Integration of Ecology and Health Research at the Catchment Scale: The Taieri River Catchment, New Zealand.

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Abstract

Interest in the relationship between ecosystem change and public health is increasing at global and local scales. This paper presents findings from an integration of ecology and health research at the scale of a river catchment, and examines geographical information systems as a means to integrate across the disciplinary and sector boundaries that characterise ecology and health concerns. The paper draws on findings from the 'Taieri Catchment and Community Health Project', a collaborative investigation of the relationship between river catchment management, freshwater ecosystems and public health in a rural river catchment in the South Island of New Zealand. Firstly, informed by an integrated conceptual framework, a series of maps were generated to take stock of existing knowledge resources available for the catchment and to provide an overview of information regarding driving forces, ecosystems, social systems, health indicators and infrastructure. Secondly, primary research was carried out to address knowledge deficits regarding direct links between ecosystems and health (through biophysical studies of the human pathogen *Campylobacter*) and between ecosystems, social systems and health (through participatory and survey research). The river catchment case study identifies valuable strategies to integrate ecology and health research and encourage a more comprehensive approach to rural and urban environmental health concerns.

Introduction

Ecology and health issues are often characterised by complex interactions between public health, ecosystems and social systems, and demand integration of themes that span the environmental and socioeconomic determinants of health (Rapport et al., 1998; Parkes et al., 2003). The 'Taieri Catchment and Community Health Project' (TC&CH Project) was undertaken in the Taieri River Catchment on the east coast of New Zealand's South Island. The project was informed by the identification of river catchments or watersheds as appropriate scales for examining the socioecological challenges of freshwater resource management (Naiman, 1992), and by interactions between biophysical and social processes that characterise environmental health issues (Cole et al., 1999). The project investigated the relationship between catchment management, freshwater ecosystems and public health issues at the catchment scale, including ecological determinants of waterborne disease and links between rural and agricultural development, ecological sustainability and socioeconomic determinants of health. Integration is important for ecology and health research and requires specific strategies or tools. GIS (Geographical Information Systems) can be used as a tool for integrating data on ecosystem and health concerns (Aron and Glass, 2001) at the catchment scale. By drawing attention to common spatial dimensions of ecology and health, GIS can provide opportunities to highlight links between people and places that cross numerous disciplinary and sector boundaries. In response to integration demands of ecology and health research this paper aims to:

- Identify opportunities and constraints of GIS as a means of integrating across the disciplinary and sector boundaries of the Taieri Catchment and Community Health Project
- Examine the role of integrated conceptual frameworks to frame the application of GIS when studying ecology and health issues
- Identify strategies to ensure the integration afforded by GIS is mirrored by integration throughout the research process

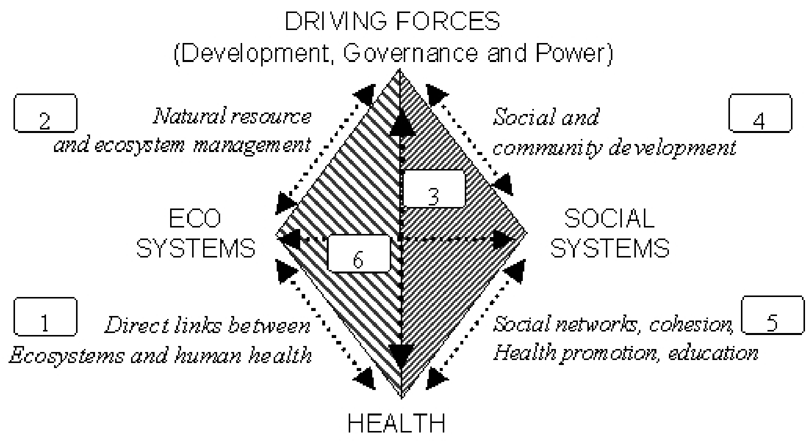
Methods

The TC&CH Project involved both biophysical and participatory research. The biophysical component of the project focussed on a multi-disciplinary study investigating the ecology of the human pathogen *Campylobacter* in an aquatic ecosystem. The distribution of thermo-tolerant *Campylobacter* (TTC) in the lower Taieri River and Lake-Wetland Complex was analysed in relation to land-use, climate, and human cases of the notifiable disease campylobacteriosis. This part of the study sought to improve understanding of the role of waterborne transmission in the epidemiology of campylobacteriosis. At 334 cases per 100,000 population, New Zealand had the highest rate of this enteric disease relative to any other developed country in 2002 (IESR, 2003).

The participatory component demonstrated the principles of Ecosystem-based Community-Oriented Participatory Action Research (ECO-PAR). The aims of the ECO-PAR process were: to better use existing information on ecosystems and health in the catchment; to fill gaps in understanding about catchment and community health issues; and to strengthen capacity for integrated, catchment-based approaches to water resource management and related public health issues. The distinguishing feature of ECO-PAR, which evolved from COPAR and PAR methodologies, is specific engagement with both ecosystems and communities (social systems) (Parkes, 2003-a). As applied to the Taieri River catchment, ECO-PAR was founded on iterative cycles of collaborative research, action and reflection with a participatory research community. This involved the participation of community reference groups and co-researchers in collaborative research initiatives, including a whole catchment questionnaire survey, the establishment of a community–university partnership, and the evolution of an externally funded multi-stakeholder community catchment forum.

The prism framework of health and sustainability depicts the relationships between governance and development, ecosystems, social systems and health (Parkes et al., 2003-a) (Fig 1). The framework highlights the link between ecosystems and social systems as determinants of health, and makes explicit the public health implications of governance, power and development processes as drivers of social and ecosystem change.

The Prism Framework is characterised by six interacting axes linking ecosystems and social systems as foundations for health and sustainability:



1. *Direct links between ecosystems nd human health* (traditional environmental health)
2. *Natural resource and ecosystem management* (use of natural resources and ecosystems services)
3. *Health services and Infrastructure* (includes waste and water services)
4. *Social and community development* (includes socioeconomic determinants of health)
5. *Social networks, cohesion, health promotion, education* (includes social capital)
6. *Linked socio-ecological systems* (both environmental and socio-economic determinants of health can be improved by processes that foster social and ecosystem benefits).

Figure 1: Converging themes in Ecology and Health research: The Prism Framework (Parkes et al., 2003)

Study site

The largely rural Taieri River catchment, in the south east of the New Zealand's South Island, has an area of 5650 km^2 and is host to a population of approximately 18,000 people. As the third longest river in New Zealand, the 318 km long Taieri River is also notable for its low volume due to its origins in the dry ranges and basin landscapes of Central Otago. Other features of the catchment include the extent of ecological research conducted in the area (Hamel, 1998; Young and Huryn, 1998; Townsend and Riley, 1999; Riley et al., 2003) and the rapid socioecological change that characterises many New Zealand Rivers (ME 1999; Tong and Cox 2000) and is exemplified in the Taieri's fertile Maniototo, Strath Taieri and Taieri Plains. Having been an important source of food for Maori in pre-European times (Tipa, 1999), the catchment has experienced 150 years of extensive and increasingly intensive agricultural development and consequent concerns regarding the quality, quantity and ongoing provision of freshwater ecosystem services (Otago Regional Council, 2000).

Catchment data and map generation

Table 1 describes the national databases that provided the foundation from which data regarding driving forces, ecosystems, social systems or health in the Taieri Catchment could be selected.

Table 1: Source, description and use of national spatially referenced data for ecology and health research in the Taieri River catchment

Spatial Database	Description (and source)
Land Information New Zealand (LINZ) and NZTopo	LINZ is the national topographic authority for mapping at 1:50,000 to 1:4,000,000 scales for defence, emergency services and government. NZTopo includes topographical features such as rivers, mountains and roads.
Land Cover Database (2000) Terralink New Zealand	A representation of broad categories of NZ land cover as determined from SPOT2 and SPOT3 satellite images captured in 1996/97. Developed and funded by Ministries of Agriculture, Forestry and the Environment, and the Department of Conservation.
Agribase (2000)	National spatial farm database (simplified version) showing major farm types on pastoral land. Farm data is collected and managed by AgriQuality New Zealand Ltd through farm visits, postal surveys and publicly available information such as Valuation Rolls. Provides information that underpins national and regional policies and programmes that benefit rural New Zealand and primary sector industries
New Zealand River Environment Classification (2002) (Snelder et al.,1999; Snelder and Guest, 2000)	River environmental classification system (draft), produced by National Institute of Water and Atmospheric Research (NIWA) for the Ministry for the Environment, Wellington. Classification is based on physical variables that control physical conditions in rivers including regional scale variables (climate); catchment scale variables (geology, topography, landcover, flood regime, source of flow)as well as valley and reach scale variables.
The New Zealand Deprivation Index, NZDep96 (1996) (Salmond and Crampton, 2001).	An area-based measure of deprivation combining 9 variables from the 1996 Census . Census variables are communication, income from benefits, employment, equivalised income, transport, support, qualifications, owned home, living space. NZDep provides a deprivation score for each meshblock. On the NZDep scale of 1-10, 10 indicates that a meshblock is in the most deprived 10% of New Zealand
EpiSurv – the National Notifiable Disease Surveillance System	The national database for notifiable diseases collated at the Institute of Environmental Science and Research. Notification data for campylobacteriosis were was obtained for the period 1997–1999 and geocoded by Critchlow Associates. Data for the period 2000–2001 was obtained directly from the local Regional Public Health Service Provider – Public Health South and had already been geocoded.
Water distribution zones for Community Drinking Water Supplies (IESR 1999, 2000, 2001)	Water distribution zones and their grading are derived from the national register for community drinking water supplies combined with the digital representation of the water distribution zone areas. A water distribution zone serving 500 or more people receives a grade that is an assessment of confidence in the risk to public health from the supply .

Selection of Taieri River catchment data and basic spatial analysis, including map generation, was undertaken using ArcMap 8.1 (©1999-2001 ESRI, Inc) GIS software. Topographical data (Fig 2) were selected from Land Information New Zealand (LINZ). Selection of data within the Taieri catchment boundary (with a buffer of 500 m) was straightforward for biophysical databases such as the Land Cover database (2000), Agribase (2000) and River Environment Classification system (2002) (Figs 3 and 4).

In contrast to biophysical and ecosystems-based data, social data are only available by meshblock. Meshblocks are the smallest geographical area for which Statistics New Zealand collects and analyses data (Statistics New Zealand, 2001). Selection of Taieri River catchment data was restricted to meshblocks that are completely within or overlapping with the Taieri catchment boundary. Overlapping meshblocks that included rural settlements external to the catchment were excluded. The New Zealand Deprivation index is one area-based socio-economic index, readily available for selection of Taieri catchment meshblocks (Fig 5).

For ethical and privacy reasons, geocoded notifiable disease data from EpiSurv must be aggregated to at least meshblock level to prevent identification of individual cases. Five years (1996–2000) of geocoded campylobacteriosis notifications were extracted from New Zealand's national disease surveillance system for the four territorial local authorities in the Taieri catchment (Fig 2). Data were assigned to Taieri catchment meshblocks where geocoding was exact (x, y coordinates) or at street level accuracy. A 5-year rate of campylobacteriosis notifications was estimated based on the number of events in 5 years and population per meshblock. These rates are divided by 5 to give an estimated annual average rate, and converted to incidence rate per 100,000 for comparisons to national figures. Due to the very small populations in some rural meshblocks, it was preferable to group and represent the estimated meshblock incidence data at the level of New Zealand Census area units. Area units are aggregations of meshblocks with a unique name referring to a geographical feature or suburb (Statistics New Zealand, 2001). Variations in the area-based estimate of annual incidence of campylobacteriosis within the Taieri River catchment are illustrated (Fig 6).

In addition to the national spatially referenced databases data (Table 1), local and regionally derived secondary data is also available. Notable sources include regulatory monitoring (Otago Regional Council, 1999) and research on freshwater ecosystems focused primarily within the catchment (Hamel, 1998; Young and Huryn, 1998; Townsend and Riley, 1999; Schallenberg and Burns, 2003; Schallenberg et al., 2003-a; Schallenberg et al., 2003-b; Townsend et al., 2003, Riley et al., 2003).

Primary ecology and health data from the biophysical and participatory components outlined in Table 2 also utilised GIS in design, analysis and/or integration. In the study of spatial and temporal patterns of thermo-tolerant *Campylobacter* in the lower Taieri, GIS was used in site selection (including type of site and predominant land use) and analysis of findings (Fig 7). Secondary data (Figs 2–6) were used in the design of participatory research, the selection of community reference groups and in a mailed questionnaire survey. Three catchment areas (lower urban, lower rural and upper catchment) were delineated using census meshblocks (Fig 8). These areas determined proportional spatial sampling from the electoral roll sample frame within the catchment, and grouping of data to assess whether opinions regarding catchment and community health issues varied according to where respondents lived.

Combined analysis of primary and secondary catchment data

There were three foci for the combined analysis of the primary and secondary data.

1. Map generation was used as a method of spatial analysis of the secondary data collected and primary research conducted.

2. The Prism Framework (Fig 1) was used to examine the knowledge strengths and deficits that inform the project and to identify opportunities for integrating different types of ecology and health research.

3. The tools and strategies for research integration were summarised with attention to the interface between quantitative and qualitative methods, and between biophysical and social dynamics of ecology and health research.

Figure 2: The Taieri River Catchment: Settlement, governance boundaries and mains roads.

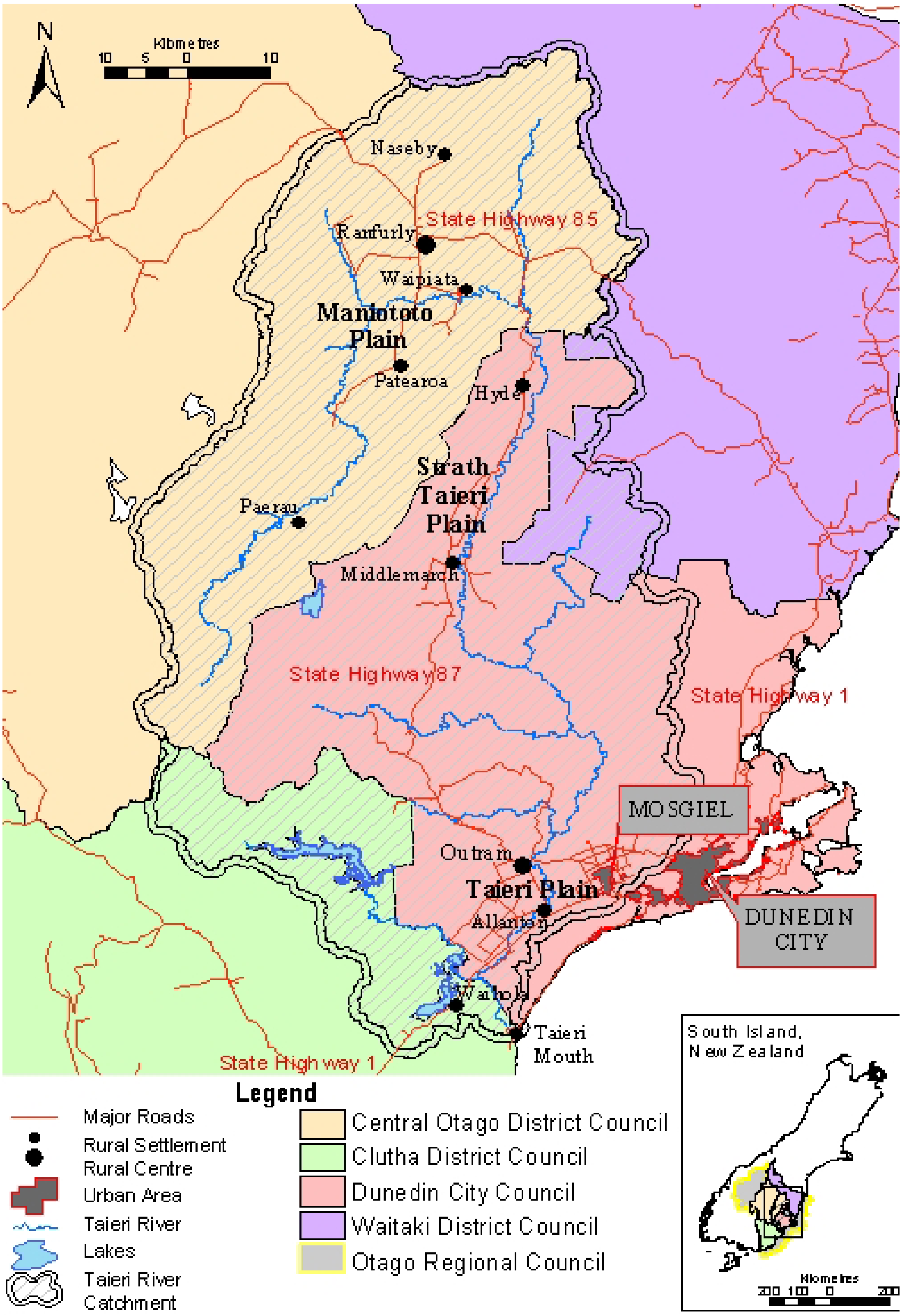
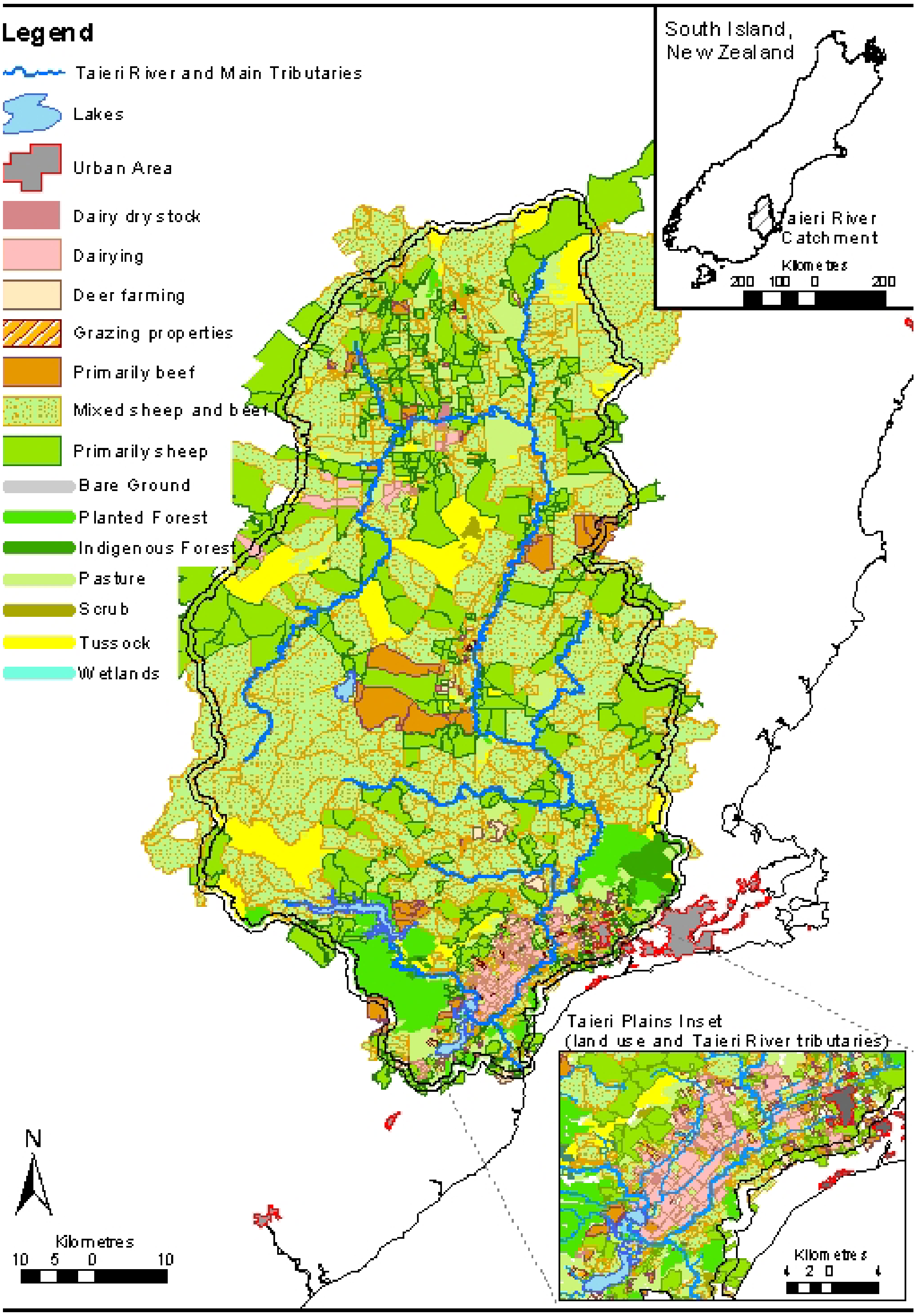
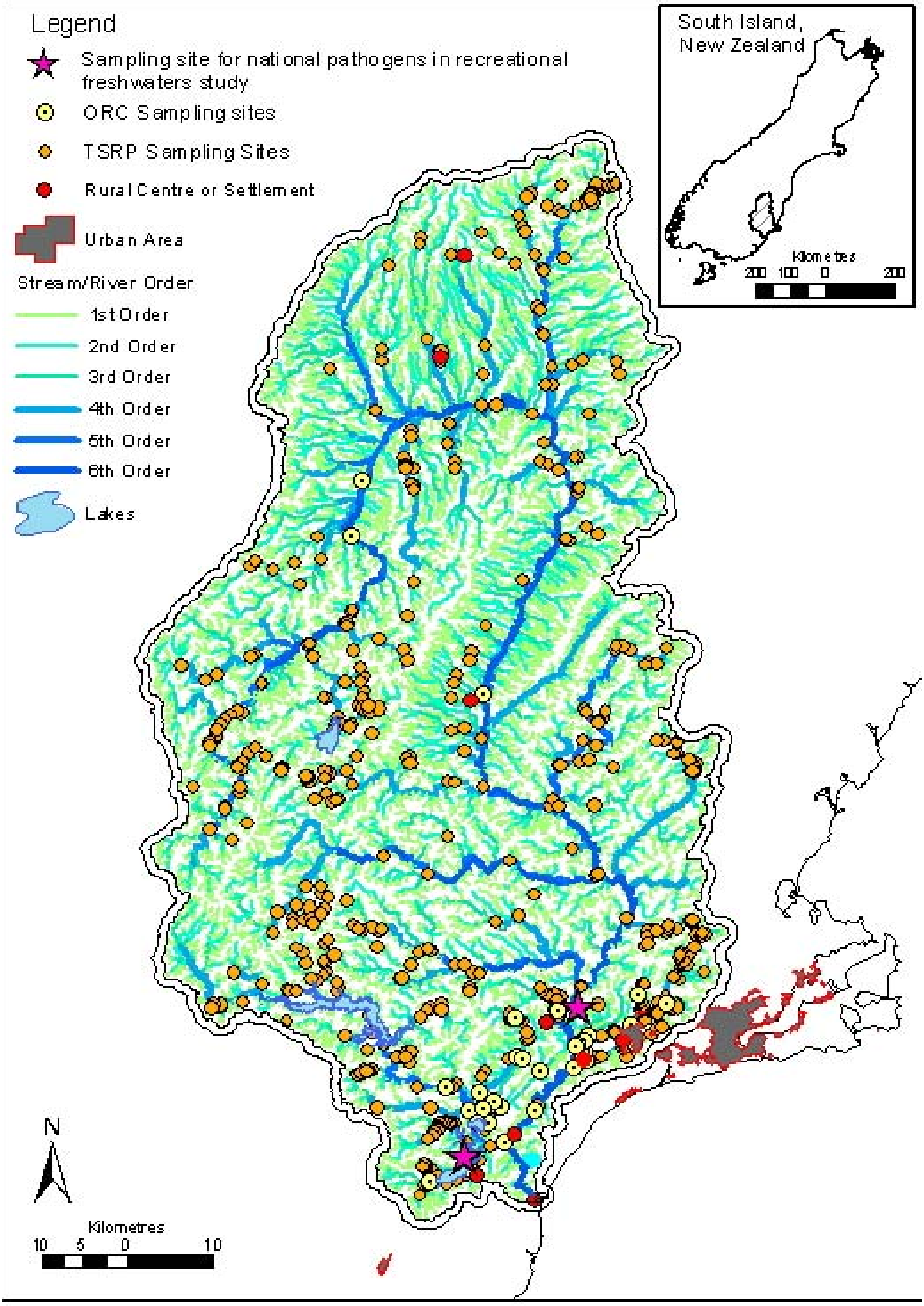


Figure 3 The Taieri River catchment:
land cover and land use



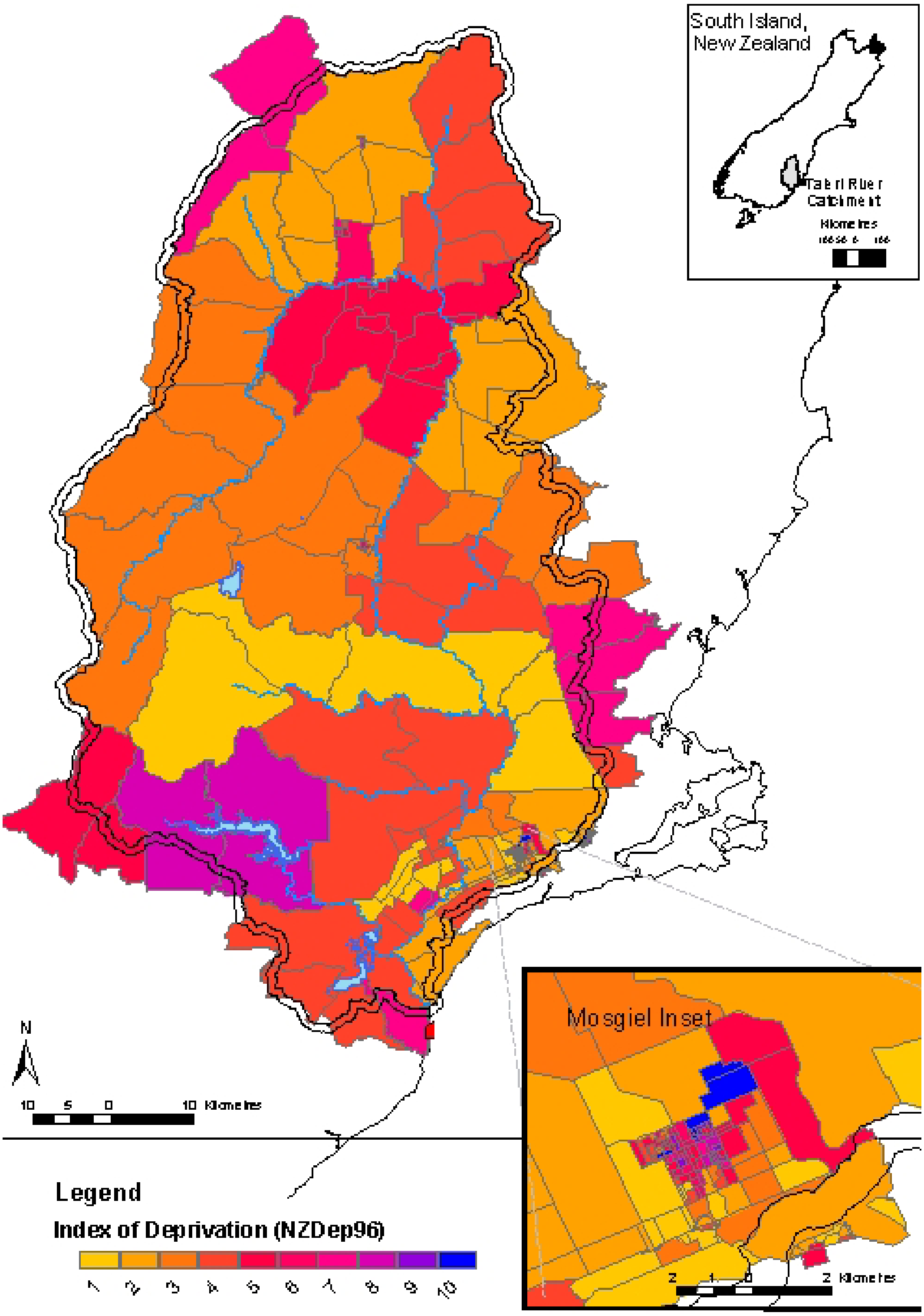
Source: River Environment Classification System (Ministry for the Envirnment, 2002) and Agribase (2001)

Figure 4 The Taieri River catchment:
freshwater ecosystems research and monitoring sites



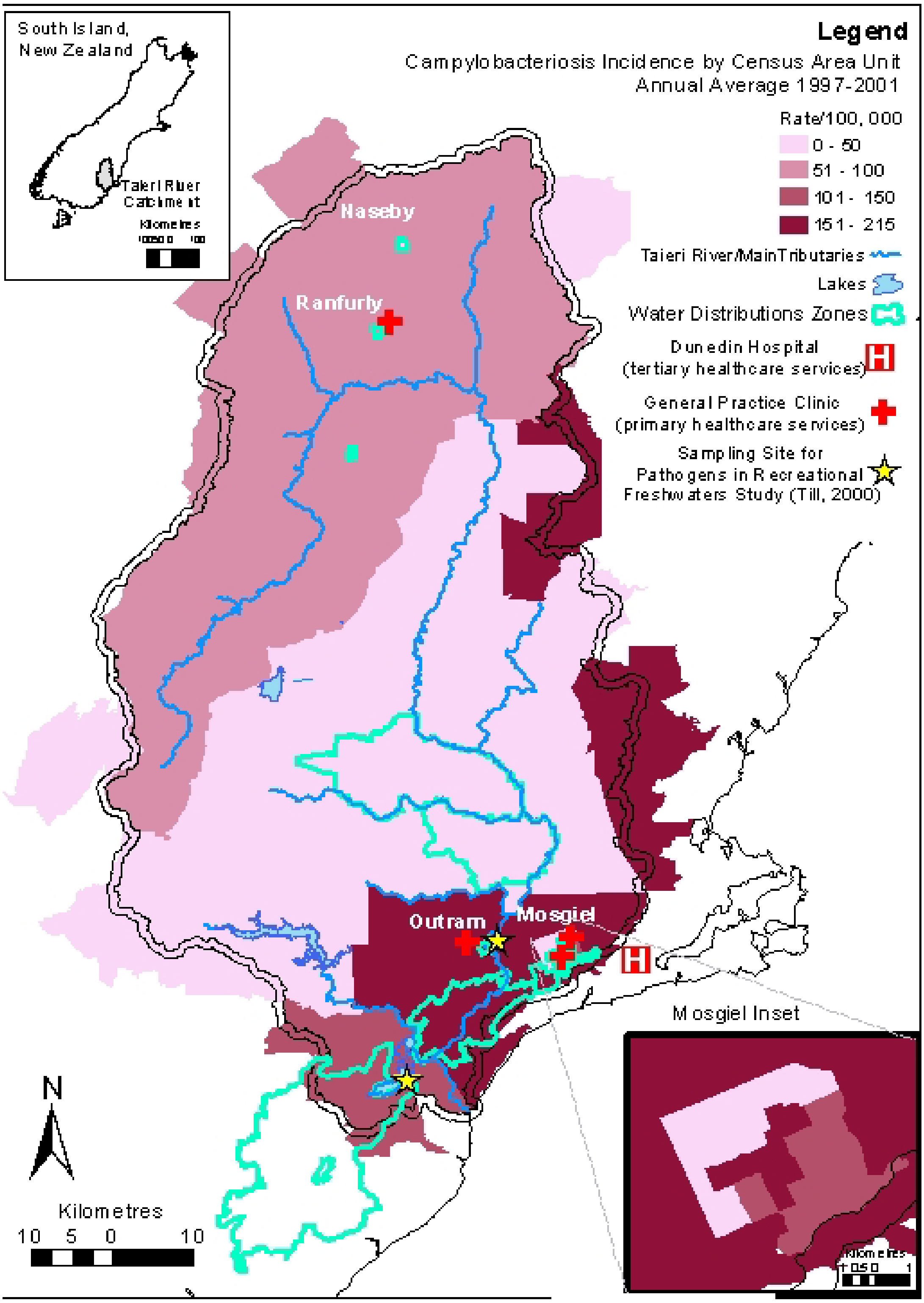
Source: Till (2000); TSRP (pers. comm.); Otago Regional Council (1999).

Figure 5 The Taieri River catchment:
Index of socioeconomic deprivation (NZDep96)



Source: New Zealand Index of Deprivation (NZDep96), Salmond and Crampton 2001

Figure 6 The Taieri River catchment: health infrastructure and incidence of campylobacteriosis



Source: Public Health South (pers. comm.), ESR (pers.comm.),

Figure 7 Lower Taieri Thermotolerant *Campylobacter* study

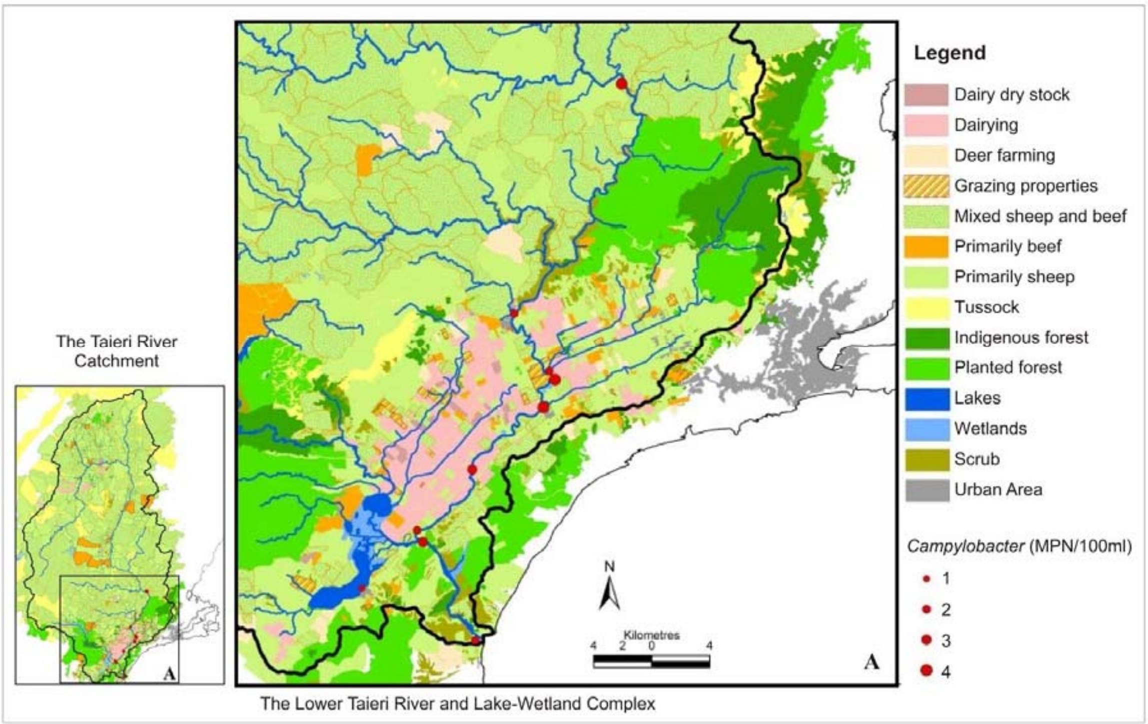
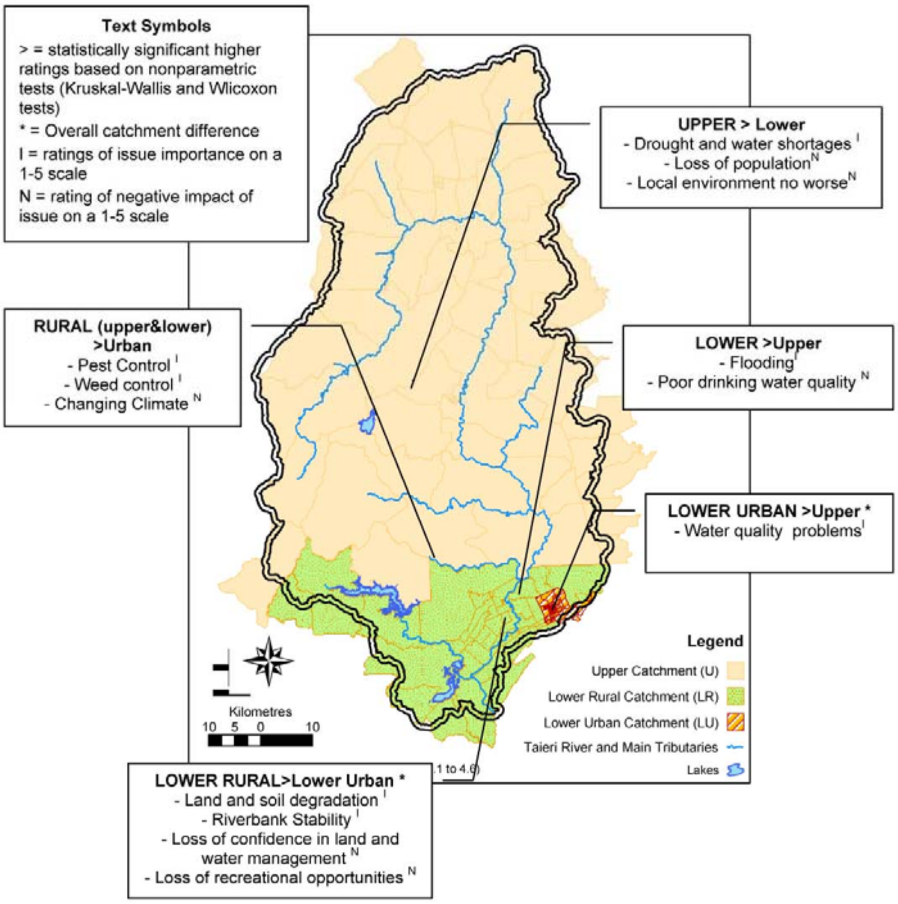


Figure 8 'The Taieri Catchment and Community Health Survey'
Overview of significant differences according to catchment location



Results

Existing knowledge strengths and weaknesses

A series of maps was generated to examine knowledge strengths and deficits in the secondary data (Figs 2–8). By presenting information about points of interest in the Prism Framework, each map contributes to a progressively more detailed understanding of the spatial interaction between driving forces, ecosystems, social systems and health concerns in the catchment. Figures 2 and 3 introduce driving forces (especially governance and development) influencing the catchment. Key settlements and governance boundaries are depicted in Figure 2, showing the catchment's proximity to the City of Dunedin (population approximately 110,000), as well as the Regional Council and four Territorial Local Authorities under whose jurisdiction the catchment falls. Under New Zealand's Resource Management Act 1991, regional councils are primarily responsible for management of land, water, soil and air resources, particularly where land use has impacts on water resources, and territorial local authorities have direct responsibility for land-related resource management, such as town planning (Pyle et al., 2001). Figure 2 depicts land cover and land use characteristics that are the most obvious indicator of developmental driving forces within the catchment. The map shows land use throughout the catchment with sheep and beef farming predominating in the upper catchment, and dairy farming dominating the land use on the lower Taieri plains and in the more fertile alluvial plains adjacent to the main stem of the river. Figure 2 also identifies areas of high conservation value in the catchment based around small areas of indigenous forest, the important lake-wetland complex in the lower Taieri area, and the areas of unfarmed tussock grassland.

Sites of research and monitoring of freshwater ecosystems (Fig 4) highlight the data-rich status of the Taieri River Catchment and their potential contribution toward understanding and responding to ecology and health concerns. Of the 384 research sites used by the University of Otago's Taieri and Southern Rivers Project, less than 5% represent sites of longitudinal data collection. In contrast, Regional Council sites are monitored monthly, except for two bi-monthly sampling sites, two trial contact recreation sites and two sites sampled for a national study of pathogens and indicators in recreational freshwaters (Till et al., 2000). Participatory research in the TC&CH Project identified a strong interest in the extent and communication of this research and monitoring information. This point of integration between different aspects of the project is developed in the discussion.

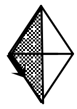
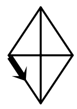
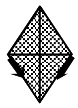
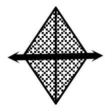
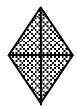
Moving from ecosystem to social characteristics, Figure 5 depicts the New Zealand Deprivation Index selected for Taieri catchment meshblocks (Table 1). The map identifies variation in the relative deprivation between catchment meshblocks showing highest deprivation scores within urban areas (see Mosgiel inset) and in isolated rural areas in the southwest of the catchment. Meshblocks with lower levels of relative deprivation are spread throughout the catchment. When compared with information from other maps and tables, the lowest levels of deprivation correspond with agricultural areas in the Taieri Plains and downlands, as well as in the southeast of the catchment on the fringes of Mosgiel and Dunedin City. When coupled with the information depicted in Figures 2 and 3, the map highlights relationships between developmental processes, natural resources and the socio-economic influences in the catchment. The perceived importance of these relationships to community health and well being was an important finding from the TC&CH Project's participatory research study (Parkes, 2003-a), providing further motivation for community involvement in ongoing multi-stakeholder initiatives in the catchment.

Figure 6 depicts selected indicators of health infrastructure and water-related disease incidence in the catchment. Based on five years of data (1997-2001), the incidence of campylobacteriosis in the Taieri catchment varies across different census area units. The map also depicts the location of the primary and tertiary health care in the catchment and the water distribution zones for community drinking water supplies. This map highlights the spatial concentration of health services and water resources infrastructure in peri-urban areas and the relative lack in rural areas.

Integrating knowledge and addressing knowledge gaps

Figures 1-6 demonstrate the use of GIS in depicting existing knowledge strengths in the Taieri catchment, the pertinence to different aspects of the Prism Framework, and the background to the primary research of the TC&CH Project. The project conducted specific ecology and health studies aimed at linking between themes of the Prism framework (Fig 1) that were inadequately addressed by existing knowledge and research. Table 2 outlines different types of ecology and health research undertaken in the project, and their relationship with the Prism Framework (Fig 1). Primary research in the project responded in particular to knowledge deficits regarding direct links between ecosystems and health, though biophysical studies of the human pathogen *Campylobacter*, and between ecosystems, social systems and health through participatory and survey research.

Table 2: Methods, Data and Themes of the Taieri Catchment & Community Health Project

Specific TC&CH Project Study	Method of Data Collection	Data types, themes, research traditions *(departmental input)*	Prisms	Prism Themes (see Figure 1)
Ecology of *Campylobacter spp.* in the lower Taieri River catchment [1,3]	Fortnightly water sampling from Lower Taieri River and Lake-Wetland complex	quantitative, biophysical sciences, (Public Health, Ecology Microbiology)		Ecosystems ↔ Health; Development (land use, – Ecosystems – Health
Molecular genetics of *Campylobacter* spp.[1]	Collection of *Campylobacter* isolates from surface water and human cases in the Taieri River catchment	quantitative, biomedical sciences, (Public Health, Microbiology)		Ecosystems ↔ Health
Participatory research with community reference groups from throughout the catchment [2,4]	Series of four community reference group meetings, whole catchment meeting, and progression to community–university partnership and TAIERI Trust	qualitative, participatory action research (ECO-PAR), (Public Health, Geography)		Full Prism: especially 'human dimensions' (governance, ecosystems, social systems) and synergies for human health
Taieri Catchment and Community Health Survey (TC&CH Survey) [2,5]	Postal Questionnaire to 11% of Taieri catchment residents on electoral roll. Designed in collaboration with community reference groups	quantitative and qualitative, social sciences, (Public Health, Geography)		Full Prism: especially Ecosystems↔ Social Systems
Spatial Data Integration [1,2]	Primary data collection (above) and secondary data from existing databases	Quantitative and Qualitative (as above, plus information Sciences)		Full Prism: Highlights gaps in existing knowledge and depicts new ecology and health research

Sources 1. Eyles (2003) doctoral thesis
2. Parkes (2003-a) doctoral thesis
3. (Eyles et al., 2003)
4. (Parkes and Panelli, 2001)
5. Parkes (2003-b) Taieri Catchment and Community Health Survey

Abbrvs: TAIERI = Taieri Alliance for Information Exchange and River Improvement
ECO-PAR = Ecosystem-based Community-Oriented Participatory Action Research

Primary research findings: biophysical and ECO-PAR studies

Drawing on findings from the *Campylobacter* study (Table 2), Figure 7 shows the observed concentrations of thermo-tolerant *Campylobacter* at different sites along the River and Lake-Wetland Complex (Eyles et al., 2003). *Campylobacter* levels varied significantly among the ten sampling sites, increasing below a major tributary entering the river and then showing a downstream decrease, reflecting the balance between inputs from surrounding land and instream losses. Along the mid-section of the river, *Campylobacter* levels decreased despite the predominance of dairy farming in this area (Fig 7). *Campylobacter* levels appeared to be unrelated to land use due to specific features such as artificial drainage channels. Sites of recreational importance were found to have lower average *Campylobacter* levels compared to other sites on the river, but on occasion were relatively high, posing a potential health risk to swimmers.

Figure 8 provides an overview of catchment differences in selected responses to the Taieri Catchment and Community Health Survey, according to whether the 496 respondents (37.5% response rate) lived the lower urban, lower rural or upper catchment. The figure provides a summary of differences in responses regarding the importance and impact of catchment issues using a 1-5 Likert scale (e.g. very high importance, important, moderate, low, very low importance). Overall differences across the three catchment areas were tested using the Kruskal-Wallis test for differences between two or more groups of ordinal data. Where significant ($p>0.05$), overall differences were also tested for upper–lower, and rural–urban catchment differences, using Wilcoxon tests for differences between two groups of ordinal data (Forrest and Anderson, 1986). Survey results provided input to other ECO-PAR phases (Table 2.)

Discussion

Research and experience with the TC&CH Project has identified challenges for integrating ecology and health research especially when relationships between ecosystems, social processes and health are considered. These challenges are discussed in relation to the combined contribution of GIS and conceptual frameworks in linking multiple sources of spatial information, data and research and as a means to integrate between biophysical and participatory research and of ecology and health research.

Combining GIS and conceptual frameworks for ecology and health research.

The information represented in Figures 2 – 6 was selected, analysed and depicted with explicit interest in taking stock of existing knowledge resources available for the catchment. The maps provide an overview of selected and available information regarding driving forces (Figs 2 and 3), ecosystems (Fig 4), social systems (Fig 5) and health indicators and infrastructure (Fig 6). The cross-sector and cross-disciplinary scope of the information presented in these maps, means it is very rare to see these themes represented together. The combination of GIS and the integrated concepts of the Prism Framework provide a systematic overview of the socioecological context of health and sustainability issues in the Taieri catchment. Systematic approaches to understanding the socio-ecological context of health issues are increasingly important for research that spans ecosystem change and human health issues. This is highlighted by proposals for ecosystems approaches to health and sustainability (Kay et al., 1999; Waltner-Toews, 2001); 'social–ecologic' systems perspectives for epidemiology (McMichael, 1999), and 'ecosocial' approaches to social epidemiology determinants of health (Krieger, 2001). The information presented in Figures 2 – 6 suggest that, when coupled with use of GIS for map generation, the inter-related themes of the Prism provide a clear and integrative framework for depicting and describing socioecological features of ecology and health research. By identifying strengths in existing knowledge, the Prism Framework pointed to knowledge deficits where existing secondary data was not readily available or existing information was poorly integrated. In response, the TC&CH Project research outlined in Table 2 required both qualitative and quantitative studies to investigate catchment and community health issues warranting attention. Furthermore, the biophysical and participatory studies outlined in Table 2 each required high levels of cross-disciplinary innovation and integration in method and analysis. It should be noted that, just as secondary data was aggregated to the catchment scale from smaller area units or spatially referenced databases, it was also necessary for the primary TC&CH Project research to focus on scales smaller than the entire catchment.

Investigation into the ecology of the human pathogen *Campylobacter* in aquatic ecosystems filled an identified knowledge deficit by providing previously unavailable knowledge of the relationship between 'ecosystems' and 'health' through ecological and molecular genetics studies. The *Campylobacter* research was also explicitly focused on the relationship between land-use and the ecology of *Campylobacter* in the Lower Taieri River catchment. This research therefore relates not only to the prism axis between ecosystems and health, but also the entire prism 'face' of governance and development, ecosystems and health. In the case of the TC&CH Project, future links between biophysical research and the social processes relating to processes of catchment management are facilitated by the establishment of the TAIERI catchment forum (TAIERI, 2003).

Bringing together the information represented in Figures 2 – 6 also enabled identification of the relative knowledge deficit on links between people and places at the local level, in particular the interactions between social systems (local communities) and ecosystems (river catchment) and their implications for both socioeconomic and environmental determinants of health. The interaction between ecosystems, social systems and public health in the Taieri catchment was examined through the ECO-PAR process outlined in Table 2. The participatory research findings provide a depth of community-based knowledge regarding catchment and community health issues that were further developed by the findings of the TC&CH Survey. The community-oriented research generated data relevant to several axes of the prism – particularly the interface between ecosystem and social systems (Table 2). In particular, the participatory research in the catchment identified a sophisticated and integrated community interest in catchment and community health issues that surpassed disciplinary and sector boundaries and was in keeping with a more holistic orientation of the Prism Framework (Parkes and Panelli, 2001; Parkes, 2003-a).

Depiction and discussion of these interrelated Prism themes within the same catchment helped to frame the challenge of how to integrate, respond to and communicate catchment information between relevant stakeholders – a dominant theme arising during the course of the ECO-PAR process. Community response to this challenge underpinned the TC&CH Project's evolution from participatory and biophysical research to a community–university partnership in the catchment. With cross-disciplinary and cross-sector support, this partnership progressed to the establishment of an externally funded multi-stakeholder 'TAIERI' catchment forum ('Taieri Alliance for Information Exchange and River Improvement' (Parkes and Panelli, 2001; TAIERI, 2003).

GIS in the design and analysis of ecology and health research

GIS proved to be a useful technique for identifying and representing knowledge strengths and highlighting knowledge deficits (Figs 2-6). However, the design and analysis of biophysical and participatory research in the TC&CH Project highlighted challenges as well as opportunities when using GIS in ecology and health research.

Conducting an investigation into the spatial relationships between levels of *Campylobacter* in the lower Taieri River (Fig 7) and the occurrence of human cases of campylobacteriosis in the associated river catchment proved to be challenging in a number of respects. Data was available on the number of notified cases of campylobacteriosis occurring over the same time period as the water sampling programme. As detailed in the methods section, it was possible to locate most notified cases in space, through geocoding of residential address data, and to assign this information to meshblocks within the Taieri catchment area. Skelly et al. (2002) describe important difficulties inherent in this process, noting that 11.6% of cases are ungeocodable and that the majority of ungeocodable cases are likely to be from rural areas. This highlights the extent to which rural disease rates may be under-estimated, especially in the Taieri River catchment where, based on 2001 census information, 36.7% of the catchment population is classified as rural, compared to the 14.3% nationally (Statistics New Zealand, 2001).

Ethical issues surrounding the presentation of disease cases can also provide challenges for this type of analysis and require the presentation of rates of disease rather than 'dots on maps'. The presentation of rates of disease can be carried out at a variety of spatial scales from the smallest available administrative area of meshblocks, to slightly larger census area units (roughly equivalent to suburbs), to larger areas such as territorial authorities (local government areas). Regardless of which administrative area is deemed relevant to a particular analysis, it is unlikely that it will overlap precisely with natural or ecological boundaries, such as catchment areas. To present ecologically relevant rates of disease, cookie-cutting techniques need to be applied, which can amplify uncertainty errors in the data.

For the reasons described above, and in particular due to the small number of cases identified from the catchment, it was extremely difficult to carry out a spatial analysis of the relationship between *Campylobacter* in the aquatic environment and cases of human disease in the community that makes use of the river's resources. These factors need to be taken into consideration in the future design and spatial analysis of studies of waterborne pathogens in the aquatic environment. The findings presented Figure 7 show that significant variation in levels of thermo-tolerant *Campylobacter* exist, and may be partially explained in terms of differences in land-use upstream and directly adjacent to the various sample sites. The variation also represents a difference in the relative risk to health associated with recreational activities at each of these sites. The findings highlight growing tensions between agricultural land use, recreational and cultural interests, and health and safety concerns in New Zealand rivers that are recognised nationally (Tong and Cox, 2000; ME, 1999) as well as by research in the Taieri (Tipa, 1999; Eyles, 2003; Parkes, 2003-a).

The participatory and survey research not only generated findings that complement the *Campylobacter* study, but also highlighted different uses that GIS may contribute to at different stages of the research process. GIS proved useful in the design stage of the TC&CH Survey (Fig 8) for defining areas for analysis of catchment variations and in the representation of findings relating to catchment differences. While demonstrating possibilities, the results presented in Figure 8 are at best an 'indicator' of findings and as such, should not be seen as an endpoint. In the TC&CH Project, the survey provided one stage within the larger process of ECO-PAR (Table 2). Furthermore, both the participatory and survey research identified limitations and questions regarding the adequacy and appropriateness of representing qualitative findings with maps. The findings depicted in Figure 8 represent only the small proportion of the survey questions that generated data suitable to be represented in relation to catchment maps. While GIS and maps were useful for design phases of reference group research, participatory research findings were not appropriately represented in this form.

The fact that not all TC&CH Project results are suitably analysed and presented using GIS highlights important tensions when attempting to integrate across different aspects of ecology and health concerns represented by different Prism themes. On one hand, the use of GIS is gaining increasing attention as an analytical tool for dealing with quantitative data concerning ecology and health relationships and environmental justice (Gatrell and Löytönen, 1998; Aron and Glass, 2001; Maantay, 2002). On the other hand, experience from the TC&CH Project highlights the challenge of ensuring that important qualitative and participatory research is not sidelined or overlooked, simply because it is not appropriate for this kind of analysis or representation and/or simply not relevant to 'show on a map'. Thus, despite the integrative potential of GIS, the challenges of comparing and integrating across qualitative and quantitative research persist. Such findings highlight that integrating ecology and health research requires the use of different and complementary strategies throughout all phases of research process.

Integration of ecology and health research

Methods and results from the TC&CH Project have shown that GIS provides one contribution within a range of techniques and tools for integration throughout the entire research process. Findings regarding integration of ecology and health research are synthesised here in relation to conceptual integration, communication, practical and technical integration, interpretation and dissemination. The TC&CH Project highlighted the importance of integrated conceptual frameworks as the basis for cross-cutting ecology and health research. In the TC&CH Project, conceptual frameworks were used as heuristic tools to inform, present and discuss research as it was being developed throughout the research process. The importance of refining and calibrating conceptual frameworks for ecology and health research was acknowledged by the researchers, and reflected in the evolution of the Prism model during the source of the TC&CH Project (Witten, 2000; Parkes, 2001; Parkes et al., 2003). Yet integrating the spectra of themes and concepts of the Prism Framework (driving forces, ecosystems, social systems and health) has important implications for communication and collaboration across different research parties – as exemplified by the range of different research styles and disciplinary input summarised in Table 2.

The study of the ecology of campylobacteriosis required input from a range of disciplines, including environmental health, freshwater ecology, microbiology and information sciences. It was particularly important to receive input from experts in freshwater ecology, in terms of site selection, sampling methodology, and sampling frequency (temporal scale). Input from the GIS field included consideration of spatial scale, and spatial analysis in terms of relating findings to land-use and climate information. This aspect of the TC&CH Project required increased communication and co-operation with relevant environmental and health agencies as the research progressed.

The participatory research in the Taieri catchment was notable for its collaboration with communities throughout the catchment, with different disciplinary researchers, and with a spectrum of environmental, health and development agencies throughout the area. The participatory action research (PAR) methodology that informed this part of the project is noted as a research process that facilitates multiple types of research collaborations across and between different stakeholder groups (Parkes and Panelli, 2001), however, the TC&CH Project is not an 'ideal' model of community-oriented PAR (Whyte, 1991; Hart and Bond, 1995; Liepins, 2000). Even so, through application and development as ECO-PAR, the research demonstrated both benefits and limitations of integrating ecosystem-based and community-oriented research.

A focus on integration throughout and between phases of the TC&CH Project via a community-university partnership and the TAIERI catchment forum has benefited dissemination of findings. Results on thermo-tolerant *Campylobacter* have been presented to the catchment community in a written form, at local community meetings and field-days, and through short articles included in community catchment newsletters distributed by the TAIERI Trust. Likewise, ongoing feedback and dissemination of participatory and survey research findings to community, research and agency participants was integral to the overall ECO-PAR process (Parkes, 2003-b).

Conclusion

The TC&CH Project has provided insights into strategies for integrating ecology and health research at the catchment scale. Our paper has illustrated ways in which GIS effectively contributed to the design, analysis and integration of ecology and health research with respect to the TC&CH Project. GIS facilitated comparison and integration of multiple types and sources of spatially referenced data at the scale of the river catchment. However, the use of GIS beyond the basic spatial analysis of map-generation was limited due to ethical sensitivities, under-representation of rural notifiable disease data, and the inappropriateness of spatial analysis for some participatory qualitative data. Building on the utility of GIS as a hypothesis generating and map-generating tool, the challenges of analysing and integrating qualitative and quantitative data will be an area of ongoing interest for ecology and health research. It is possible that GIS-based strategies may further enhance dialogue and participatory action research when diverse community and scientific knowledge can be compared or integrated through the varying lenses and perspectives of spatial information systems.

The Prism Framework was usefully applied alongside GIS to frame and identify health and sustainability issues of concern in the Taieri river catchment. An additional challenge for ecology and health research is the presentation of findings in accessible, intelligible formats that are relevant to a variety of audiences including the general public. Experiences from the TC&CH Project suggest that the combined use of GIS with the Prism Framework helps to prioritise integration throughout the research process, including during the dissemination of research findings. The Taieri river catchment case study illustrates that the combination of GIS and the Prism Framework encourages the integration of ecology and health research and can lead to more comprehensive responses to contemporary health and sustainability challenges.

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References

Aron JL, Glass GE (2001) Geographic Information Systems, Chapter Three. In: Aron JL and Patz JA (eds.) Ecosystem Change and Public Health: A Global Perspective. John Hopkins University Press, Baltimore.

Cole DC, Eyles J, Gibson BL, et al. (1999) Links between humans and ecosystems: the implications of framing for health promotion strategies. Health Promotion International 14:65-72.

Eyles, R (2003) Ecosystem change and *Campylobacter* in freshwaters: case studies from the Taieri and Motueka river catchments. (Doctoral thesis). Department of Public Health, Department of Zoology and Department of Information Science, University of Otago, Dunedin.

Eyles R, Townsend C, Niyogi D (2003). Spatial and temporal patterns of *Campylobacter* contamination underlying public health risk in the\ Taieri River, New Zealand. Journal of Environmental Quality. 32: 1820-1828.

Forrest M, Anderson B (1986) Ordinal scale and statistics in medical research. British Medical Journal 292: 537-538.

Gatrell A, Löytönen M (1998) GIS and Health. GISData VI. Series Editors Masser I and Salge F. European Science Foundation/Taylor and Francis Ltd, London.

Hart E, Bond M (1995) Action Research for Health and Social Care: A Guide to Practice. Open University Press, Buckingham.

Hamel J (1998), Research in the Taieri Catchment. Ecology Research Group, Occasional Paper No.1, Ecology Research Group, University of Otago, Dunedin.

IESR - Institute of Environmental Science and Research (1999) Annual Review of the Microbiological Quality of Drinking-Water in New Zealand 1998. Prepared by Institute of Environmental Science and Research (ESR) by Andrew Ball for the Ministry of Health, Wellington. http://www.moh.govt.nz/moh.nsf/wpg_Index/Publications-Index.

IESR - Institute of Environmental Science and Research (2000) Annual Review of the Microbiological Quality of Drinking-Water in New Zealand 1999. Prepared by Institute of Environmental Science and Research (ESR) by Andrew Ball for the Ministry of Health, Wellington. http://www.moh.govt.nz/moh.nsf/wpg_Index/Publications-Index.

IESR - Institute of Environmental Science and Research (2001) Annual Review of the Microbiological Quality of Drinking-Water in New Zealand 2000. Prepared by Institute of Environmental Science and Research (ESR) by Andrew Ball for the Ministry of Health, Wellington. http://www.moh.govt.nz/moh.nsf/wpg_Index/Publications-Index.

IESR - Institute of Environmental Science and Research (2003) Infectious diseases in New Zealand 2002. Annual Surveillance Summary. Prepared by Institute of Environmental Science and Research (ESR) by Elizabeth Sneyd and Michael Baker for the Ministry of Health, Wellington. httpp://www.esr.cri.nz.

Kay JJ, Regier HA, Boyle M, et al. (1999) An ecosystem approach for sustainability : addressing the challenge of complexity. Futures 3:721-742.

Krieger N (2001) Theories for social epidemiology in the 21st century: an ecosocial perspective. International Journal of Epidemiology 30:668-677.

Liepins R (2000) Exploring rurality through 'community': discourses, processes and spaces shaping Australian and New Zealand rural communities. Journal of Rural Studies 16: 325-341.

Maantay J (2002) Mapping environmental injustices: pitfalls and potential of Geographic Information Systems in assessing environmental health and equity. Environmental Health Perspectives 110 (Suppl 2): 161-172.

McMichael AJ (1999) Prisoners of the proximate: Loosening the constraints on epidemiology in an age of change. American Journal of Epidemiology 149(10): 887-897.

ME - Ministry for the Environment (1997) The State of New Zealand's Environment, 1997. New Zealand Ministry for the Environment, Wellington.

ME - Ministry for the Environment (1999) Making Every Drop Count: the National Agenda for Sustainable Water Management. Action plan. Draft for Public Comment. New Zealand Ministry for the Environment, Wellington.

Naiman R (1992) Watershed management. Balancing sustainability and environmental change. Springer, New York.

Otago Regional Council (1999) Taieri River Catchment Monitoring Report. Otago Regional Council, Dunedin. No.99/316.

Otago Regional Council (2000) Water Quality and Habitat Issues Related to Lakes Waihola and Waipori. Otago Regional Council, Dunedin. No.99/447.

Parkes M (2003-a) Linking Ecosystems and Social Systems for Health and Sustainability: Public Health Lessons from the Taieri River Catchment (Doctoral thesis). Department of Public Health and Department of Geography. Otago, Dunedin

Parkes, M (2003-b) The Taieri Catchment and Community Health Survey. Geography and Health Research Report Series No. 2. Department of Geography, University of Otago & Public Health South. Dunedin.

Parkes M, Panelli R (2001) Integrating Catchment Ecosystems and Community Health: The Value of Participatory Action Research. Ecosystem Health 7:85-106.

Parkes M, Panelli R, Weinstein P (2003) Converging paradigms for environmental health theory and practice. Environmental Health Perspectives. 111: 669-675

Pyle E, Ward RC, McBride G, et al. (2001) Establishing watershed management in law: New Zealand's experience. Journal of the American Water Resources Association 37:783-793.

Rapport D, Costanza R, McMichael AJ (1998) Assessing Ecosystem Health: Challenges at the interface of social, natural and health sciences. TREE (Trends in Ecology and Evolution) 13:397-402.

Riley, R, Townsend, C, Niyogi, D, Arbuckle, C and Peacock, K. (2003) Headwater stream response to grassland agricultural development in New Zealand. New Zealand Journal of Marine and Freshwater Research 37: 389-403.

Salmond C, Crampton P (2001) NZDEP96 – What does it measure. Social Policy Journal of New Zealand (Issue 17):82-100.

Schallenberg M, Burns C (2003) A temperate, tidal lake-wetland complex. II Water quality and implications for zooplankton community structure. New Zealand Journal of Marine & Freshwater Research. 37: 429-447.

Schallenberg M, Burns C, Peake BM (2003a). A temperate, tidal lake-wetland complex. I Water balance and ecological implications. New Zealand Journal of Marine & Freshwater Research. 37: 415-428.

Schallenberg M, Hall C, Burns C (2003b) Consequences of climate-induced salinity increases on zooplankton abundance and diversity in coastal lakes. Marine Ecology Progress Series. 251: 181-189.

Skelly, C., W. Black, M. Hearnden, R. Eyles, and P. Weinstein (2002) Disease surveillance in rural communities is compromised by address geocoding uncertainty: a case study of campylobacteriosis. Australian Journal of Rural Health 10: 87-93.

Snelder T, Guest P (2000) The 'river ecosystem management framework' and the use of river environment classification as a tool for planning. Prepared for Ministry for the Environment. Project No.:MFE90506. National Institute of Water & Atmospheric Research Ltd. NIWA Client Report: CHC00/81.

Snelder T, Weatherhead M, O'Brien R, et al. (1999) Further development and application of a GIS based river environment classification system. Prepared for the Sustainable Management Fund, Canterbury Regional Council and Environment Waikato by National Institute of Water & Atmospheric Research Ltd. NIWA Client Report: CHC99/41.

Statistics New Zealand (2001) 2001 Census of Population and Dwellings. http://www.stats.govt.nz .

TAIERI (2003) Taieri Alliance for Information Exchange and River Improvement website. www.taieri.net.nz

Till D, McBride G, Ball A, et al. (2000) Pathogens and Indicators in New Zealand Recreational Freshwaters., 1st World Congress (10th Health-Related Water Microbiology Symposium), International Water Association, Paris.

Tipa G (1999) Taieri River Case Study. Environmental Performance Indicators: Technical Paper No. 58. Maori Indicators Case Study. Prepared for the Environmental Performance Indicators Programme of the Ministry for the Environment by Gail Tipa on contract for the office of Te Runanga o Ngai Tahu. Ministry for the Environment, Wellington.

Tong R, Cox G (2000) Clean and Green? The New Zealand Environment*.* David Bateman, Auckland.

Townsend C, Doledec S, Norris R, et al. (2003) The influence of scale and geography on relationships between stream community composition and landscape variables: description and prediction. Freshwater Biology. 48: 768-785.

Townsend C, Riley R (1999) Assessment of river health: accounting for perturbation pathways in physical and ecological space. Freshwater Biology 4: 393-405.

Waltner-Toews D (2001) An ecosystem approach to health and its applications to tropical and emerging diseases. Cadernos de Saúde Pública. Reports in Public Health 17 (Suppl):7-36.

Whyte W (1991), Participatory Action Research. Sage, London.

Young R, Huryn A (1998) Organic carbon dynamics during inundation in a floodplain reach of the Taieri River. In Hamel, J. (ed .) Research in the Taieri Catchment. Ecology Research Group, Occasional Paper No.1. Ecology Research Group, University of Otago.