

# Flushing flows for the control of nuisance periphyton growth in the Opuha-Opihi River system (2004-2006)



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Prepared for

## Opuha Dam Ltd

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## **Executive Summary**

- 1. This study assessed the removal of nuisance periphyton in the Opuha and Opihi Rivers resulting from flood releases (hereafter flushing flows or flushes) from the Opuha Dam. The Opuha and Opihi Rivers sustain populations of brown trout and quinnat salmon. Perceptions among some stakeholders are that periphyton growth in the Opuha and Opihi Rivers has been excessive in recent years, particularly in the Opuha River below the dam, and that the construction of the Opuha Dam (1997) and the subsequent flow regime downstream has been partly responsible for increased nuisance periphyton coverage (primarily due to a more stable flow regime).
- 2. Four flushing flows occurred between December 2004 and February 2006. Periphyton cover and biomass was measured before and after each flushing flow to assess the effectiveness of flushes for periphyton removal. Stream invertebrate densities and community structure were measured to examine changes in non-targeted biota caused by flushes. The first flush occurred on 6 March 2005 and changed baseflow from 7.3 m<sup>3</sup>/s to a peak flow of 18.1 m<sup>3</sup>/s below the dam for ca. 4 hours (a 2.5x change in the Opuha and a 1.4x change in the Opihi River at the SH1 Bridge 56 river-km downstream). The second event on 13 May 2005 resulted in a change from baseflow of 2.7 m<sup>3</sup>/s to peak flow at 21.8 m<sup>3</sup>/s below the dam, a 8.1x change in flow below the dam (2.1x change in the Opihi at the SH1 Bridge). The third (17 December 2005) and fourth (6 February 2006) events both had peak flows at 21 m<sup>3</sup>/s below the dam. However, the December 2005 event started from a baseflow of 2.7 m<sup>3</sup>/s and resulted in a 7.8x change in flow while the February 2006 event started at a baseflow of 5.3 m<sup>3</sup>/s and resulted in a 3.9x change in flow.
- 3. Nuisance periphyton cover in the Opuha and Opihi rivers, defined as long filamentous green algae (FGA; >2cm long) and thick mats (>3 mm thick), peaked during late summer 2005 and in December 2006. In late summer 2005, nuisance periphyton in the Opuha River covered 10-30 % of the stream bed and was dominated by thick mats of *Phormidium* sp. (Cyanobacteria). In December 2006, nuisance periphyton consisted of both thick *Phormidium* sp. mats and long FGA (>2cm long). In general, nuisance periphyton cover in the Opihi River was lower than in the Opuha River. However, at Hanging Rock Reserve on the Opihi River (~5 river-km downstream from the Opuha-Opihi confluence and ~35 river-km from dam), thick brown mats of stalked diatoms (mainly *Gomphoneis* sp.) covered ~ 55% of the riverbed in May and December 2005 prior to flushing flows.
- 4. Flushing flows were most effective at removing nuisance periphyton from the riverbed near the dam. Percent removal of nuisance periphyton after each flushing flow decreased with distance downstream from the dam. Each flushing flow reduced thick mat and long FGA cover but did little to reduce the cover of medium thick mats (1-3 mm) and short FGA (<2 cm). The second flushing flow (6 March 2005) was more effective at removing nuisance periphyton than the first, particularly in the Opuha River near the dam (100% removal of thick

mats and long FGA). However, effectiveness declined rapidly downstream; removal of thick mats and long FGA was 38% at 12 river-km from the dam and 27% in the Opihi at Hanging Rock Bridge. These results suggest that there was insufficient shear stress, fine grain scouring, or bedload movement to reduce thick mats and long FGA growths to thin biofilms beyond the vicinity of the dam (i.e., more than ~ 15 river-km downstream). Our ability to assess the effectiveness of flushes in removing nuisance periphyton in the Opihi River (i.e., below the Opuha/Opihi confluence ~ 25 river-km downstream) was impaired by the co-occurrence of natural floods in the upper Opihi catchment. It is likely that the furthest downstream study site (Opihi River at SH1 Bridge ~56 river-km from dam) was too far downstream to detect direct effects of flushes from the Opuha Dam because the magnitude of flow change (resulting from flushing flows) was always  $\leq 2.1x$  baseflow discharge.

- 5. Benthic invertebrate communities in the Opuha River were dominated by Diptera (true flies). Ephemeroptera (mayflies)/Plecoptera (stoneflies) /Trichoptera (caddisflies) or EPT taxa were relatively uncommon on February and June 2005 sampling dates. Communities with high relative abundance of EPT taxa are typically indicative of benthic habitat conditions with low algal biomass and high water quality. Diptera and EPT proportions resulted in low SHMAK scores (a multi-metric index that uses macroinvertebrate community composition to assess water quality). EPT taxa are typically common in both unregulated river systems and natural lake outlets (40-85% of relative abundance) and their absence can indicate degradation of physical habitat and/or water quality. Depending on flow regimes, invertebrate communities below dam outlets are expected to be similar to natural lake outlet communities. There were small increases in the proportion of EPT taxa and invertebrate SHMAK scores following the March and May 2005 flushes. However, attributing shifts in macroinvertebrate assemblages over time to specific events such as flushes requires quantitative samples, high sampling intensity and long-term data acquisition. Therefore it is too soon to relate long-term benthic invertebrate community composition changes to the implementation of flushing flows.
- 6. Beginning with the February 2006 flush, quantitative benthic invertebrate sampling was initiated at 3 sites along the Opuha River. This sampling protocol was used to test for differences between pre-and post-flush macroinvertebrate communities. In February, pre-flush communities were dominated by Diptera, oligochaetes (worms) and nematodes (50-75% of relative abundance at most sites) and had low relative abundances of EPT taxa (<30% at most sites). There were no significant changes in macroinvertebrate assemblages following the February 2006 flush (i.e., no significant change in taxon richness, total density, or relative composition).
- 7. In the Opuha River, the development of periphyton under elevated stable flows (8-14 m<sup>3</sup>/s) during wet summer conditions (2004-05) and dam maintenance (late March 2005) may have affected the resistance of periphyton communities to subsequent flushing flows. For example, flushes following periods of (stable) low flow (e.g.,  $<5 \text{ m}^3/\text{s}$  at the dam) are predicted to remove more periphyton than flushes following stable high flow (e.g.,  $8 \text{ m}^3/\text{s}$  at the dam). In

the former case, periphyton is poorly attached, and bed shear is effective at removal. In the latter case, periphyton is more securely attached and shear stress is less effective at removal.

- 8. We recommend the following measures that may increase the effectiveness of flushing flows and encourage the development of an adaptive flow management scheme for control of nuisance periphyton:
  - (a) Increase the flood magnitude. During the 2006-07 field season 35 m<sup>3</sup>/s will be tested. This is the current maximum flow possible through the downstream weir (DSW) gate. However, there is the risk of undermining the foundation footings below the DSW gate when flows exceed 15 m<sup>3</sup>/s (see Discussion section for more information). Therefore, Opuha Dam Ltd. has only agreed to release higher flows for these trials and has no long-term agreement to continue to release 35 m<sup>3</sup>/s flushes after the 2006-07 and 2007-08 trials are completed.
  - (b) Prior to flushes, hold discharge below the dam at a minimum acceptable flow (i.e., ensuring ample fish habitat along the river corridor) for 5-10 days preceding flushing flow. However, it is recognized that current Resource Consents set minimum flow guidelines that may not allow for extended low flows during certain parts of the year (e.g., March October to maximize fish habitat).
  - (c) Consider sediment additions to provide additional scour potential. We have proposed to carry out a sediment addition experiment during the 2007-08 field season in an effort to calibrate a sediment routing model and explore the effectiveness of smallscale sediment additions at removing nuisance periphyton.
  - (d) Consider mechanical disruption of tightly packed areas of streambed (will be trailed in 2007-08 field season).
  - (e) Work with Environment Canterbury and other stakeholders to develop acceptable guidelines for "topping-up" natural flood events, which can serve the same function as flushing flows. Currently, Resource Consents for the operation of Opuha Dam do not allow for topping-up natural freshets.
  - (f) Continue the monthly monitoring programme to provide data on periphyton growth. If periphyton cover exceeds MfE Guidelines the dam operator will be notified.
  - (g) Consider operational or infrastructural alterations to provide occasional higher magnitude flushing flows that might approach the historic mean annual flood (i.e., 90-100 m<sup>3</sup>/s). The need to consider this option will be more evident after the 2006-08 field seasons when several ~35 m<sup>3</sup>/s flushes will be trialled.



## 1. Background

This study was designed to establish strategies for controlling nuisance periphyton in the Opihi River. The river is a highly utilized recreational waterway and sustains populations of brown trout and quinnat salmon. Perceptions among some stakeholders are that periphyton growth in the Opuha and Opihi Rivers has been excessive in recent years, particularly in the Opuha River below the dam, and that the construction of the Opuha Dam (1997) and the subsequent flow regime downstream has been partly responsible for increased nuisance periphyton coverage (primarily due to highly stable flows; A. Meredith, ECan, personal communication). The aim of this project was to determine if flushing flows from the Opuha Dam could be effective at removing nuisance periphyton growths in the Opuha and Opihi Rivers.

Standards to be achieved from the programme were those cited in the MfE Periphyton Guidelines (Biggs 2000a):

- 1. Maximum periphyton cover as mats greater than 3 mm thick shall not exceed 60%.
- 2. Maximum periphyton cover as long filamentous algae growths (>2 cm) shall not exceed 30%.

A flushing flow programme was recommended (see below) based on a preliminary analysis of the nutrient status and hydrology of the Opihi system.

#### 1.1. Objectives

The objectives of the study were to:

- Document periphyton coverage in the Opuha-Opihi system over the summer growing season (December 2004 to May 2005).
- Assess the effectiveness of flushing flows at removing thick periphyton mats and long filamentous algae in the Opuha-Opihi system (4 flushing flows between December 2004 and February 2006).
- Document changes in periphyton and benthic macroinvertebrates in the Opuha-Opihi system in response to flushing flows.



#### **1.2.** Factors Influencing Periphyton Growth in Rivers

Growth of periphyton in rivers is determined by a series of complex interactions between hydrology, water chemistry and biotic factors, resulting in a process of biomass gains and losses over time (Biggs 1996). Previous studies have demonstrated that the magnitude and frequency of floods regulates the accrual of periphyton biomass in large New Zealand Rivers (Clausen and Biggs 1997, Biggs et al. 1999). High discharge events reduce periphyton biomass by: 1) increasing shear stress thereby causing sloughing of periphyton material; 2) scouring and abrading by fine sand; 3) mobilising bed material and causing periphyton detachment while substrate is tumbling along the streambed (Biggs et al. 1999).

Periphyton growth rate and biomass accumulation between floods (i.e., during lowflow periods) can be affected by nutrient concentrations, light, water temperature, and invertebrate grazing (Bothwell 1989, Biggs 2000b). Prolonged periods of low stable flows in rivers with elevated nutrient concentrations can result in very high periphyton biomass. Many species of algae have physiological constraints that limit their nutrient uptake rates. Other species are limited by diffusion of nutrients across the cell membrane and if the rate of diffusion is increased the cell can continue to incorporate essential nutrients into the synthesis of new cell material. In this latter case, elevated nutrient concentrations in stream water increases diffusion rates to cells at the base of the matrix and enhances growth and accumulation of the periphyton matrix. If invertebrates cannot consume periphyton at a rate equal to or greater its rate of production then periphyton mats or filaments increase local biomass until cells die and slough to the water column or physical forces remove them from the stream bottom.

Proliferations of FGA or thick cyanobacterial mats can cause severe diel fluctuations in dissolved oxygen and pH leading to fish stress (or death) (Quinn and Gilliand 1989). Periphyton proliferations can also reduce the number of free-living "cleanwater" invertebrates such as mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) (called EPT taxa) and increase non-biting midges (Chironomidae), worms (Oligochaeta) and nematodes (Quinn and Hickey 1990). Thick periphyton mats or FGA proliferations can also reduce benthic invertebrate diversity and lower grazing rates of herbivorous invertebrate taxa (Biggs 2000a). Many EPT taxa are important food items for both native and introduced fish, and thus it is desirable to manage rivers for enhancement of these insects.

## 2. Opuha-Opihi River

The Opuha River at Skipton Bridge is a hill-fed gravel-bed river with a catchment area of 458 km<sup>2</sup> and a pre-dam (1963-1996) mean annual discharge of 9.8 m<sup>3</sup>/s (minimum and maximum mean annual discharge 5.2 and 14.8 m<sup>3</sup>/s). The average annual



maximum daily flow for the pre-dam period (1963-1996) was 114 m<sup>3</sup>/s and the maximum daily flow was 346 m<sup>3</sup>/s recorded on 19 May 1994. Land-use in the catchment is predominantly low-intensity sheep and beef grazing. River nutrient concentrations at Skipton (Table 1) are intermediate compared to a New Zealand national assessment (Close and Davies-Colley 1990). Periphyton communities in the Opihi River system have been typically dominated by Ulothrix/Oedogonium (filamentous green algae) (Norton 1995), similar to other South Island braided rivers such as the Hurunui and Ashburton Rivers (Biggs 1990). Data from a 15-month study indicated that, prior to the Opuha Dam construction, periphyton biomass in the Opihi River (at SH1 Bridge) was relatively low, with mean and maximum biomass of 29  $mg/m^2$  and 210  $mg/m^2$ , respectively (Biggs and Close 1989). In recent years, periphyton biomass in the lower portions of the catchment have been high and dominated by undesirable cyanobacteria (i.e., Phormidium spp.)(A. Meredith ECan personal communication). This periphyton proliferation has led to concerns by community advocacy groups and anglers that the cyanobacteria are contributing to poor trout habitat conditions, potentially to tainting of trout and salmon flesh, and may be toxic if ingested (e.g., by dogs and/or stock). Periphyton communities in the Opuha River below the dam appear to be dominated by diatoms and FGA at high biomass levels. These periphyton communities are thought to be generally poor habitat for benthic biota and tend to be aesthetically undesirable. The construction of the Opuha Dam raised concern that reduced flow variability in the Opuha and the lower Opihi has caused periphyton to proliferate and has altered periphyton composition. Periodic flushing flow releases from the Opuha Dam may be an effective management tool to remove nuisance periphyton communities (biomass removal) and select for more desirable types of periphyton communities.

**Table 1:**Water chemistry (mean from monthly samples  $\pm 1$  S.D.) at 3 sites on the Opuha and<br/>Opihi Rivers during the study period (January 2004 - May 2006). Source - National<br/>Networks River Water Quality Database, G. Bryers, NIWA Hamilton. Samples n = 29<br/>unless noted.

Variable	Opuha at Skipton Bridge	Opihi at Rockwood	Opihi at Waipopo
Temperature (°C)	10.5 ± 4.3	10.2 ± 3.8	11.9 ± 4.0
Specific conductance (µS/cm)	46.0 ± 5.3	84.4 ± 9.4	78.4 ± 11.4
рН	7.6 ± 0.1	$7.7 \pm 0.2$	7.6 ± 0.2
Black disk (m)	1.9 ± 0.8	2.2 ± 1.2	$3.0 \pm 1.3$
NO <sub>3</sub> -N (µg/L); n = 25	152.6 ± 53.0	863.6 ± 337.2	355.4 ± 152.8
NH₄-N (μg/L); n = 25	4.8 ± 2.5	9.5 ± 17.9	4.7 ± 2.1
TN (μg/L); n = 28	313.8 ± 78.3	1018.2 ± 389.2	454.5 ± 167.1
DRP (μg/L); n = 25	$1.2 \pm 0.8$	6.7 ± 14.9	2.1 ± 1.4
TP (μg/L); n = 28	20.6 ± 40.3	48.9 ± 175.2	7.5 ± 5.1
TN:TP (min, max); n = 28	31 (3, 62)	123 (2, 328)	84 (17, 294)



#### 2.1. Flow Management

Using a preliminary analysis of nutrient concentrations in the Opuha-Opihi system (Biggs 2000a) and previous experimental work in New Zealand (Biggs and Close 1989, Biggs and Thomsen 1995, Clausen and Biggs 1997) we predict an accrual time to peak biomass of between 40-70 days. Data from the Okuku River (Biggs and Stoketh 1996) and from the 100 Rivers Survey (Biggs et al. 1990) indicate that peak periphyton biomass during prolonged stable summer periods would be in the neighbourhood of 350 mg/m<sup>2</sup> chlorophyll *a* (Chl<sub>a</sub>) (Biggs 2000b), which exceeds the MfE recommended guideline of 200 mg/m<sup>2</sup> Chl<sub>a</sub>.

The magnitude and frequency of flows required to effectively remove nuisance periphyton cannot be predicted with certainty. In order to minimize the duration of nuisance periphyton dominance, the flow management programme should ensure that flushing flow frequency is greater than the observed or expected accrual period required to reach peak biomass. Therefore, we recommended a flushing flow frequency during the warm season (December-May) to be 30-40 days. Based on flushing flows from other New Zealand gravel-bed rivers (Biggs and Close 1989, Biggs and Thomsen 1995), we originally recommended that the magnitude of a given flushing flow be in the neighbourhood of 4-6x baseflow or approximately an additional 16-20 m<sup>3</sup>/s on top of the typical 4 m<sup>3</sup>/s baseflow for the Opuha River. We recommended flushing flow durations of 2-3 hours with sufficient ramping periods on both sides of the flood hydrograph. We also recommended that, when possible, flushing flows occur during natural floods to increase flood peaks downstream from the dam. However, resource consents for the operation of the Opuha Dam limit the option of "topping-up" of natural freshets.

The effectiveness of the flushing flows at removing nuisance periphyton growth will gradually decline downstream as the peak flood wave is dampened due to river floodplain widening (particularly downstream of the Skipton Bridge) and near-bed drag forces that cumulatively attenuate peak flows. Further, the effectiveness of flushing in reducing nuisance periphyton depends on (among other factors) mobilisation of fine and small grain bed material that can physically abrade periphyton mats. Mobilisation of fine material will depend on bed armour layer conditions and availability of fine material in the river channel.



## 3. Methods

#### 3.1. Benthic Habitat Assessments

Periphyton cover, benthic invertebrate communities, substrate composition, and water velocity were assessed at 5 or 6 marked sites (depending on the flushing flow; see text below site list) in the Opuha and Opihi Rivers, as follows (Figure 1):





#### **Opuha River**

- 1. 200m downstream from Opuha Dam
- 2. Skipton Bridge 12 river km from dam
- 3 Chota Bari Farm access (February 2006 flush only) 19 river km from dam

#### **Opihi River**

4. Raincliff Bridge – 500 m upstream from Opuha-Opihi confluence



- 5. Hanging Rock Bridge below Opuha River confluence 34 river km from dam
- 6. State Highway 1 Bridge (SH1 Bridge) below Opuha River confluence 56 river km from dam

Thus study encompassed two field seasons 2004-05 and 2005-06. Study sites and variables measured differed between years.

During the 2004-05 field season (December 2004 – June 2005), periphyton cover was visually estimated at approximately monthly intervals as well as before and after flushing flows. Unscheduled spills from the dam occurred during the first two months of the study period (December-January) due to high runoff in early summer and again in March and April due to routine dam maintenance. Consequently there were two scheduled flushing flows (7 March and 13 May 2005) when pre/post flushing flow data were obtained, and two assessments made following unscheduled spills (13 January and 14 April 2005). Our final field visit on 13 June 2005 occurred one month after the 13 May flush and was intended to quantify changes in benthic invertebrate communities following the 1<sup>st</sup> season of the flushing flow programme.

During the 2005-06 field season (December 2004 – March 2006) there were two scheduled flushing flows (17 December 2005 and 8 February 2006). The Chota Farm site (3 in above list) was added for the February 2006 flush to provide more complete coverage on the Opuha downstream from the dam. Surveys of periphyton biomass were made within one week prior to and 1-day after each flushing flow. All transect points were marked to ensure repeated surveys of the same locations.

#### 3.1.1. Periphyton

Percent cover of periphyton was quantified using the SHMAK Rapid Assessment Method 1 at a single riffle at each of the 5-6 sites (Biggs et al. 2002). Percent cover of each periphyton category was visually estimated at 10 equally spaced intervals along a transect running across the wetted channel. Pre-flush and post-flush estimates at each site were compared to evaluate the effects of each flushing flow release on each periphyton category.

Periphyton biomass (as chlorophyll *a*  $[Chl_a]$  and ash free dry mass or AFDM) was measured using Quantitative Method 1b in the Stream Periphyton Monitoring Manual (Biggs and Kilroy 2000) before and after the December 2005 and February 2006 flushing flow. Periphyton was scraped from known areas of 5 rocks collected at equally spaced intervals at each riffle. Scrapings were stored frozen (-32°C) until



analysis. Samples were thawed in the lab and homogenised, then split onto two Whatmann GFF filters for separate analysis of AFDM and  $Chl_a$ . Lab analysis of  $Chl_a$  followed Biggs and Kilroy (2000). Chlorophyll *a* concentration was corrected for phaeophytin content by measuring absorbance of the extracts after acidifying the samples with 1 N HCL. Concentrations of the extract were then used to calculate  $Chl_a$  density per unit area (mg/m<sup>2</sup>). AFDM was determined by filtering algal biomass onto pre-ashed Whatman GFF filters, drying and weighing to determine dry weight, ashed at 500°C for 1 hour, and then reweighed to determine AFDM content.

Significant differences in periphyton biomass between pre- and post-flush sampling were determined using two-factor ANOVAs (site and date [pre and post flush dates]) for each response variable. Significant differences were determined at p<0.05 followed by Tukey HSD test with multiple comparisons to determine pairwise differences between sites if either the main effect or the interaction term was p < 0.05.

#### **3.1.2.** Benthic Invertebrates

To provide a preliminary assessment of the flushing flow regime, benthic macroinvertebrate assemblages were visually assessed using a rapid assessment protocol at all sites prior to the first scheduled flushing flow on 24 February 2005 and 1 month after the second flushing flow on 18 June 2005. Invertebrate composition was assessed semi-quantitatively at each site (same riffle as for periphyton) using a modified version of the SHMAK Rapid Assessment Method 1 (Biggs et al. 2002). Invertebrates were counted on 10 cobbles collected at equally-spaced intervals across each riffle. A kick net was held immediately behind the rock as it was removed from the river to catch any motile animals that drifted from the rock. Invertebrates scrubbed from each rock were sorted into 17 taxonomic categories and counted.

The relative percentage of invertebrates from the families Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies)(%EPT) and Diptera were compared across sites. SHMAK invertebrate scores, also indicators of stream water quality, were calculated for each transect (see SHMAK Rapid Assessment Method 1 in Biggs et al. 2002).

In February 2006, benthic macroinvertebrate assemblages were quantitatively sampled to assess the impact of a flushing flow on invertebrate densities and community composition. Five Hess samples (250  $\mu$ m mesh netting; 0.089 m<sup>2</sup>) were collected randomly from a single riffle at each site (sites 1-3 on the Opuha River) on 8 February 2006 (pre-flush) and again on 9 February 2006 (post-flush). All invertebrates in each sample were sorted and identified to the lowest possible taxonomic level (typically genus or species for insects and family or higher for non-insect taxa). Ash free dry



mass (AFDM) of the organic material remaining in benthic invertebrate samples (Hess samples) after invertebrates were removed was determined in order to test for pre- and post-flush differences.

Pre- and post-flush differences at each site in invertebrate density  $(\log_{10}[x+1])$ , total taxon richness, EPT richness, and benthic organic matter AFDM were compared using two-way ANOVA (3 sites \* 2 dates). Post hoc Tukey HSD tests with multiple comparisons were used to assess pairwise differences (p < 0.05). Spatial and temporal variation (among sites and between pre- and post-flush periods) in invertebrate assemblages were assessed using Correspondence Analysis. Density data were  $\log_{10}(x+1)$  transformed prior to analysis (Statistica 7.1, StatSoft, Inc., Tulsa, Oklahoma, USA).

#### **3.1.3.** Habitat Assessments

Substrate size frequency was measured at each site at 10 points along a transect running across the river channel according to the methods outlined in the SHMAK manual (Biggs et al. 2002). Substrate composition was characterised using percent composition of 6 categories: bedrock, boulders, large cobbles, small cobbles, gravel, sand and silt determined by passing randomly-selected particles collected from each point through a gravelometer (a.k.a., Wolman frame). Substrate composition at each site was summarized as the percent of observations in each size category.

Near-bed current velocities (within ~2cm of river bed) were measured at 10 points across the same riffle used for periphyton sampling at each site on a single date prior to (May 12, 2005) and during the 13 May 2005 flushing flow (excluding the Waipopo site, due to overnight flood arrival). The magnitude of change in water velocity during the flushing flow was estimated as the ratio of the site-average velocity before and during the flush.

### 4. Results

#### 4.1. Hydrology

Median flows in the Opihi and Opuha Rivers during the 2004-05 study period (December-May) were 107-130% of the longer-term (1998-2005) summer medians, calculated for the 7-year period following dam construction (Table 2). Median flows in the lower Opihi River (SH1 Bridge flow recorder, Environment Canterbury data) were 30% higher (10.2  $\text{m}^3$ /s) in 2004-2005 compared to long-term summer medians,



and the lower Opihi River had almost double the number flood events (3x median) compared with the previous 7-years (median 7.7  $\text{m}^3$ /s) (Figure 2).

Table 2:Median flows and frequency of significant floods (3x median) over the summer season<br/>(1 Dec. – 31 May) during the 2004-05 and 2005-06 study periods, and the long-term<br/>average since the construction of the Opuha Dam. Data from Environment Canterbury<br/>and Alpine Energy Ltd.

Variable	Opuha @ Dam Outlet	Opihi @ Rockwood	Opihi @ SH1 Bridge
2004-05 study period median flow (m <sup>3</sup> /s)	6.84	3.16	10.10
2005-06 study period median flow (m <sup>3</sup> /s)	6.94	2.30	8.89
Long-term summer median flow (1998-2005) (m <sup>3</sup> /s)	6.40	2.77	7.70
2004-05 study period 3x median flood frequency	4	6	6
2005-06 study period 3x median flood frequency	1	11	9
Long-term summer 3x median flood frequency (1998-2005)	2.0	5.2	3.2

Spillage from the Opuha Dam during the 2004-05 study period was greater than the long-term record, with a 7% increase in median summer flow, and four floods exceeding 3x median flow compared with a long-term average of two summer season floods per year. The period from December 2004 to February 2005 was particularly wet and resulted in 4 flood events recorded at the Opihi River SH1 gauge exceeding the 99<sup>th</sup> percentile of the mean daily flow (70 m<sup>3</sup>/s).

During the 2005-06 summer period, the median flow in the Opihi River was 16% lower than the longer-term average summer median but there were 11 floods > 3x median. Median flow below the Opuha Dam during the 2005-06 study period was nearly identical to median flow during the 2004-05 study period (Table 2).

Flushing flows on 6 March, 13 May, and 17 December 2005 and 9 February 2006 all resulted in peak flows near 20  $\text{m}^3$ /s but the relative change in discharge below the dam ranged from 2.5 to 8.1 times baseflow preceding the flushing flow (Table 3).

#### 4.2. Periphyton Cover Estimates (SHMAK Methodology)

Thick (>3 mm) periphyton mats and long (>2 cm) filamentous algae (FGA) appeared in summer 2004-2005 throughout the Opuha River and at Hanging Rock Bridge on the Opihi River (Figures 2 and 3). During summer 2004-05, FGA cover exceeded the MfE





**Figure 2:** Mean cover of thick periphyton mat (>3 mm; black bars) and long FGA (>2 cm; gray bars) at five sites in the Opuha and Opihi Rivers, and the river flows over the 2004-05 study period. Flushing flows released from the Opuha Dam are indicated by arrows, 0 = no coverage and nd = no data.





**Figure 3:** Mean cover of thick periphyton mats (>3 mm; black bars) and long FGA (>2 cm; gray bars) at six sites in the Opuha and Opihi Rivers and river discharge during the 2005-06 study period. Flushing flows released from the Opuha Dam are indicated by arrows, 0 = no coverage and nd = no data.



**Table 3:**Mean flow just below the dam (Opuha River) and at the SH1 Bridge (Opihi River)<br/>prior to the flushing flow, maximum flow during the flush, and the magnitude of flow<br/>change for the 4 flushing flows from March 2005 – February 2006.

Site / date	Mean pre-flush flow (7-d mean; m <sup>3</sup> /s)	Maximum flow during event (m <sup>3</sup> /s)	Flushing flow magnitude (x baseflow)
Opuha below downstream weir	<u> </u>		
6 March 2005	7.3	18.1	2.5
13 May 2005	2.7	21.8	8.1
17 December 2005	2.7	21.5	7.8
8 February 2006	5.3	21.0	3.9
Opihi River at SH1 Bridge			
6 March 2005	7.4	10.6	1.4
13 May 2005	6	12.8	2.1
17 December 2005	15.4	23.0	1.5
8 February 2006	4.0	7.8	1.9

guideline (30% coverage by filaments >2 cm long) on a single sampling date at both the Skipton Bridge site (24 February 2005) and the site below the dam (12 May 2005). Cover by thick periphyton mats (>3 mm thick), comprised mainly of black/brown *Phormidium* mats, covered 10-30% of the streambed at the Opuha River sites, with a tendency for greater cover closer to the river banks. In the Opihi River, summer cover by thick mats and FGA was very low at both the Raincliff Reserve site upstream of the Opuha confluence, and at Waipopo downstream of the SH1 highway bridge (Figure 2). At the Hanging Rock Reserve site, approximately 5 km downstream from the Opuha-Opihi confluence, thick brown mats of stalked diatoms (mainly *Gomphoneis* sp.) were present in late summer (May 2005). During summer 2005-06, FGA cover exceeded the MfE guideline on a single sampling date only at the dam and cover by thick periphyton mats did not exceed MfE guidelines (Figure 3).

Figures 4-7 show periphyton percent cover estimates from each site before and after each flushing flow. In general, periphyton cover by thick mats or filamentous growths was greater at Opuha sites compared to Opihi sites (Figures 4-7). The March 2005 flushing flow converted thick mats to medium mats at the dam and Skipton sites and converted long FGA to short FGA at Skipton (Figure 4). Long FGA was removed from the dam and Skipton sites after the May 2005 flushing flow (Figure 5), and thick mats were converted to medium mats at the dam and Hanging Rock Reserve sites. After the December 2005 flushing flow, long FGA at the dam and Skipton Bridge sites were reduced from coverages near MfE guidelines (30% of stream bed) to zero (Figure 6). Prior to the February 2006 flush, long FGA cover was near the MfE guideline below the dam and at Skipton Bridge and thick mat cover was just below MfE guidelines at the Hanging Rock Reserve site (Figure 7). The February 2006 flushing flow reduced long FGA and thick mats to <10% cover of the stream bed.





Figure 4: Mean cover  $(n=10 \pm SE)$  of periphyton growth forms at 5 sites in the Opihi and Opuha Rivers before black bars) and after (gray bars) the 6 March 2005 flushing flow. Peak discharge during the flush was 18 m<sup>3</sup>/s (2.5x baseflow at the dam) and was maintained at the dam for 3 hours. MfE guidelines are 60% cover by thick mats and 30% cover by long FGA.





**Figure 5:** Mean cover  $(n=10 \pm SE)$  of periphyton growth forms at 5 sites in the Opihi and Opuha Rivers before black bars) and after (gray bars) the May 13, 2005 flushing flow. Peak discharge during the flush was 22 m<sup>3</sup>/s held over 6 hours, resulting in an increase in flow of 8.1x in the Opuha River below the dam and 2.1x in the Opihi at the SH1 Bridge. MfE guidelines are 60% cover by thick mats and 30% cover by long FGA.





**Figure 6:** Mean cover  $(n=10 \pm SE)$  of periphyton growth forms at 5 sites in the Opihi and Opuha Rivers before black bars) and after (gray bars) the December 17, 2005 flushing flow. Peak discharge during the flush was 21.5 m<sup>3</sup>/s held over 6 hours, resulting in an increase in flow of 7.8x baseflow in the Opuha River below the Dam and 2.1x baseflow in the Opihi at the SH1 Bridge. MfE guidelines are 60% cover by thick mats and 30% cover by long FGA.





**Figure 7:** Mean cover  $(n=10 \pm SE)$  of periphyton growth forms at 5 sites in the Opihi and Opuha Rivers before black bars) and after (gray bars) the February 9, 2006 flushing flow. Peak discharge during the flush was  $21 \text{ m}^3$ /s held over 6 hours, resulting in an increase in flow of 3.9x baseflow in the Opuha River below the Dam and 2.1x baseflow in the Opihi at the SH1 Bridge. MfE guidelines are 60% cover by thick mats and 30% cover by long FGA.

#### 4.3. Periphyton Biomass

Periphyton biomass and  $Chl_a$  concentrations were quantified before and after flushes in December 2005 and February 2006 (Figures 8 and 9). Post-flush periphyton biomass levels and  $Chl_a$  concentrations were not significantly different from pre-flush conditions (p > 0.05) at any site after the December 2005 flush. However, the trend was for a reduction in biomass and chlorophyll *a* just below the dam and at Skipton following both flushes (Figures 8 and 9) but the variability among samples from each site was too great to detect significant changes between pre- and post-flush conditions.





**Figure 8:** Mean periphyton biomass (AFDM; upper panel) and chlorophyll *a* standing stock (Chl<sub>*a*</sub>; lower panel) at 5 sites in the Opuha and Opihi Rivers (see Figure 1 for site locations) before (shaded) or after (open) the 17 December 2005 flushing flow (see Table 3 and Figure 3 for flow statistics and hydrograph). Dashed horizontal lines are recommended guidelines for NZ Rivers. n = 5 for all bars.





**Figure 9:** Mean periphyton biomass (AFDM; upper panel) and chlorophyll *a* standing stock (Chl<sub>*a*</sub>; lower panel) at 3 sites in the Opuha River (see Figure 1 for site locations) before (shaded) or after (open) the 8 February 2006 flushing flow (see Table 3 and Figure 4 for flow statistics and hydrograph). Dashed horizontal lines are recommended guidelines for NZ Rivers. n = 5 for all bars.

Biggs (2000) and Biggs & Kilroy (2000) suggested that above certain limits (lines in Figures 8 and 9) periphyton biomass and  $Chl_a$  concentrations may degrade recreational, aesthetic, and angling experiences in rivers. They further defined "proliferation" of algae on the stream bed at a threshold  $Chl_a$  concentration of 200 mg/m<sup>2</sup> and suggested limits of 120 mg/m<sup>2</sup>  $Chl_a$  and 35 g/m<sup>2</sup> AFDM of periphyton for the protection of recreation, aesthetics, and trout habitat. All sites, except for Waipopo in December 2005, exceeded the periphyton AFDM and  $Chl_a$  guidelines for the protection of recreation, aesthetics, and trout habitat during pre-flush visits in December 2005 and February 2006. Biomass and  $Chl_a$  at several sites during postflush visits in December 2005 and February 2006. Biomass and  $Chl_a$  at several sites during postflush visits in December 2005 and February 2006. Biomass and  $Chl_a$  at several sites during postflush visits in December 2005 and February 2005. Therefore, these flushes were effective at removing nuisance periphyton growths below the dam and at Skipton to biomass concentrations below suggested regulatory limits.



#### 4.4. Benthic Invertebrate Communities

Data from semi-quantitative benthic invertebrate samples in February and June of 2005 (before and after the first two flushing flows) are shown in Figure 10. In general, SHMAK invertebrate scores and %EPT were lowest at the dam, Skipton, and Hanging Rock Reserve sites where there was greater cover of thick periphyton mats and filamentous green algae compared to the Raincliff and Waipopo sites. Invertebrate communities at Opuha River sites and at the Hanging Rock Reserve site (Opihi below Opuha confluence) were dominated by sessile periphyton mat-dwelling taxa, predominantly chironomids (midges), which comprised 70-95% of the community (Figure 10). Macroinvertebrate communities from natural lake outlets (i.e., natural flow regimes) in New Zealand have been shown to be dominated by free-living EPT taxa (40-85%) (Harding 1994, Scarsbrook 2002). By extension, if the Opuha Lake outlet were a natural lake outlet, we would expect invertebrate communities below the outlet to be similar in composition to those reported by Harding (1994) and Scarsbrook (2002). The low densities of EPT taxa (10-30%) and dominance by sessile taxa such as chironomids in the Opuha River suggests that invertebrate communities are impacted by algal proliferations or by other properties associated with flow regulation (Biggs 2000a) like bed armouring.

SHMAK invertebrate scores, % EPT, and % Diptera metrics for the dam, Skipton, and Hanging Rock Reserve sites were similar and low among dates. A lower SHMAK score at Raincliff in June 2005 compared to February 2005 was the result of low numbers of EPT taxa and high densities of Diptera. This change (February to June 2005) coincided with the development of stalked diatom mats (mainly *Gomphoneis* sp.) in autumn (May-June) as flows in the upper portion of the Opihi stabilised (see Figures 2 and 4).

There were no significant differences (ANOVA p > 0.05) in total density, total richness, or EPT richness between pre- and post-flush quantitative invertebrate samples at the three Opuha sites in February 2006 (Figure 11A-C). Invertebrate samples from Skipton Bridge had the highest mean densities and lowest mean total and EPT richness. Relative abundance of Diptera was higher at the dam (ca. 35% of relative abundance [R.A.]) and Skipton (34% of R.A.) than at Chota (11% of R.A.). Relative abundance of Diptera in post-flush samples was lower than in pre-flush samples (data not shown) but this difference was not significant (ANOVA p > 0.05). The only significant difference between pre- and post-flush samples was the total organic matter content (Figure 11D) of samples collected at the dam and Skipton (ANOVA p < 0.019 and 0.043, respectively).





Figure 10: Mean benthic invertebrate community metrics (n=10; error bars  $\pm$  1 SE) at five sites in the Opuha and Opihi Rivers prior to (February 2005) and following (June 2005) the flushing flow trials. High SHMAK scores and % EPT (Ephemeroptera, Plecoptera and Trichoptera taxa) are indicators of high quality benthic habitats, whereas high % Diptera (mainly chironomids) is an indicator of poor benthic habitat quality.





Figure 11: Total density (panel A), taxon richness (panel B), EPT richness (panel C), and benthic organic matter standing stock (panel D) from quantitative macroinvertebrate sampling before (shaded) and after (open) the 8 February 2006 flushing flow. Lower and upper bounds of each box are minimum and maximum values, the solid line = median, and dashed line = mean value from n = 5 samples per site visit.



Results of the Correspondence Analysis (Figure 12) indicated that effects of the February 2006 flushing flow on invertebrate communities were minimal. Further, the analysis revealed that differences among sites were greater than pre- versus postdifferences at each site. At the dam site, three taxa were found in greater abundance than at Skipton or Chota, and these taxa distinguished the dam invertebrate community from other sites. These three taxa, Aoteapsyche raruraru, Hydra sp., and Daphniidae, are typically found in lake outlets or are transported from the lake to the outlet. Aoteapsyche raruraru, a caddisfly that filter-feeds on organic particles, a food source that is particularly abundant at lake outlets due to export of lake derived phytoplankton and zooplankton. Many Daphniidae species are planktonic and these individuals (as well as *Hydra*) may have their origin in the lake and therefore probably do not represent persistent benthic invertebrate taxa. Taxonomic differences between communities at Skipton and Chota were less clear, but the caddisflies Pycnocentria spp. and Paroxythira hendersoni were more common in Skipton samples, while caddisflies Hydrobiosis clavigera, Pycnocentria evecta, and Costachorema sp. were more common at Chota. The ecological explanation for these invertebrate community differences between Skipton and Chota has yet to be explored.

Two general ecological relationships were of interest with regard to invertebrate communities along the Opuha River. First, it is well known that benthic invertebrate communities in rivers below dams have a tendency to be similar to communities found in lake outlets (Suren et al. 2002). These communities are often dominated by filterfeeding taxa, such as simuliids (a.k.a., sand flies) and certain caddisfly taxa (e.g., Trichoptera: Hydropsychidae), that originate in the lake. Second, prolific growth of periphyton on streambeds can result in changes in invertebrate community composition (Quinn and Hickey 1990, Biggs 2000b). In general, invertebrates indicative of low periphyton biomass streams (such as mayflies, stoneflies, and caddisflies) are outnumbered by less mobile (sessile), periphyton mat-dwelling taxa such as non-biting midges (Diptera: Chironomidae) and worms (Oligochaeta). Invertebrate communities dominated by midges and worms are thought to be suboptimal for drift feeding fish, such as trout and salmon. Low invertebrate SHMAK scores at all sites (with the possible exception of Opihi sites at Raincliffs and Waipopo) and the dominance by midges in most samples suggests that invertebrate communities were indicative of medium to high nuisance periphyton cover. Due to the prevalence of filter-feeding taxa, the invertebrate community below the dam was indicative of a lake outlet community influenced by high periphyton biomass.





Dimension 1; Eigenvalue: 0.16 (32.5% of Inertia)

**Figure 12:** Correspondence Analysis (CA) of macroinvertebrate taxa quantitatively (ind./m<sup>2</sup>) sampled from 3 sites along the Opuha River before and after the February 2006 flushing flow trial. Upper panel contains the site scores based on taxa at each site for pre and post flush samples (error bars are 2 \* standard deviation of 5 replicates for each treatment). Lower panel contains each taxons score for the first 2 dimensions of the CA solution. See appendix Table 1 for taxon abbreviations.



#### 4.5. Habitat Assessments - Substrate and Flow Characteristics

The grain-size distribution of riverine sediment along the Opuha/Opihi reflected a size sorting gradient where larger particles were more abundant just below the dam and decreased downstream while small particles increased as a percentage of all particle sizes observed in the streambed (Table 4). Sediment composition at Raincliff Reserve on the Opihi River (above confluence with Opuha) was similar to that observed on the Opuha River at Skipton Bridge, but Raincliff Reserve had more sand on the riverbed surface.

		Opuha		Opihi – above confluence	Opihi – below confluence	
Substrate type	Size class (mm)	Below Dam	Skipton Bridge	Raincliff Reserve	Hanging Rock	Waipopo
% Bedrock	>4096	10	0	0	0	0
% Boulders	256-4096	5	10	10	5	5
% Cobbles	64-256	75	85	70	65	55
% Gravel	2-64	10	4	5	20	25
% Sand	<2	0	1	10	10	15

### **Table 4:**Sediment grain size proportions in the Opuha and Opihi Rivers on 24 February 2005.

Change in near-bed velocity was greatest (2.3x pre-flush measurements) at the site just below the dam outlet during the May 2005 flushing flow (Table 5). The highest change in velocity also corresponds to the greatest change in discharge due to the flushing flow, illustrating the dampening of the flood wave with downstream distance. The downstream attenuation of peak discharge and near-bed velocity coincides with the downstream attenuation of thick periphyton mat removal during the flushing flow (Table 5).

**Table 5:**Mean near-bed water velocity across the river channel (n = 10) prior to (12 May 2005)and during (13 May 2005) flushing flow (22 m³/s for 6 hrs), and the resulting<br/>periphyton removal by the flush at 4 sites downstream of the Opuha Dam.

	Opuha River		Opihi River	
Variable	Below Dam	Skipton Bridge	Hanging Rock Bridge	Waipopo
Mean pre-flushing flow near-bed velocity (m/s)	0.44	0.68	0.67	0.53
Mean flushing flow near-bed velocity (m/s)	1.0	0.82	1.1	nm
Magnitude velocity change	2.3x	1.2x	1.6x	nm
Periphyton removed (% thick mats and long filaments)	100%	37%	28%	0%



## 5. Discussion

Flushing flows were effective to varying degrees at removing nuisance periphyton from the beds of the Opuha and Opihi rivers. Where periphyton cover exceeded MfE guidelines for recreational use and trout habitat (Biggs 2000), flushes effectively reduced nuisance periphyton (long FGA and thick mats). However, effectiveness of removal decreased with distance downstream. Flushing flows tended to shift periphyton on the riverbed from communities dominated by thick mats and long FGA to communities dominated by medium thick (1-3 mm) mats and short (<2 cm) FGA. Although we observed sloughed periphyton and fine sediment in suspension during the flushing flows (photo in Figure 13), it appears that there was insufficient energy to completely remove these thick periphyton growths, and re-set the community to a thin biofilm. The river channel becomes less constrained after it exits the Opuha Gorge immediately upstream of Skipton Bridge, and floodwaters spread laterally as the active floodplain becomes more braided. As a consequence, near-bed stream velocities were lower at sites downstream of the gorge (only measured during the 13 May 2005 flush), such as at Skipton Bridge (1.2x change in magnitude of near-bed velocity) and Hanging Rock Bridge (1.6x), compared with immediately below the Opuha Dam (2.3x) (Table 5). The reduction in peak discharge and near-bed stream velocity with distance downstream from the dam corresponded to decreased nuisance periphyton removal. For instance, the May 2005 event in the Opuha River immediately below the dam resulted in a 100% loss of thick mat and FGA cover, but only 37% and 28 % reductions at Skipton and Hanging Rock Bridge, respectively.



Figure 13: Skipton Bridge site during 13 May 2005 flushing flow.



Other factors that appear to limit the effectiveness of flushing flows at removing nuisance periphyton in the Opuha River are the availability of fine-sediment for scouring, the lack of bed sediment movement during flushes, and pre-flush hydrology. Sediment trapping behind the dam reduces sand and fine gravel transport through the system and may reduce scouring (photos in Figure 14). Several riffles downstream of the Opuha Dam lack surface deposits of fine material (Table 5), with only 1% fines present in riffles at Skipton Bridge, versus >10% throughout the Opihi River. However, observations along lateral margins of runs and in backwaters indicate that fine material is present in lateral deposition zones along the Opuha River.



**Figure 14:** Picture of the Opuha River (Skipton Bridge) streambed along the river margin before and after the flushing flow event on 13 May 2005.

It is evident that many riffles and runs between the dam and Skipton Bridge have not been "re-worked" (i.e., no bed movement) in recent years and these riffles are essentially tightly packed cobbles filled with some gravel. It is therefore likely that considerably larger flows (>50 m<sup>3</sup>/s) would be required to generate sufficient sheer stress for substantial bedload movement. If future flow events require resetting periphyton communities to thin biofilms or increasing removal effectiveness downstream then flushing flows should be designed to break up tightly packed cobbles, mobilize the bed (including abrasive fine sediments), and redistribute material from local deposition zones. Large flood events that cause substantial bedload movement ("channel maintenance flows") are likely to be higher than the maximum flow (~35 m<sup>3</sup>/s) that can currently be released from the Opuha Dam (see discussion below).

Periphyton acclimate to flow conditions, becoming more tightly attached to substrate under extended duration of high flow/high shear stress (Biggs and Close 1989), such as during elevated baseflow. For example, flushes following periods of (stable) low flow (e.g.,  $<5 \text{ m}^3/\text{s}$  at the dam) are predicted to remove more periphyton than flushes following stable high flow (e.g.,  $8 \text{ m}^3/\text{s}$  at the dam). In the former case, periphyton is



poorly attached, and bed shear is effective at removal. In the latter case, periphyton is more securely attached and shear stress is less effective at removal. Consequently, change in flow magnitude is also an important hydrograph component to consider when designing a flow management regime aimed at removing nuisance periphyton growth. The tight attachment of periphyton under sustained flows (8-14 m<sup>3</sup>/s) higher than long-term baseflow due to abnormally wet early summer conditions (e.g., December-January 2005), and dam maintenance (e.g., March-April 2005) probably reduced the effectiveness of flushing flows (e.g., as observed in March and May 2005). Others have also noted this phenomenon in other NZ rivers (Biggs and Thomsen 1995). Lower baseflow conditions (3-4 m<sup>3</sup>/s) for 7-10 days preceding a flushing flow of 30 m<sup>3</sup>/s may result in better removal of nuisance periphyton growths and maintenance of lower overall biomass in the Opuha River.

During the 2006-08 field seasons NIWA will continue the work presented here. However, higher magnitude flows will be conducted (i.e., maximum flows from the dam at 35 m<sup>3</sup>/s). The downstream weir (DSW) gate below the Opuha Dam is designed to safely accommodate a flow of 15 m<sup>3</sup>/s (Greg Skelton personal communication). The actual gate dimensions allow for a 40 m<sup>3</sup>/s discharge. However, the nature of the upstream storage reservoir volume (in the weir pond below the dam) and limitation of the operational pond inlet volume of 15 m<sup>3</sup>/s results in a rapidly reducing driving head to an extent that sustainable flow is only predicted to be ~30 m<sup>3</sup>/s. Further, there is the risk of undermining the foundation footings when flows exceed 15 m<sup>3</sup>/s. Therefore, Opuha Dam Ltd. has only agreed to release higher flows for these trials and has no long-term agreement to continue to release 35 m<sup>3</sup>/s flushes after the 2006-07 and 2007-08 trials are completed.

One additional point regarding the operation of the Opuha Dam should be mentioned. The lower weir pond below the Opuha Dam has a fusible embankment built into its downstream weir (DSW). This fusible embankment is designed to give way during a 1-in-5 year flood event. In January 2002, the DSW fusible embankment operated to pass a flood event. Since 2003, the Opuha Dam has been operated with a 2 m drawdown in the lake and this drawdown volume has captured flows resulting from heavy precipitation events and prevented them from passing through the system. The collapse of the fusible embankment would add between 10,000 and 15,000 m<sup>3</sup> of potentially mobile sediment to the river below the dam (G. Skelton, pers. comm.). This sediment addition may enhance bed-scour during subsequent flushing flows however, a 1 in 5 yr event has yet to be realized.

In addition to the trials of flushing flows set at  $\sim 35 \text{ m}^3/\text{s}$ , several new study variables will be added to quantify relationships between hydrological forces and sediment transport (e.g., bed shear stress and grain size mobilization relationships). These added components are part of a broader programme on Water Allocation issues in



Canterbury funded by the Foundation for Research Science and Technology (FRST). The future research taking place in the Opuha River will include: (a) quantifying sediment, algae, and invertebrates in transport during flushing flows; (b) quantifying deposition of sediment associated with flushing flows; (c) measuring seasonal changes in algae, invertebrate, and fish communities in the Opuha (at Chota) and Opihi Rivers (at Raincliff Bridge); and (d) calibrating a sediment routing model to better determine near-bed shear stress required to mobilise and transport bed sediment. Further, we are currently planning two "sediment treatments" to flushing flows in summer 2007-08: 1) adding discrete quantities of small gravel and sand to riffles in the Opuha and tracking the movement of this material during and after flushing flows and periphyton removal associated with this addition; and 2) mechanically disrupting 2-3 tightly packed riffles near Skipton and tracking both the movement of disturbed bed sediments during and after flushing flows and the response of nuisance periphyton below these disturbed areas. These "treatments" are meant to help calibrate a sediment routing model to improve sediment transport predictions and to measure periphyton response to these disturbances to determine feasibility of these treatments as management techniques for nuisance periphyton.

## 6. Conclusions and Recommendations

Results from four monitored flushing flows indicated that these flows can be an effective tool for reducing/managing nuisance periphyton to intermediate levels below the Opuha Dam. However, flushing flows that peak at 20-30 m<sup>3</sup>/s are only effective at sites close to the dam and effectiveness decreases with distance downstream. Higher magnitude flushes are currently being trialled (2006-07 field season). The current infrastructure of the dam limits the peak magnitude of controlled flushes to ~35 m<sup>3</sup>/s. One of the original recommendations for these flushing flows was to time flushes to co-occur with natural floods to maximize periphyton removal at downstream sites. However, resource consents and safety requirements constrained this approach since public notice is required prior to flushing flows, thereby limiting the dam operators' ability to release water on short notice.

To determine timing of individual flushing flows, an adaptive management plan is currently being developed. Specifically, routine periphyton monitoring along the Opuha, particularly in summer months, is providing information on the extent of nuisance periphyton cover. If periphyton cover exceeds MfE Guidelines the dam operator will be notified.

We recommend the following measures to increase the effectiveness of flushing flows and to develop adaptive management for controlling of nuisance periphyton:



- 1. Increase the flood magnitude. During the 2006-07 field season 35 m<sup>3</sup>/s will be tested. This is the current maximum flow possible through the lower weir gate. However, there is the risk of undermining the foundation footings below the downstream weir gate when flows exceed 15 m<sup>3</sup>/s (see Discussion for more information). Therefore, Opuha Dam Ltd. has only agreed to release higher flows for these trials and has no long-term agreement to continue to release 35 m<sup>3</sup>/s flushes after the 2006-07 and 2007-08 trials are completed.
- 2. Prior to flushes, hold discharge below the dam at a minimum acceptable flow (i.e., ensuring ample fish habitat along the river corridor) for 5-10 days preceding flushing flow. However, it is recognized that current Resource Consents set minimum flow guidelines that may not allow for extended low flows during certain parts of the year (e.g., March October to maximize fish habitat).
- 3. Consider sediment additions to provide additional scour potential. We have proposed to carry out a sediment addition experiment during the 2007-08 field season in an effort to calibrate a sediment routing model and explore the effectiveness of small-scale sediment additions at removing nuisance periphyton.
- 4. Consider mechanical disruption of tightly packed areas of streambed (will be trailed in 2007-08 field season).
- 5. Work with Environment Canterbury and other stakeholders to develop acceptable guidelines for "topping-up" natural flood events, which can serve the same function as flushing flows. Currently, resource consents for the operation of Opuha Dam do not allow for topping-up natural freshets.
- 6. Continue the monthly monitoring programme to provide data on periphyton growth. If periphyton cover exceeds MfE Guidelines the dam operator will be notified.
- 7. Consider operational or infrastructural alterations to provide occasional higher magnitude flushing flows that might approach the historic mean annual flood (i.e., 90-100 m<sup>3</sup>/s). The need to consider this option will be more evident after the 2006-08 field seasons when several ~35 m<sup>3</sup>/s flushes will be trialled.



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Phyllum		
Sub-phylum		
Class		
Order		
Fa	amily	
	Taxon	Abbreviatio
Arthropoda		
Insecta		
Coleopter	a	
EI	midae	
	Elmidae adult	ELMIDA
	Elmidae larvae	ELMIDL
Collembo	la	
	Collembola	SPRTAI
Diptera		
Cł	nironomidae	
	Chironomus spp.	CHIRON
	Maoridiamesa spp.	MAORID
	Orthocladinae	ORTHOC
	Pupating chironomids	PUPCHI
	Tanypodinae	TANYPO
	Tanytarsus vestertinus	TANYVE
Er	npididae	
	Empididae	EMPIDI
M	uscidae	
	Muscidae	MUSCID
Si	muliidae	
	Austrosimulium spp.	AUSTRO
Tij	pulidae	
	Aphrophilia neozelandica	APHNEO
Ephemere	optera	
Le	eptophlebiidae	
	Austroclima jollyae	AUSJOL
	Austroclima spp.	ACLIMA
	Deleatidium spp.	DELEAT
Megalopt	era	
Co	prydalidae	
	Archichauliodes diversus	ARCDIV

**Appendix 1:** Taxa and abbreviations used in CA ordination shown in Figure 12. Taxa present in 4 or fewer samples were excluded from the analysis.



nyilum		
Sub-phylum		
Class		
Order		
	Family	
	Taxon	Abbreviatio
Tricho	ptera	
	Conoesucidae	
	Olinga feredayi	OLIFER
	Pycnocentria	PYCNOC
	Pycnocentria evecta	PYCEVE
	Pycnocentrodes spp.	PYCNOS
	Hydrobiosidae	
	Costachorema spp.	COSTAC
	Hydrobiosidae	HYDDAE
	Hydrobiosis clavigera	HYDCLA
	Hydrobiosis copis	HYDCOP
	Hydrobiosis parumbripennis	HYDPAR
	Hydrobiosis spp.	HYDROS
	Neurochorema confusum	NEUCON
	Neurochorema spp.	NEUROS
	Psilochorema macroharpax	PSIMAC
	Psilochorema spp.	PSILOS
	Hydropsychidae	
	Aoteapsyche raruraru	AOTRAR
	Aoteapsyche spp.	AOTEAP
	Hydroptilidae	
	Oxyethira albiceps	OXYALB
	Paroxyethira hendersoni	PARHEN
	Leptoceridae	
	Hudsonema amabilis	HUDAMA
	Polycentropodidae	
	Polyplectropus puerilis	POLPUE
Chelicerata		
Arachnida		
Acaria		
	Acarina	MITES
Crustacea		
Branchiopoda	à	
Cladoo	cera	
	Chydoridae	



Phyllum		
Sub-phylum		
Class		
Order		
	Family	
	Taxon	Abbreviation
	Chydoridae	CHYDOR
	Daphnidae	
	Daphnidae	DAPHNI
Copepoda		
	Copepoda	COPEPO
Ostracoda		
	Ostracoda	OSTRAC
Annelida		
Oligochaeta		
	Oligochaeta	WORMS
Cnidaria		
Hydrozoa		
Hydroid	lea	
	Hydradae	
	<i>Hydra</i> spp.	HYDRAS
Mollusca		
Gastropoda		
Basom	matophora	
	Lymnaeidae	
	<i>Lymnaea</i> spp.	LYMNAE
	Physidae	
	<i>Physa</i> sp.	PHYSA
	Planorbidae	
	<i>Gyraulus</i> spp.	GYRAUL
Caenog	gastropoda	
	Hydrobiidae	
	Potamopyrgus antipodarum	POTANT
Nematoda		
	Nematoda	NEMATO