New Zealand coldwater springs and their biodiversity

Mike Scarsbrook, José Barquín and Duncan Gray

SCIENCE FOR CONSERVATION 278

Published by
Science & Technical Publishing
Department of Conservation
PO Box 10420, The Terrace
Wellington 6143, New Zealand

Cover: Pearse Resurgence, near Motueka.
Photo: José Barquín.

Science for Conservation is a scientific monograph series presenting research funded by New Zealand Department of Conservation (DOC). Manuscripts are internally and externally peer-reviewed; resulting publications are considered part of the formal international scientific literature.
Individual copies are printed, and are also available from the departmental website in pdf form. Titles are listed in our catalogue on the website, refer www.doc.govt.nz under *Publications*, then *Science & technical*.

ISSN 1173-2946 (hardcopy)
ISSN 1177-9241 (web PDF)
ISBN 978-0-478-14289-1 (hardcopy)
ISBN 978-0-478-14290-7 (web PDF)

This report was prepared for publication by Science & Technical Publishing; editing by Sue Hallas and layout by Lynette Clelland. Publication was approved by the Chief Scientist (Research, Development & Improvement Division), Department of Conservation, Wellington, New Zealand.

In the interest of forest conservation, we support paperless electronic publishing. When printing, recycled paper is used wherever possible.

CONTENTS

New Zealand coldwater springs and their biodiversity

Mike Scarsbrook[1], José Barquín[2] and Duncan Gray[3]

[1] National Institute of Water & Atmospheric Research Ltd, PO Box 11115, Hillcrest, Hamilton 3251, New Zealand. Email: m.scarsbrook@niwa.co.nz

[2] Instituto de Hidráulica Ambiental "IH Cantabria", Grupo de Emisarios, Submarinos e Hidráulica Ambiental, Universidad de Cantabria Avda. Los Castros s/n 39005, Santander, Cantabria, Spain

[3] School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand

ABSTRACT

Coldwater springs are a significant component of the New Zealand landscape, yet they have received little attention from freshwater ecologists and conservation managers. Recently, a major research effort has been directed towards understanding the invertebrate biodiversity values of coldwater springs, identifying key environmental drivers of biodiversity patterns, and setting out a framework for spring management. Coldwater springs contain a highly diverse invertebrate fauna, including species from both surface and groundwater ecosystems, and also species that appear to be restricted to spring habitats (e.g. some hydrobiid snails and isopods). Biodiversity patterns are strongly influenced by flow permanence, disturbance history, elevation, catchment land use and riparian vegetation structure. Springs and their biota face significant threats from unsustainable use of groundwaters and the destruction of spring habitats. Management of springs, particularly on lowland alluvial plains, should be intimately linked with groundwater management so that spring flows and groundwater quality are maintained at the aquifer scale. Protection and rehabilitation of springs may also be required at the local scale, especially on private land, so that representative habitats are maintained within the landscape. A number of knowledge gaps are identified that may affect our ability to effectively manage and protect coldwater springs. This report identifies coldwater springs as important components of New Zealand's freshwater ecology that require more conservation attention than they have received to date; ways to address these omissions are suggested.

Keywords: springs, macroinvertebrates, biodiversity, land use, ecotones, conservation, knowledge gaps

Scarsbrook, M.; Barquín, J.; Gray, D. 2007: New Zealand coldwater springs and their biodiversity. *Science for Conservation 278*. Department of Conservation, Wellington. 72 p.

1. Introduction

Springs are formed when the water table intersects with the earth's surface, or groundwater rises to the surface through rock faults, fractures or depressions (Death et al. 2004). Springs form groundwater-dependent ecosystems (GDEs) (Hatton & Evans 1998). As they occur when groundwater flow paths intersect the earth's surface, their defining physico-chemical characteristics (e.g. thermal and hydrological stability) are controlled by the hydrogeological properties of their parent aquifer (van der Kamp 1995). Springs occur throughout the landscape, but vary greatly in morphology and size, ranging from minor seepages from bedrock faces, to alluvial springs in braided river landscapes, to resurgences in karst (e.g. Riwaka River resurgence, near Motueka), up to very large vents discharging many thousands of litres per second (e.g. Waikoropupu Springs, Takaka). A unique characteristic of springs is that they form a three-way zone of interaction between groundwater, surface water, and terrestrial ecosystems.

Environmental stability, and the location of springs at the interface between several distinct ecosystems, has led ecologists to suggest that springs are 'hot spots' for aquatic biodiversity. A good example of the important contribution of springs to aquatic (and terrestrial) biodiversity is illustrated by research in arid areas of inland Australia (Knott & Jasinska 1998) and the United States (Sada 2005). Springs provide small mesic (moist) refuges in arid landscapes and have been critical to the survival of indigenous peoples, European explorers and settlers, and their livestock. They also have a distinctive flora and fauna, with high levels of local endemism (Knott & Jasinska 1998), particularly among animals with restricted powers of dispersal (e.g. hydrobiid snails, amphipods and some fish). For example, Ponder & Clark (1990) identified 12 hydrobiid species of a single genus (*Jardinella*) in just four mound spring groups of southwestern Queensland. All species were endemic to a particular spring group.

The positioning of springs at the interface of groundwater, surface water and terrestrial ecosystems has led to inevitable conflicts between human resource use within these ecosystems and the natural ecosystem integrity of springs (Sada 2005). Human activities can have significant effects on the parent aquifer (e.g. effects on water quantity and quality), the spring (e.g. water supply takes and riparian habitat modification by stock grazing and trampling) and the connectivity between the spring and other aquatic habitats (e.g. isolation of springs in a degraded landscape) (Smith 2002). Overall, spring habitats, and the biological diversity they support, can be regarded as controlled by a natural environmental template that is overlain by varying levels of human impact. Conservation of spring systems will generally depend on two issues: maintenance of groundwater quantity and quality and minimisation/mitigation of anthropogenic disturbance to the springs themselves and their associated habitats (Knott & Jasinska 1998).

During the 1990s a number of reviews of spring ecology were published in countries other than New Zealand (Williams & Danks 1991; Ferrington 1995; Botosaneanu 1998). These reviews have provided a solid knowledge base for the development of management strategies to protect the biodiversity values inherent in springs (e.g. Sada et al. 2001), and have also provided an impetus for more focused ecological studies that address particular knowledge gaps (e.g. Hoffsten & Malmqvist 2000; Smith & Wood 2002; Sada 2005). In New Zealand, our knowledge of coldwater springs has lagged far behind that of North America, Europe and Australia. There have been very few published ecological studies of coldwater springs, and this lack of knowledge is recognised as a constraint to management and protection of these valuable resources.

Over the last 5 years a significant research effort has been directed at addressing this knowledge gap. Funding from the Department of Conservation (DOC), the Foundation for Research, Science and Technology (FRST) and the New Zealand Dairy Industry has supported spring biodiversity research by the National Institute of Water & Atmospheric Research (NIWA). In addition, postgraduate studies at Massey University and the University of Canterbury have added significantly to our ecological understanding of pristine spring systems. Barquín (2004) sampled invertebrate communities from springs and springbrooks in four National Parks around New Zealand (Arthur's Pass, Kahurangi, Tongariro and Egmont). Gray (2005) focused his studies on the ecology of braided river springs, with much of the research located in the upper Waimakariri River catchment, Canterbury, South Island.

1.1 OBJECTIVES

The principal aims of this report are to summarise the state of our knowledge regarding the ecology of New Zealand coldwater springs, and to utilise this knowledge to identify management approaches. This report is structured around four specific objectives:

- Identify biodiversity values of coldwater springs in New Zealand
- Determine key environmental drivers of spring biodiversity
- Identify anthropogenic threats to spring ecosystems and quantify effects
- Determine appropriate spatial scales and strategies for conservation and management of spring habitats

In this report we summarise the major findings of research under each objective, and draw on international published literature to summarise our state of knowledge with respect to biodiversity values in springs. We also provide recommendations for more effective conservation of spring biodiversity and suggest a framework for management of New Zealand's coldwater springs.

1.2 DEFINITIONS AND SCOPE OF REPORT

A spring is a defined area where a natural discharge of groundwater returns to the surface (van Everdingen 1991; White 2005). One significant area of confusion in the literature is caused by misuse of the term 'spring' when referring to 'springbrooks' (Erman & Erman 1995). Springs have distinct physico-chemical and biological characteristics, which become modified as groundwater mixes within a surface water body (e.g. changes with distance downstream in a springbrook; Barquín 2004). However, defining the point at which a spring becomes a springbrook, or a spring-fed wetland, is problematic, as changes occur gradually and vary with the environmental variable being measured. Also, the transition from spring to springbrook depends on the size of the spring and its receiving waterbody (e.g. springbrook, river, wetland or lake). McCabe (1998) introduced a definition based on thermal characteristics, using temperature variation to define the transition from spring to springbrook as the point at which temperature variation exceeds 2°C. This definition requires intensive monitoring of each spring, which is often impracticable. Throughout this report we refer to springs wherever our sampling occurred within a few metres of a defined source of groundwater discharge, and where physico-chemical conditions were assumed to reflect groundwater influence; otherwise, we use the term springbrook.

Throughout this report we refer to springs as 'ecotones'. This reflects the unique position of springs at the interface between groundwater, surface water and terrestrial ecosystems (Fig. 1). An ecotone is a zone of interaction and exchange between adjacent ecosystems. Ecotones possess specific physical and chemical attributes, biotic properties, and energy and material flow processes, but each is unique in its interactions with adjacent ecosystems (Naiman & Decamps 1997). Contemporary stream ecology recognises an important role for ecotones in the structural (e.g. community structure, biodiversity) and functional attributes (e.g. carbon and nutrient dynamics) of freshwater ecosystems (Naiman & Decamps 1997; Ward & Tockner 2001).

As groundwater-dependent ecosystems (GDEs), springs are controlled by groundwater level, discharge flux from the aquifer and groundwater quality (Sinclair Knight Mertz 2001). These ecosystems include terrestrial vegetation communities, river base flow systems, aquifer and cave ecosystems, wetlands, and springs. In Australia, management of GDEs is a state and federal issue and a number of management recommendations have been identified to protect them from a range of anthropogenic threats. We suggest that the GDE framework will be useful for managing springs and other groundwater habitats in New Zealand.

Biological diversity (biodiversity) is much more than species or genetic diversity. It also includes functional (process) diversity and habitat diversity (Ward et al. 1999). The New Zealand Biodiversity Strategy (DOC 2000)

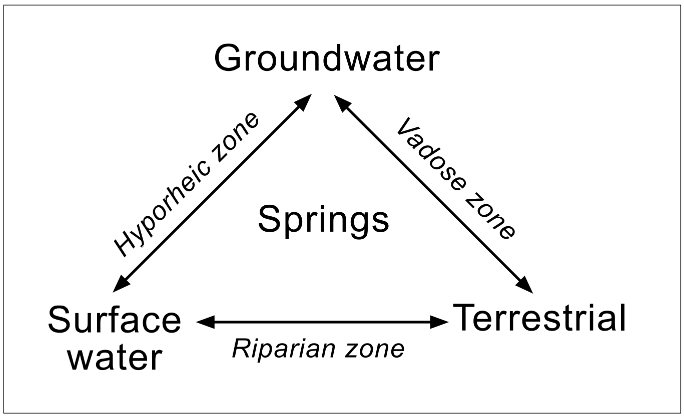


Figure 1. Springs form a three-way ecotone, or zone of interaction, between groundwater, surface water and terrestrial ecosystems. Other ecotones include the riparian zone (stream banks), the vadose zone (unsaturated soils) and the hyporheic zone (streambed interstices).

defines biodiversity as 'the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems'. Components include genetic diversity, species diversity and ecological (ecosystem) diversity. In this report we address all three of these aspects of biodiversity as they relate to springs habitats.

Our report is restricted to describing biodiversity in coldwater springs (i.e. springs in which temperatures do not exceed 20ºC). We do not include mineral springs (i.e. springs having Total Dissolved Solids > 1000 mg/L), or thermal springs (i.e. springs with a mean annual temperature more than 5°C greater than mean annual air temperature). Death et al. (2004) provide a useful review of the biodiversity values occurring in New Zealand's geothermal springs.

2. Springs in the landscape

Springs are surface expressions of groundwater flow processes which, in turn, are controlled by geology, climate and topography (Fetter 1980). Hence, the location of a spring in the landscape, and its environmental characteristics (e.g. discharge rate, flow permanence, temperature, water chemistry and substrate) are controlled by the hydrogeological setting of the spring and its parent aquifer (van der Kamp 1995).

Hydrogeologists recognise a wide variety of spring types, and several physical classification schemes have been developed to describe the interaction between springs, the underlying groundwater and the surrounding landscape. The most basic classification separates gravity springs (in which water flows down an elevation gradient) and artesian springs (in which the potentiometric level of groundwater is higher than the land surface and the water discharges under pressure). Fetter (1980) described five main classes of springs:

- *Depression spring*—A topographical depression intersects an unconfined aquifer.
- *Contact spring*—A permeable, water-bearing stratum overlies an impermeable stratum. Water discharges where the contact zone between the strata intersects the land surface.
- *Fault spring*—A faulted, impermeable rock stratum is located downslope of a groundwater flow path.
- *Sinkhole spring*—The process of dissolution of carbonate rocks (karstification) has led to the development of a sinkhole that has intersected the water table.
- *Fracture spring*—The fracture zone between two opposing rock strata provides a flow path for groundwater to discharge.

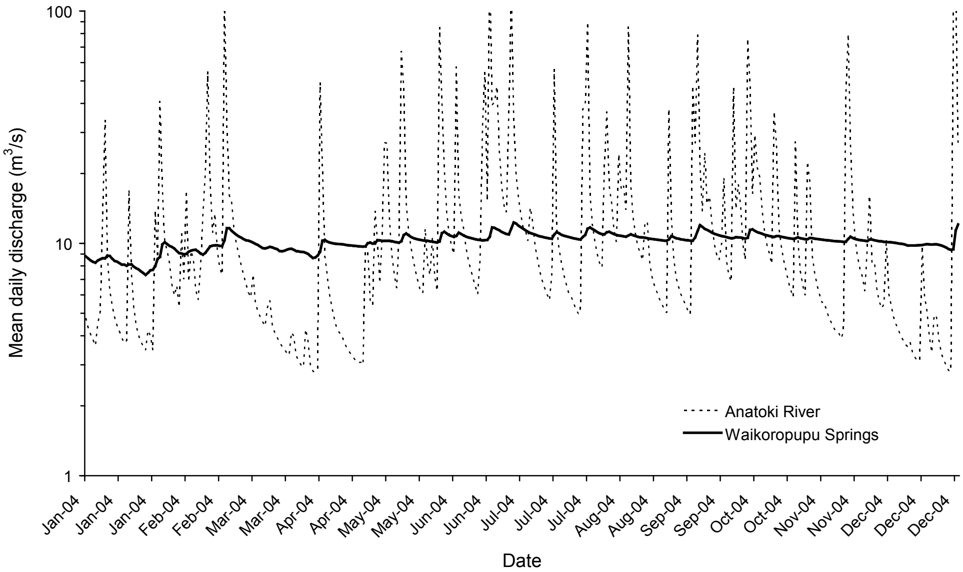
In addition to classifications proposed by hydrogeologists, some classification schemes have also been proposed by aquatic biologists (e.g. Zollhöfer et al. 2000). The most common of these was first proposed by Steinman (1915), who developed a typology based on flow patterns:

- *Limnocrene*—A spring discharges through the bed of a pond or lake (e.g. Waikoropupu Springs).
- *Rheocrene*—A spring's discharges form a flowing stream (e.g. Riwaka Resurgence).
- *Helocrene*—Small springs (seepages) form a spring-fed marsh.

It is interesting to note that classifications proposed by biologists tend to stress the role of springs as source of surface water habitats, whereas definitions put forward by hydrogeologists tend to focus on springs as the endpoint of groundwater flow paths. In this report we do not provide a full classification of spring types. Instead, we characterise springs by their underlying geology and land-use characteristics. In terms of underlying geology, we recognise three major types of springs in the New Zealand landscape:

- *Karst springs*—Springs are a conspicuous feature of karst areas, because groundwaters tend to become concentrated in relatively large fissures or conduits that are found in these areas (Williams 2004). The largest karst spring complex in New Zealand is Waikoropupu, which drains the karst aquifer of the Takaka Valley (Williams 2004). Other main areas of karst in New Zealand include the King Country (central North Island) and the Punakaiki area (West Coast, South Island). Karst springs tend to be more permanent than other spring types, because of their size and the age and stability of the geological formations they drain. Karst springs also tend to have lower hydrological stability than other spring types, often subtly tracking changes of flow in the catchment (Fig. 2), as a result of high levels of connectivity between the catchment, the caves and conduits within the aquifer and the spring outlets (White 2005).

Figure 2. Discharge hydrograph for the main vent of Waikoropupu Springs (site 52903) and the nearby Anatoki River (site 2870013). Data supplied by Tasman District Council.



- *Volcanic springs*—Different types of aquifers can feed volcanic springs. They may form in a variety of volcanic situations, for example in andesitic lava flows (e.g. Ohinepango Springs, Ruapehu) or fractured basalts (e.g. Western Springs, Auckland). Water in this latter type of aquifer travel through cracks and fissures formed when the once-liquid magma solidifies and cools. Springs usually originate where there is a change in the geology, for example from confining lava flows to volcanic breccia (e.g. Bubbling Springs, Taranaki). The age of these springs will be highly dependent on the history of the volcanic region. For example, springs located on the western flanks of Mt Ruapehu rest on lahars and river sediments that have not been disturbed or highly altered for 20 000 years (Thornton 1985) (e.g. Waitaiki Spring), whereas springs on the eastern side of the mountain have experienced a series of major disturbances in the last 200–4000 years (Neall et al. 1999) (e.g. Ohinepango Springs and Waihohonu Springs). Mt Taranaki presents a similar example. Springs on the southeast side of the mountain rest on deposits that have remained undisturbed for the last 10 000 years, whereas springs on the eastern side (e.g. Bubbling Springs) may have received lahars some 500–1000 years ago (Soons & Selby 1992). Volcanic springs tend to have high permanence and exhibit a high degree of hydrological stability.
- *Alluvial springs*—Aquifers feeding alluvial springs have a sedimentary origin (unconsolidated glacial and fluvial alluvium). The sediments have intergranular porosity which allows water to move through them. Springs from alluvial aquifers usually form where the water table meets the ground surface (i.e. they are usually depression springs). As a consequence, alluvial springs tend to migrate along channels as groundwater levels rise and fall. This type of spring was termed a 'linear spring' in the typology of Zollhöfer et al. (2000), and is commonly observed in alluvial river valleys (e.g. Waimakariri River and Selwyn River/Waikirikiri, Canterbury). Alluvial springs often arise where groundwater flow paths are forced upwards by impermeable strata. Examples are seen along the eastern edge of Ruataniwha Plains, in the southern Hawke's Bay area, where the underlying aquifers are forced upwards by the limestone strata of the Raukawa Range to the east of the plains (HBRC 2004). Most alluvial springs originated after the deposition of glacial colluvium from the upper Quaternary, which implies that the oldest of these springs may be 15 000–10 000 years old. The permanence of alluvial springs is strongly controlled by the characteristics of the parent aquifer—springs draining shallow, unconfined aquifers will tend to have lower permanence than artesian springs fed by deeper, confined aquifers.

2.1 ENVIRONMENTAL TEMPLATE OF SPRINGS

Spring habitats are characterised by thermal constancy, and relative hydrological stability (van der Kamp 1995). These features vary among spring types, but in comparison with streams which are dominated by run-off, springs are highly stable environments. There are few flow recorders in springs in New Zealand. One exception is the main vent of Waikoropupu Springs, which is closely monitored because of concerns about the effects of upstream water abstraction and land use on flows in this internationally recognised system.

By comparing the springs' discharge with that of the nearby Anatoki River (Fig. 2), it is clear that the springs respond relatively quickly (albeit subtly) to rainfall and exhibit flow recession during drier periods (note that the log scale tends to exaggerate the variation in the spring flows and under-represent those of the river).

Hydrogeologists use spring hydrographs to measure spring permanence, using the flow recession time constant. This is the time required for flow to decrease to 37% of the initial value during prolonged dry periods (van der Kamp 1995). The recession times of springs may vary from a few hours to decades and are strongly related to the hydrogeological context of the underlying aquifer. Spring permanence is proportional to aquifer storage capacity and residence time, and inversely proportional to permeability of the parent formations (van der Kamp 1995). Evapotranspiration loss around springs, particularly those surrounded by heavy natural vegetation, can have significant effects on spring permanence, with some springs drying up completely during hot, dry weather when evapotranspiration losses are greatest.

The characteristic thermal stability of springs reflects the constant temperature of groundwater below about 10 m depth (van der Kamp 1995). The average water temperature for most springs is approximately equal to the average mean air temperature of the area (van der Kamp 1995). This provides a simple means of separating coldwater and thermal springs based on temperature alone.

The thermal stability of springs is also used to delineate springs from springbrooks (Barquín 2004), although the extent of the spring will depend on discharge, the residence time (rheocrenes have lower residence time than helocrenes) and the amounts of solar radiation reaching the water (controlled by factors such as shade and altitude). The change in thermal regime downstream of a spring is illustrated in Fig. 3. Water temperature measured during summer 2004 in a small spring and springbrook at the base of the Kaimai Ranges, northern North Island (MS, unpubl. data), shows significant increases in temperature variation within 80 m of the spring (Fig. 3).

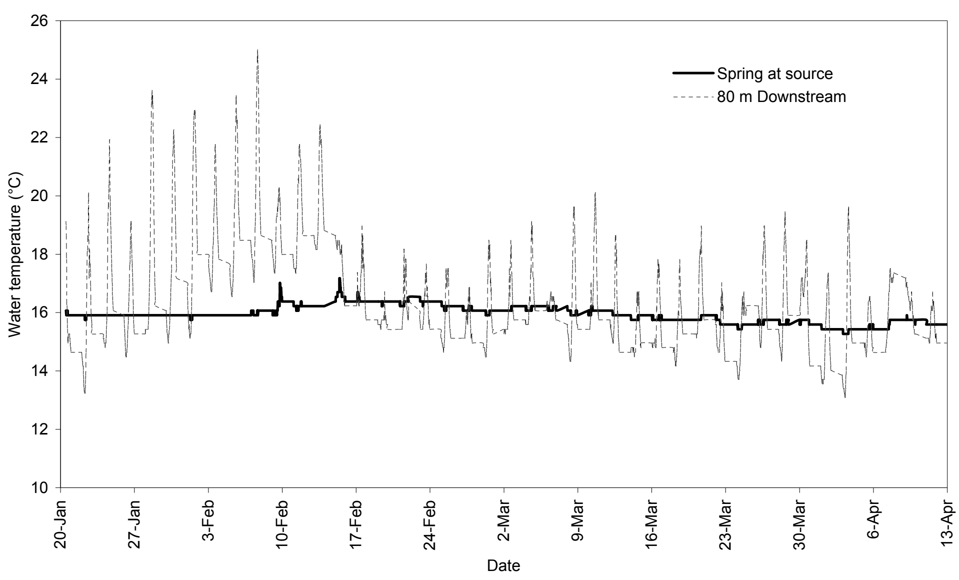


Figure 3. Water temperature variation along a small Waikato springbrook. Time period covered 40 days in summer 2004.

Spring water chemistry is often very different from the water chemistry of streams fed by run-off in the same region (McCabe 1998). In addition, spring water chemistry often changes significantly over relatively short distances. Such sharp environmental gradients are a characteristic feature of ecotones (Naiman & Decamps 1997). Water chemistry in springs reflects the chemical signature of the parent aquifer that has been modified by interactions with soils and air as it resurfaces. An example of this interaction is provided by spring water pH. Groundwaters tend to have increased levels of acidity, as the CO_2 that is abundant in them is transformed through dissolution into carbonic acid. As water wells up at springs, it immediately comes into contact with the atmosphere, where CO_2 levels are lower. The process of equilibration leads to increases in pH (van der Kamp 1995). For example, average pH (± SD) for five springbrooks at the base of the Kaimai Ranges increased from 5.84 (0.46) at the source to 7.08 (0.33) c. 80 m downstream (MS, 2004, unpubl. data). Similar, but inverted responses, are often seen with levels of dissolved oxygen in springs. Oxygen-poor groundwaters quickly equilibrate with the oxygen-rich atmosphere at springs. Where iron-rich, acidic, oxygen-poor groundwaters emerge, springs are often highlighted by obvious iron flocculation and the presence of iron bacteria.

2.2 NEW ZEALAND SPRINGS

In some areas of New Zealand, springs have always provided Maori with a reliable supply of fresh water and the value of this resource has been reflected in a wealth of legends and traditional practices (F. Thorne, Ngati Hikairo, 2005, pers. comm.). Recent work by NIWA with Tainui iwi around Kawhia Harbour on the west coast of the North Island has identified significant historical and cultural values assigned to springs by the local people. In pre-European times, springs provided the only reliable source of fresh water on the Kawhia peninsula, which is underlain by a series of small sand aquifers. From earliest settlement of the area, the springs around Kawhia peninsula have also provided significant food gathering and growing sites, e.g. tuna (eels, *Anguilla* spp.) and taro, (*Colocasia esculenta*), and water sources for irrigation of kumara (sweet potato, *Ipomoea batatas*) crops. It is highly likely that other iwi throughout New Zealand have had a long history of association with coldwater springs, and their cultural and historical values may provide a useful addition to assessments of biodiversity value. For example, current research on karst ecosystems (FRST Contract No. C01X0503) is utilising traditional knowledge of Ngati Maniapoto iwi to build a database of culturally and historically significant sites around Waitomo, central North Island. Many of the sites are associated with caves (e.g. burial sites) and springs (e.g. water sources).

Springs are an important source of human water supply in contemporary New Zealand (White 2001). The communities of Whangarei, Pukekohe and Rotorua, along with many smaller localities, use springs as water supplies (see Fig. 4A, B). Other important uses include bottling of water (e.g. Blue Spring, Putaruru, central North Island), and water supplies for fish farming (e.g. Waikoropupu Springs). Tourist operations also make use of coldwater spring complexes, particularly around Rotorua (e.g. Paradise Valley springs,

Continue to next file: sfc278a.pdf