Biodiversity of Te Waikoropupü Springs

Assessment and vulnerabilities to reduced flows

Prepared for Ngati Tama ki Te Waipounamu Trust

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Executive summary

This report reviews available information on the biodiversity of Te Waikoropupü Springs, the largest freshwater springs in the southern hemisphere. This information was compiled as one set of information that Ngati Tama ki Te Waipounamu Trust would consider when participating in a review of applications for consents to take groundwater from a bore located close to the Springs.

Two main and several smaller springs, all within c. 130 m of each other, comprise Te Waikoropupü Springs, which are supplied by two karst and one alluvial aquifers. These discharge 9,000-10,600 L/second of high quality, extremely clear water, which is 3-8 years old, at a constant temperature (11.7 °C), and contains c. 0.5 % seawater (Williams 1977, 2004).

A rich aquatic flora of diatoms, blue-green, green, golden and red algae, mosses, liverworts and flowering plants occurs within the Springs. This flora is also remarkable because it includes unusual plant associations: fully submerged beds of mosses and liverworts, many occurring elsewhere only in terrestrial habitats, and two mosses with unusual growth forms.

Fifty-four benthic invertebrates inhabit the springs basin, and another 80 occur in the associated streams (total recorded biodiversity is 134 species), placing these springs amongst the more biologically diverse in New Zealand. The basin's biodiversity is remarkable for the extremely high densities of a common snail, the presence of two species apparently endemic to the system, supporting the northern-most population of two caddisflies and the only South Island population of a freshwater amphipod.

The biodiversity of Te Waikoropupü Springs' aquifers is unknown because only one collection from within the aquifer was available. Given the aquifers' hydrogeological diversity, and the biodiversity associated with other Takaka Valley groundwater, and the high biodiversity of karst and alluvial aquifers in New Zealand and internationally, a diverse fauna is expected within the aquifers. Many species endemic to this aquifer system and/or Takaka Valley are expected.

Te Waikoropupü Springs is recognised as a wetland complex of international significance (Ramsar Convention criteria). They were considered internationally significant from a hydrological perspective and by the International Union for the Conservation of Nature (IUCN). A Water Conservation Order under the Resource Management Act 1991 was recommended for their protection, and a past Minister of Conservation noted the Springs as among other wetlands vital to New Zealand's future.

Groundwater ecosystem services appear integral to many of the values associated with Te Waikoropupü Springs, especially the water's high quality and clarity. The ecosystem processes underlying these ecosystem services occur within a dynamic balance of groundwater level, groundwater velocity, organic carbon, dissolved oxygen and other factors. Thus, sustaining Te Waikoropupü Springs and their high values depends on maintaining healthy, living ecosystems within the Takaka Valley aquifers. This may be best achieved via a conservative approach and by giving special attention to all human impacts (flow permanence, water velocity, dissolved oxygen, organic carbon, nitrate, etc.), individually and in combination, incremental and cumulative, to ensure the future of these ecosystem services and Te Waikoropupü's values.

1 Introduction

This report presents an overview of the biodiversity of Te Waikoropupü Springs based on available information. Ngāti Tama ki Te Waipounamu Trust (Ngati Tama) requires this overview as one set of information that it would seek to include in considering the merits of any resource consents that could potentially affect the diverse values of this hydrogeologically remarkable spring and aquifer system (Williams 2004). At the time of preparation, the information is considered relevant to a judicial review of consents granted by Tasman District Council (TDC) to Kahurangi Virgin Waters Ltd for:

- groundwater extraction (up to 12.5 L/sec or 567 m^3/day) from an existing bore (WWD 6011, 114 m depth) located c. 240 m southwest of the Fish Creek Springs,
- installing a second bore (WWD 23991, c. 4 m from WWD 6011; to 120 m depth) adjacent to the existing one, to replace bore WWD 6011, and
- transferring bore WWD 6011's consent to take groundwater to the new bore (WWD 23991).

Water extraction from any aquifer potentially increases environmental risks facing important local groundwater-dependent biodiversity, such as that inhabiting subsurface groundwater ecosystems, springs, groundwater-dependent rivers and streams (e.g., see Fenwick in press). These risks would usually be identified and assessed by the consenting authority prior to granting or renewing consents. Thus, this report aims to identify and document the biodiversity of key groundwater-dependent ecosystems potentially affected by groundwater extraction close to Te Waikoropupü Springs, and to independently assess any potential effects arising from the consented takes.

2 Approach

This report synthesises available information from diverse sources into a single document on the biodiversity values associated with Te Waikoropupü Springs (the Springs), their tributary aquifers and associated streams and rivers flowing from the Springs. It includes information from Tasman District Council (TDC) and the Department of Conservation (DOC), as well as other sources. The review focuses on the biodiversity and functioning of groundwater-dependent ecosystems (GDEs) within the area potentially affected by any abstraction close to the Springs. Available information and data are integrated into a review identifying GDEs, their known and likely biodiversity values, and the potential effects of reduced groundwater availability.

Subsurface groundwater biodiversity (notably stygofauna[1]) and ecosystems are considered, although there is scant information on local communities and species. Available information on surface GDEs, such as Te Waikoropupü Springs, the springs' basin, other smaller subsidiary springs in the immediate vicinity, seeps, and spring-fed streams are considered. No information on any immediately adjacent wetlands was available.

Five museum collections (one from each of NIWA's Invertebrate Collection, Canterbury Museum, New Zealand Arthropod Collection; two collections from Dr John Stark of Stark Environmental) of unidentified stygofaunal invertebrates were examined as part of this project.

[1] Stygofauna, fauna (mostly invertebrate animals) inhabiting groundwater.

3 The Te Waikoropupü Springs system

Te Waikoropupü Springs and their aquifers have received substantial hydrogeological investigation, yet considerable uncertainty remains over some important aspects including the contributions of the three aquifers to each of the Springs' discharges, extent and locations of submarine discharges, and sources and mechanisms for seawater mixing. This report provides a summary of key aspects to establish a context for this report, when read alone.

3.1 Hydrogeology

Te Waikoropupü Springs flow into the Te Waikoropupü River, a lowland tributary to the Takaka River. The Springs comprise multiple springs, together forming a very large karst resurgence, some 7-15 m above sea level (Williams 2004, Stewart & Thomas 2008). The two largest vents, Main Spring and Dancing Sands Spring, together discharge c. 10.3 m^3/second (or 10,300 L/second) on average into the springs basin (c. 7 m depth). Some 200 m south of Main Spring, 12 smaller springs together discharge 3.3 m^3/second of water into Fish Creek (Williams 2004, Mueller 1991, Stewart & Thomas 2008), which joins the Te Waikoropupü River c. 200 m downstream of Main Spring.

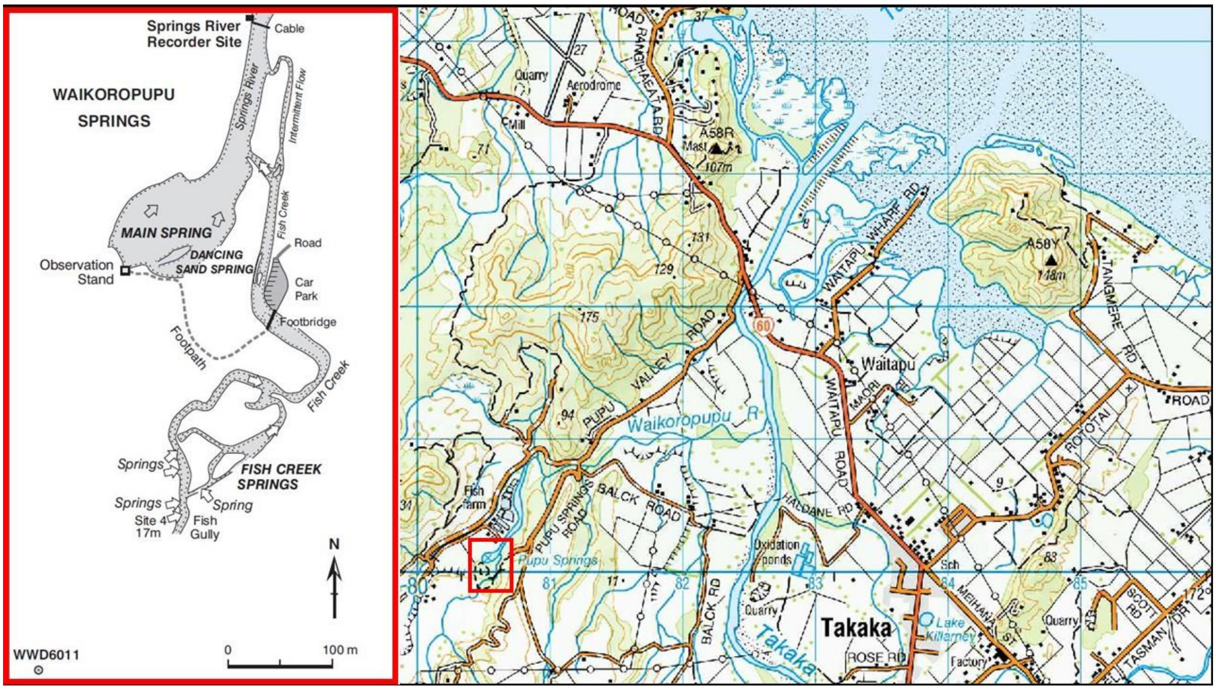

Figure 3-1: Locations of the Te Waikoropupü Springs Main Spring, Dancing Sands Spring and Fish Creek Springs relative to each other and the bore WWD 6011 (left) and the Takaka River and coast (right). The springs basin comprises the ovate pool encompassing Main and Dancing Sands springs. Detailed Springs map: from Stewart & Thomas (2008).

The Takaka River is the main river within the extensive Takaka Valley and is joined by the Waikoropupü River c. 2 km below the Springs. Its tributaries receive water from the surrounding ranges, many of which include significant karst environments.

Three aquifers are associated with and contribute water to the Springs. The karstic Arthur Marble Aquifer underlies the Takaka valley floor, extending some 25 km from Upper Takaka (top of the valley) to the coast. Unconfined over its southern, inland half, it is overlain by very cavernous Takaka limestone and/or permeable alluvial gravels (Thomas 2001). The lower, seaward half of the Arthur Marble Aquifer is confined by overlying impervious coal measures (layers). The Arthur Marble Aquifer appears karstified (eroded by water into caverns and/or tunnels) to >100 m depth, and perhaps several hundred metres deeper (Thomas 2001). It is recharged mostly from river flows on the valley floor and is thought to discharge both in the Springs and beyond the coast. The aquifer residence time (or age) for water emerging from the Springs is between 3-5 or 3-8 years (Mueller 1991, Thomas 2001).

The Takaka Limestone Aquifer (30-60 m thick) overlies the mid-section of the Arthur Marble Aquifer, where the two are indistinguishable. To the east and north the coal measures which confine the Arthur Marble Aquifer intercede, separating the two as the Arthur Marble Aquifer becomes confined.

The Takaka Gravel Aquifer, comprising alluvial sands and gravels, fills the Takaka Valley floor to depths of 5 - c. 60 m, overlying the Takaka Marble Aquifer (both unconfined and confined portions) and the Takaka Limestone Aquifer (Thomas 2001; Thomas & Harvey 2013).

3.2 Flow variation

The two main springs (Main and Dancing Sands springs) discharge 10,000 L/s, on average, and the Fish Creek Springs average discharge of 3,300 L/s, with annual mean discharges from Main Spring varying from c. 9,000 to 10,600 L/s (Figure 3-2; Thomas & Harvey 2013).The other springs also vary in discharge, with the Fish Creek Springs ceasing to discharge during extended droughts (Thomas & Harvey 2013).

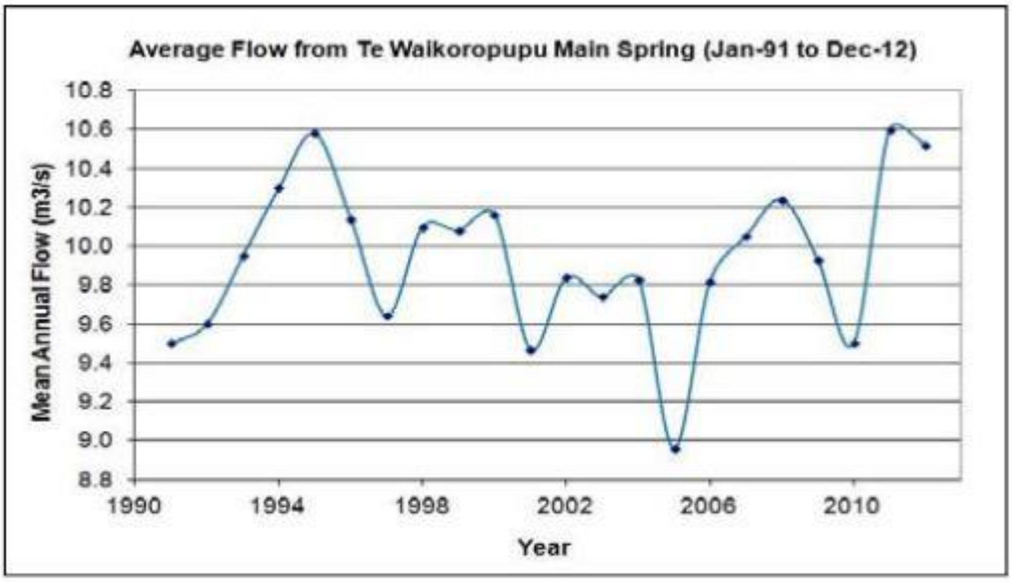

Figure 3-2: Mean annual flows from the Main Spring at Te Waikoropupü Springs over 1991-2011. From: Thomas and Harvey 2013.

Table 3-1: Discharge statistics for Fish Creek Springs and Te Waikoropupü Main Spring measured at bore GW 6013. MALF, Mean annual low flow. From Thomas & Harvey (2013).

Recorder Site	Mean	Median	7 day low flow (L/s)				Analysis Period
			MALF	5 year	10 year	20 year	
Fish Creek Spring	3476	3546	665	127	-	-	1985-2013
Main Spring	9890	9940	7717	6718	6379	6129	1999-2013

3.3 Water quality

Water quality from Te Waikoropupü's springs is high, although it contains elevated calcium bicarbonate resulting from dissolution of limestone (Michaelis 1976, Mueller 1991). Slightly elevated concentrations of chloride (Main Spring and Dancing Sands Springs, 0.2-0.65 %; Fish Creek Springs, 0.1 %), sodium and bromide indicate mixing with small amounts (0.4-0.6 %) of seawater, and seawater inputs appear to increase with increasing flow from the Springs (Michaelis 1976, Mueller 1991).

Springs water is consistently cool temperature at 11.7 °C (Michaelis 1976). It has remained 54-66% saturated with dissolved oxygen concentrations since the early 1970's (Michaelis 1976, Young pers. comm.), indicating considerable aeration during the water's 3-8 year passage to the Springs. Nutrient concentrations are low, although there is a longer term trend of gradually (0.9%/year) increasing nitrate concentrations from 0.3 mg/L in the early 1970's to c. 0.4 mg/L in 2014-15 (Michaelis 1976, Young pers. comm.). Concentrations of dissolved reactive phosphorus remain low (<0.01 mg/L), as do other indicators of water quality (Young pers. comm.).

4 Aquatic biodiversity of the Springs and associated ecosystems

4.1 Springs and associated streams

There has been only one intensive study of the biodiversity and ecology of Te Waikoropupü Springs. This was made by Frances Michaelis, with her results presented in her doctoral thesis (1974) and in subsequent papers (1976, 1977, 1980). Subsequently, DOC undertook additional surveys of aquatic plants (e.g., DOC 2000, Fife et al. 2004, Doehring 2012). Reports on annual monitoring of the benthic biota of streams associated with the Springs (Stark & colleagues) are included here because these streams are part of the overall aquifer-springs groundwater-dependent ecosystem.

4.1.1 Flora

The Springs' aquatic flora is visually striking and adds considerably to biodiversity through the diversity of plant species, the unusual plant associations and by providing considerable habitat diversity for invertebrates. The very clear water and constant temperature (11.7 °C) provide excellent conditions for several aquatic plants (DOC 2000). Most conspicuous are the floating seed plants (angiosperms), dominated by three introduced species: watercress (*Nasturtium microphyllum*[2]), *Callitriche stagnalis*, and *Lemna disperma* around the margins (Michaelis 1977). The reed *Juncus microcepahlus* and the native *Myriophyllum triphyllum* dominated some deeper areas, whereas mosses and liverworts covered other deeper areas.

The total diversity of plants known from the Springs is 38 species (Table 4-1, Appendix A). None of these species was considered to be threatened or uncommon in New Zealand (de Lange et al. 1999, 2009). However, the flora does have some special attributes.

Mosses and liverworts were among the Spring's more unusual aquatic inhabitants. Liverworts are rarely important elements of the in consistently submerged benthic flora, except in headwater streams (Hynes 1972), but three species (*Neesioscyphus phoenicorhizus*, *Lophocolea austrigena*, *L. minor*), along with two mosses (*Cratoneuropsis relaxa, Cyathophorum bulbosum*), covered almost 30% of the spring basin bed (Michaelis 1977).

Some of the mosses within Te Waikoropupü are commonly found submerged in streams and considered truly aquatic (e.g., *Cratoneuropsis relaxa*, *Fissidens rigidulus*, *Echinodium hispidum*, *Chiloscyphus austrigenus* (Fife et al. 2004), whereas at least one, *Cyathophorum bulbosum*, is known elsewhere only from damp rocks (Beever et al. 1992). Another (*Hypopterygium filiculaeforme*) is more characteristic of damp, steam-side habitats and is not usually submerged (Beever et al. 1992).

Another notable feature of the Springs' floristic biodiversity is the unusual form of the moss *Cratoneuropsis relaxa*. Although this species grows in emergent and submerged habitats elsewhere in New Zealand, the morphology of submerged (c. 1->6 m depth) *C. relaxa* in Te Waikoropupü Springs is so different, that one taxonomist established a new family and genus for these specimens (Hypnobartlettiaceae, *Hypnobartlettia*) (Beever et al. 1992). A more recent evaluation revealed close similarities in detailed structure between *Hypnobartlettia* specimens from Te Waikoropupü and *C. relaxa* specimens found elsewhere. Molecular (DNA) data were equivocal, but, on the balance of available evidence, the evaluation concluded that this moss from Te Waikoropupü is *C. relaxa* and not a new species in a new family (Beever & Fife 2008). Nevertheless, the presence of this unique

[2] Identified as *Roruppia nasturtium-aquaticum* by Doehring 2012.

growth form in this unusual habitat prompted the view that "special effort should be made to preserve its habitat [Te Waikoropupü Springs]" (Fife et al. 2004, p2).

Another moss (*Depranocladus aduncus*) also exhibits an unusual growth form within Te Waikoropupü Springs, adding to the biodiversity value of populations in this habitat (Fife et al. 2004). Two mosses (*Cyathophorum bulbosum*, *Radula* ?*buccinifera*) were found only at one location (Fish Creek) within the Springs, but occur elsewhere in New Zealand (Fife et al. 2004).

Species of four cosmopolitan algal genera (*Batrochospermum* sp., *Hildenbrandia rivularis* (both red algae), *Vaucheria* sp. (golden alga), *Achnanthes* sp. (diatom)), all characteristic of hard water (karst) springs world-wide, dominated the Springs' flora (Michaelis 1977), with *Vaucheria* forming pure mats in some areas (Fife et al. 2004). Cyanophytes (five species) also were common, along with five diatom species.

Table 4-1: Numbers of species of each group of plants reported from Te Waikoropupü Springs. See Appendix A for full list and sources.

Taxon	Number of species
Diatoms	6
Cyanobacteria	6
Chlorophyta	2
Chrysophyta	1
Rhodophyta	3
Mosses	9
Liverworts	5
Vascular plants	6
Total flora	38

The Springs' aquatic flora was monitored annually from early 1991 to at least 2012 (DOC 2000, Doehring 2012) to track changes in pest species and other impacts. Hand-removal of watercress was initiated during 1994-5 (DOC 2000) and continued to at least 2012 (Doehring 2012). *Juncus* colonised areas cleared of watercress, doubling the area that it occupied by 2000 (DOC 2000). Hand-weeding of watercress continued and, from 2006, weed management included removing *Juncus* to sustain bryophyte communities, one of the Springs' special floral characteristics (Doehring 2012). Monitoring also tracked areas denuded by divers during entry and exit, leading to all swimming and diving activity in the Springs being prohibited in January 2006 (DOC 2009). Subsequent monitoring reported increased algal and bryophyte cover and decreased bare rock within the springs basin by 2012, most markedly around the Dancing Sands Spring (Doehring 2012). The exotic march bedstraw (*Gallium palustre*) was first reported in the Springs in 2005 as a few large patches (Strickland 2005) and, by 2012, it occupied a larger number of smaller patches, but a similar total area (30% of total transect length) to its 2005 population (Doehring 2012). Control of *Gallium* by hand-weeding, similar to that used for watercress was also recommended (Doehring 2012).

Elements of the Springs' aquatic plant biodiversity were identified as special in the directory of New Zealand wetlands (Cromarty & Scott 1996). The mosaic of mosses, liverworts and other aquatic plants was considered unique within New Zealand, particularly because the two liverworts *Lophocolea* and *Neesioscyphus phoenicorhizus* formed extensive, permanently submerged areas in the Springs rather than in their usual damp rocks habitats (Cromarty & Scott 1996).

4.1.2 Benthic invertebrates

Fifty-four benthic invertebrate taxa[3] were reported from the springs basin (Michaelis 1974, 1977). In contrast, >105 species were reported from shallower stream beds of Fish Creek and the Te Waikoropupü River below the springs basin (see Appendix B) from >20 yearly monitoring surveys (Stark & Pugsley 1986; Stark 1993, 1999-2015). In addition to sampling different habitats (spring versus riverine), the two studies differed considerably in sampling effort and duration. Michaelis (1974, 1977) sampled over 15 successive months (October 1970-February 1972; c. 96 samples taken). In comparison, Stark sampled five points biannually for 13 years (1987-1999), annually for a further seven years (2006) and, subsequently, four sites annually (seven years, 2007-2014; 27 total sampling occasions, 4-5 sampling points, 193 sampling events; Stark 2014). Stark's monitoring sampling was generally much more intensive than Michaelis's usual single samples/sampling, comprising triplicate Surber samples and D-net samples (Stark 2014). Both the intensity of sampling and the longer duration of sampling appear to contribute to the much greater diversity reported by Stark's surveys. Also, the better taxonomic knowledge and availability of much improved identification tools probably facilitated greater taxonomic resolution, further increasing the reported biodiversity of the later (Stark various) surveys.

Another reason for the differences in reported biodiversity between the two investigations is that their objectives differed. Much of Michaelis's (1974, 1977) sampling was aimed at determining the total composition of invertebrate communities. Stark's (Stark & Pugsley 1986, Stark various) sampling for monitoring did include macrophytes, but probably comprised mostly watercress (*Nasturtium microphyllum*), which dominated sampling site 3 (Stark 2010) and only at wadeable depths. Further, Michaelis focussed on identifying as much of the biodiversity as possible, whereas Stark focussed on groups that are proven indicators of ecological condition. Specifically, Michaelis (1977) reported 16 species from the lesser known groups (Platyhelminthes to Copepoda in Table 4-2) and 17 species of the Ephemeroptera, Plecoptera and Trichoptera (the EPT taxa widely used for monitoring), compared with two and 73 species, respectively, in these groups reported by Stark (Stark & Pugsley 1986, Stark various).

Because these two sets of biodiversity investigations differed in location and habitat, methods, purpose, timing and durations, their combined results produce the best understanding of biodiversity for the surface waters associated with Te Waikoropupü Springs. Thus, the biodiversity of the Springs alone totals some 54 species, and that of the streams totals 105 species. The combined freshwater invertebrate biodiversity directly attributable to groundwater sourced via the Springs totals 134 taxa (Table 4-2). In addition to numbers of species, the extremely high densities of the small snail (*Potamopyrgus antipodarum*, >30,000 snails/m^2) was considered to be among the remarkable features of the Springs' invertebrate biodiversity (Cromarty & Scott 1996).

[3] We use the term "taxa" (plural; singular = taxon) rather than species because some organisms were not identified to species level. For example, Michaelis distinguished three types of nematode worms, but identified them only to family level, implying that there may have been more than one species present within each type or family.

Table 4-2: Comparison of reported biodiversity (numbers of taxa) of Te Waikoropupü Springs basin (Springs) and associated streams (streams). Data from Michaelis (1974, 1977), Stark & Pugsley (1996), Stark (1993-2014).

Major group	Springs total species	Streams total species	Combined total species
Platyhelminthes (flatworms)	3	0	3
Rotifera (rotifers)	2	0	2
Nematoda (roundworms)	3	0	3
Annelida (worms)	2	1	2
Tardigrada (water bears)	1	0	1
Acarina (mites)	2	0	2
Ostracoda	2	1	2
Copepoda	1	0	1
Amphipoda	2	2	2
Decapoda	2	2	2
Mollusca (snails & bivalves)	3	4	6
Odonata (damselflies)	3	0	3
Coleoptera (beetles)	1	3	3
Meglaoptera (dobsonflies)	0	1	1
Trichoptera (caddisflies)	13	52	56
Ephemeroptera (mayflies)	5	14	14
Plecoptera (stoneflies)	1	7	7
Diptera (true flies)	8	18	21
Total	54	105	134

No aquatic insects are known to be endemic to Te Waikoropupü Springs, although the Springs represent the northern-most record for the caddisflies, *Hydrobiosis chalcodes* and *H. johnsi*. These two species are typically associated with cold-water, alpine streams, with *H. johnsi* generally found at higher altitudes (median 800 m above sea level) than *H. chalcodes* (median 470 m above sea level). Approximately 400 km separates the Te Waikoropupü Springs' population of *H. johnsi* from the nearest known population in the Tasman Valley (South Canterbury high country), whereas only 100 km separates the Springs' population of *H. chalcodes* from the nearest population in the Gowan River. Also, the caddisfly *Rakiura vernale*, known from Stewart Island and scattered locations along the West Coast and northwest Nelson, is close to its northern limit (Pakawau Creek at the base of Farewell Spit) at the Springs.

Te Waikoropoupü Springs is a notable important location for the amphipod *Paracalliope karitane*. The Springs represent the only known South Island location for this abundant North Island amphipod.

DOC's Te Waikoropupü Springs Management Plan (2009) reported 43 indigenous aquatic animals, with its surveys[4] adding to the taxa identified by Michaelis (1974, 1977) (DOC 2009). That report considered that "half of these species may be endemic to Te Waikoropupü Springs" (i.e., not reported elsewhere in the Te Waikoropupü Springs Reserve) (DOC, 2009: 36). Our compilation of species records (Appendix B) indicates 27 taxa reported from the Springs that were not reported from elsewhere in the reserve, and two species (*Spathula alba*, *Paraleptamphopus* sp.) were unique or endemic (unknown anywhere else in New Zealand or beyond) to the springs basin (or aquifer) itself.

Springs are renowned for their high biodiversity values (e.g., Scarsbrook et al. 2007) because of their higher productivities and numbers of species relative to most stream ecosystems (e.g., Digby 1999), and some studies (e.g., Smith & Wood 2002, Collier & Smith 2006) showed differences in macroinvertebrate community structure between the main stems of streams and rivers. Springs tend to have high biodiversity because they are ecotonal environments[5]: they interface between groundwater and surface water environments. Te Waikoropupü Springs are no exception and support both surface water and groundwater species, as well as being the specific habitat for groundwater taxa such as the flatworm *Spathula alba* and amphipod *Paraleptamphopus* sp. We suspect that several additional groundwater species (notably smaller crustaceans, Tateidae (formally Hydrobiidae) snails) are present within the Springs themselves, but remain undiscovered. This may be because these colourless and generally small invertebrates are easily overlooked by researchers using methods suited to sampling surface water faunas.

The aquatic invertebrate biodiversity of Te Waikoropupü Springs is generally typical of that known from other New Zealand karst springs (Scarsbrook et al. 2007). The apparent absence of Tateidae snails, other than the ubiquitous *Potamopyrgus antipodarum*, almost certainly is due to their small size and difficult identification, as well as the need for intensive, habitat-specific surveys to collect some of these groups of invertebrates. Several short-range endemic[6] tateid snails occur in the region and within the Takaka River catchment, supporting the notion that specialist spring and/or stygofaunal tateids are likely within cryptic habitats associated with the contributing aquifers and the Springs' vents.

We examined four collections of crustaceans from Te Waikoropupü Springs surface waters for this report (Appendix C). All collections included specimens of amphipods that proved to be an unnamed (undescribed; new to science) species within the Family Paraleptamphopiidae, and belongs to the genus *Paraleptamphopus*[7], as presently defined (Michaelis (1974, 1977) correctly identified it as *Paraleptamphopus* n. sp.). The species is larger than most species of the family, based on our detailed knowledge of this family and, as far as can be determined without further investigation, is probably a local (i.e., short-range) endemic confined to the Takaka Valley and possibly to Te

[4] Results of these surveys were not available to us.
[5] Ecotone: a transition zone between two major habitat types or environments, in this case groundwater and surface water environments.
[6] Short-range endemic species: animals that lack dispersal capabilities and with very restricted geographic distributions, frequently known from a single location (often a single catchment). These are akin to island species where the surrounding marine waters (or other barriers) prevent dispersal and gene flow. Subterranean stygofauna and terrestrial subterranean faunas typically comprise short-range endemics.
[7] The Family Paraleptamphopidae comprises two described genera and four described (named) species (Fenwick 2006). Work in progress reveals that species presently assigned to the genus *Paraleptamphopus* more correctly belong to at least two genera.

Waikoropupü Springs. Specimens examined had small eyes, which, along with remnants of purple body pigmentation, indicates that the species is typically a spring and occasional stream dweller.

Species of this family occur throughout the South Island and much of the North Island in both groundwater and surface water habitats (Fenwick 2001, Sutherland 2005). Two genera are formally known, but others await description. One genus (*Ringanui*) includes unpigmented and blind, strictly stygofaunal species and, so far, is known only from Canterbury's alluvial aquifers (Fenwick 2006). The other, *Paraleptamphopus*, appears ubiquitous in New Zealand and includes both unpigmented, stygofaunal and pigmented surface-dwelling species.

Amphipods and other crustaceans tend to dominate springs and groundwater faunas (Danielopol 2000, Fenwick 2000, Scarsbrook et al. 2003) and, because the diversity of crustaceans generally increases with increased water conductivity (c. 100 mg chloride/L, Stewart & Thomas 2008), other species of amphipods also are likely to inhabit Te Waikoropupü Springs (Scarsbrook et al. 2007).

Overall, total invertebrate biodiversity was high for Te Waikoropupü Springs basin compared with that at other New Zealand springs: it ranged between 21 species in the Waitaki area to 61 in Southland and Waikato (Scarsbrook et al. 2003). With 52 taxa (possibly more species), Te Waikoropupü Springs was moderately high, especially if the combined stream and springs biodiversity (>130 species) is counted. We believe that the biodiversity of Te Waikoropupü Springs may be considerably higher than these numbers indicate because of their high habitat diversity and because improved collecting practices and identification tools (including molecular (DNA)) targeting smaller crustaceans and molluscs are now available. Overall, the ecosystem is not well understood, especially in terms of vulnerability to human impacts. In particular, the spring flows required for sustaining the spring basin's biodiversity and ecosystem is unknown.

4.2 Aquifers

4.2.1 Biodiversity

Alluvial aquifers contain significant biodiversity. Bacteria, Fungi and Protozoa inhabit almost all aquatic habitats, including groundwater. Aquatic invertebrate animals also inhabit most aquifers world-wide, with some known from aquifers 3.6 km below the surface. New Zealand's alluvial aquifers support diverse microbial (Sirisena et al. 2013) and invertebrate communities (Scarsbrook et al. 2003), including some crustaceans up to 25 mm long. Much of this invertebrate stygofauna is rarely seen because it is difficult to access, collect and identify.

Karst aquifer systems also contain significant biodiversity and have received considerable attention in Europe, North America and Australia (e.g., Culver & Sket 2000, Elliot 2007, Humphreys 2008). Karst groundwater systems in New Zealand also contain invertebrate stygofauna (e.g., Fenwick 2011).

Collections held by NIWA indicate that New Zealand's stygofauna comprises >500 species in nine main groups (Scarsbrook et al. 2003). Most of these collections and species are from alluvial aquifers and some of these represent ancient lineages. The stygofauna adjacent to Canterbury's Selwyn River (a foot-hills river) is very diverse compared with that in European and North American aquifers. This local fauna comprised 41 probable species[8] distinguished by visual examination of morphology. These were 23 crustaceans, three insects, and the balance were annelids, flatworms, snails, nematodes, hydrozoans, mites, and tardigrades (Larned et al. 2015). A similar biodiversity is

[8] Most New Zealand stygofauna species are new to science and unnamed. Thus, they have not been "described" scientifically, so consistently recognising each species and determining the numbers of species present is very imprecise.

expected within the Takaka Valley unconfined aquifers and oxic parts of the confined aquifer, both in terms of numbers of species and the composition of the stygofauna.

Many of the species expected to inhabit the Takaka Valley aquifers almost certainly will be restricted to the Takaka River catchment. Intensive sampling of Canterbury's alluvial aquifers reveals that their stygofaunas comprise many short-range endemic species. For example, one isopod species (*Phreatoicus typicus*) and four readily recognised amphipod species inhabiting aquifers between the Waimakariri and Selwyn rivers appear restricted to this area, being replaced by different species in equivalent aquifers both north and south (e.g., Wilson & Fenwick 1999, Fenwick 2001, 2006, unpublished).

World-wide, molecular techniques are revealing additional diversity within groundwater biotas at all levels (e.g., work in Australia identified several cryptic species, many restricted to small discrete aquifers (e.g., Finston 2004, Cooper 2007). DNA analyses of one amphipod from alluvial aquifers alongside Canterbury's Waimakariri River revealed unexpectedly high differentiation between headwater and lower plains populations compared with that for stream insects (Fenwick & Smith, unpublished data).

Karst aquifers contributing water to Te Waikoropupü Springs may be similarly diverse and include numerous short-range endemic species. These karst aquifers and the Springs are contiguous with the Takaka Valley unconfined alluvial aquifer and some overlap of species between these habitat types is likely. Karst aquifer species known from the general area show that stygofauna does inhabit these aquifers, and that the species are mostly new to science and restricted to discrete geographic areas. For example, collections from the Takaka water supply cave yielded a new genus and species (*Bilistra millari*) of isopod crustacean restricted to caves in the Pohara area. Two other species of this genus also were discovered, each restricted to a discrete karst aquifer system: *B. cavernicola* in karst cave stream tributaries to the Riwaka River, and *B. mollicopulans* in a cave near Karamea (Bruce & Sket 2004). Minute tateid snails are another example of high diversity and short-range endemism both in the Takaka karst aquifers and across New Zealand (Table 4-3; Haase 2008): five distinct species are known, four from separate single locations only. In yet another example of stygofauna in New Zealand karst systems, stygofauna was collected from 28% of 40 traps set at 2-40 m depth in the Pearse Resurgence (Motueka Valley). These yielded an undescribed species of the New Zealand endemic amphipod family Paraleptamphopidae, a minute gastropod snail, oligochaete worms and a colourless flatworm (Fenwick 2011).

Table 4-3: Tateidae snails known from the Takaka Valley. From Haase (2008). R, rare; C, common.

Species	Relative abundance	Locations found	Endemic to Takaka Valley
Opacuincola caeca	R-C	East Takaka, at entrance to Gorge Creek Cave	Endemic
Opacuincola lentesferens	C	Near Upper Takaka, at entrance to Commentary Cave	Endemic
Opacuincola ignorata	C	Near Upper Takaka, at entrance to Sims Cave	Endemic
Opacuincola geometrica	R	East Takaka, at entrance to Gorge Creek Cave	Endemic
Catapyrgus fraterculus	R	Upper Takaka & Paturau, cave streams	Not endemic

This assessment of biodiversity associated with groundwaters sustaining Te Waikoropupü Springs is based on very limited information. There are very few useful collections of this biodiversity because it is difficult to access, most of stygofaunal species are small and difficult to distinguish by conventional taxonomic approaches, the groups of invertebrates involved require specialists for collecting and undertaking the subsequent taxonomic investigation, such specialists are increasingly rare, and funding for this type of fundamental science is minimal to non-existent. In particular, we are aware of just one sampling from wells in the system, and none from hyporheic (zone beneath and alongside a stream bed where surface water mixes with shallow groundwater) or other subsurface habitats.

The contents of that one sampling comprised a single specimen of a small colourless amphipod assigned to the Family Paraleptamphopidae (Appendix C). This single specimen, presumably from alluvial groundwater between the confluence of the Takaka and Anatoki rivers, appears to be a second new species, this one more similar to *Paraleptamphopus subterraneus* than to the specimens from Te Waikoropupü Springs.

Based on past collecting effort, known biodiversity and work elsewhere in New Zealand, therefore, we predict a diverse stygofauna within the aquifers contributing to Te Waikoropupü Springs, especially the alluvial aquifer and more finely fractured and oxic zones of the two marble aquifers. These findings also show the presence of several known short-range endemic species inhabiting the aquifers contributing to Te Waikoropupü Springs, and indicate that there are likely to be many more similar species once more intensive, groundwater-specific sampling can be undertaken. Given the likely high biodiversity and the small geographic ranges of many of these, a precautionary approach to managing these aquifers seems necessary to ensure that this likely locally-restricted biodiversity is protected.

4.2.2 Groundwater ecology

Water flowing into the ground and entering an aquifer usually contains dissolved oxygen and dissolved and fine particulate organic carbon, both of which are gradually consumed by natural biological and chemical processes within the aquifer. Organic carbon is frequently carried into well-developed karst aquifers as plant debris, including leaves, twigs and branches (Gibert et al. 2000, Poulsen & Lavoie 2000), and, if the karst is in higher rainfall, forested areas, the water itself may contain substantial coloured (tea coloured) dissolved organic matter. There is no or minimal re-oxygenation of this water until it is discharged above ground and has direct contact with air or surface water. Thus, oxygen is usually depleted along an alluvial aquifer's flow path. The same is true for confined karst aquifers, but contact between water and air in unconfined or incompletely saturated karst allows for some re-oxygenation. Dissolved organic carbon, the primary energy source for the groundwater ecosystem, is similarly depleted along groundwater flow paths, although it may be variously replenished from roots penetrating groundwater or water percolating from the land surface.

We have no data on the organic carbon content of groundwater or spring water in the Takaka Valley, but measurements of the Te Waikoropupü Springs waters' very high visual clarity and its optical purity indicate extremely low concentrations of both particulate and dissolved organic matter, especially coloured dissolved organic matter (CDOM). Canterbury's alluvial aquifers are generally low in organic carbon compared with most surface waters (Williamson et al. 2012). For example, the dissolved organic carbon concentrations in groundwater adjacent to the Selwyn River at Hororata (and farther downstream) were 0.5-1.7 mg/L and averaged 1.7 mg/L under rural land near

Templeton. In contrast, concentrations averaged 4.3 mg/L immediately down-gradient of the Templeton wastewater disposal site (aquifer with high hydraulic conductivity[9], Fenwick et al. 2004) and 8.1 mg/L adjacent to Leeston township (fine grained aquifer with very low hydraulic conductivity), and 9.6-18.2 mg/L immediately down-gradient of Leeston's wastewater treatment facility (Hartland et al. 2011).

In the absence of light and photosynthetic plants, groundwater ecosystems depend directly or indirectly on organic carbon from surface environments for their food or energy. This is mostly in the form of dissolved or very fine particulate organic carbon carried into the aquifer by in-flowing surface waters, but may be supplemented by plant roots and their exudates, and any buried organic matter (see Fenwick et al. 2004, Boulton et al. 2008). Some of this organic carbon is in the form of CDOM, substances that generally give water its colour.

Most groundwater bacteria are incorporated into biofilms that coat sediment particles. Biofilms consist of extracellular polymeric substances (slime) produced by and enveloping the microbes, binding them to the surfaces of all particles in aquatic environments. Given the vast surface areas of aquifer substrate within alluvial aquifers, these biofilms are collectively huge and are the major functional component within most groundwater ecosystems. Biofilms within karst systems probably are similarly large because they cover flooded rock surfaces not only of caves and tunnels, but also all surfaces reached by water, including those within microscopic crevices and fissures well away from main tunnels and caves.

Organic matter in groundwater becomes incorporated into biofilms, which, in turn, are consumed by stygofaunal invertebrates (some stygofauna appear to be strictly predators). Biofilms generally are slow to develop and their bacterial communities naturally effect transformations of dissolved substances in groundwater, particularly reduction-oxidation sensitive substances, thereby changing groundwater chemistry and affecting water quality. Stygofauna grazing controls biofilm development, and both grazing and burrowing activities stimulate biofilm growth rates. Thus, biofilms and stygofauna are complementary components within most natural alluvial aquifer ecosystems, inter-dependent and dynamically balanced.

Under some conditions, especially excessive organic carbon availability and reduced stygofaunal densities, excessive biofilm growth can clog finer parts of aquifers or even entire aquifers. Such bioclogging is well-known in some engineered biofilm applications (e.g., Shammas & Wang 2010). Bioclogging reduces aquifer conductivity, slowing groundwater flows, so that dissolved oxygen concentrations within the aquifer decline generally. Also, the increased bacterial communities that create bioclogging utilise more dissolved oxygen, potentially leading to hypoxic (low oxygen) or anoxic (no dissolved oxygen present) conditions.

As oxygen concentrations decline, a sequence of different metabolic pathways is used by bacteria (some may use more than one pathway; in many cases different bacteria which use the favoured pathway predominate). By-products of these pathways change from carbon dioxide to ammonium, iron, hydrogen sulphide and methane (Middelburg & Levin 2009), many of which are toxic to stygofauna and degrade water quality. Few stygofauna survive such anoxic conditions, thus eliminating the invertebrates that normally control bioclogging, further exacerbating the physicochemical change (notably the redox conditions) and groundwater quality.

[9] Hydraulic conductivity is a measure of the ease with which groundwater can move through pore spaces or fractures, and depends mostly on the aquifer material's permeability.

4.2.3 Water clarity

The water of aquifers supplying Te Waikoropupü Springs are amongst the clearest of any known surface freshwaters, surpassed only by Blue Lake in the upper South Island (Gall et al. 2013). The extremely high visual clarity and near optical purity of Te Waikoropupü Springs' water give it the "unusual blue-violet colour only seen in the very clearest of waters" (Davies-Colley & Smith 1995: 255) and result from two natural processes. First, physical filtration by the media through which the source waters flow (e.g., soils, alluvium, etc.) removes essentially all suspended particles (clay particles, phytoplankton cells, etc.), a key factor in its visual clarity (Davies-Colley & Smith 1995). Second, natural coloured organic matter is all but absent (scarcely detectable), removed by ecosystem processes, to create water that is optically very pure (Davies-Colley & Smith 1995).

4.2.4 Ecosystem services

Natural, alluvial groundwater ecosystem processes, as described above, thus remove organic contaminants, help maintain the groundwater's aerobic nature, and sustain water quality and its hydraulic conductivity. Removal of CDOM is an important part of these processes for maintaining Te Waikoropupü Springs water quality, although Davies-Colley & Smith (1995: 255), in discussing processes underlying the remarkable clarity of the Springs' water, attributed this function to "chemical adsorption on the calcite mineral surfaces of the rock (Mount Arthur marble) comprising the aquifer".

The Takaka Valley groundwater ecosystems deliver two vital ecosystem services to sustaining the high human values (cultural, spiritual, economic, recreational) of Te Waikoropupü Springs and the associated groundwater: (1) they help to maintain water quality, including clarity, by removing organic matter, and (2) they help to deliver this water to the Springs by maintaining aquifer hydraulic conductivity. Both biofilm microbes and stygofauna are integral, complementary components of the processes delivering these services. Thus, sustaining the processes delivering these ecosystem services requires management protection of the aquifer biodiversity and ecosystem functioning, as with rivers.

5 Discussion

This review identifies several special features of the known biodiversity associated with Te Waikoropupü Springs and their tributary aquifers (the Takaka Marble Aquifer (confined and unconfined) and the unconfined Takaka Gravel Aquifer). These biodiversity values merit protection, indicating the need to minimise any human impacts on the aquifer-Springs system. The Springs themselves currently are accorded limited protection under the Te Waikoropupü Springs Scenic Reserve, principally in recognition of their scenic values, and there is no specific protection for the biodiversity and ecosystems within their tributary aquifers.

In comparison, almost 20 years ago, Te Waikoropupü Springs and aquifers were identified as a wetland complex of international importance (Cromarty & Scott 1996), based on Ramsar Convention standards for international quality, principally biodiversity and human values. At that time and subsequently, a Water Conservation Order was considered necessary to protect these values (Cromarty & Scott 1996)[10]. Te Waikoropupü Springs and its aquifers together are considered internationally significant from hydrological and ecological perspectives (Williams 1977, 2004) and are included in the International Union for the Conservation of Nature's (ICUN) Project Aqua listing of internationally significant water bodies (Luther & Rzoska 1971, Williams 1977). The New Zealand Geopreservation Inventory lists Te Waikoropupü Springs as a site of international significance, and the list of World Natural Heritage sites for New Zealand noted considerable value in adding Te Waikoropupü Springs to Kahurangi National Park (DOC 2006).

Further, the New Zealand Minister of Conservation (1996) considered that protection of all identified Ramsar wetlands/wetland complexes, including the Springs and its aquifers, was *"vital to our* [New Zealand's] *biodiversity and the well being of future generations"* (Cromarty & Scott 1996: 2). Recognising that the state of the Te Waikoropupü Springs depends on upstream activities and conditions, the Directory of Wetlands in New Zealand noted that a catchment management plan to protect the aquifer and Springs would be available by 1994 (Cromarty & Scott 1996), but we are unaware of any such plan. Despite these attributes and recognition of Te Waikoropupü Springs' high biodiversity and other values, the Springs continue with scenic reserve protection for their biodiversity and ecosystems and for their contributing aquifers.

In 2008, the Department of Conservation collaborated with Manawhenua ki Mohua and Tasman District Council to develop a Te Waikoropupü Springs Management Plan (DOC 2009). That plan's first objectives concerned biodiversity:

> *"Preservation, protection and recognition of the national and international significance of the indigenous biodiversity and ecosystems of Te Waikoropupu.*
>
> *Protection and preservation of the intrinsic values of Te Waikoropupu that provide benefit and enjoyment to the public" (DOC 2009: 64).*

The plan's third objective also is relevant here:

> *"Protection, preservation and recognition of the quantity, quality and mauri/life force of Te Waikoropupu Springs as nationally and internationally significant waters and as a taonga/treasure and wahi tapu/sacred site" DOC 2009: 68).*

[10] We understand that an application for a Water Conservation Order to protect the Springs and its tributary aquifers was submitted to the Minister in 2014 and has yet to be resolved.

The two biodiversity objectives seem consistent with the significance of the Te Waikoropupü Springs' biodiversity, as outlined in this report. The water quantity and quality objective also seems consistent with protecting both the Springs' and the aquifers' biodiversity, because changes in water quantity and quality pose greatest threats to spring biodiversity (e.g., Williams 1977, 2004, Death et al. 2004, Scarsbrook et al. 2007, Fenwick in press).

Flow permanence (water quantity or continuity of water supply) is considered the main determinant of spring floral and invertebrate biodiversity, and interacts with regional biodiversity (see Scarsbrook et al. 2007 for review). Scarsbrook et al. (2007) identified eight taxa considered exclusive to permanent springs, all of which were present at Te Waikoropupü Springs. Flow permanence is such a strong influence on biodiversity because water is required by all aquatic plants and animals to sustain life, for physical support, for respiration and usually for obtaining energy or food. Thus, ephemeral flow apparently excludes surface water species with low mobilities (e.g., freshwater snails, crustaceans, etc.) from springs (Scarsbrook et al. 2007), and, because these groups in invertebrates dominate stygofaunas, it is an equally important influence on aquifer biodiversity.

Another element of water supply in streams, rivers and aquifers is the effects of hydrodynamics (e.g., water velocity and depth) on biodiversity and ecosystem processes. This is an established field of applied research for surface water management, termed ecohydraulics[11]. As water levels drop in both rivers and aquifers, water depths and velocities decrease, habitat space is reduced and habitat characteristics change. These changes have several effects important to biodiversity and ecosystems: the rate of oxygen replenishment and removal of carbon dioxide and other wastes is reduced, food supplies may be reduced, temperatures change (mostly increase), and species adapted to faster flowing waters may be replaced by others better adapted to life in static or slow-flowing waters (Fenwick in press). Reductions in dissolved oxygen concentrations can have dramatic effects on groundwater (and hence spring water) quality: as oxygen becomes less available, the redox potential may alter, triggering a series of microbial metabolic changes that further degrade water quality (see section 4.2.2). Such changes in water quality, in turn, usually lead to changes in the stygofaunal biodiversity as species less tolerant of the new conditions are replaced by more tolerant ones, leading to changes in ecosystem processes and delivery of ecosystem services (e.g., Boulton et al. 2008, Fenwick in press).

Consequently, any water abstraction from a flowing water body, such as an aquifer, spring or river, may, in some lesser or greater degree, change water flows, levels, velocities and the transport of essential dissolved substances. Individually, such water abstractions may be considered negligible, but during annual low flows and extreme climate events, small individual reductions in water levels (e.g., from water takes), especially cumulatively, may result in significant effects on biodiversity and ecosystems. Examples of such effects include several lowland alluvial rivers, such as Canterbury's Selwyn River, where the cumulative effects of numerous groundwater takes have resulted in reduced flows within lower reaches and longer, more frequent periods with no flows through middle reaches (McKerchar & Schmidt 2007). The Selwyn River was renowned for its yields of large brown trout through the mid-twentieth century, but trout numbers recorded in a perennially flowing, lower reach declined markedly in response to this changed water regime (Millichamp 2008). Equivalent information on invertebrates is not readily available for the Selwyn River or Te Waikoropupü Springs, but clearly such change would have a marked effect on stream benthic invertebrates in the Selwyn River's middle reaches.

[11] Groundwater ecohydraulics appears to be completely overlooked by New Zealand's groundwater resource managers.

Other factors, whether natural or human-induced, are additional influences on spring biodiversity, and the relative importance of each factor will vary with the magnitude of each effect (see Scarsbrook et al. 2007). Water quality is one of the most important considerations. The cumulative effects of multiple small inputs of contaminants, like the cumulative effect of multiple small abstractions, may be equally substantial and have significant adverse effects on water quality and biodiversity. For example, the cumulative effects on water quality of multiple, diffuse nitrate inputs from land use activities along the flow paths of streams, rivers and aquifers are well documented in New Zealand (e.g., Stewart et al. 2011). Such contamination can exceed concentrations recommended for sustaining biodiversity and ecosystem functioning (e.g., Stewart et al. 2011, MfE 2014). While beyond the scope of this review, consideration of such cumulative effects on the water quality of Te Waikoropupü Springs and its aquifers is another vital element for sustainably managing this system for its biodiversity and ecosystem values. We note these cumulative effects here because they and the effects of combinations of factors (e.g., reduced velocities and increased nitrate concentrations together) are rarely considered, yet may have synergistic effects on the biodiversity and ecosystem function.

The consented abstraction from bore WWD 6011, comprising c. 0.1% of the mean annual low flow and 0.2% of the minimum flow for the entire Te Waikoropupü Springs complex (Bealing 2004, Stewart & Thomas 2008), is small relative to discharges from the whole system, but is one of many takes from the system. Indeed, probably every holder of a consent for water abstraction from the contributing aquifers and river could argue that their take is small relative to whole system flows. We further note that bore WWD 6011 was considered to intercept water that otherwise would go to the Fish Creek Springs (Bealing 2004). The consented 12.5 L/second equates to c. 4 % of these springs' mean flow, 4 % of their minimum flow (Stewart & Thomas 2008), or 100 % of their flow when they cease flowing (Bealing 2004). Clearly, this water take will affect biodiversity and ecosystems within the Fish Creek Springs and immediately connected parts of their contributing aquifer/s by reducing spring and groundwater permanence and velocities, at least during times of lower spring discharges.

For these reasons, it seems important to consider all potential direct and indirect effects on biodiversity and ecosystems in evaluating the merits of proposed water takes from this system. Water abstraction is one of several human-induced stressors on the aquifer-Springs system with potential to adversely affect the aquifers' and Te Waikoropupü Springs' biodiversity and ecosystems. Therefore, a conservative approach seems appropriate, one that recognises the uncertainties and risks associated with determining the effects of water abstraction, and considers the effects of all human impacts, cumulatively and in combination, on the overall aquifer-Springs system, especially its biodiversity values and ecosystem services. As far as we are aware, these effects have not been considered for the consent applications and the extension decision for groundwater abstraction from bore WWD 6011.

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Appendix A Biodiversity of aquatic plants reported from Te Waikoropupü Springs.

From Michaelis 1977, Fife et al. 2004, Doehring 2012. *, indicates exotic species.

Major group	Genus species	Reference
Diatoms	*Achnanthes* sp.	Michaelis 1977
	Cocconeis placentula	Michaelis 1977
	Cymbella sp.	Michaelis 1977
	Gomphonema sp.	Michaelis 1977
	Navicula sp.	Michaelis 1977
	Synedra sp.	Michaelis 1977
Cyanobacteria	*Chroococcidiopsis* sp	Fife et al. 2004
	Entophysalis rivularis	Michaelis 1977
	Nostoc parmeloides	Michaelis 1977
	Nostoc verrucosum	Michaelis 1977
	Microcoleus? sp.	Michaelis 1977
	Oscillatoria? sp.	Michaelis 1977
Chlorophyta	*Chaetophora elegans*	Michaelis 1977
	Spirogyra sp.	Michaelis 1977
Chrysophyta	*Vaucheria* sp.	Michaelis 1977, Fife et al. 2004, Doehring 2012
Rhodophyta	*Batrachospermum* sp.	Michaelis 1977
	Bostrychia harveyi	Fife et al 2004
	Hildenbrandia rivularis	Michaelis 1977

Major group	Genus species	Reference
Mosses	*Acrocladium cuspidatum*	Michaelis 1977
	Bryum blandum	Fife et al. 2004
	Calliergonella cuspidata	Fife et al. 2004
	Cratoneuropsis relaxa	Michaelis 1977, Fife et al. 2004, Doehring 2012 (all as *Hypnobartlettia fontana*)
	Cyatophorum bulbosum	Michaelis 1977, Fife et al. 2004
	Drepanocladus aduncus	Michaelis 1977, Fife et al. 2004
	Echinodium hispidum	Michaelis 1977, Fife et al. 2004
	Fissidens rigidulus	Michaelis 1977, Fife et al. 2004
	Hypopterygium filiculaeforme	Michaelis 1977
Liverworts	*Chiloscyphus austrigenus*	Fife et al. 2004
	Lophocolea austrigena	Michaelis 1977
	Lophocolea minor	Michaelis 1977
	Neesioscyphus phoenicorhizus	Michaelis 1977
	Radula ?*buccinifera*	Fife et al. 2004
Vascular plants	**Callitriche stagnalis*	Michaelis 1977
	**Gallium palustre*	Doehring 2012
	**Juncus microcephalus*	Michaelis 1977, Doehring 2012
	**Lemna disperma*	Michaelis 1977 (as *L. minor*)

Major group	Genus species	Reference
	Myriophyllum triphyllum	Michaelis 1977 (as *M. elatinoides*), Doehring 2012
	**Nasturtium microphyllum*	Michaelis 1977, Doehring 2012 (as *Rorippa nasturtium-aquaticum*),

Appendix B Invertebrate animals reported from Te Waikoropupü Springs, Te Waikoropupü River and tributaries.

Based on literature records (Micahelis 1977, Stark & Pugsley 1986, Stark various), but does not include all species from downstream locations reported by Stark (various). R, abundance is rare, C, common, A, abundant, P, present (abundance not known); bold font indicates not reported from the Te Waikoropupü River and tributaries. gen. et sp., new genus and species. fam, family. subfam., sub family.

Major group	Genus species	Pupu Springs	Te Waikoropupü River & tribs	Reference
PLATYHELMINTHES (flatworms)	*Cura pinguis*	**R**		Michaelis 1977
	Spathula alba	**C**		Allison 1997; probably recorded as Dugesia sp. by Michaelis 1997?
	Temnocephala novaezelandiae	**R**		Michaelis 1977
ROTIFERA (rotifers)	?*Lecane* sp.	**R**		Michaelis 1977
	Fam. Flosculanidae sp.	**R**		Michaelis 1977
NEMATODA (roundworms)	Fam. Chromadoridae gen. et sp.	**P**		Michaelis 1977
	Fam. Dorylanidae gen. et sp. 1	**P**		Michaelis 1977
	Fam. Dorylanidae gen. et sp. 2	**P**		Michaelis 1977
ANNELIDA (worms)	Fam. Haplotaxidae	**P**		Michaelis 1977
	Lumbriculus variegatus	**R-C**		Michaelis 1977, Stark & Pugsley 1986
	Class Oligochaeta		R	Michaelis 1977, Stark & Pugsley 1986
TARDIGRADA (water bears)	Indet. gen. et sp.	**R**		Michaelis 1977
ACARINA (mites)	*Tryssaturus* sp.	**R**		Michaelis 1977
	Zelandobates sp.	**R**		Michaelis 1977
OSTRACODA	*Herpetocypris pascheri*	C	C	Michaelis 1977
	Indet. gen.et sp.	**P**		Michaelis 1977

Major group	Genus species	Pupu Springs	Te Waikoropupü River & tribs	Reference
COPEPODA	*Tropocyclops prasinus*	**A**		Michaelis 1977
AMPHIPODA	*Paracalliope karitane*	P	P	Michaelis 1977; Stark & Pugsley 1986; Hogg et al. 2005
	Paraleptamphopus sp.	P	P	Michaelis 1977; Stark & Pugsley 1986; Hurley 1975
DECAPODA	*Paranephrops planifrons*	R-C	R	Michaelis 1977, Stark 2014
	Paratya curvirostris	R-C	R-C	Michaelis 1977, Stark 2014
MOLLUSCA (snails & bivalves)	*Austropeplea tomentosa*		P	Stark 2009
	Gyraulus kahuica		P	Stark 2006
	Pseudosuccinea columella	**R**		Michaelis 1977 (as *Lymnaea columella*)
	Physa acuta		C	Michaelis 1977, Stark 2014
	Potamopyrgus antipodarum	A	R-A	Michaelis 1977, Stark 2014
	Sphaerium novaezelandiae	**R**		Michaelis 1977
ODONATA (damselflies)	*Austrolestes colensonis*	**P**		http://naturewatch.org.nz/observations/1483128
	Hemicordulia australiae	**P**		http://naturewatch.org.nz/observations/1483194
	Xanthocnemis zealandica	**R**		Michaelis 1977
COLEOPTERA (beetles)	*Hydora* sp.	R	C	Michaelis 1977, Stark 2014
	Fam. Hydraenidae		C	Stark 2014
	Fam. Ptilodactylidae		P	Stark 2005
MEGALOPTERA (dobsonflies)	*Archichauliodes diversus*		R-A	Stark 2014
TRICHOPTERA (caddisflies)	*Aoteapsyche sp.*		R-C	Stark & Pugsley 1986
	Aoteapsyche colonica		P	Trichoptera database
	Aoteapsyche raruraru		P	Trichoptera database
	Beraeoptera roria		C	Stark & Pugsley 1986

Major group	Genus species	Pupu Springs	Te Waikoropupü River & tribs	Reference
	Confluens olingoides		R-A	Stark 1993, 1999
	Costachorema sp.		R-C	Stark 1999
	Costachorema xanthopterum		P	Stark & Pugsley 1986
	Helicopsyche albescens		C-A	Stark & Pugsley 1986
	Helicopsyche poutini	**R-C**		Michaelis 1977
	Helicopsyche sp.		A	Stark 2014
	Hudsonema amabile	R	A	Michaelis 1977
	Hudsonema alienum		P	Stark 2014
	Hydrobiosella sp.		R	Stark 1999
	Hydrobiosis chalcodes		P	Trichoptera database
	Hydrobiosis clavigera		R	Stark 2014
	Hydrobiosis copis		R	Stark 2014
	Hydrobiosis gollanis		P	Trichoptera database
	Hydrobiosis johnsi	**P**		Trichoptera database
	Hydrobiosis parumbripennis	R-C	R-C	Michaelis 1977
	Hydrobiosis soror		P	Trichoptera database, Stark 2014 report
	Hydrobiosis sp.	R	R	Michaelis 1977
	Hydrochorema crassicaudatum		R	Stark 2014
	Hydrochorema tenuicaudatum		P	Trichoptera database
	Neurochorema confusum		R	Stark 2014
	Neurochorema forsteri		P	Stark 2011
	Oeconesus maori	P	R	Michaelis 1977 (as Oeconesidae), Trichoptera database

Major group	Genus species	Pupu Springs	Te Waikoropupū River & tribs	Reference
	Olinga feredayi		C	Stark & Pugsley 1986, Stark 2014 (as Olinga sp.)
	Oxyethira albiceps		R-C	Michaelis 1977 (as Oxyethira sp.), Stark & Pugsley 1986, Stark 2014
	Paroxyethira eatoni complex		P	Stark 2008
	Paroxyethira hendersoni		P	Trichoptera database, Stark 2014 report
	Philorheithrus agilis		P	Trichoptera database
	Plectrocnemia maclachlani		P	Trichoptera database
	Polyplectropus puerilis	R-C	R-C	Michaelis 1977
	Psilochorema bidens		R	Stark & Pugsley 1986
	Psilochorema macroharpax		P	Stark 2005
	Psilochorema sp.	P	R	Michaelis 1977
	Psilochorema tautoru	**R-C**		Michaelis 1977
	Pycnocentria evecta		R-C	Stark 2014, Stark & Pugsley 1986
	Pycnocentria gunni	R-A	R	Michaelis 1977 (as Conuxia gunni)
	Pycnocentria sylvestris		R-A	Stark & Pugsley 1986
	Pycnocentria sp.		R	Stark 2014
	Pycnocentria funerea		P	Stark 2008
	Pycnocentria hawdonia		P	Trichoptera database
	Pycnocentria sylvestris		P	Stark 2011
	Pycnocentrodes aureolus		P	Trichoptera database
	Pycnocentrodes sp.		R-C	Stark 2014, Stark & Pugsley 1986
	Rakiura vernale	**R-C**		Michaelis 1977
	Synchorema tillyardi		P	Trichoptera database
	Triplectides dolichos		P	Trichoptera database
	Triplectides obsoleta		R	Stark & Pugsley 1986

Major group	Genus species	Pupu Springs	Te Waikoropupü River & tribs	Reference
	Zelolessica cheira	R-A	R-C	Michaelis 1977, Stark & Pugsley 1986
	Zelolessica sp.		C	Stark & Pugsley 1986
	Zelolessica meizon		P	Stark 2003
EPHEMEROPTERA (mayflies)	*Austroclima jollyae*	P	R	Stark 1993, 1999, Hitchings 2014
	Austroclima sepia		R-A	Stark 2014, Hitchings 2014
	Coloburiscus humeralis		R-C	Stark 2014, Hitchings 2014
	Deleatidium autumnale		P	Hitchings 2014
	Deleatidium fumosum	P	P	Towns & Peters 1996, Hitchings 2014
	Deleatidium lillii		P	Hitchings 2014
	Deleatidium myzobranchia	P	P	Michaelis 1977, Hitchings 2014
	Deleatidium sp.		R-A	Michaelis 1977
	Icthybotus hudsoni		P	Stark 2004
	Mauiulus luma		C	Stark 1993
	Neozephlebia scita	R	R-C	Michaelis 1977; Towns 1983, 1993, Stark 2014, , Hitchings 2014
	Nesameletus ornatus		R	Stark 2014 (as N. sp.), Hitchings 2014
	Zephlebia spectabilis		P	Stark 2007
	Zephlebia versicolor	P	P	Michaelis 1977; Stark 2011
PLECOPTERA (stoneflies)	*Austroperla cyrene*		C	Stark 2014
	Megaleptoperla diminuta	C	R-C	Michaelis 1977
	Megaleptoperla grandis		R	Michaelis 1977
	Stenoperla prasina		R-C	Stark 2014
	Taraperla howsei		P	Stark 2014
	Zelandobius furcillatus		R	Stark 2014
	Zelandoperla decorata		C	Stark & Pugsley 1986
DIPTERA (true flies)	Fam. Anthomyiidae	R	R	Stark & Pugsley 1986

Major group	Genus species	Pupu Springs	Te Waikoropupū River & tribs	Reference
	Aphrophila neozelandica		R-A	Stark & Pugsley 1986
	Aphrophila sp.		A	Stark 2014
	Ceratopogonidae (pupae)		R	Stark & Pugsley 1986
	Chironomus zealandicus	R-C	R	Michaelis 1977; Stark & Pugsley 1986
	Chironomus sp. 'a'		C	Stark & Pugsley 1986
	Fam. Empididae		R	Stark 2014
	Fam. Ephydridae	**R**		Michaelis 1977
	Tribe Eriopterini		R	Stark 2014
	Limonia sp.	**R**		Michaelis 1977
	Limnophora sp.	**P**		Michaelis 1977
	Neocurupira tonnoiri		P	Stark 2005
	Maoridiamesa sp.	P	R-A	Stark & Pugsley 1986; Stark 2014
	Subfam. Orthocladiinae	C	R-A	Michaelis 1977, Stark & Pugsley 1986; Stark 2014
	Paradixa sp.		R	Stark 1993
	Paralimnophila skusei		P	Stark 2004
	Polypedilum sp.		P	Stark 2005
	Fam. Stratiomyidae	R	P	Michaelis 1977; Stark & Pugsley 1986
	Subfam.Tanypodinae		R	Stark 2014
	Tribe Tanytarsini		R-C	Stark & Pugsley 1986; Stark 2014
	Zelandotipula sp.		P	Stark 2004
TOTALS		54	105	

Appendix C Collections of invertebrates from Te Waikoropupü Springs and aquifers.

Collections known based on previous taxonomic investigations. Identifications to genus & species by GD Fenwick, August 2016, previous identifications under Details of collection. Numbers of specimens in brackets after identification.

Genus, species	Major group	Collection reference number	Collection owner	Details of collection
Paraleptamphopus sp. (13)	Amphipoda	NIWA 113771, site Z7964	NIWA	Pupu Springs. Collector: D.E. Hurley, 25 January 1970. Labelled: *Paraleptamphopus* sp., identified by DEH.
Paraleptamphopous sp. (5)	Amphipoda	NZ King Salmon Site 1	NIWA (ex Stark Environmental)	Salmon Farm, Pupu Springs, Nelson. Collector: Yvonne Stark, 22 Feb 2001. Monitoring site 1 (north end of spring basin), kick net.
Paraleptamphopous sp. (1) *Paracalliope karitane* (2)	Amphipoda Amphipoda	NZ King Salmon farm	NIWA (ex Stark Environmental)	Salmon Farm, Pupu Springs, Nelson. Collector: Yvonne Stark, 2011-2014. Kick net.
Parleptamphopus sp. (>100, 10 slides)	Amphipoda	CM unreg. 14	Canterbury Museum	Pupu Springs. Collector: unknown, 30 December 1926. Labelled: *Paraleptamphopus subterraneus*.
Paraleptamphopus sp. (1)	Amphipoda	NZAC 150	NZ Arthropod Collection	Takaka. Collector: G. Kuschel, 2 August 1973.