Small stream ecosystems and irrigation:
An ecological assessment of water abstraction impacts

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Abstract

Small streams are often used for small-scale water abstractions, but the effects of these water abstractions on the instream environment, invertebrate communities and ecosystem functioning of small permanent streams is poorly understood. This research extends current knowledge by surveying existing water abstractions and completing flow manipulation experiments in the field. Reduced discharge often decreases water velocity, water depth, and wetted channel width and can increase sedimentation, modify the thermal regime and alter water chemistry. In a survey of sites upstream and downstream of existing water abstractions, I found that downstream sites had higher densities of invertebrates, but fewer taxa sensitive to low water quality compared with upstream sites. There were greater differences in physicochemical characteristics such as velocity and conductivity and in invertebrate communities between upstream and downstream sites on streams where a larger proportion of total discharge was abstracted. Using before-after, control-impact (BACI) designed experiments, weirs and diversions were created to experimentally decrease discharge by over 85% in each of three small streams, ranging from pristine to low water quality. The response of invertebrates to short-term (one-month) discharge reduction was to accumulate in the decreased available area, increasing local invertebrate density. After a year of reduced flow, the density of invertebrates and percentage of mayflies, stoneflies and caddisflies decreased at the pristine site, whereas only taxonomic richness decreased at the mildly polluted stream. Reduced discharge had no affect on the invertebrate community at the stream with the lowest water quality. Reduced discharge had little influence on leaf decomposition rates, but distances travelled by released coarse particulate organic matter (CPOM) increased with increasing discharge. The effects of reduced discharge on primary production were not consistent between streams. Overall, the severity (magnitude/duration) of flow reduction appeared to influence invertebrate responses to water abstraction although the outcomes of water abstraction were dependent on the invertebrate assemblage present in each stream.

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This project was possible because of the generosity of the landowners at Kiriwhakapapa Stream and Booths Creek, who allowed weirs and diversions to be installed on their properties, and assisted with the resource consent process. Also, the technical and financial support provided by the Department of Conservation (DOC) and Greater Wellington Regional Council (GW), especially Lindsay Chadderton (DOC) who arranged funding and Matt Rowland (GW) who assisted with the resource consent process and built weirs and diversions for the flow reduction experiments.

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Arrangement of this thesis and note on authorship

The chapters in this thesis were written as manuscripts for publication in refereed journals. This has led to some repetition among the chapters, particularly for the methods. In addition, the numbering of figures, tables and photographic plates restarts for each chapter. Manuscripts are co-authored to acknowledge the contribution of others as appropriate. In particular, the input of my principal supervisor, Russell Death, who contributed to developing the project concept, editing manuscripts, administering project funding and generally discussing the ongoing developments in the project. Also, the contribution of Alex James, fellow PhD student, who simultaneously studied aspects of invertebrate behavioural responses to experimental flow reduction, and so had significant input into the development of the flow reduction experiment. Alex and Russell worked with me to combine two separate literature reviews of individual and population (AJ) and community (ZD) responses to reduced flow into a manuscript suitable for publication. For each of the data chapters, my input was the greatest, I planned the research, undertook fieldwork, analysed data and wrote the manuscripts. The invertebrate drift and refugia usage data used in Chapters 3, 4 and 7 was collected by Alex James and included in these chapters to make them more complete for publication purposes.

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General Introduction

There is an increasing awareness that small stream ecosystems have water requirements (e.g., Baron *et al.* 2002, Richter *et al.* 2003), although there is a shortage of scientific data describing the quantity and timing of water required to protect these ecosystems (Richter 1993). Not only is it necessary to sustain stream ecosystems for ecological reasons, but the maintenance of adequate water quality and quantity ensures the ongoing usefulness of water resources for out of stream uses. However, the increasing size and urbanisation of the human population, along with a continually expanding area of irrigated land are among the factors leading to an increasing global demand for water resources (Postel 1997, Arnell 1999). Increased demand alone would make it more difficult to balance the needs of human society with the requirements of freshwater ecosystems, but changes to climate are expected to complicate matters further. Recent predictions suggest that as well as lowering summer flows, climate change may extend the duration of low flows (Gibson *et al.* 2005), and increase the competition between in and out of stream uses for water (Meyer *et al.* 1999). To manage increasing demands on water resources, we need to improve our understanding of the water requirements of stream ecosystems and the environmental, social and economic costs of water losses from them.

Even in New Zealand, where freshwater availability is among the highest in the world (United Nations 2003), river flow regimes are "one of the most contentious water management issues" (Ministry for the Environment 1998). As well as water withdrawals from large rivers for hydroelectricity and major irrigation schemes, there are many water abstractions from smaller streams for purposes such as domestic water supply and small-scale irrigation. These small-scale water abstractions tend to receive less media attention than major water projects. However, the ecological value of small streams can be high and information about the impacts of flow reduction is particularly scarce for these small streams (Ministry for the Environment 1998). The stress of water abstraction is likely to be greatest during the summer period in New Zealand for several reasons. Many small water abstractions are utilised only through the summer season for irrigation, elevated water temperatures and algal proliferations are more likely at this time, and permitted abstractions can be relatively high as a percentage of total discharge during low flow periods.

Flow influences stream invertebrates by controlling characteristics of the physical habitat (Hart & Finelli 1999, Bunn & Arthington 2002). Water abstraction can alter many aspects of the instream environment, including water velocity and depth (e.g., Minshall & Winger 1968, McIntosh *et al.* 2002), wetted width (e.g., Gore 1977, Cowx *et al.* 1984), sedimentation (e.g., Castella *et al.* 1995, Wood & Armitage 1999), and water temperatures (e.g., Mosley 1983, Rader & Belish 1999). Consequently, flow reduction might initiate changes to the invertebrate community by altering the availability and suitability of habitat for invertebrates. Changes to the instream environment and invertebrate communities with flow reduction might also affect ecosystem functioning. For example, water velocity, sedimentation and water temperature can influence leaf breakdown rates (Webster & Benfield 1986, Royer & Minshall 2003).

To address the lack of information about the impacts of water abstractions on small streams, the goal of this thesis was to investigate the effects of flow reduction (not complete drying) on the instream environment, invertebrate communities and ecosystem functioning in small permanent streams (Table 1). I hypothesised that water abstractions would decrease habitat availability and suitability for invertebrates, resulting in changes to the composition of invertebrate communities to reflect the slower flowing conditions. I also predicted that changes to the physicochemical characteristics of the instream environment would alter the rate of ecosystem processes downstream of these water abstractions. The objectives of this research were to:

- Examine the responses of invertebrate communities to existing water abstractions in an observational study (Chapter 2).
- Create whole stream flow reductions to gain more control over the volume and timing of water abstraction and enable the collection of before and after data at control and impact sites in order to:
    - Assess changes to environmental characteristics and the invertebrate community in response to both short-term flow reduction (Chapter 3), and one year of flow reduction (Chapter 4).
    - Test the effects of reduced flows on ecosystem functioning (Chapter 5).
- Individually assess the effects of decreased water velocity and increased filamentous algae on invertebrates in a small-scale instream channel experiment (Chapter 6).

- Synthesise the findings of this study into an article that communicates the main outcomes of the research to a management audience (Chapter 7).

Table 1. Timeline of research undertaken for this thesis

Timing	Research activities
Early to Mid 2003	Observational study of invertebrate communities at sites upstream and downstream of existing water abstractions
Late 2003 to Early 2004	**Short-term (1 month) experimental flow reductions** Pre-diversion sampling: December 2003-March 2004 1 month flow reduction: between March and May 2004 Weirs removed, normal flow restored: May 2004
Late 2004 to Early 2006	**Longer-term (1 year) experimental flow reductions** Pre-diversion sampling: November 2004-January 2005 1 year flow reduction: January 2005-January 2006 Weirs remain in place
Early 2006	Instream channel experiments completed between February and May 2006

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