SPRING HABITATS IN THE STYX RIVER CATCHMENT

Community Monitoring of Priority Conservation Spring Sites

prepared by **Jens Martin Zollhoefer** on behalf of **Christchurch City Council**

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All relevant quality control information in relation to environmental data is identified, has been reviewed and is approved for release.

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Table of Contents

A Summary

This report

This report identifies priority spring conservation sites in the Styx River catchment, provides guidelines for habitat management to achieve the desired environmental outcomes, and a community based monitoring program.

Objectives

The main objectives of this report are to identify and designate six priority conservation sites of significant spring habitats based on physical habitat features and biodiversity data, and to provide monitoring guidelines for members of the community. These are based on habitat management objectives that preserve and enhance the ecological values of six selected springs with high natural assets. The aim of the community monitoring program is to raise the profile of spring habitats, and detect negative effects from land use changes in the catchment such as falling water levels or reduced water clarity as early as possible. The monitoring results are made publicly available on the Styx website (www.thestyx.co.nz), which will be regularly updated.

Priority conservation springs in the Styx River catchment: Spring No. 1 (Headwater of Styx River; 161 Gardiners Rd)

The headwater[1] of the Styx River consists of a series of in-stream rheocrenes[2] and contains by far the largest and most spectacular clusters of groundwater vents in the Styx River catchment. Biodiversity and faunal integrity of one investigated groundwater vent outranked all other investigated springs. The groundwater amphipods found here are of a size previously unseen in the City's waterways.

Habitat management objectives focus on conservation; i.e. maintaining current levels of water quantity and quality, and secondly replacing the exotic riparian vegetation with native species over time.

Community monitoring comprises assessing stormwater quality from upstream subdivisions during storm events, a detailed habitat description, and the monitoring of discharge volume. The discharge of single vents can easily be measured with a large plastic bag of known volume[3]. Alternatively, a council operated flow monitoring station could monitor the total of the spring vents' discharge at Harewood Park.

Spring No. 2 (330 Styx Mill Rd, Styx River)

The Spring No. 2 is a significant cluster of four to five groundwater vents in a short side-channel rheocrene at the base of the true right bank. It currently has low in-stream ecological values.

The spring habitat is currently overgrown, mainly with blackberries and *Convolvulus* along the riparian margins, and watercress *(Nasturtium officinale)* in the riverbed. Habitat management objectives focus on riparian restoration, i.e. removing rubbish, cutting back and replacing exotic vegetation with natives.

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[1] Refers to the current Styx River headwater between Sawyers Arms Road and Gardiners Road.
[2] See section 4.1 for definition of spring types.
[3] The method is described in Appendix A.

Community monitoring measures the success of the transition to natural riparian margins, shading and substrate composition. Invertebrate sampling could monitor the success of the habitat restoration.

Spring No. 3 (33 Willowview Drive, Redwood subdivision, Styx River)

Spring No. 3 is the largest limnocrene[4] in the catchment with a short spring creek on the true right bank of the Styx River. Riparian vegetation currently consists of exotic grasses and the spring creek is overgrown with watercress *(Nasturtium officinale)*, which is where most of diverse and abundant aquatic invertebrate fauna was found.

Habitat management objectives focus on riparian buffer restoration and aquatic weed management.

Community monitoring measures the success of the revitalisation process.

Spring No. 4 (near Belfast/Blakes Rd, Kaputone Creek)

Spring No. 4 is a medium-sized side channel rheocrene with sand and gravel in a small area where groundwater emerges, and a thick layer of silt over the rest of the habitat. Stock (cattle) access has caused riparian damage.

Habitat management objectives focus on restoring a riparian buffer with native vegetation. Silt removal with a suction truck could be considered after a riparian buffer is established.

Community monitoring measures the success of the revitalisation process, which should include an extension of gravelly (un-silted) areas.

Spring No. 5 (near Guthries/Factory Rd, Kaputone Creek)

Spring No. 5 is a side channel limnocrene on the true right bank of the lower Kaputone Creek with a thick layer of silt over sandy substrate. Stock access has heavily damaged the riparian margins but the spring has a good potential to become a feature in the recently acquired reserve.

As in the Spring No. 4, habitat management objectives focus on restoration of riparian vegetation and silt removal.

Community monitoring measures the success of the revitalisation process, which should include an enlargement of gravelly (un-silted) areas.

Spring No. 6 (470 Cranford St, Avon/Styx watershed)

Spring No. 6 is a large manmade limnocrene in a paddock with currently low ecological value. However, if connected to Tyson's Drain and revitalised the spring could serve as a stepping-stone between the Avon and Styx catchments; i.e. the spring could aid the dispersal of animals from stream habitats that have an affinity for spring systems.

Habitat objectives focus on increasing the hydraulic conductivity, planting riparian vegetation and silt removal.

Community monitoring measures the success of the revitalisation process, which should include the removal of silt.

[4] See section 4.1 for definition of spring types.

Conclusion

The headwater of the Styx River along Gardiners Road contains by far the most significant springs habitats in the catchment.

A diverse aquatic fauna has also been recorded in Spring No. 3, north of Redwood subdivision. The other habitats are seriously impacted by stock access and siltation but have significant potential for restoration.

1 Background

1.1 Hydrobiology of springs

Aquatic invertebrates abound in streams and rivers throughout New Zealand. However, in light of the overriding effect of disturbance, it is the smaller tributaries that generally contain most species that are special to a region (Huryn *et al.* 2003). Springs proved to be biodiversity hotspots in Canterbury's braided river systems (Gray, 2005), which is in contrast to international findings in catchments with less natural disturbance (Zollhoefer, 1999). Several authors have suggested a refugial role for springs in the river system (e.g. Van Erdingen 1991). Scarsbrook *et al.* (2005) suggest that springs may provide significant thermal refugia for native fish and invertebrates in alluvial lowland springs in the Canterbury Plains where river temperature can exceed critical temperatures for key stream invertebrates.

In the constant water temperatures of springs and in the absence of physical disturbance from floods, there live a diverse range of aquatic invertebrate species that can be classified as crenophiles and crenobionts – animals from stream habitats that either have an affinity for spring systems, or depend entirely on them. Many springs act as refuges for fish and invertebrates during floods when conditions get harsh in the main channel. Consequently, springs constitute an important part of river corridor biodiversity.

Generally, spring habitats in the Styx catchment have a stable discharge regime, constant temperatures between 11 and 14 °C, elevated but stable levels ionic enrichment, and sometimes low concentrations of dissolved oxygen. The sudden exposure of groundwater at the spring surface results in rapid changes in these variables within the spring creeks (Gray 2005).

1.2 Spring habitat conservation

Springs are emotionally appealing habitats that have fascinated and inspired humankind throughout its existence. Consequently, significant springs like the Waikoropupu springs have been protected throughout history. Conversely, smaller springs – and they are the bulk of the habitats, have largely been overlooked, until recently.

On a national scale, the Department of Conservation (DoC), in collaboration with the National Institute for Water and Atmospheric Research (NIWA) has recently developed a national database for the fauna and flora of freshwater springs in order to increase our knowledge and raise the awareness about these special habitats (Scarsbrook *et al.* 2005).

Waterways are important for Christchurch. Natural asset condition reports of the city's four catchments have been prepared (e.g. Barker *et al.* 2005a, 2005b), and numerous local studies exist for fish and invertebrate communities. However, the ecology of the city's springs has not been previously investigated and is not well understood. Many springs and headwaters have dried up in the past, and changes in land use are thought to cause further loss of spring flow amenity values, habitats and biodiversity.

On a catchment level, Christchurch City Council (CCC) has identified and mapped 31 springs in the Styx catchment. The identification of priority conservation sites aims to enable a focused allocation of resources and to facilitate community-based monitoring of a manageable number of habitats. It can also be used to support public involvement in hands-on spring habitat revitalisation projects. Similar programmes have been applied in Europe and have proven successful to stop the decline in biodiversity.

2 This Report

This report identifies priority spring conservation sites in the Styx River catchment, provides guidelines for habitat management to achieve the desired environmental outcomes, and proposes a community based monitoring program.

2.1 Objectives

The objectives of this report are:

1. To identify and designate six priority conservation sites of significant spring habitats based on physical habitat features and biodiversity data.
2. To raise public awareness and improve our understanding of springs in the Styx River catchment.
3. To develop habitat management objectives that preserve and enhance the ecological values of six selected springs with high natural assets.
4. To provide monitoring guidelines for members of the community. The guidelines aim to detect negative effects from land use changes in the catchment such as falling water levels or reduced water clarity, as well as positive changes from improved habitat management. The community based monitoring program enables volunteers to recognise occurring changes and threats as early as possible. It will also raise community awareness and understanding of the catchment's springs as an important habitat.
5. The monitoring results will be made publicly available on the Styx website (www.thestyx.co.nz), which will be regularly updated as new monitoring results become available.

3 Methodology

3.1 Data mining

The identification of the most significant spring habitats in the Styx River catchment is based on the analysis of two CREAS data sets (2004/05 and 2007), and discussions with CCC staff. Ilja Van Nieuwpoort, CCC Senior Information Technician partitioned out spring habitats larger than 1 metre in diameter from the CREAS data set. Christine Heremaia, Dr Trevor Partridge, Peter Hayward and Manfred von Tippelskirch referred me to springs that were known to them or identified during the CREAS fieldwork in 2005 and 2007.

There has been no formal review or process for tracking springhead restoration in New Zealand. Hence, the identification of priority conservation sites and suggested habitat management objectives are based on the obvious management need, proven river management tools and professional estimates, rather than on unbiased empirical approaches.

3.2 Investigations

3.2.1 Functional feeding groups

Functional feeding groups were assigned to all invertebrate taxa by categorising their food preference in order to describe the food web of the spring communities (refer to chapter 4.4 for details).

3.2.2 Biodiversity index and taxa number

A Surber sampler (500 cm^2, 0.5 mm mesh) was used to collect ten stratified random samples to achieve in a total sampled area of 0.5 m^2 per spring on each sampling date. Depending upon the substrate composition, the ten Surber samples were taken in the meso-habitats of submerged aquatic plants, organic debris, different grain sizes of mineral substrates and riparian margin according to the Sampling Protocol C2, (Stark *et al.* 2001).

Spring No. 6 is not wadeable, and stratified Surber samples that represent 0.5 m^2 could not be taken; a qualitative sample of the shallower parts of the spring pond was taken instead. This 'incomplete' sample of the limnocrene did not allow for a comparative analysis of biodiversity and functional feeding groups.

The field survey doubled as a test-run for the monitoring survey data sheets. Physical and legal access and security issues were identified.

Biodiversity indices for the spring communities were calculated with the Shannon-Wiener Index[5]. The Shannon-Wiener index is defined as:

$$H = -\text{sum}\ (p_i * \ln\ [p_i])$$

[5] The index has also been called the Shannon-Weaver index, or Shannon index. It is a measurement that takes into account species richness and proportion of each species within the community. The index comes from information science.

The first step is to calculate p_i, which is the abundance of a given taxon divided by the total number of the individuals found at the spring. Than this number is multiplied by the log of the number. While you may use any base (e.g. 10), the natural log (ln) is commonly used. Shannon-Wiener's biodiversity index is simply the negative sum of each of the pi*ln [pi] values. The index is a measure that accounts for both species richness and the proportion (or evenness) of each species of the community. It has been a useful tool to terrestrial and aquatic ecologists for many years and helps to understand the structure of a community. It also allows a ranking of different habitats based on numerical values.

4 Priority conservation spring habitats in the Styx River catchment

4.1 Spring types

Early in the history of hydrobiology, Steinmann (1915) used prevalent flow patterns in order to describe and classify springs into three basic types:

a. **Limnocrenes**: Groundwater emerges at the bottom of a lake. Limnocrenes have many similarities to small cold mountain lakes. The clearly defined pond of Spring No. 3 is a good example of a limnocrene in the Styx catchment.

b. **Rheocrenes**: The emerging groundwater forms the headwater of a watercourse; resembling first order streams. The groundwater vents along the Styx headwaters upstream of Gardiners Road Bridge are rheocrenes.

c. **Helocrenes**: Groundwater emerges by diffuse seepage in soft sediment, often forming spring-fed marshes. Many springs of the natural Styx River catchment are thought to have been helocrenes. Today an extensive network of drainage channels drains the water from most of the formerly marshy areas to allow agricultural or urban landuse.

Despite many weaknesses, and apparently because of its simplicity Steinmann's typology has endured generations of limnologists, and is still used today. Although most springs in the Styx River catchment show features of more than one of the categories, the typology is useful and enables a basic description of the spring that gives biologists an idea of what can be expected.

Most springs in the Styx River catchment are rheocrenes; the groundwater emerges either within the mainstem of the river or drainage canal, or in off-channel habitats such as sloughs, alcoves or small side channels. Most helocrenes are drained, and Spring No. 3, for instance is a stunning limnocrene. Today, an extensive network of drains lowers the near-surface groundwater table in most parts of the catchment collecting water that was probably forming a mix of rheocrenes and helocrenes (in swamps) in the natural landscape.

4.2 Spring names

None of the investigated springs are formally named. Christchurch City Council is currently developing guidelines for naming of public spaces and features adjacent to waterways and wetlands in the Styx catchment, and proper naming will be based on these (Heremaia 2007).

An overview of the investigated springs, their geographic location, and the nearest street address is given in Table 1.

Table 1. Location of six priority conservation spring sites in the Styx River catchment.

Number	Spring No. 1	Spring No. 2	Spring No. 3	Spring No. 4	Spring No. 5	Spring No. 6
Spring type	Rheocrene	Rheocrene	Limnocrene	Rheocrene	Rheocrene	Limnocrene
Sub-/ Catchment	Styx headwater	Styx	Styx	Kaputone	Kaputone	Styx/Avon Catchment Drain network
GPS: Northing	5748394	5748884	5749131	5750395	5750873	2479562
GPS: Easting	2477392	2476872	2479511	2480817	2481781	5746154
Street address	161 Gardiners Rd	330 Styx Mill Rd	33 Willowview Drive	Belfast Rd east of Blakes Rd	34 Guthries Rd	470 Cranford St

4.3 Aquatic invertebrates of springs in the Styx River catchment

Recent research has identified a huge diversity of spring fauna, particularly within the Hydrobiidae (Mollusca) and groundwater amphipods (Scarsbrook *et al*. 2005, Sutherland 2005). However, much of this detailed knowledge is inaccessible to ecologists and managers, due to the highly specialised nature of species identification in these groups.

Flatworms (Turbellaria, or triclads) occur in large numbers in Spring No. 1, and are thought to represent two species, *Cura pinguis* (the common lowland flatworm), and *Spathula fontinalis*, a species, which Nurse (1949) described as *'found abundantly in small streams from springs which have a soft bottom, few stones and a good growth of water cress'*. However, currently neither local nor regional authorities seldom identify triclads as abundant in their aquatic monitoring programmes (Figure 1).

The taxa list should therefore to be considered as 'work in progress' that is expected to extend in the future when new simplified species identification tools become available, and members of the community monitoring team are able to increase the resolution of their identified taxa.

Figure 1. Flatworms (Turbellaria): The common lowland triclad *Cura pinguis* (left) and the rare (?) *Spathula fontinalis.* The identification of *Spathula* is not verified.

Phreatogammarus c.f. *fragilis* specimens found in the Styx headwater were larger than any of the subterranean crustaceans that occasionally occur in invertebrate samples around Christchurch (McMurtrie, pers. comm.) (Figure 7). With a body length of up to 13 mm (21 mm total) these blind and unpigmented crustaceans are one of the largest subterranean, cave-dwelling forms in Canterbury (Winterbourn 1983, Chapman & Lewis 1976). Very little is known about their biology.

The Styx River supports a more diverse and abundant aquatic invertebrate fauna than either the Avon or the Heathcote Rivers (Taylor 1999). Further, the Styx River's invertebrate fauna was found to be more uniformly distributed and abundant – of particular note is the abundance of caddis fly larvae – compared to their relative paucity in the Avon and Heathcote.

The springs' fauna was sampled in late summer (April) 2007. In addition an earlier sample from Spring No. 3 (taken in September 2006) was included in the taxa list. Late summer is a time where fewer taxa can be found than in springs. Spring No. 6 was excluded from the analysis due to the different sampling method (see chapter 3.2).

4.4 Habitat and food webs of aquatic invertebrates

Many of New Zealand's aquatic invertebrates are feeding generalists. The familiar horny cased-caddisfly *Olinga,* for instance usually feeds by browsing and shredding, but will also scavenge carcasses of fish or other invertebrates. Crayfish can be considered the ultimate omnivorous feeding generalist and can legitimately be placed in just about any recognised feeding group such as detritivores, filter feeders, shredders (herbivores) and predators (Huryn *et al*. 2003).

Nevertheless, *main* functional feeding groups can be assigned to most invertebrate taxa by categorising their food preference in order to describe the food web of the invertebrate community. For this purpose the main functional feeding groups predators, herbivores and detritivores were assigned to the 45 taxa in Table 2.

Ecologists have analysed food webs of aquatic invertebrate communities in order to explain how different organisms within an ecosystem feed upon one another. The three main levels (1) predators, (2) detritivores, and (3) herbivores correspond to the various 'job descriptions' within an ecological community.

Job description: Predators

> Predators are often large and fast invertebrates such as damselflies. They get their energy by devouring other animals. Top predators in the Styx River catchment springs are the damselflies and triclads.

Job description: Herbivores

> Herbivores are scrapers, grazers or piercers that eat producers; i.e. plants such as algae or higher aquatic plants. The snail *Potamopyrgus* and the mayfly *Deleatidium* are typical herbivores occurring in the springs of the Styx catchment.

Job description: Detritivores

> Detritivores are shredders, collectors or filter feeders that eat a mixture of leaf litter, woody debris and the bodies of dead organisms. Detritivores that deal with coarse debris like leaves are shredders; they break the leaves down into smaller pieces until it becomes a cloud of particles that collectors and filter feeders utilise.

4.4.1 Top-down and bottom up controlled spring communities

The six springs display remarkably different food webs, which is thought to be a function of their degree of shading and siltation. Mature riparian trees shade the riverbed and limit the productivity of the biofilm in the Styx River headwater Spring No. 1 (Figure 6). The trees also shed leaves and branches; i.e. provide coarse particulate organic matter (CPOM) for detritivores like shredders, collectors and filter feeders. The result is a food web where predators like the triclads *Cura pinguis* and *Spathula fontinalis* are more dominant than in all other investigated springs. At Spring No. 1 seven percent of all individuals are predators, compared to three percent in Spring No. 3 and No. 5, and 1% in Spring No. 4. The Spring No. 4 sample did not contain any predators (Figure 2). Consequently, the Spring No. 3 can be described as top-down controlled where predators reduce the naturally lower numbers of herbivores and detritivores even further.

The other 5 springs are characterised by insignificant numbers of predatory invertebrates, or the apparent absence of them in the Kaputone's Spring No. 4, and thus can be described as bottom-up controlled communities. Thick layers of silt and/or excessive growth of macrophytes support large numbers of detritivores like the omnipresent crustacean *Paracalliope fluviatilis*, or the herbivorous and just as omnipresent snail *Potamopyrgus antipodarum*. The lack of gravelly substrate (100 % embeddedness in most parts of these springs) in combination with the lack of shelter and habitat for bottom-dwelling predators is thought to be responsible for the lack of predators in silted and overgrown springs.

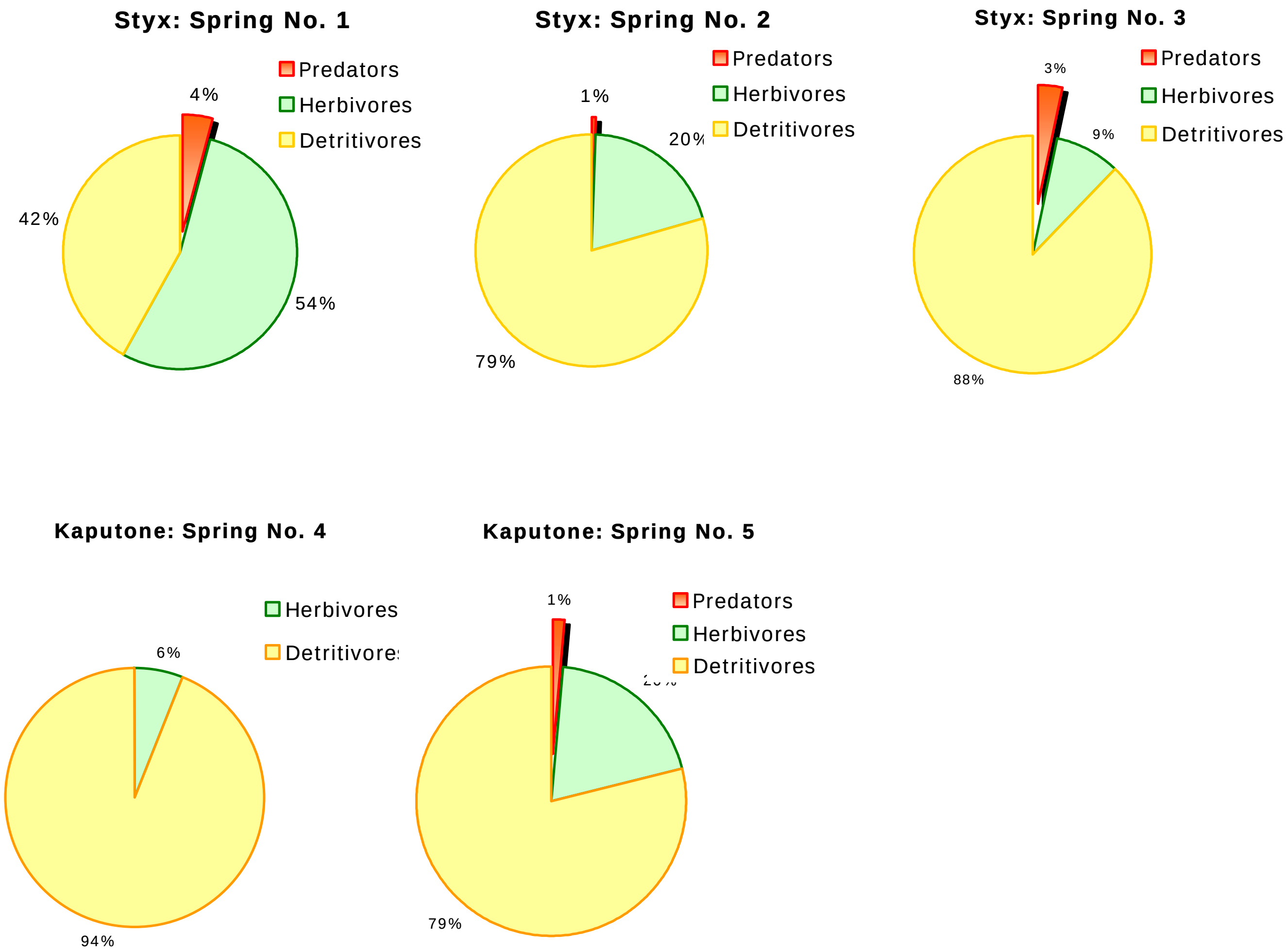

Figure 2. Functional feeding groups (predators, herbivores, detritivores) of aquatic invertebrates in five springs in the Styx River catchment. Spring no. 6 was excluded from the functional feeding group analysis due to the different sampling method.

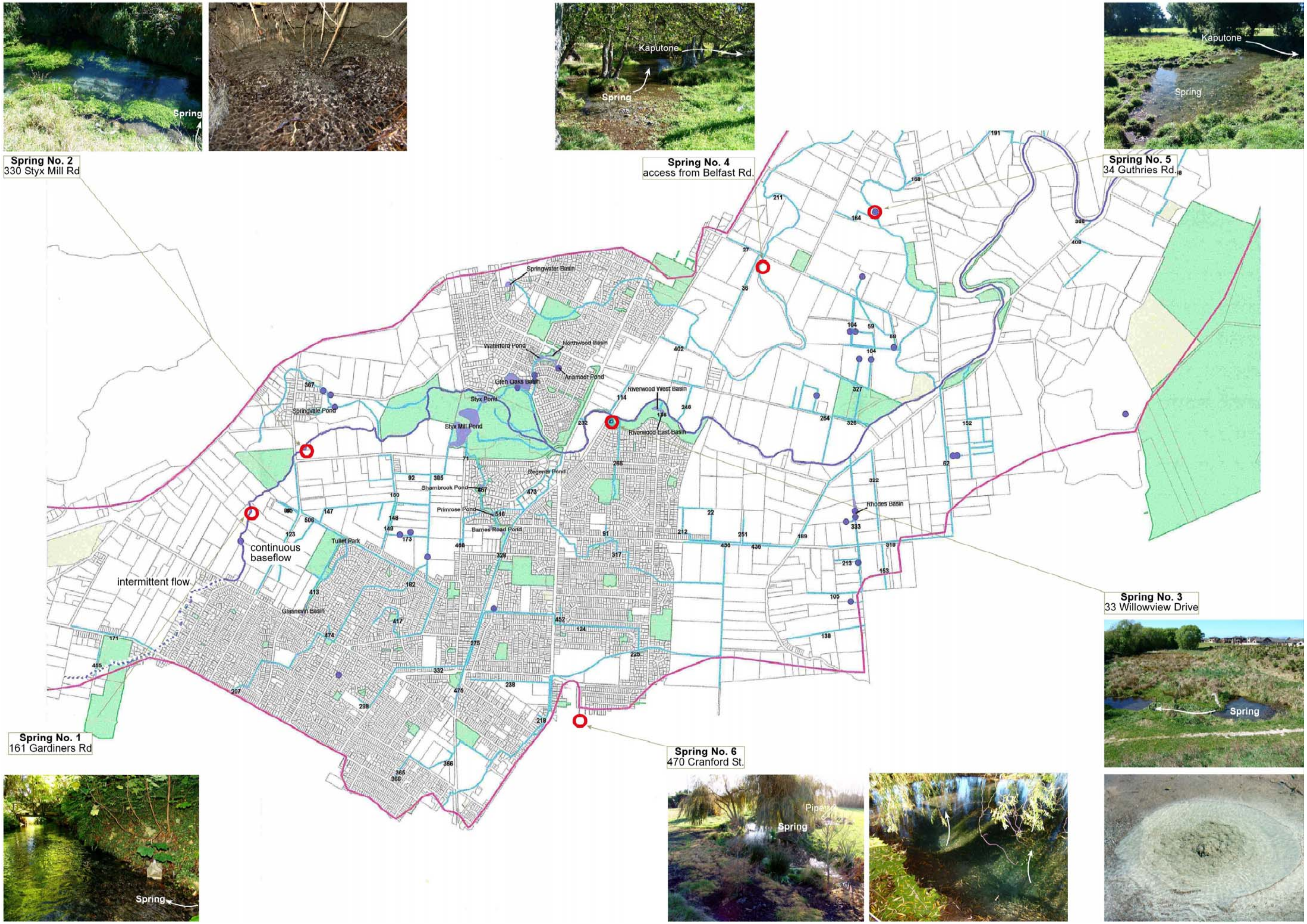
Spring
Spring No. 2
330 Styx Mill Rd
Kaputone
Spring
Spring No. 4
access from Belfast Rd.
Kaputone
Spring
Spring No. 5
34 Guthries Rd.
Springwater Basin
Waterford Pond
Northwood Basin
Anamoor Pond
Glen Oaks Basin
Styx Pond
Styx Mill Pond
Springvale Pond
Riverwood West Basin
Riverwood East Basin
Regents Pond
Shambrook Pond
Primrose Pond
Barnes Road Pond
Tullet Park
Glasnevin Basin
Rhodes Basin
continuous baseflow
intermittent flow
Spring No. 3
33 Willowview Drive
Spring
Spring No. 1
161 Gardiners Rd
Spring
Spring No. 6
470 Cranford St.
Pipe
Spring

Figure 3 (previous page). Location of investigated priority conservation springs in the Styx River catchment.

Table 2. Aquatic invertebrates of six springs in the Styx River catchment.

				Spring No. 1	Spring No. 2	Spring No. 3(a)	Spring No. 3(b)	Spring No. 4	Spring No. 5	Spring No. 6
		Catchment/sub catchment		Styx	Styx	Styx	Styx	Kaputone	Kaputone	Styx/Avon
Taxa			FFG	$0.5 m^2$	$0.5 m^2$	$0.5 m^2$	$0.5 m^2$	$0.5 m^2$	$0.5 m^2$	qualitative sample
				Apr-07	Apr-07	Sep-06	Apr-07	Apr-07	Apr-07	Apr-07
Crustacean		Cladocera	D			4		52	50	
		Copepoda	D			48				
		Ostracoda	D			95	14			
		Paracalliope fluviatilis	D	340	1440	5448	3376	540	286	
		Phreatogammarus spp.	D	18						
		Paraleptamphopus sp.	D	10	10		8	2	2	
Diptera										
Ceratopogonidae sp.			H		10		4	2		
	Empididae	sp.	H			1				
	Ephydridae	sp.	H			2		4		
	Chironomidae	Orthocladiinae	D	2		251		46	5	
		Tanypodinae	D			3				
		Tanytarsini	D		12	8	18	14		
		Chironomus sp.	D	6		14				
	Simuliidae	Austrosimulium	D				1			
	Tipulidae	sp.	D				2			
	Dixidae	Nothodixa/Paradixa	D				1		2	
	Psychodidae	sp.	H				1			
	Muscidae	sp.	D						1	
Hemiptera		*Sigara* sp.	H			2				+
		Microvelia. Sp.	H				1			
Mollusca		*Physa/Physella* sp.	D			131	22	4	3	+++
		Pisidium sp.	D	4		6	2	15		
		Potamopyrgus antipodarum	H	464	360	446	198	38	84	+++
Nematoda		Nematoda	D			14				
Oligochaeta		Oligochaeta	D	8	2	37	18	8	28	++
Turbellaria		*Cura pinguis*	P	19	6	2	4		4	+
		Spathula fontinalis	P	12	2		2		1	
Coleoptera		*Dytiscidae* sp.	P		2					
Trichoptera		*Oecetis unicolor*	P			3				
		Oeconesus sp.	H	20		1				
		Oxyethira albiceps	H			46	17		10	
		Paroxyethira hendersoni	H			103	4			++
		Plectrocnemia	P							
		Polyplectropus sp.	P	3		2	8			
		Psilochorema sp.	P	1		1	8			
		Pycnocentrodes sp.	H	6		20				
		Pycnocentria sp.	H	3		2				
		Edpercivalia sp.	P	2						
		Triplectides cephalotus	D	2		2				
		Triplectides obsoletus	D	3		2				+
		Hydrobiosis parumbripennis	P	2						
		Hudsonema amabile	P	1						
Ephemeroptera		*Deleatidium* sp.	H	12						
Zygoptera		*Austrolestes colensonis*	P			18	1			
		Xanthocnemis zealandica	P			202	14		2	+
Sum of taxa				**21**	**9**	**29**	**22**	**11**	**13**	**(8)**
Biodiversity index (Shannon-Wiener)				**1.36**	**0.64**	**0.98**	**0.39**	**1.03**	**1.29**	
Main Functional Feeding Group			P = predators			H = herbivores: scrapers, grazers, piercers			D = detritivores: shredders, collectors, filter feeders	

4.5 Taxa numbers and diversity

The number of taxa per spring and the Shannon-Wiener's diversity index strongly correlates in four out of five springs. The highest diversity index (1.32) was computed for Spring No. 3 in the Styx headwater where 21 taxa were found (Table 2, Figure 4). Only nine taxa were recorded in the Hobday spring, which had low a diversity index of 0.64.

The highest taxa number in the April sample series (22) was recorded in Spring No. 3. However, the dominant abundance of the amphipod *Paracalliope fluviatilis* lowers the diversity index to 0.47. The September sample of Spring No. 3 contained 29 taxa and had a much higher diversity index of 0.98 (Figure 4).

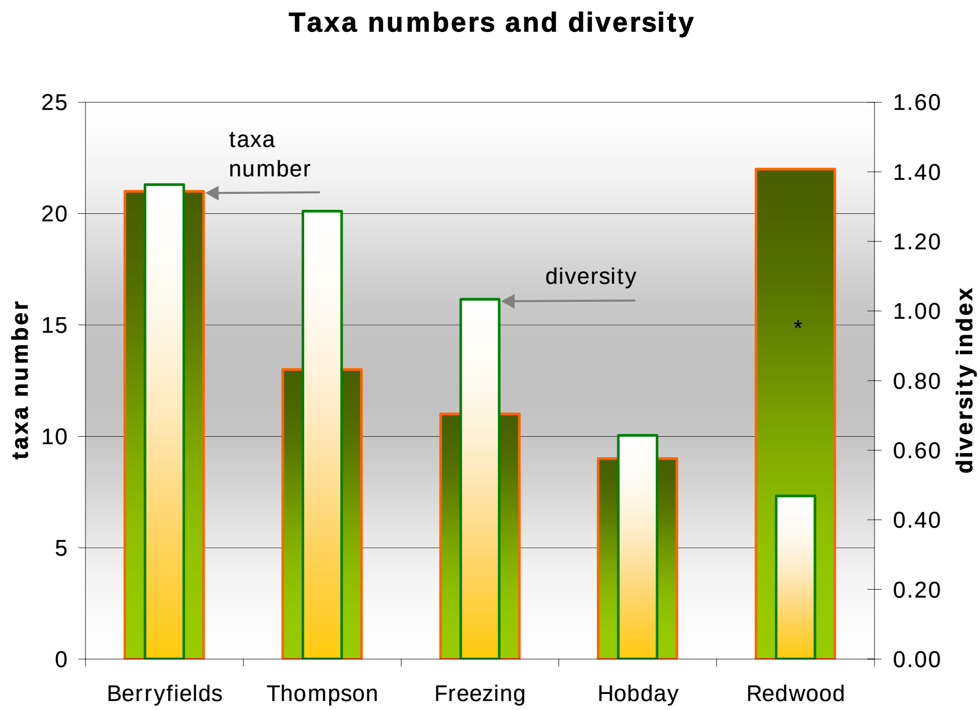

Figure 4. Taxa number (broad columns, left y-axis) and Shannon-Wiener diversity index (narrow columns, right y-axis) of five springs in the Styx River catchment based on an April 2007 sample. The asterisk at the Spring No. 3 indicates a diversity index of 0.98 from a September 2006 sample.

4.6 Habitat Management Objectives

4.6.1 Logical structure of management objectives

It is generally accepted that catchment management objectives should focus on maintaining and restoring natural processes that create and preserve habitat rather than manipulating instream habitat (Roni *et al.* 2002).

Consequently, objectives presented here are based on three elements: (1) protection of existing high quality habitats, (2) protection and enhancement of natural catchment wide processes like spring flows, water quality and connectivity of different habitats, and (3) site specific techniques. On this basis the management objectives are structured hierarchically:

(a) Initial efforts should focus on the protection of high quality areas with good connectivity and intact biological processes.

(b) Catchment wide connectivity is considered (large scale). This includes the development of an integrated catchment management plan, stormwater and land-use impacts. An example for connectivity: Springs act as refuges for fish during flood events. Eight of the nine native freshwater fish species in the Styx River require sea access to complete their life cycle. Taylor *et al.* (2000) identified considerable scope in improving sea-going (diadromous) native fish habitat in the catchment, particular in the lower reaches.

(c) For springs with reasonably good connectivity within the catchment, efforts focus on restoring riparian and hydrologic processes (intermediate scale). All six springs have considerable scope to improve their riparian habitats.

(d) In-stream habitat enhancement on a local scale is employed after larger scale natural processes are restored. Siltation (both, suspended and settled) has broad implications on aquatic invertebrates and limits spring biodiversity severely. Silt and other fine particulate matter forms thick bed layers on five out of the six springs.

Table 3. General spring habitat management objectives based on issues and expected ecological outcome.

Issue	Explanation	Management objective	Ecological outcome
Discharge of untreated and unattenuated stormwater	Untreated stormwater discharges silt. Siltation is identified to be the single most important issue limiting the habitat quality in the catchment's springs.	Retrofit untreated and stormwater discharge. Flood attenuation is of lesser concern in the Styx.	Some of the silt that clogs the sediment is transported downstream. Embeddedness decreases in some areas.
The springs in the headwater are dry; the original headwater is a dry stormwater swale.	Changes in the hydrologic regime are thought to be due to increased impervious surface area and drainage of near surface groundwater	Monitor stormwater runoff in upstream subdivisions to assess its impact (if any) on the current headwater springs.	Currently high ecological values of the headwater along Gardiners Road are maintained. Species richness increases over time.
Migration barriers	Weirs and pipes fragment the river continuum into island habitats	Increase instream and riparian connectivity to allow up- and downstream migration.	Increased biodiversity.

Table 2 (cont.)

Issue	Explanation	Management objective	Ecological outcome
Riparian damage caused by stock or the public	Springs are much more sensitive to riparian damage than rivers. Stock access causes siltation, loss of riparian habitat, lack of shading, increased summer temperatures.	Establish buffer zones. Prevent trampling on a minimum of several meters on each side of the springs. Exclude stock and manage visitors. Financial compensation might be necessary.	Intact land/water gradient of aquatic, riparian and terrestrial habitats. Species richness and habitat diversity increases significantly.
Exotic macrophytes: ▪ *Nasturtium officinale* (Watercress) ▪ *Potamogeton crispus* (Curly pondweed)	Watercress and/or curly pondweed grow excessively in some springs and cover the entire aquatic habitat. But exotic or not – most aquatic invertebrates were found in submerged vegetation.	Plant riparian vegetation that provides shade. Reduce nuisance growth only partly and replace with native *Potamogeton cheesemannii* and *Myriophyllum propinquum*.	Natural plant diversity is maintained.
Exotic riparian forest	Native riparian forest species are replaced (mainly by European willows) and other species.	Replace exotic trees carefully; leave canopy intact. Establish indigenous riparian flora and control natural succession.	Indigenous riparian forest is established over time. Spring species are adapted to shade, limited nutrient input, limited temperature variance.

5 Investigated springs

5.1 Spring No. 1 (Styx River headwater)

Based on city council information 11 spring vents currently form the headwaters of the Styx River between Sawyers Arms Road and Gardiners Road (Figure 5). No baseflow exists upstream of Sawyers Arms Road, however, the old riverbed periodically discharges treated stormwater from upstream subdivisions.

Figure 5. Spring locations in the headwaters of the Styx River. The once perennial baseflow upstream of Gardiners Road is reduced to intermittent flows of (mainly) stormwater.

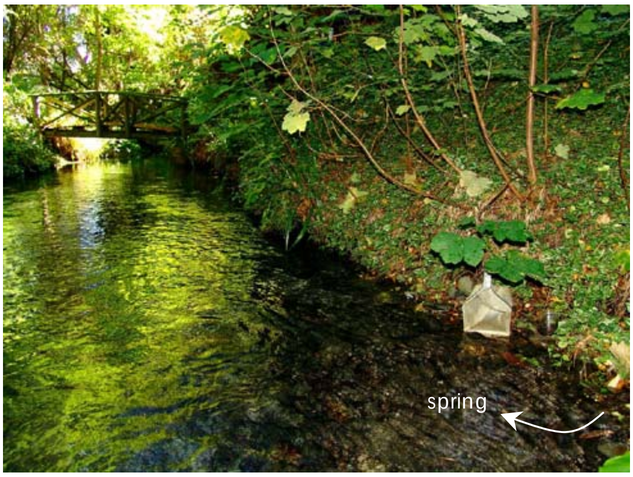

Figure 6. Spring No. 1 at the true right bank of the Styx River headwater at the back of 161 Gardiners Road (top) and detail of groundwater vent (bottom).

Habitat Location and Description

Location: NZMS 260-M35: 4839-7739

Spring type: In-stream rheocrene at the bottom of the true right bank (Figure 6).

Sediment: The sediment is a mix of sand and cobbles with high organic and mineral substrate diversity. It appears to be in its natural state.

Baseflow: According to neighbouring residents the investigated spring vent has perennial flow of clear water. The estimated discharge at the time of inspection was 5-10 l/s.

Riparian vegetation: Established forest of deciduous trees. Understorey and overstorey (moss/grass, bush, trees) consist of exotic species; native riparian vegetation is virtually absent.

Access

The esplanade strip grants public access along the river between CCC's nursery in Harewood Park and the upstream boundary of 161 Gardiners Road. As a courtesy, residents can be contacted prior to "intruding" their backyard.

Aquatic Invertebrates

The fauna of the investigated spring vent at Spring No. 1 stands out in many respects: It is the only habitat where the large subterranean amphipod *Phreatogammarus* was found, although *Paraleptamphopus* is also present along with the ubiquitous *Paracalliope fluviatilis*. *Phreatogammarus* specimens were 13 mm in body length (21 mm total), which is considerably larger than any of the subterranean crustaceans that occasionally occur in invertebrate samples around Christchurch (McMurtrie, pers. comm.) (Figure 7).

Secondly, Spring No. 1 is the only spring where the clean water indicating mayfly *Deleatidium* was found, and larger numbers of predatory triclads than in any of the other samples. Of particular note is also the abundance of caddis fly larvae, which were represented by 10 taxa, with three species identified that were not recorded in any of the other springs.

Of note, 12 bully eggs were in the sample - with the fry clearly visible in all.

Based on taxa number and composition, the high diversity index, low degree of substrate embeddedness with no significant siltation, it is assessed that this stretch of the Styx River outranks all other springs in terms of biological significance for the catchment.

Figure 7. Amphipods collected at the Styx headwater: Size comparison of two subterranean species *Phreatogammarus* c.f. *fragilis* (body length 13 mm, overall 21 mm), *Paraleptamphopus* and *Paracalliope fluviatilis* (3 mm) (top to bottom). *Phreatogammarus* of this size has not been reported previously for Christchurch.

Habitat Management: Issues and Objectives

No issues need to be addressed urgently. The connectivity of the habitats is very good, as the riverbed is more or less in its natural state. Consequently, habitat management objectives focus on maintaining the current water quantity and quality. Careful replacement of exotic riparian vegetation with natives (leaving the canopy more or less intact) should be considered.

Objective 1: Monitor stormwater runoff quality from upstream subdivisions during storm events to ensure that the high water quality is maintained.

Objective 2: Monitor discharge volume. The discharge of vents can easily be measured by placing a plastic bag with a known volume over the vent while a second person measures the time that it takes to fill the bag. The discharge is expressed in l/sec. Alternatively, a council operated flow monitoring station could monitor the total of the spring vents' discharge below the significant clusters at Harewood Park.

Objective 3: Schedule replacement of exotic trees by leaving the canopy more or less intact, and plant an indigenous understorey. Establish indigenous flora of appropriate genetic provenance and leave forest to controlled natural succession. When exotic trees surround springs the canopy should not be removed to avoid full exposure to sunlight and increased temperature variance. The conversion to indigenous vegetation can be achieved within 10-20 years; i.e. in three to four interventions.

The headwater of the Styx River contains by far the largest and most spectacular clusters of spring vents in the Styx River catchment. Both, diversity and faunal integrity based on functional feeding group outrank all other investigated springs.

Conservation should be of highest priority.

Community Monitoring

The general monitoring survey as outlined on the Styx website. In addition:

- Monitor first flush stormwater runoff quality during storm events upstream of the spring vents; e.g. at the Sawyers Arms Road Bridge and assess whether it impacts on the quality of the current headwater.
- The installation of a flow-monitoring station downstream of the first cluster of groundwater vents (at 123 Gardiners Road) could be considered. This would provide reliable discharge data from the uppermost vents and indicate if the current headwaters of the Styx are stable or are of reducing flow regime.

5.2 Spring No. 2 (Styx catchment)

Figure 8. Spring No. 2 at the true right bank of the lower Styx River headwater at 330 Styx Mill Road (top), and detail of two of the vents (bottom left), and watercress *Nasturtium officinale* in the spring.

Habitat Location and Description

Location: NZMS 260-M35 4888:7687

Spring type: Side-channel rheocrene at the bottom of the true right bank.

Sediment: The sediment is soft sand and silt with remnants of rubbish (metal) and some coarser material.

Baseflow: Perennial baseflow is assumed. Cluster of four to five groundwater vents.

Riparian vegetation: Overstorey is missing. Understorey consists of mainly exotics like blackberry and *Convolvulus.* The spring habitat is currently overgrown, mainly with blackberries and *Convolvulus* along the riparian margins, and watercress *(Nasturtium officinale)* in the riverbed.

Aquatic Invertebrates

The faunal integrity of the Hobday Spring is currently very low; the spring comprises nine taxa. The omnipresent small crustacean *Paracalliope fluviatilis* dominates the community, and caddisflies are absent (Table 2). This results in a low diversity index of 0.64 (Figure 4).

Habitat Management: Issues and Objectives

Issues: Exotic riparian vegetation has overgrown the spring completely.

Habitat management objectives focus on riparian restoration, i.e. removing rubbish, cutting back and replacing exotic vegetation with natives. Some key aquatic and riparian flora species recommended are listed in Table 4 below.

Aquatic habitat restoration: It is desirable to replace the watercress with *Myriophyllum propinquum* and *Potamogeton cheesemannii*. The plants can be sourced in local streams. It is suggested to hand-weed the watercress and pondweed, and re-plant the short spring creek with *Myriophyllum propinquum* and/or *Potamogeton cheesemannii*.

Figure 9. Desired submerged aquatic plants *Myriophyllum propinquum* (far left) and *Potamogeton cheesemannii* (centre and right).

Riparian habitat restoration: The riparian species listed in Table 4 are capable of forming a stable buffer zone around the spring margins. Riparian plants provide shelter, shade and food in form of woody debris, leaf litter and other coarse particulate organic matter (CPOM). They should be selected and planted to achieve a partly shaded spring habitat, once the vegetation is established.

Table 4. Suitable aquatic and riparian plants for plantings around springs and spring streams. Note that more species than shown are suitable for the upper banks.

Plant species	Habitat			
	Aquatic	Water's edge	Lower bank	Upper bank
Myriophyllum propinquum	■			
Potamogeton cheesemannii	■			
Typha orientalis	■	■		
Schoenoplectus validus	■	■		
Eleocharis acuta	■	■	■	
Carex secta		■	■	
Carex maorica		■	■	
Blechnum minus, B. chambersii, B. fluviatile		■		
Cyperus ustulatus		■	■	
Phormium tenax		■	■	■
Juncus gregiflorus, J. pallidus, J. sarophorus			■	■
Coprosma propinqua, C. pedicellata, C. parviflora			■	■
Myrsine divaricata			■	■
Leptospermum scoparium			■	■
Dacrycarpus dacrydioides			■	■

Community Monitoring

The general monitoring survey as outlined on the Styx website is to be used to monitor the transition to natural riparian margins, shading and substrate composition.

The success of the habitat restoration process is monitored by two invertebrate samples in spring and summer.

> The large size of the groundwater vents, and the presence of a short spring creek (a side channel to the Styx River) represent a large potential for restoration that extends the currently low ecological values.

5.3 Spring No. 3 (Styx catchment)

Habitat Location and Description

Location: NZMS 260-M35 4913:7951

Spring type: side channel limnocrene with a short spring creek on the true right bank of the Styx River.

Sediment: Soft sand in the spring bowl (wadeable), gravel in the upper spring creek and un-wadeable silt in the lower spring creek before its confluence with the Styx River.

Baseflow: Perennial baseflow. Three to four large clusters of groundwater vents.

Riparian vegetation: Overstorey is missing. Understorey of mainly exotic grasses. The spring creek, which is where the bulk of the aquatic invertebrates are is overgrown with watercress (Figure 10).

Figure 10. Spring No. 3 at the true right bank of the Styx River, north of Redwood subdivision. Overview (top), overgrown spring creek (bottom left), spring bowl with the most scenic sand 'volcanoes' in the catchment (bottom right).

Access

Road access is from 33 Willowview Drive, and the spring is publicly accessible. The spring is located in the reserve to the north, east of the railway line.

Aquatic Invertebrates

The spring creek shows much higher invertebrate abundances than the spring bowl. The sandy areas of upwelling groundwater are uninhabitated. A total of 36 taxa are recorded from two samples. The autumn sample comprised 22 taxa, whereas 29 taxa were recorded in a September 2006 sample (Table 2). A noticeable feature of the spring creek is the remarkable caddisfly diversity represented by nine species.

Habitat Management: Issues and Objectives

Issues: Lack of shading, exotic vegetation and some riparian damage are the main issues.

Habitat management objectives focus on riparian restoration, i.e. removing rubbish and replacing exotic vegetation with natives that will partly shade the spring area in the future.

Aquatic and riparian vegetation: It is desirable to replace the watercress and curly pondweed with *Myriophyllum propinquum* and *Potamogeton cheesemannii* Figure 9. The plants can be sourced in local streams. It is suggested to hand-weed the watercress and pondweed, and re-plant the spring area in two consecutive years, reducing the loss the spring bowl area in one winter and the spring creek area during the next winter in order to maintain undisturbed re-colonisation areas for invertebrates.

Some key aquatic and riparian flora species recommended are listed in Table 4. These species are capable of forming a stable buffer zone around the spring margins and will form both, a visual backdrop and natural barrier that channels visitors. Riparian plants provide shelter, shade and food in form of woody debris, leaf litter and other coarse particulate organic matter (CPOM). The landscape plan aims to achieve a partly shaded spring habitat, once the vegetation is established.

Community Monitoring

The general monitoring survey as outlined on the Styx website is to be used to monitor the transition to natural riparian margins, shading and a natural substrate composition.

The success of the habitat restoration process is monitored by two invertebrate samples in spring and summer. Note that the spring bowl is wadeable but virtually uninhabitated; hence there is no need to take samples there. Most aquatic invertebrates are in the submerged aquatic plants and gravelly substrate of the spring creek.

Spring No. 3 is the largest limnocrene in the catchment with currently high instream values in the spring creek and significant potential for restoration.

5.4 Spring No. 4 (Kaputone Creek)

Habitat Location and Description

Location: NZMS 260-M35 5039:8081

Spring type: Side channel rheocrene.

Sediment: Gravel and sand in the area of emerging groundwater; a thick layer of silt covers the rest of the spring creek to its confluence with the Styx River.

Baseflow: Perennial baseflow is assumed. Groundwater is seeping through the sediment.

Riparian vegetation: Overstorey comprises mature elder trees. Understorey of mainly exotic grasses riparian damage from stock access.

Access

The spring is situated on the true right bank of the Kaputone approximately 100 metres south of Blakes Road.

Figure 11. Spring No. 4 at the true right bank of the Kaputone mid reaches near the Blakes/Belfast Road intersection. Groundwater emerges from the unsilted area.

Aquatic Invertebrates

The aquatic invertebrate community of the April 2004 sample was inconspicuous and comprised only 11 taxa with the omnipresent amphipod *Paracalliope fluviatilis* as the most abundant species, followed by small Cladocera, chironomids and the ubiquitous snail *Potamopyrgus antipodarum.* Hyporheic species, caddisflies and mayflies were absent. This is the only spring where no predatory invertebrates were found (Figure 2).

Most taxa and individuals are concentrated in the small un-silted patch where groundwater emerges; only few *Paracalliope* and snails inhabit the thick layer of silt in the rest of the habitat and in the short spring creek towards Kaputone Creek.

Habitat Management: Issues and Objectives

Issues: Livestock has grazed the riparian vegetation of the Spring No. 4. This caused stream bank erosion, siltation, decreased water quality and changes in the riparian water table. Siltation is the most important issue to be addressed.

Objective 1: restore native aquatic and riparian vegetation with species listed in Table 4. Stock appears to be excluded by now but the extend of previous damage to riparian margin and very low current velocities leaves little hope that the spring will recover to its natural state by simply planting native riparian vegetation.

Objective 2: Silt removal with a suction truck in stages could be considered.

Objective 3: Initial plantings of submerged aquatic vegetation in gravel substrate (after silt removal) (Table 4) could be considered.

Community Monitoring

The general monitoring survey as outlined on the Styx website is to be used to monitor the transition to natural riparian margins, shading and a natural substrate composition.

The success of the habitat restoration process is monitored by two invertebrate samples in spring and summer. Note that the silted spring area is wadeable but virtually uninhabitated; hence there is no need to take samples there until the silt is removed. Most aquatic invertebrates are in the gravelly (unsilted) substrate where the groundwater emerges (Figure 11).

> The Spring No. 4 is the only spring in the Kaputone sub-catchment where a small un-silted patch remains. The invertebrate fauna of silted areas is depleted.

5.5 Spring No. 5 (Kaputone Creek)

Habitat Location and Description

Location: NZMS 260-M35 5087:8178

Spring type: side channel limnocrene on the true right bank.

Sediment: The sediment is wadeable. It consists of sandy gravel covered by a thick layer of silt.

Baseflow: Perennial baseflow is assumed. Numerous small groundwater vents.

Riparian vegetation: Overstorey is missing. Understorey of exotic grasses.

Figure 12. Spring No. 5 at the true right bank of the lower Kaputone.

Aquatic Invertebrates

Aquatic invertebrates of the April 2007 sample comprised 13 taxa of ubiquitous and lentic species. Nonetheless, the diversity index of 1.29 was comparatively high due to the relatively even spread of the taxa. The lack of submerged aquatic vegetation and lack of gravelly substrate result in low abundances.

Habitat Management: Issues and Objectives

Issues: For decades livestock grazed the riparian vegetation of the Thompson Spring. This caused stream bank erosion, spring habitat sedimentation and widening, increased temperatures, decreased water quality and changes in the riparian water table. Stock appears to be excluded by now but due to the extend of previous damage to riparian margin and very low current velocities, there is little hope that the spring will recover to its natural state by simply planting native riparian vegetation.

Objective 1: restore native riparian vegetation with species listed in Table 4.

Objective 2: Silt removal with a suction truck in stages can be considered.

Objective 3: Initial plantings of submerged aquatic vegetation in gravel substrate (after silt removal) (Table 4) can be considered.

Community Monitoring

The general monitoring survey as outlined on the Styx website is to be used to monitor the transition to natural riparian margins, shading and a natural substrate composition.

The success of the habitat restoration process is monitored by two invertebrate samples in spring and summer. The soft sediment in the spring area is wadeable. Most aquatic invertebrates are in the thin algae layer of the sediment.

The Spring No. 5 is a side-channel limnocrene of remarkable size. Revitalisation has the potential to develop it into a significant spring habitat, and a feature in a reserve area.

5.6 Spring No. 6

Habitat Location and Description

Location: NZMS 260-M35 7956:4615

Spring type: manmade limnocrene in a paddock. The spring drains into Tyson's Drain via a 73 meters long plastic pipe southeast of the spring (Figure 14).

History: Farmer Graeme Walsh excavated this medium-sized limnocrene in 1991 to collect emerging groundwater that previously formed a spring-fed marsh with several diffuse seepages. The pond was extended around 2002 to capture an additional seepage.

Figure 13. Spring No. 6 near 470 Cranford Street draining into Tyson's Drain near the southern watershed of the Styx River catchment. Recently extended part (foreground above), groundwater vents at the bottom of the lake (bottom left), and access footbridge (bottom right).

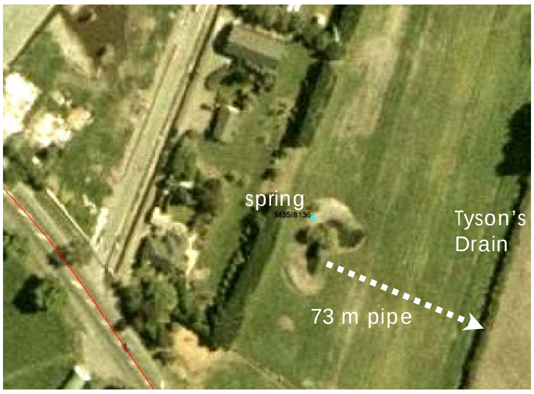

Figure 14. Aerial photograph of Spring No. 6 (limnocrene) east of 470 Cranford Street.

Sediment: The spring is too deep for waders. The sediment consists of sand covered with silt, except in areas where groundwater exfiltrates.

Baseflow: Perennial discharge is assumed from four to five more than one metre deep groundwater vents at the bottom of the pond. Estimated discharge at the point of inspection: 5-10 l/s.

Riparian vegetation: One approximately 15-year-old willow and understorey of exotic grasses with some native and exotic riparian plants.

Aquatic Invertebrates

The spring pond is not wadeable; hence a suitable invertebrate sample could not be taken with the Surber sampler close to the groundwater vents. A non-area specific sample of the vegetation above the substrate in the vicinity was taken instead. It comprised eight invertebrate taxa; none of them was rare or remarkable. The molluscs *Physa/Physella* and *Potamopyrgus antipodarum* were the dominant taxa. Oligochaetes and triclads *(Cura pinguis)* were present, as were lentic species like *Xanthocnemis zealandica* (red damselfly) and the waterboatmen *Sigara* (Table 2).

Habitat Management: Issues and Objectives

Issues: The riparian buffer is too narrow, herbicides have been used, and the drainage pipe obliterates the river continuum.

Objective 1: Excavate a spring creek between the pond and one of the nearby drains, preferably Tyson's Drain.

Objective 2: Enhance existing riparian vegetation. The current riparian vegetation provides little buffer and needs to be extended. Herbicides shall be avoided.

Objective 3: Silt removal with a suction truck can be considered after an adequate riparian buffer is established. Minimum width of the buffer is 3 – 5 metres.

Objective 4: Initial plantings of submerged aquatic vegetation after silt removal (Table 4) can be considered.

Community Monitoring

The general monitoring survey as outlined on the Styx website is to be used to monitor the transition to natural riparian margins and a natural substrate composition.

The success of the habitat restoration process is monitored by two invertebrate samples (not exceeding 0.5 m^2) in spring and summer. The soft sediment of the pond area is wadeable, however, a diverse aquatic invertebrate fauna is not expected before the spring is hydraulically better connected to the rest of the catchment, siltation is reduced and larger areas with submerged aquatic vegetation is established.

The Spring No. 6 is a large limnocrene with a great potential if connected to Tyson's Drain. Its location near the Styx/Avon watershed could serve as a stepping-stone that assists the dispersal of crenophile taxa.

6 Recipe for a healthy spring

6.1 Healthy springs

A healthy spring in the Styx catchment will show many of the following features:

- ✓ Good connectivity of the spring with the rest of the catchment. This includes terrestrial and in-stream connectivity; e.g. good fish access both to and from the main channel, and the sea.
- ✓ Riparian buffer is several metres wide: Native vegetation includes trees and provides shade on parts (50%) of the water surface.
- ✓ High water quality.
- ✓ High aquatic biodiversity; i.e. high and naturally spread numbers of invertebrate taxa including predators and fish inhabit the spring.
- ✓ Some submerged native aquatic vegetation (not excessive growth) suitable for spawning fish and providing food and habitat for invertebrates (this depends on the degree of shading).
- ✓ A range of sediment types dominated by sand or gravel and including some organic matter in form of leaves and wood.

6.2 Signs of unhealthy springs

Unhealthy springs in the Styx River catchment show one or several of the following:

- × Lack of connectivity both, terrestrial and aquatic. E.g. spring surrounded by monoculture, disconnected from the mainstem. Restricted fish movement due to barriers in the waterway or low water levels.
- × Lack of shade from riparian vegetation causing high water temperatures (>14°C) in summer and excessive growth of submerged (exotic) aquatic vegetation.
- × Bank erosion (e.g. from stock access).
- × Reduced baseflow or lack thereof during late summer when the near surface groundwater table is low.
- × Low levels of dissolved oxygen (<5mg/l) due to organic pollution of the groundwater.
- × Reduced clarity (< 100 cm) e.g. after storm events.
- × Low aquatic biodiversity; i.e. few ubiquitous invertebrate species are very abundant and dominate the fauna.

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