);

- Opuha River about 500 m below the downstream weir (at the Dam periphyton monitoring site);
- Opuha River at Skipton (at the Skipton periphyton monitoring site);
- Opuha River about 500 m upstream of the confluence with the Opihi (at the Confluence periphyton monitoring site).

Loggers were set to record temperature at 15-minute intervals. Because of the risk that the loggers would be washed away in floods, we downloaded data at intervals during the season. The loggers most vulnerable to flood effects were those in the South Opuha, which is a flood-prone river with a very mobile gravel bed; and in the Opuha at the Confluence, where channel migration occurs in high flows.

In addition to the loggers deployed as part of this project, 15 minute temperature data was also available from telemetered monitoring at three depths in Lake Opuha, just behind the dam. Data is collected at this site by ECS Ltd on behalf of Opuha Water Ltd.

We also obtained mean daily temperatures from the Environment Canterbury temperature logger at Opihi at Rockwood up to mid-March 2014.

5.2 Results

5.2.1 NRWQN data

Times of water temperature measurements at all three sites were more variable in the pre-dam period than in the post-dam period (Table 5-1), although all measurements have been collected before mid-day. Before 1999, the measurements were not always taken on the same day at the three sites. After 2003, the sites have been generally visited in sequence on the same day: Opuha at Skipton, Opihi at Rockwood, then Opihi at SH1. Filtering the data to remove records at extreme times reduced numbers of records to low levels. Therefore we used all of the data and interpreted the results accordingly. The average times of measurement were all early in the day (Table 5-1). At Skipton in particular, the measurement time of 08:38 is likely to capture the minimum daily temperature.

Table 5-1: Summary of times of temperature measurements at three sites in the Opihi catchment in pre- and post-Opuha Dam periods. Note the wider range of times in the pre-dam period at all three sites.

		Time of temperature measurement (h)		
Site	**Period**	**Average time**	**Earliest**	**Latest**
Opihi at Rockwood	pre-dam (1989 to 1999)	09:09	07:55	10:15
	post-dam (2003 to 2013)	09:14	08:40	09:30
Opuha at Skipton Bridge	pre-dam (1989 to 1999)	08:38	07:30	09:40
	post-dam (2003 to 2013)	08:38	08:10	09:10
Opihi at SH1	pre-dam (1989 to 1999)	09:53	08:30	11:35
	post-dam (2003 to 2013)	09:46	09:30	10:10

Mean monthly water temperature at all three sites has generally been higher in the post-dam period than the pre-dam period, but the difference has been most pronounced at Skipton. Even with the measurement time variability in the pre-dam period, average water temperatures measured in March, April and May have increased by up to 3.5 °C in the post-dam period (Figure 5-1). No overlap in the error bars indicates a highly significant increase. The difference at Skipton is also greater than at the two Opihi sites in all other months, with least difference in September. The observed slight temperature increase at Rockwood may be due to climatic changes, but is also likely to be influenced by the slightly later average sampling time post-dam (approximately 5 minutes later than pre-dam for this site – temperatures change rapidly at the time of day measurements were taken, for example see Figure 5-3).

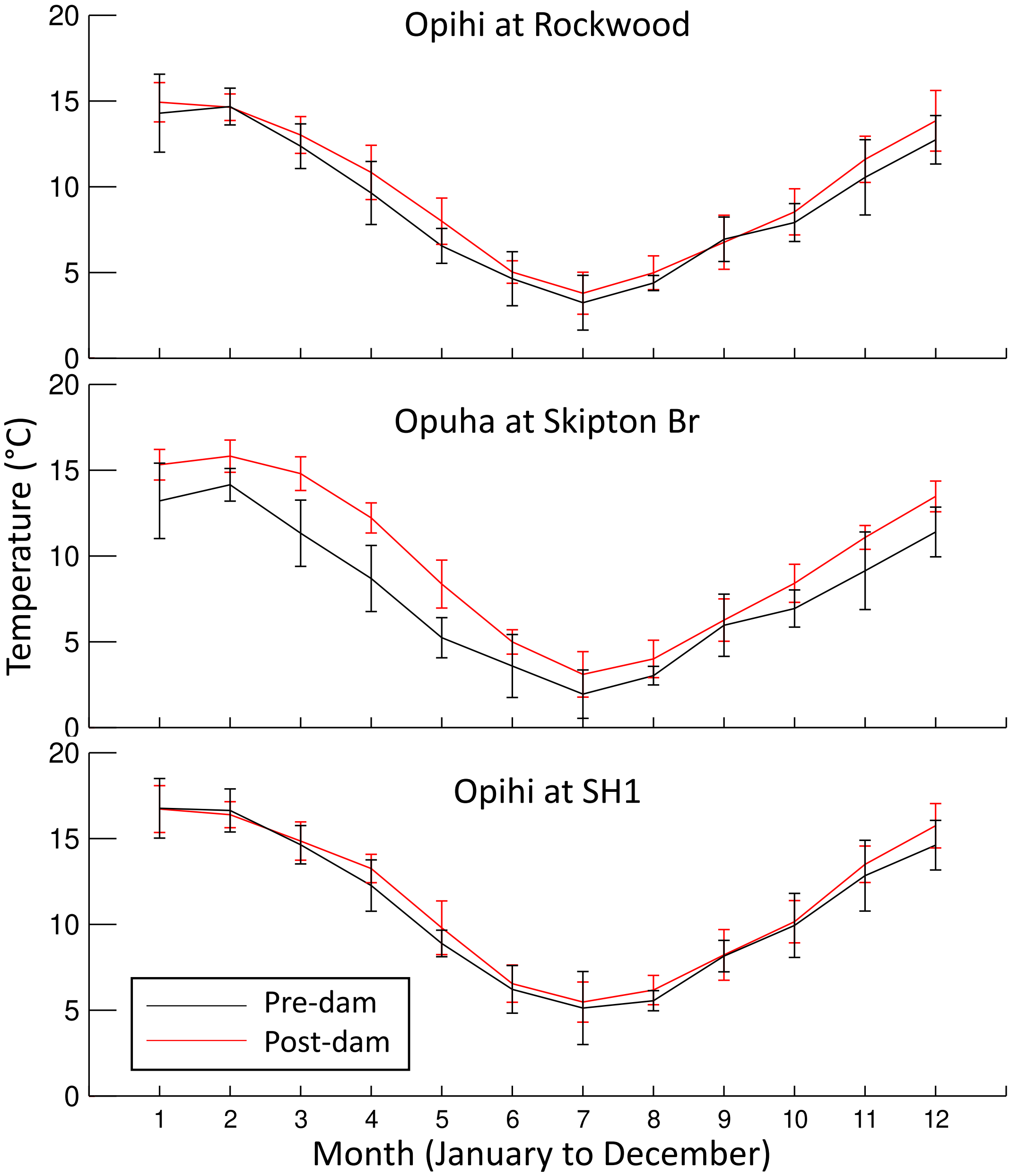

Figure 5-1: Mean temperature measured at three sites in the Opihi catchment in pre- and post-Opuha Dam periods, by month. Error bars are standard deviations. Note that the mean time of day for measurements did not differ between periods at Opuha at Skipton, and was less than 10 minutes at the Opihi sites (Table 4-1).

5.2.2 Temperature loggers

Logged data were retrieved for various periods from the five sites, with the shortest record at the South Opuha (17 January to 12 March). A logger deployed in the South Opuha in December 2013 was washed away in floods in early January, and the replacement logger was also lost in floods in April.

Water temperatures in the North and South Opuha, upstream of Lake Opuha, were similar to each other and consistently 2-3 °C lower than at the sites within and downstream of the lake (Figure 5-2).

In the lower Opuha, daily and diurnal variations were muted at the Dam site, reflecting the lake temperature record (Figure 5-2, Figure 5-3). Full diurnal variation (in comparison with the North and South Opuha records) was almost restored 13 km downstream at Skipton. Here, minimum and maximum daily temperatures were only marginally damped compared to those at the Confluence site (Figure 5-3).

Average daily mean temperatures were calculated at all river sites over a month (17 January to 16 February) when complete data from the Environment Canterbury recorder at Opihi at Rockwood were also available. This showed that mean temperature in the Opihi upstream of the confluence was also lower than in the Opuha below the dam, though the difference was smaller (Table 5-1).

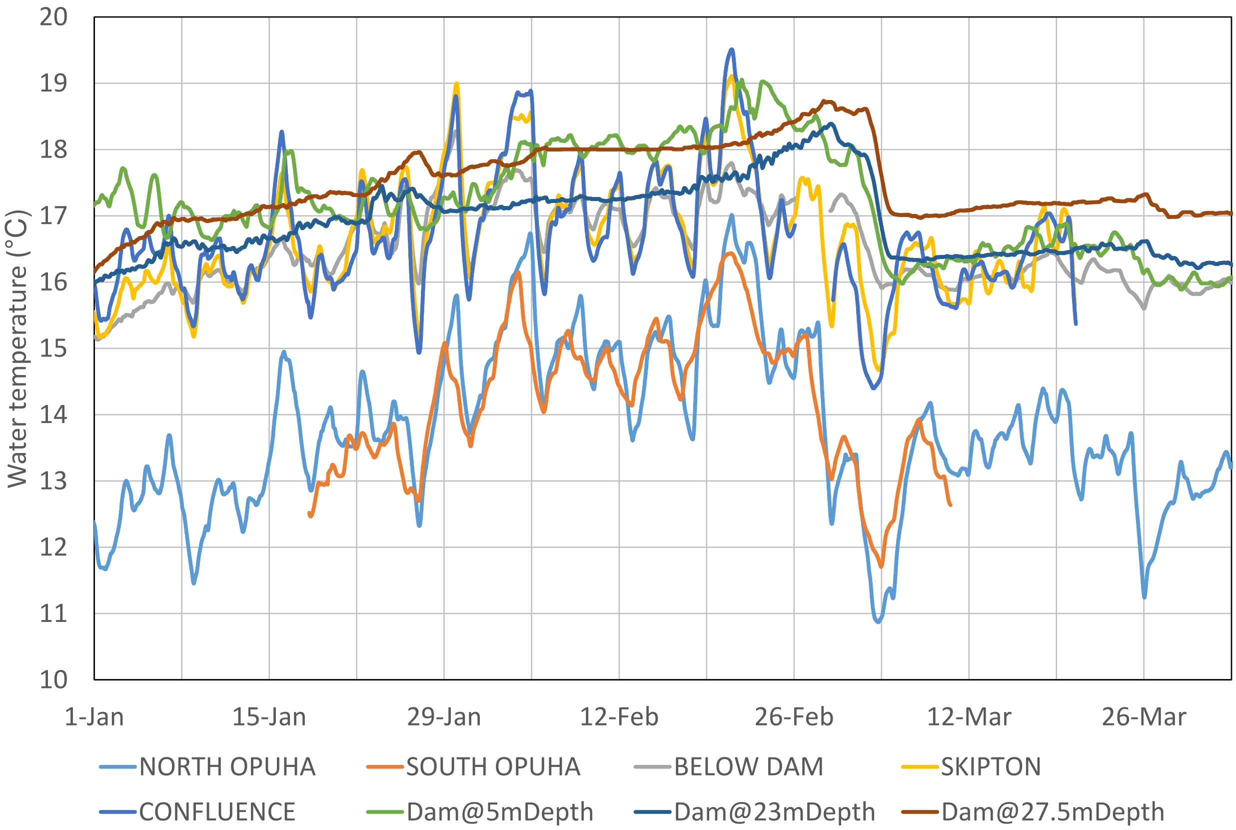

Figure 5-2: Running daily mean temperatures at five sites in the Opuha catchment and three sites in Lake Opuha, January to March 2014.

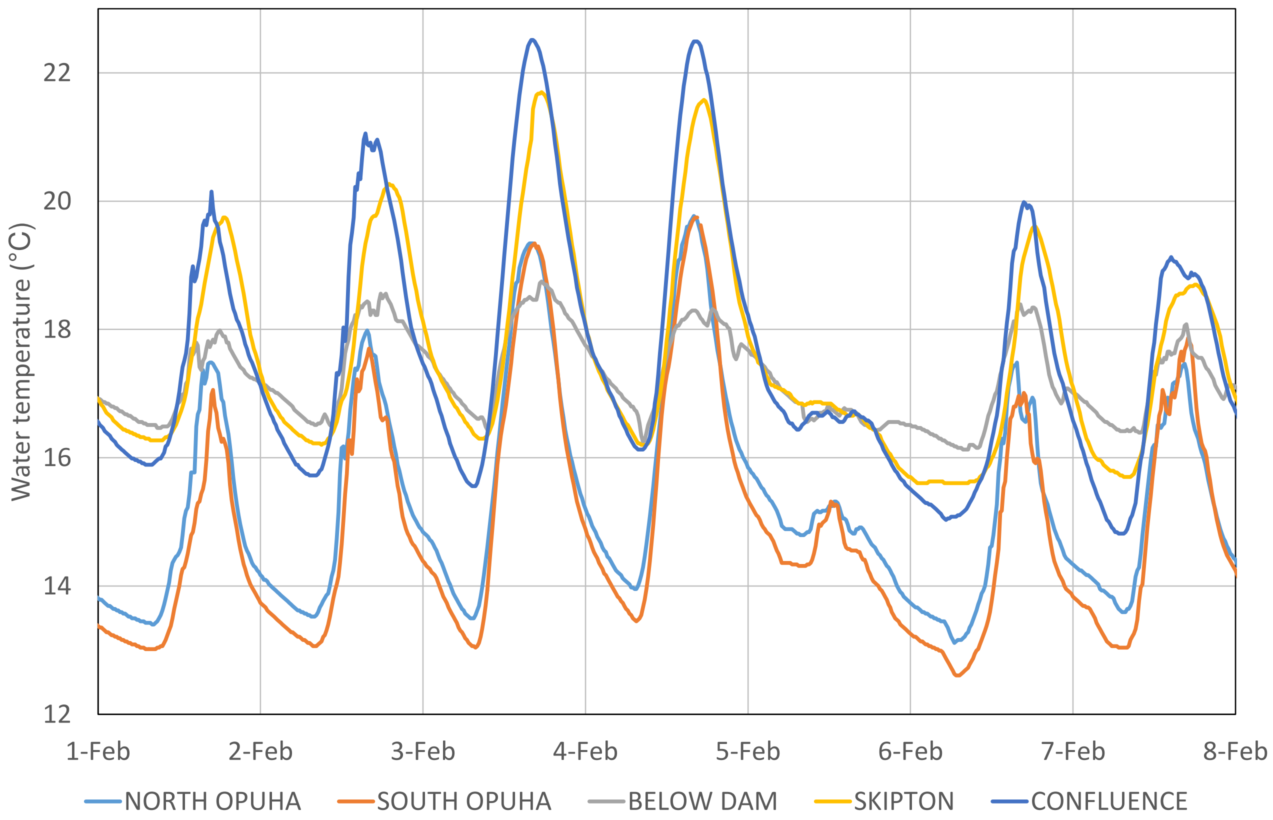

Figure 5-3: Temperature records (15 minute intervals) at five Opuha River sites, 1 – 8 February 2014.

Table 5-2: Average and maximum mean daily water temperatures at six sites in the Opihi catchment, 17 January to 16 February 2014.

		Mean daily temperature (°C)	
Site	**Collected by:**	**Average**	**Maximum**
North Opuha	NIWA	14.5	16.4
South Opuha	NIWA	14.2	16.2
Opuha at Dam	NIWA	17.0	18.0
Opuha at Skipton Br	NIWA	17.1	18.5
Opuha at Confluence	NIWA	16.9	18.8
Opihi at Rockwood	ECan	16.0	17.9

5.3 Discussion

The NWRQN data indicate that minimum daily water temperature in the Opuha River at Skipton may have increased by as much as 3 °C in late summer and autumn following installation of the dam. Biologically this is likely to be a significant increase. For example, in streamside channel experiments, periphyton biomass increased when water temperature was artificially raised by just 1.4 °C (Piggot et al. 2011).

The 2014 temperature data confirmed the pattern spatially: water temperature in the two main inflows to Lake Opuha were always significantly lower than those in Lake Opuha and in the river downstream of the lake

Higher water temperatures the Opuha River may be significant in terms of suitability of the river for *Phormidium*. The probability of high cover by *Phormidium* in two rivers in the Wellington region increased with water temperature (from about 15 °C, calculated as a 5-day mean) and low flows (Heath et al. 2011). These findings were used to inform a simple decision tree for predicting *Phormidium* proliferations (MfE and MoH 2009) because the 15 °C threshold was so marked.

The NRWQN data indicate that the water temperature increase associated with the dam may have shifted temperature conditions at Opuha at Skipton Bridge from below the threshold for *Phormidium* to above the threshold. However the NRWQN data were all collected early in the morning, when water temperature is generally at the diurnal minimum. Calculations using the 2014 data from Skipton indicate that the 5-day average is generally 1-2 °C higher than the mean daily minimum temperature. Referring back to the NRWQN data in Figure 5-1 we see that the pre-dam post-dam difference could still have resulted in a change at the critical level, especially in mid-summer. The 2014 data confirm the pattern: mean daily water temperature in the North and South Opuha did not exceed 15 °C in the warmest period of the record, while all three sites on the Opuha were well over the threshold.

Higher water temperatures have also been shown to favour didymo stalk production (Kilroy and Bothwell 2014) although no thresholds have been identified. Cell growth, as well as stalk production, responds to increasing temperature. For example, laboratory cultures of didymo have been most successful in temperatures of 18 °C (Kuhajek and Wood 2014). The broad geographical distribution of didymo indicates that this species is confined to areas which have distinct seasonality and cold winters (Kilroy et al. 2007). The water temperature increase in the Opuha since installation of the dam appears to have been most pronounced in summer. It is likely that the much smaller increases in winter have not affected the general temperature requirement for didymo presence, but the higher summer water temperatures may exacerbate blooms.

5.4 Conclusions

The combination of the NRWQN data and more detailed data collected in the Opuha catchment in summer 2013-14, support the hypothesis that increased water temperature following installation of the Opuha Dam has led to more favourable conditions for *Phormidium* proliferation in the river. Published observations in other rivers confirm the link between temperature and *Phormidium*. Generally warm summer temperatures in the Opuha River also favour blooms of didymo. Other factors in the Opuha (e.g., nutrient concentrations (not discussed in this report) and hydrological regime) may also contribute to an environment that favours algal blooms. Note that the link between *Phormidium* and water temperature is a correlation at present (i.e., a hypothesis), but could be tested experimentally.

6 Study 4: Effects of exposure on periphyton development and removal

During the survey period from December 2013 to April 2014, we took the opportunity to conduct experiments at Skipton Bridge. The aim was to investigate the effects of varying flows on periphyton in the varial zone. Exposing periphyton to air when water levels fall will kill at least some algae by a combination of desiccation and heat. This sets back periphyton accrual, but does the effect last long enough for flow reduction to be an effective strategy for reducing overall periphyton cover? Exposure of periphyton on cloudy days or overnight will have less effect than on sunny days, but could make the algae make more vulnerable to flushing flows (i.e. high water velocities) by weakening the mats. Our experiments were designed as small-scale pilot studies that could be repeated on a larger scale following promising results.

The experiments addressed the following questions:

1. To what extent does periodic (e.g., weekly) exposure for short periods (1- 4 h) starting at early stages of development curtail periphyton growth compared to growth under continuous immersion? [This simulates a situation where the river can be drawn down for short periods to expose areas at the margins.]

2. To what extent does longer exposure (e.g., overnight) of more developed mats alter the susceptibility of mats to removal during high flows (= higher water velocities)? [This simulates a situation where the river could be drawn down for a day or so to store water for a subsequent flushing flow.]

3. To what extent does a single exposure of periphyton at an early stage of development reduce periphyton accumulation in the long term?

It is recognised that there are other important factors to consider when deciding to reduce flows temporarily (fish, invertebrates, etc.) but in many years there are times when the river is running well above the minimum flow. Reducing flow temporarily, while staying within the minimum flow limits, could provide a potential technique to help mitigate nuisance periphyton.

6.1 Methods

The experiment was initially started on 23 December 2013, by placing an array of artificial substrates (paving tiles) in the Opuha River, and allowing them to colonise with periphyton. The idea was that substantial cover would have developed by mid- to late February, when a flushing flow was expected to be scheduled. Experimental treatments would include a four-way comparison of the effect of pre-exposure to air or no exposure, and exposure to the flushing flow or not. Unfortunately the experiment was vandalised (stolen) in early February. The final experimental design therefore accommodated the flushing flow at an earlier stage of periphyton development. On 4 February 2014, two arrays of substrates for growing periphyton (paving tiles and river cobbles) were set up in the Opuha River, upstream of Skipton Bridge.

6.1.1 Cobble experiment

We used 30 river stones as substrata. Flat, round cobbles approximately 150 mm diameter were collected from the gravel bar on the true left, just upstream of Skipton Bridge. This bar has been exposed for years. Therefore the cobbles were not expected to be precolonised by any algae that would affect subsequent periphyton growth.

The cobbles were numbered with waterproof ink, then placed in the river in an array of 5 x 6 (Figure 6-1a), in an area of gravel with uniform depth and water velocity. Sets of six cobbles were assigned to five different treatments:

- C1. Short-term exposure during development stage. Six cobbles were removed from water for 2 – 4 h on 17 Feb, 26 Feb, 10 March and 20 March[1];
- C2. Controls. No exposure, no high flows. Six cobbles remained undisturbed and immersed at their original site for the entire time (except for control disturbance at the time of the removal of other stones to fast flow treatments);
- C3. No exposure, high flows. On 21 March, six cobbles were removed directly to a new location in fast-flowing water for 7 h;
- C4. Long-term exposure, normal flows. Six cobbles were exposed overnight (5 pm to 10 am) on 20 March, then returned to their original location in the tile array on 21 March;
- C5. Long-term exposure, high flows. On 20 March, six cobbles were exposed overnight (5 pm to 10 am) then on 21 March returned to a new location in fast-flowing water for 7 h.

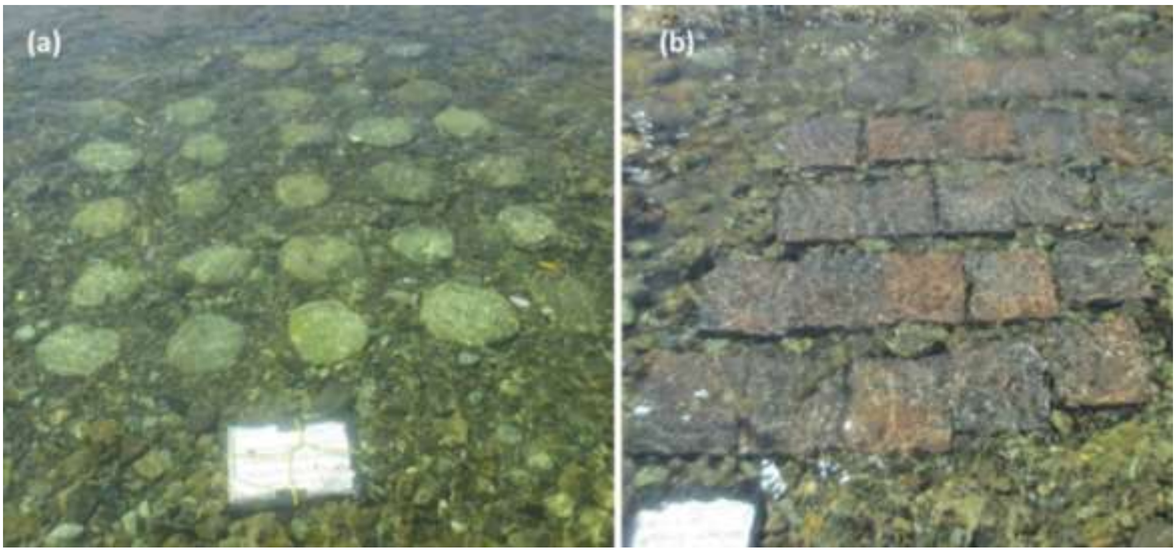

Figure 6-1: The cobble (a) and paver (b) arrays deployed in the Opuha River on 4 February 2014.

[1] Before the flushing flow on 27 February all the cobbles were removed from the river late in the day on 26 February, and placed in a shaded location in bins full of river water because we expected that the unstable gravel they were sitting on would move in the flushing flow and cause the experimental cobbles to move or become buried. All were returned to approximately their original positions early on 28 February, following the flush

All cobbles were photographed and sampled on 21 March following the high-velocity treatment. A large circle of periphyton (uniform area) was scraped from the top of each cobble. Samples were analysed in the laboratory for ash-free dry mass (AFDM). AFDM is a measure of the amount of organic material in a sample. It is particularly appropriate for measuring biomass of didymo because the mats comprise mostly non-living stalk material rather than cells.

Samples were analysed by oven-drying (105 °C) until they reached a constant weight in foil dishes, re-weighing, then ashing for 4 hours at 400 °C. Ash-free dry mass is the difference between the dried and ashed weights. All data were normalised to AFDM per square meter.

6.1.2 Paver experiment

An array of 25 pavers (dimensions 230 x 160 x 40 mm) was placed in the river about 150 m upstream of the Cobble experiment (Figure 6-1b). The pavers were numbered with waterproof ink and left to colonise for 3 weeks. On the day before the flushing flow the pavers were assigned into four experimental groups:

P1. No exposure, no flush. Six pavers were left in their positions, except that they were not exposed to the flushing flow. Instead they were removed to bins full of river water, placed in the shade, and returned to their positions in the river on the morning of 28 February, following the flushing flow.

P2. No exposure, flush. Seven pavers were left in their positions in the river during the flushing flow.

P3. Exposure, no flush. Six pavers were removed from the river on 26 February and left exposed to air for approximately 6 h, before removing them to bins full of river water, placed in the shade. They were returned to their positions in the river the morning of 28 February.

P4. Exposure, flush. Six pavers were removed from the river on 26 February and left exposed to air for approximately 6 h. They were then returned to their positions in the river, and exposed to the flushing flow.

The array was then left undisturbed for 10 days. On 10 March, the periphyton on each paver was sampled by scraping off a defined area. The samples were analysed in the laboratory for AFDM, as above. The outcome of this experiment was that the flushing flow had no effect on biomass. We therefore reassigned pavers in treatments P1 and P2 for a second experiment. In this experiment, we removed half of the pavers from the array on 20 March (6 that had been exposed on 26 February, and 6 that had not been exposed) and relocated them in an area of faster flows. The pavers were left in fast water overnight, then returned to their positions in the array. The periphyton on each paver was sampled by scraping off a defined area (that had not been sampled previously), and the samples were analysed for AFDM.

As a final test, we collected a third quantitative sample for AFDM analysis from each paver on 4 April. The aims were to determine (a) whether any differences in biomass due to exposure to fast flow were delayed because the fast flows scoured off cells rather than stalk material (therefore there would be fewer cells remaining to generate more biomass), and/or (b) whether the effects of the exposure to air on 26 February would still be detectable almost 40 days later.

6.1.3 Water depths and velocities

We measured water depth and velocity at multiple points in both arrays, using a Marsh-McBirney Flow-Mate. These measurements allowed us to check whether biomass was related to differences in velocity within the range measured across the arrays. The same area of fast-flowing water was used for transposing substrata in the two experiments. Water velocities and depths were measured at multiple locations in this area, and care was taken to place the cobbles and tiles so that there was no gradient in velocity corresponding to the exposed and unexposed substrata.

6.1.4 Data analysis

In the Cobble experiment, we first compared treatments C1 and C2 (the Short-term exposure trial). We used a two-sample t-test to determine whether there was a significant difference between the treatments.

Two-way Analysis of Variance (ANOVA) with Exposure and Flow as factors was used to detect differences in AFDM between treatments C2, C3, C4 and C5 (the Overnight exposure, Fast flow trial). A significant interaction between Exposure and Flow would indicate that cobbles exposed overnight responded differently to high flows than those not exposed overnight.

In the Paver experiment, repeated measures ANOVA was used to determine whether there were any differences between treatments over the time series of three samples (10 March, 21 March and 4 April).

In all cases a probability level of 5% ($P < 0.05$) indicated a statistically significant difference between the means.

6.2 Results

6.2.1 Water depths and velocities

The cobble array in the Cobble experiment was located in an area with uniform water depths and velocities (Table 6-1). Velocity was more variable over the Paver experiment array (high standard deviation in Table 6-1), but we detected no correlation between biomass, or biomass change and velocity. We therefore assumed that within the range over the arrays velocity did not confound the results of the drying and fast-flow treatments. Water velocity in the fast flowing area was almost double that in the original location for the cobbles, and depth was similar. For the pavers, both mean depth and velocity in the fast-flowing are were more than double that in the original paver area.

Table 6-1: Statistics for water depths and velocities measured at substrate experiments in the Opuha River, February - April 2014. Cobbles and pavers were transferred to the same area of fast flows (at different times) for the "fast flow" treatment.

	Experiment:	Cobbles		Pavers	
Measurement	**statistic**	**original**	**fast**	**original**	**fast**
Depth (m)	Mean	0.34	0.42	0.13	0.41
	Standard deviation	0.02	0.09	0.02	0.09
	Minimum	0.30	0.34	0.09	0.32
	Maximum	0.38	0.64	0.16	0.64
Velocity (m/s)	Mean	0.55	0.96	0.37	0.95
	Standard deviation	0.06	0.10	0.10	0.12
	Minimum	0.45	0.86	0.14	0.68
	Maximum	0.63	1.08	0.54	1.08

6.2.2 Cobble experiment

Short-term exposure trial

The experiment ran for 45 days (4 February to 21 March). Following four exposures for an average of 3 hours at 11-13 day intervals, mean biomass as AFDM on the exposed cobbles (treatment C1) was less than half that on the control cobbles (treatment C2) (Figure 6-2).

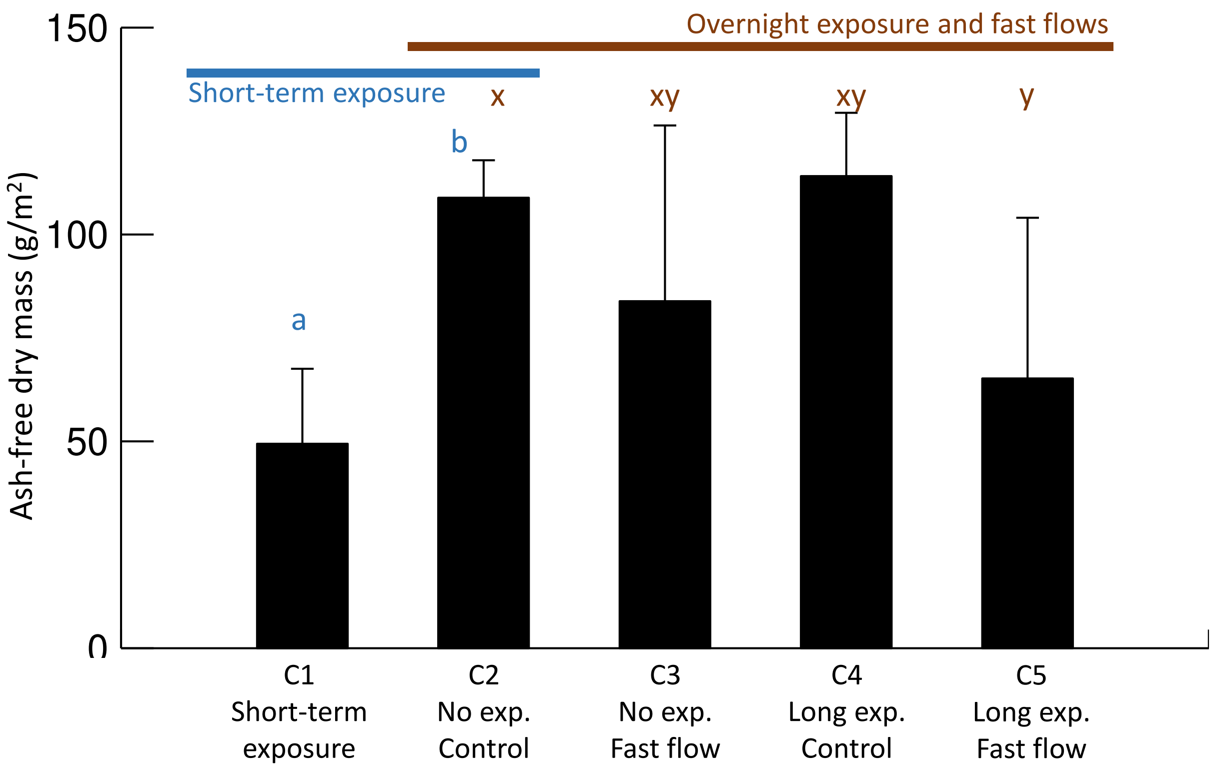

Figure 6-2: Mean ash-free dry mass measured on cobbles from different treatments on 20 March 2014. The short-term exposure experiment had the same controls as the overnight (long) exposure - fast flow experiment. Different letters over bars indicate significant differences, matching letters indicate no statistically significant differences. n = 5.

Overnight exposure, fast flow trial

The cobbles transposed to fast flows on 21 March (treatments C3 and C5 combined) had significantly less biomass than the control cobbles (treatments C2 and C4 combined) (73 ± 35 g/m^2 versus 111 ± 11 g/m^2 AFDM). When the samples were split into the treatments with and without overnight exposure, only treatment C5 (which had been exposed overnight) differed significantly from the controls (Figure 6-2). The two-way ANOVA confirmed no significant interaction between Exposure and Flow.

6.2.3 Paver experiment

The flushing flow on 27 February occurred 22 days after the pavers were deployed to colonise. Biomass measured on 10 March, 11 days after the flushing flow, did not differ between pavers exposed and not exposed to the flushing flow. Pavers exposed to air on 26 February had much lower biomass (as expected): under 40% of the biomass on pavers not exposed.

By 20 March biomass had visibly increased. Exposure of half of the pavers to faster flows did not affect biomass as measured on 21 March, but biomass on the pavers that had been exposed to air on 26 February was still lower (64%). Biomass measured on 4 April showed that the fast flow treatment also had no effect in the longer term (for example, by removing cells rather than stalks). The effects of the exposure to air on 26 February were still evident, with biomass on these pavers on average 67% of that on the pavers not exposed to air (Figure 6-3). Repeated measures ANOVA confirmed no significant interactions between the Fast Flow and Control treatments (in either the Exposed or Control treatments).

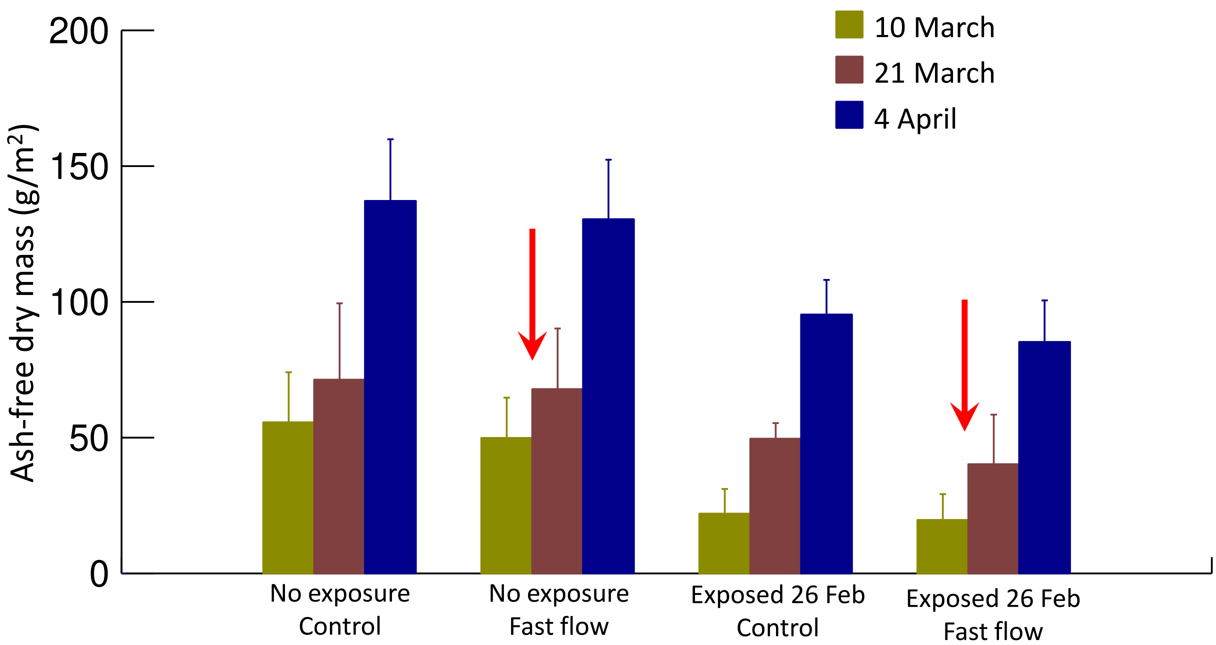

Figure 6-3: Mean ash-free dry mass measured from samples scraped from defined areas of pavers on three dates. The red arrows indicate the time of the fast flow treatment (20 March). There

were differences over time and between pavers exposed and not exposed, but the fast flow treatment had no effect in the short term (21 March), or in the long term (4 April).

6.3 Discussion

These experiments on effects of exposure to air and high water velocity on periphyton should be treated as small-scale pilot studies which would provide guidance on whether larger trials might be worthwhile. Therefore the results are indicative only.

6.3.1 Effects of exposure to air

The results of both the Cobble and Paver experiments demonstrated that exposure of periphyton to air for a few hours after 3 weeks growth set back biomass accrual significantly (as recorded in samples collected on 10 March). The exposure on 26 February was in full sunlight and resulted in obvious desiccation of the algae. Therefore desiccation presumably killed most of the algae, as would be expected.

The other three of the four short exposures in the Cobble experiment were on overcast days. The difference in appearance of cobbles after up to 4 hours out of the water was quite subtle (Figure 6-4). Nevertheless, biomass on the exposed cobbles after 3 weeks was only 45% of that on the controls, compared to 65% on the pavers after the same time following exposure to sunlight on 26 February for 7 hours. This suggests that the additional exposures on overcast days did have some effect. However, the result is not definitive because the substrata were different.

Figure 6-4: Example of the appearance of the same cobble in the Cobble experiment, before and after exposure on two dates. Exposure in full sunshine of 26 February completely dried out the mat, while exposure in overcast conditions on 20 March produced incomplete drying.

The pavers were left in the water for a further 10 days growth (10 – 20 March), after which the difference in biomass between exposed and control pavers remained consistent. In other words biomass accumulation was occurring at the same rate on the exposed and control pavers.

6.3.2 Effects of fast flows

Removal of cobbles to the high-velocity area had more effect relative to the controls than removal of the pavers to the high-velocity area (for which no effect was detected). This was in spite of a smaller difference in velocities for the cobbles. This result highlighted that substrate could be crucial to the response of didymo mats to high flows. The pavers have rough surface with many small crevices, which probably provide firm and sheltered attachments for didymo cells. The greywacke cobbles on the other hand are smooth with few obvious crevices. This difference indicates that any further experiments would be better conducted using cobbles rather than pavers. The pavers have the advantages of uniform size and ease of repeated sample collection on the same paver. However, they do not provide results that represent what would occur in the river.

6.3.3 Effect of fast flows and overnight exposure

To demonstrate that exposure to air overnight made didymo mats more vulnerable to the effects of higher water velocities, we would need to see a significant difference between treatments C3 and C5 in the cobble trial. Mean biomass in treatment C5 was 75% of that in treatment C3. However, variability in the amount of biomass lost from the cobbles, combined with a small number of replicates (n = 6) meant that the difference was not statistically significant. The fact that biomass in treatment C5 (and not C3) was different from that in the controls hints that the overnight exposure might have had an effect. A repeat of the experiment with more replicates would be likely to provide a definitive answer.

6.4 Conclusions

The main conclusions from the exposure experiments were:

(a) Overnight exposure of a well-developed didymo mat on river cobbles may have increased susceptibility to sloughing. The experiment would need to be repeated using many more replicates to confirm this or not. If confirmed, the result would indicate that a strategy of lowering river levels as far as possible overnight prior to a flushing flow might increase the effectiveness of the flush

(b) Any exposure to air will set back biomass development. The effects may persist for weeks.

(c) Any repeat experiments should be run using cobbles rather than pavers. First, people do not steal cobbles. Second, although the pavers are convenient and easy to sample, they do not represent river conditions very well.

7 Overall conclusions

Key findings from NIWA's 2013-2014 periphyton investigations on the Opuha River are:

1. The February 2014 flushing flow was larger and of much longer duration than all previous artificial flushing flows. With the current dam infrastructure there is little more that can be done to increase the flow rate or duration of flushes released from the dam.

2. The flush successfully mitigated the problem of detached nuisance periphyton clogging irrigation takes which was causing operational concerns prior to the flush.

3. The flush deposited much less organic material along the banks of the Opihi River and the river mouth lagoon/hapua than previous monitored flushes. Reduced deposition was likely a result of:

    – The longer duration flush.

    – The river mouth being opened mechanically immediately prior to the flush.

    – The timing of the rising limb of the flush hydrograph coinciding with low tide.

4. Monitoring showed the flush was significantly more effective at removing periphyton at all three monitoring sites than previous monitored flushes.

5. Periphyton coverage did increase rapidly after the flush but it took significantly longer to return to pre-flush levels than after previous trial flushes (longer than 1 month at Skipton and Confluence sites).

6. Bed shear stresses exceeding 45 N/m^2 during the flush were found to result in greater than 50% reduction in cover while shear stresses less than 35 N/m^2 show very variable reduction in cover. This supports and adds certainty to shear stress thresholds used during analysis in Measures and Bind (2012) which identified 40 m^3/s as a required flow for effective flushing.

7. Areas of bed that are exposed to higher shear stresses during normal flows were found to recover more slowly to the effect of the flush, and showed lower periphyton cover on average over the whole monitoring period.

8. Water temperatures in the Opuha downstream of the lake are consistently 2-3°C higher during summer and autumn as a result of the dam. This temperature difference is likely to have a significant effect on periphyton, with previous research demonstrating small temperature differences can cause significantly increased biomass. Previous research highlights 15°C as an important threshold above which high cover of *Phormidium* becomes more likely. The dam effect on the Opuha does increase the proportion of time water temperature is above this threshold.

9. Experiments into the effects of exposure of periphyton to air showed:

    – Any exposure to air (short or long, even on overcast days) sets back biomass development.

    – Overnight exposure of a well-developed didymo mat prior to flushing may increase the effectiveness of the flush.

A number of these findings are useful for informing improved management of nuisance periphyton in the Opuha. The increased effectiveness of the February 2014 flush (including greater periphyton removal and slower regrowth) suggest that future flushes should try to replicate its maximised peak flow and longer duration. Future flushes should also be timed so the rising limb of the hydrograph arrives at the coast on a low/rising tide to minimise deposition around the river mouth lagoon/hapua.

The observed effect of shear stress reducing periphyton regrowth and mean cover, and the effect of exposure to air reducing biomass suggest that increasing short term (hours-days) flow variability may be a useful technique to help mitigate nuisance periphyton. Increased flow variability could be implemented with minimal operational impact during any periods when average flow is raised above minimum flow requirements. Increased flow variability could help complement flushing flows by improving flush effectiveness and slowing regrowth after flushing.

Knowledge of the effect of the dam on water temperatures is not directly useful for informing management of nuisance periphyton. It does however provide a potential partial explanation of the reasons for increased periphyton growth downstream of the dam. This will be useful to consider alongside Environment Canterbury’s investigation into water chemistry effects.

8 Acknowledgements

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Appendix A Monitoring forms

The following forms were used by both Environment Canterbury and NIWA. The visual assessment form (next page) shows the distance of each view from the transect marker. The form includes columns for recording either water velocity or substrate composition (as in the example).

Visual assessment of periphyton: monitoring form

Sampling team: ……………………………………………………………..………………………..

River: Opuha **Site:** Below Dam

Date: ………………. **Time:** …………..…. **GPS:** E …….…………..……. N: …………………

Photos taken? yes / no ref. (if yes)……….. **Water temp.** …… **Specific Cond.** ………

Site/weather observations ………………………………………………………………..……..

…………………………………………………………………..………………………………………

………

………

Max. depth viewed ……….. **Average Depth** ……………… **%Shading** ………..

Substrate composition:

Bedrock	
Boulder (> 25 cm)	
Large cobble (12 – 25 cm)	
Small cobble (6 – 12 cm)	
Gravel (0.2 – 6 cm)	
Sand (gritty, <0.2 cm)	
Silt (fine, not gritty)	

A. Bank-side estimate of periphyton cover

Filaments (> 2 cm long)	Mats (> 2 mm thick)	Total cover (all algae)	Macrophytes (submerged)	Macrophytes (emergent)

Periphyton transects start on True Left of river. Four transects with five views on each.

B. Opuha at Below Dam. Including substrate **Date: ……………………** **Time: …………………………**

View	Distance from TL	Distance if different	No algae	Film	Sludge	Mats	Phormi-dium	Didymo	Dg thick. (mm)	Fils_ green	Fils_ other	Macro-phytes	Bou	LCob	SCob	Grav	Sand	Silt
1	5																	
2	10																	
3	13																	
4	16																	
5	18																	
6	6																	
7	9																	
8	12																	
9	15																	
10	18																	
11	4.5																	
12	7.5																	
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14	13.5																	
15	16.5																	
16	4																	
17	7																	
18	10																	
19	13																	
20	16																	