Ecosystem Services Review of Water Storage Projects in Canterbury: The Opihi River Case

By Dr Edward J. S. Hearnshaw[1], Prof Ross Cullen[1] and Prof Ken F. D. Hughey[2]
[1]Faculty of Commerce and [2]Faculty of Environment, Society and Design
Lincoln University, New Zealand

Contents

Ecosystem Services Review of Water Storage Projects in Canterbury: The Opihi River Case

By Dr Edward J. S. Hearnshaw[1], Prof Ross Cullen[1] and Prof Ken F. D. Hughey[2]
[1]Commerce Faculty and [2]Environment, Society and Design Faculty,
Lincoln University, New Zealand

> When the well runs dry we know the true value of water
>
> Benjamin Franklin

Executive Summary

❖ There is an ever-increasing demand for freshwater that is being used for the purposes of irrigation and land use intensification in Canterbury. But the impact of this demand has lead to unacceptable minimum river flows. In an effort to resolve these problems water storage projects that hydrologically modify rivers are considered.

❖ In order to consider the full range of values of the impact of impounding rivers, local and regional governments are considering the use of an ecosystem services approach. Ecosystem services are the various benefits that people can obtain from ecosystems.

❖ In this report an ecosystem services review is undertaken using a method that evaluates each ecosystem service with a selection of indicators. Specfically, in order to adequately capture ecosystem services, both biophysical and socio-economic indicators need to be considered.

❖ To demonstrate an ecosystem services review, the method is used to assess the impact of the Opuha Dam on the ecosystem services provided by the Opihi River.

❖ A summary table of the impacts of the Opuha Dam is developed. It shows that there is conclusive evidence for a positive impact on only one ecosystem service, that of **Freshwater Supply**. The impact on other ecosystem services is uncertain, mixed or inconclusive.

❖ The inconclusiveness in the ecosystem services review about the impact on many ecosystem services occurs because only a few ecosystem services are adequately captured by both biophysical and socio-economic indicators. Hence, efforts are needed to develop further indicators for many ecosystem services.

❖ Once these indicators are developed, an ecosystem services index can be established to quantify changes to the level of ecosystem services.

Key words: Ecosystem services, ecosystem services index, ecosystem services indicators, ecosystem services review, irrigation, river ecosystems, water storage projects.

1.0 Introduction

In recent times, there has been an increased demand from the agricultural sector in New Zealand for abstracting water resources for irrigation. This demand is particularly strong in Canterbury. This is understandable as the Canterbury region experiences high levels of evaporation through dry summers and yet has the potential for its agricultural land to be extensively irrigated. For these reasons, Canterbury has the largest allocation of abstracted water for consumptive use and the highest dependency on irrigation in New Zealand (*Figure 1*). In fact, 70 per cent of the nation's irrigated area is found in this region (Ministry for the Environment, 2006). Nevertheless, the supply of water is limited making it essential that the sustainable management and use of water resources is appropriately considered.
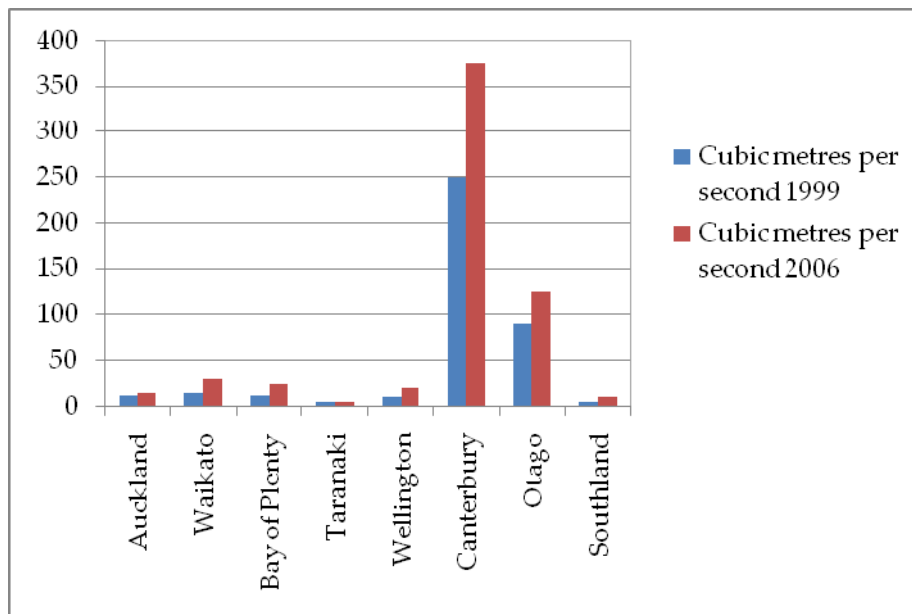

Figure 1: Weekly water allocation by regions (cubic metres per second) within New Zealand for years 1999 and 2006 (adapted from Ministry for the Environment, 2006).

Irrigation enables farmers to substantially intensify their agricultural operations. Irrigated farms can generate three times the farm income of non-irrigated farms (Harris Consulting, 2006). Intensification can result in improved profitability either by greater levels of agricultural production through increased stocking rates with existing land use practised or a change by farmers towards more productive land use (*e.g.* sheep farming/mixed cropping to dairy farming/vegetable production). The effects of irrigation through the abstraction of water from rivers and groundwater aquifers in Canterbury are increasingly evident as much land use intensification has occurred over the past 20 years (Parkyn & Wilcox, 2004). Accordingly, today irrigation is viewed as a vital component to the region's land-based economy. However, to meet ever-increasing (or even insatiable) demand for freshwater to irrigate agricultural land, it is necessary to ensure a reliable freshwater supply for the region. The reliability of freshwater supply is important. The less reliable the water supply the less viable land use intensification becomes. Hence, an unreliable freshwater supply can cause increasing uncertainty in the agricultural planning of farmers and the subsequent adoption of conservative and potentially inefficient agricultural practices (Canterbury Regional Council, 1995).

The need for a reliable freshwater supply is expected to increase as the high evaporation potential found in Canterbury is likely to be further exacerbated through climate change. Climate change in the Canterbury region is expected to lead to higher long-term temperatures, increased frequency of soil moisture deficits, increased primary production, greater climatic variability including more frequent extreme weather (*e.g.* droughts and floods), rising sea levels, increased risk of diseases and invasive non-native species, and lower mean annual rainfalls (Canterbury Mayoral Forum, 2009). Hence, evidently, climatic changes will have both positive and negative impacts on the supply of freshwater and the productivity of agricultural operations.

While much irrigation in Canterbury uses run-of-river surface water schemes, there is a realization that much of this water has reached its maximum allocation limits while retaining acceptable minimum river flows to sustain aquatic health (Canterbury Mayoral Forum, 2009; Harris Consulting, 2009). This realization has led to increased interest in water storage projects through the impoundment of rivers by the construction of dams. Dams make it possible to regulate, stabilize and augment minimum river flows downstream of the dam and store water upstream through the creation of reservoirs or artificial lakes. With the potential of reliable and increased freshwater supply resultant from river impoundment, it is possible for farmers to irrigate their farms and intensify land use in an attempt to maximize profitability.

However, while the impoundment of rivers through dam construction can result in significant benefits, it also can come at a 'cost', especially to river ecology. Indeed, from a historical perspective, it appears that water storage projects have placed much emphasis on short-term economic concerns with little regard for the actual functioning and health of river ecosystems (Dyson *et al*., 2003). These concerns have been noted by Bryan Jenkins, the current chief executive of Environment Canterbury (Canterbury Regional Council), who states that "… there are issues that need to be looked at [with dam construction], such as the possible spread of [algae], the mixing of the waters, sustainability and cost" (Worrall, 2007). Moreover, in addition to the problems of dams, scientists have long recognized the negative impact of land use intensification on rivers. Land use intensification, especially the conversion of low intensity sheep farming to high intensity dairy farming, often leads to a substantial increase in the application of fertilizers (Harris Consulting, 2006). The increased levels of nutrients (*e.g.* nitrates) applied with intensified agricultural practices can, through surface runoff pollute rivers. This increased concentration of pollutants in rivers can degrade water quality and the ecology of the river through excessive primary production of algae through a process known as eutrophication. But, even if water quality is not degraded following land use intensification, the abstraction of water can still degrade the ecology of rivers if they do not sustain adequate minimum river flows that consider the ecological functioning of the river in question (Dyson *et al*., 2003). For example, in the early 1990s prior to the extensive water abstraction from Canterbury's Hakataramea River, there is little evidence the minimum river flows were adversely affecting salmon numbers. However, increased water abstraction during the 1990s appears to have resulted in the decline of this salmon fishery (*Figure 2*) (Fish and Game, 2009).
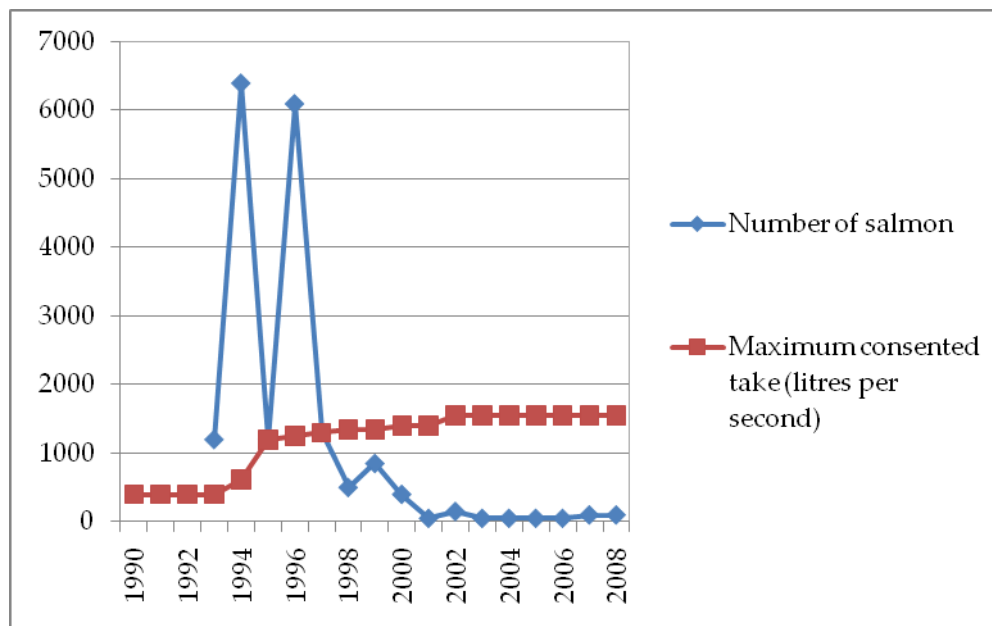
Figure 2: Number of salmon in the Hakataramea River against its maximum consented take (litres per second) for the purposes of irrigation (Fish and Game, 2009).

Given the potential positive and negative impacts from water abstraction and river impoundment, water availability and water storage are now critical issues for local and regional government in the Canterbury region (Canterbury Mayoral Forum, 2009). The 'wickedness' (Rayner, 2006) or complexity of Canterbury's water allocation and water storage problem has in recent times become very apparent, especially with a shift in emphasis towards the consideration of all values and not just values relating to the direct consumptive use of water resources (Frame & Russell, 2009). Today, water resources are valued for a multitude of reasons including highly important non-use values, such as those obtained from conservation and the spirituality concerns of Māori (Canterbury Mayoral Forum, 2009). No longer can Māori and conservation issues be ignored or disproportionately represented relative to economic development aspirations, as has occurred in the past, when considering the economic evaluation of many environmental projects (Frame & Russell, 2009). Thus, evaluations of water storage projects need to appropriately represent and integrate all values associated with water resources and rivers for their findings to be considered politically justifiable.

Despite this need to appropriately consider and integrate all values, standard economic approaches have often only considered tangible use values which are readily quantified into a monetary metric (Young *et al.*, 2005; Farber *et al.*, 2006). A consequence of only focusing on these tangible use values is that less tangible use and non-use values are taken for granted and not made explicit into a monetary metric. For all intents and purposes, these less tangible values are given an implicit value of zero, so that evaluation inherently neglects and overlooks the full range of values that are provided by river ecosystems (Loomis *et al.*, 2000; Navrud, 2001; Dyson *et al.*, 2003; Barkmann *et al.*, 2008). An example of this is found with the evaluation of a dam scheme proposed on the Colorado River in the 1960s. The economic evaluation for this dam scheme applied cost benefit analysis. The evaluation considered only revenue generated from hydroelectric production in its evaluation. It ignored many of the less tangible use and non-use values supplied by the river. Thus, the possibility of

8

underestimating the actual value of this river eventuated because of a poor account of the full range of values provided by this river ecosystem (Ackerman *et al.*, 2007). Incidentally, there are two obvious reasons why some values like use values are more tangible than non-use values. First, tangible use values are easily recognizable as people are often immediately dependent on these values. Secondly, unlike some use and non-use values, tangible use values have a long history of being efficiently traded in the marketplace (Layke, 2009).

The need to consider and integrate all values has lead to the consideration of evaluating environmental projects and especially water storage projects using an ecosystem services approach. The approach of ecosystem services has been popularized by some notable studies (*e.g.* Costanza *et al.*, 1997), including the landmark *Millennium Ecosystem Assessment* project (Capistrano *et al.*, 2006). Specifically, ecosystem services are the myriad of values or benefits that are actually provided by ecosystems (Daily, 1997). Hence, ecosystem services are 'valued' ecological functions. The significance of the ecosystem services approach is that it can promote and ensure that the full range of values provided by ecosystems are considered and appropriately integrated in evaluations. It can achieve this end because it allows much greater transparency to all values provided by ecosystems. Given this capacity for transparency, the ecosystem services approach is adopted and applied in this report by way of a review of a water storage project in Canterbury.

2.0 Ecosystem Services

To date, while many researchers have recognized the potential of the ecosystem services approach, there is still much debate on how to apply it in the evaluation of environmental projects. For example, one critical debate is how best to define the complete set of ecosystem services that are provided by ecosystems. There have been various classifications of ecosystem services developed, each with arguments to support the use of the classification devised (Capistrano *et al.*, 2006; Barkmann *et al.*, 2008). However, despite the various classifications, according to Raymond *et al.* (2009) the set of ecosystem services established by the *Millennium Ecosystem Assessment* project remains the most recognizable and well-developed. For this reason, this classification has been broadly developed herein. Specifically, in the *Millennium Ecosystem Assessment* project, there is a taxonomy of four classes of ecosystem services. However, in this report only three of these four classes of ecosystem services are adopted. This is because one class referred to as supporting ecosystem services (*e.g.* **Nutrient Cycling, Primary Production**) are services that reflect ecological processes and in turn produce other ecosystem services (Barkmann *et al.*, 2008; Layke, 2009). The three classes investigated are provisioning ecosystem services which provide benefits through goods that are obtained from the ecosystem, regulating ecosystem services which provide benefits through controlling and regulating various ecological functions, and cultural ecosystem services which provide non-material benefits including non-use benefits (*Table 1*). It is with the inclusion of cultural ecosystem services that we can account for the intrinsic values of a river through accounting for its **Conservation** and **Spiritual Values** (Dyson *et al.*, 2003).

Classes of ecosystem services	Ecosystem services	Description of ecosystem service
Provisioning ecosystem services	**Food**	Ecosystem supplies food produce (*e.g.* fish, grains, wild game, fruits)
	Fibre	Ecosystem supplies extractable renewable raw materials for fuel & fibre (*e.g.* fuelwood, logs, fodder)
	Freshwater Supply	Ecosystem supplies freshwater for use & storage
	Biological Products	Ecosystem supplies biological resources that can be developed into biochemicals for medicinal or commercial use
	Abiotic Products	Ecosystem supplies extractable non-renewable raw materials such as metals and stones for commercial use
Regulating ecosystem Services	**Climate Regulation**	Ecosystem regulates air temperature and precipitation and acts as a source of and sink for greenhouse gases
	Disease Regulation	Ecosystem regulates the abundance of pathogens
	Water Regulation	Ecosystem regulates hydrological flows (*i.e.* surface water runoff, groundwater recharge/discharge)
	Water Purification	Ecosystem purifies & breaks down excess nutrients in water
	Pest Regulation	Ecosystem regulates the abundance of invasive or pest species
	Erosion Control	Ecosystem controls potential biological catastrophes & stabilizes against erosion, thus, retaining soils
	Natural Hazard Regulation	Ecosystem regulates and protects against extreme natural events (*i.e.* floods or droughts)
Cultural ecosystem services	**Educational Values**	Ecosystem provides opportunities for non-commercial uses (*e.g.* archaeological values, knowledge systems).
	Conservation Values	Ecosystem provides existence values for species including important values relating to biodiversity
	Aesthetic Values	Ecosystem provides aesthetic qualities
	Spiritual Values	Ecosystem provides spiritual and inspirational qualities
	Recreational Values	Ecosystem provides opportunities for recreational uses

Table 1: The various ecosystem services that an ecosystem may provide (adapted from Curtis, 2004; Capistrano *et al.*, 2006).

MacDonald and Patterson (2008) recently undertook a study of ecosystem services in Canterbury to determine the total economic value of various ecosystem types (*e.g.* agricultural systems, rivers, wetlands and lakes) found in the region. This study confirmed the importance of Canterbury's agricultural systems and rivers for its regional economy. It determined that agricultural systems are the most valuable ecosystems and that freshwater supply and water regulation are the most important ecosystem services provided by rivers. From the estimates determined, it was concluded that rivers account for 43.3 per cent of the total economic value of ecosystem services in Canterbury, whereas the national average is only 20.3 per cent. However, while the study undertaken by MacDonald and Patterson (2008) is valuable, in that it indicates the importance of various ecosystem services to the region, the study was not ecosystem specific. Moreover, the study considered only five ecosystem services (**Food**, **Freshwater Supply**, **Water Regulation**, **Water Purification** and **Recreational Values**) and estimated their total economic value for various ecosystem types and not changes to ecosystem services as a result of a particular environmental project. Yet,

what is critical information for policy relevant evaluations of environmental projects is the change in the various ecosystem services provided (National Research Council, 2005; Layke, 2009).

Whilst the ecosystem services approach is a viable means of evaluating the full range of values provided by an ecosystem, there are few studies that have adopted the approach for the evaluation of environmental projects, let alone water storage projects (Hoeinghaus *et al.*, 2009). One reason for this, as previously explained, is that there is still much debate about the complete and appropriate set of ecosystem services to be used. However, even if a set of ecosystem services were unanimously agreed upon, there still remain a number of challenges. For instance, when applying the ecosystem services approach, ideally one should have a thorough ecological understanding of the ecosystem investigated (Farber *et al.*, 2006). This requirement makes sense as ecosystem services derive from the "complex interactions between biotic and abiotic components of ecosystems" (De Groot *et al.*, 2002). Nevertheless, obtaining a thorough ecological understanding is difficult, as ecosystems are complex systems. The complexity of ecosystems makes them highly variable, which in turn limits our understanding their behaviour. Moreover, the complexity of ecosystems highlights that they are path dependent systems. That is, when investigating ecosystems their history matters. Consequently, it is not always possible to compare ecosystems with other ecosystems even if they are of the same ecosystem type. In fact, it may not always be appropriate to compare the same ecosystem from different points in time (National Research Council, 2005).

Given the significance of history of each ecosystem when considering the ecosystem services it provides and in an effort to further improve the utilization of the ecosystem services approach this report demonstrates an 'ecosystem services review'. This ecosystem services review is different to, but not contradictory with, a type of ecosystem services review undertaken recently by Hanson *et al.* (2008). The demonstration of an ecosystem services review undertaken here attempts to indicate the impact and change of the various ecosystem services considered from a water storage project (*i.e.* dam and reservoir) constructed on a river in Canterbury. In many respects this ecosystem services review resembles an 'impact assessment' from an ecosystem services perspective.

The review involves a multiple step methodology (*Figure 3*). In the first step (*Section 3*) a general ecological description and history of the river ecosystem and the water storage project is established. Then, in the second step (*Section 4*), the list of ecosystem services provided by the ecosystem are considered, which leads to reasoned hypotheses being developed as to the impact of the water storage project on each ecosystem service. Finally, the ecosystem services review is completed by the selection of appropriate indicators for each ecosystem service (*Section 5*), which attempt to ascertain changes in each ecosystem service as a result of the water storage project. The use of indicators is significant as it provides a means to quantify the change on each ecosystem service from the water storage project, without necessarily requiring each ecosystem service to be transformed and quantified in dollar values. While it is possible to capture changes in the full range of ecosystem services using a monetary metric, it requires the employment of non-market valuation that is costly, labour intensive and time-consuming (Baskaran *et al.*, 2010). Hence, in applying this multiple step methodology, various methods are used including a

systematic literature review, interviews with experts and stakeholders including Māori, site visits, quantitative and qualitative data collection and retrieval, and trend analysis.
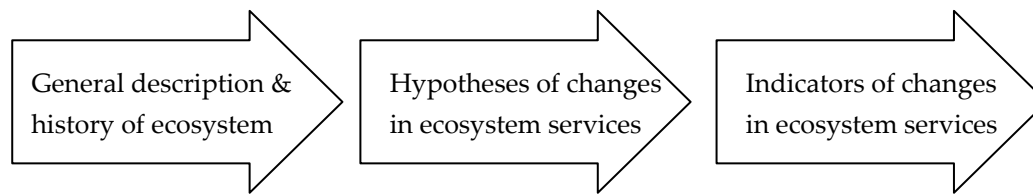

Figure 3: The various methodological steps in the ecosystem services review.

In order to demonstrate an ecosystem services review and keeping with the problematic issue of water availability and the reliability of its supply in Canterbury, the case of the Opihi River is investigated. The Opihi River is an ideal river system to investigate for at least two reasons. First, the river is rain-fed. These rain-fed rivers have proportionately more water abstracted from them than larger alpine-fed rivers (Canterbury Mayoral Forum, 2009). Secondly and critically, the Opihi River has been hydrologically modified by the Opuha Dam, for the primary purpose of storing water and ensuring a reliable supply of freshwater for irrigation. Accordingly, the ecosystem services review undertaken attempts to provide some much needed analysis as to how the ecosystem services provided by the Opihi River have changed with this water storage project. This ecosystem services review is expected to be revealing, as Young (2005) has observed that the uncertain *ex-ante* (or forward-looking) evaluations of water storage projects are often overly optimistic when compared with *ex-post* (or review) evaluations. Scudder (2005), an expert in dam engineering, has also indicated these sentiments by stating that when the future potential of large dams is evaluated, "benefits are overstated and costs understated." Various reasons can explain this occurrence. These include amongst others: the lack of the full range of values being appropriately considered, the lack of uncertainty being appropriately accounted for in evaluations including no account of potential unexpected events, and the lack of consideration for the seemingly 'irreversible' character of dams (Scudder, 2005).

3.0 The Opihi River and the Opuha Dam

In this section a general description and history of the Opihi River and its catchment is given. Then, the development of the Opuha Dam scheme, which was commissioned for the purposes of storing water and augmenting minimum river flows on the Opihi River, is discussed. This information is used to broadly indicate the spatio-temporal scale for the ecosystem services review undertaken in the following sections.

The headwaters of the Opihi River are found in the foothills of the Southern Alps at elevations of up to 2200 metres (de Joux, 1982). From these headwaters the river flows through the Timaru downlands and over the Canterbury Plains (*i.e.* including the Levels Plains area) to the coast. The entire catchment of the Opihi River is made of three additional rivers or tributaries (*Figure 4*). These tributaries are the Tengawai River, the Opuha River and the Temuka River. The Opuha River and the Temuka River also have tributaries. These are the North Opuha and South Opuha Rivers on the Opuha River and the Waihi, Hae Hae Te Moana and Kakahu Rivers on the Temuka River. Despite these many tributaries the primary concern of this report is the Opihi River and in particular the part of the Opihi River from the confluence where the Opihi River and the Opuha River converge to the coast.
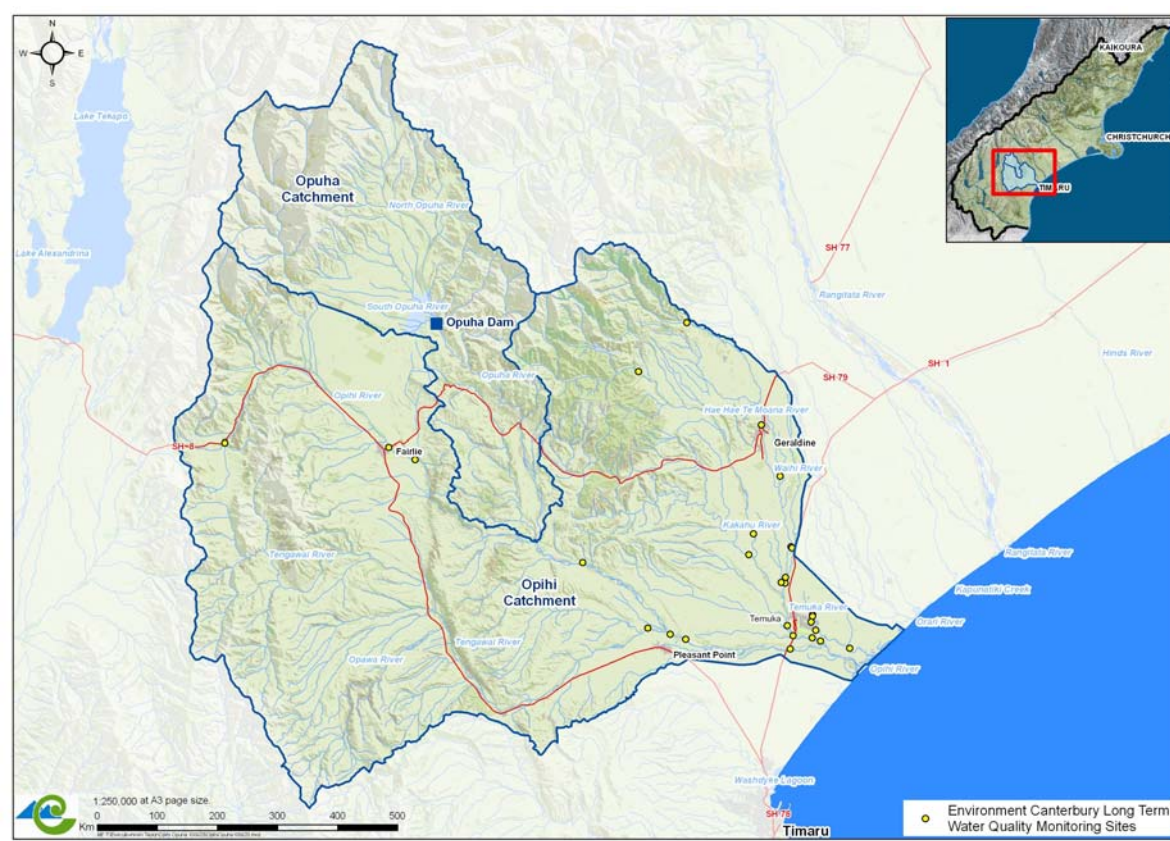
Figure 4: An outline of the catchment of the Opihi River and its tributaries.

The total catchment area of the Opihi River and its tributaries is approximately 245,000 hectares. *Table 2* details the sub-catchment areas for each of the rivers that make up the entire catchment of the Opihi River. Within this catchment area there are a range of land uses. These land uses include extensive grazing on the foothills, intensive dairy farming and cropping on the downlands and Levels Plains. While agriculture predominates the land use of the catchment there is also some non-native production forestry and a small conservation area of native forest, wetlands and swampland (Environment Canterbury, 2000). Historically, wetlands and swampland were far more prevalent in the Opihi River catchment (Scarf, 1984). These wetlands and swampland once provided a natural storage of water to the catchment, but were significantly reduced through drainage and the ongoing pressure for such land to be made agriculturally productive.

Sub-catchment	Area (ha)	Area percentage
Opihi	62,857	26
Opuha	64,192	20
Tengawai	48,811	26
Levels Plains	8,702	3
Temuka	61,101	25
Total catchment area	245,663	100

Table 2: The sub-catchment areas (hectares) for the Opihi River catchment.

The various rivers that make up the catchment of the Opihi River are all rain-fed. Peak river flows normally occur during the winter months. The average rainfall in the catchment is approximately 860 millimetres. However, rainfall ranges from 1400 millimetres in the foothills to 550 millimetres at the coastal river mouth. The average rainfall during the irrigation season (September to April) is approximately 700 millimetres in the foothills and only 420 millimetres at the coast (Canterbury Regional Council, 1990).

The strong winds and low annual rainfall during summer months results in the catchment being prone to drought conditions. Drought conditions in an agricultural sense are defined to occur when soil moisture levels fall below the permanent wilting point for agricultural pastures. These drought conditions severely impact on the productive use of the agricultural land. In an effort to overcome these droughts and soil water deficiencies for agricultural production, the Levels Plains Irrigation Scheme was developed in 1936. This run-of-river surface water scheme abstracts water from the Opihi River and has provided up to 3700 hectares within the catchment. However, despite this irrigation scheme, the demand for water often exceeded its supply. This was especially the case during the numerous drought conditions experienced during the 1980s (Canterbury Regional Council, 1990).

The result of these dry summer months coupled with the excessive abstraction of water from the Levels Plain Irrigation Scheme lead to the Opihi River often having very low river flows. In fact, sometimes the Opihi River dried up completely (Scarf, 1984; Worrall, 2007). Consequently, various ecosystem services have become lost or degraded. For all intents and purposes when the Opihi River was dry it was, according to one local Fish and Game officer, "a dead river" (Worrall, 2007). As a dry river, not only is the health of the river completely degraded, but the local economy and communities that rely on the river for its services are also degraded.

It is important to recognize that while the Levels Plains Irrigation Scheme is undoubtedly the cause of unacceptable minimum river flows in the Opihi River resulting in the loss or degradation of many ecosystem services, the natural state of the river still had periods where it would on occasion dry up. For example, historical records indicate that while water abstraction has increased the frequency in which the Opihi River has dried up, there have been periods (*e.g.* 1915, 1931-1932) in which the river would dry up naturally (Scarf, 1984).

Apart from the degradation of the ecosystem service **Freshwater Supply** used for irrigation, the adverse consequences of low minimum river flows in the Opihi River resulted in a decline in water quality evident through increasing water temperatures, decreasing dissolved oxygen levels and a reduction in the capacity of the river to assimilate pollutants (Canterbury Regional Council, 1990). The poor water quality in the Opihi River in turn resulted in the degradation of various ecosystem services that are associated with the loss of habitat for fish and other aquatic life (*e.g.* the ecosystem services **Food**, **Recreational Values**). Furthermore, the inadequate river flows were unable to keep the river mouth to the sea open for extensive periods of time. While the closure of the river mouth on the Opihi River is a natural feature, low flows resultant from water abstraction increase the likelihood of this occurring. This inability of the river mouth to open, exacerbated problems of poor water quality in the neighbouring Opihi Lagoon and prevented game and native fish migrating out to sea. The limited fish passage to the sea and poor water quality of the Opihi River and its

lagoon were key factors in the declining population of fish and availability of mahika kai (Dacker, 1990; Scarf, 2009; pers. comm.). Mahika kai, which translates to 'food works' and is a term for food resources gathered by Māori using traditional methods, was once abundant in the Opihi River prior to intensive agricultural operations in the catchment (Waaka-Home, 2010; pers comm.).

With the noticeable degradation of some ecosystem services, the idea of constructing a dam for the Opihi River in an effort to store water and augment minimum river flows was reconsidered during the early 1990s. This idea of constructing a dam in the Opihi River was first mooted in 1905. It was maintained that a dam would through water storage provide a reliable supply of freshwater for the purposes of irrigation downstream of the dam. In addition, the augmented minimum river flows were foreseen to allow improvements to some ecosystem services including improving the degraded recreational fishery that was once of national importance. Indeed, Graynoth and Skrzynski (1973) once expressed that "the Opihi is very valuable for angling and possibly unique in New Zealand in that all its tributaries are fairly evenly utilized by anglers with a high and steady rate of success."

The *ex-ante* impact assessment of a dam, to be located on the Opuha River, provided strong indications that the proposed Opuha Dam scheme would generate many economic and environmental benefits. Some of these anticipated benefits, apart from irrigation and improved recreational fishing, included hydroelectric production and the creation of a 710 hectare reservoir in Lake Opuha. The many benefits expected from the proposed Opuha Dam scheme highlighted the multiple purpose nature of the dam.

A number of negative impacts were also anticipated. These included the limited number of flushing flows downstream of the dam resulting potentially in the increased likelihood of algal growth and the loss of natural character on the Opihi River (Canterbury Regional Council, 1995). However, despite these negative impacts it was believed that the benefits would outweigh the few environmental costs (Worrall, 2007). In fact, in the case of the loss of natural character it had been maintained that a return to the natural state of the Opihi River prior to the Levels Plains Irrigation Scheme would still be unsatisfactory for the purposes of adequately meeting the demand for freshwater (Canterbury Regional Council, 1995). Hence, given even a return to a natural state was not considered adequate, dam construction appeared necessary. Consequently, despite some objections made by the Department of Conservation and the Royal Forest and Bird Protection Society, the commission tasked with reviewing the *ex-ante* evaluation of the Opuha Dam scheme gave its consent. Interestingly, while the dam did consider impacts to conservation, local Māori were not consulted as to their position on the suitability of constructing a dam on the Opuha River (Waaka-Home, 2010; pers. comm.). This once again highlights the significant problem of not accounting for all values in evaluations and also reiterates the usefulness of an ecosystem services review, which provides a systematic means to appropriately account for the full range of values provided by an ecosystem.

Dam construction went ahead in 1996, and despite a devastating and unexpected dam breach during construction after a period of heavy rain in 1997 the dam was fully operational by the end of 1998 (Worrall, 2007). *Figure 5a*, *Figure 5b*, *Figure 5c* and *Figure 5d* show the Opihi River, Opuha Dam spillway, Lake Opuha and the Opihi Lagoon, respectively.

Figure 5: (a) Opihi River near Waipopo.

Figure 5: (*b*) The Opuha Dam spillway from the top of the dam.

Figure 5: (*c*) Lake Opuha from the top of the dam.

Figure 5: (*d*) The Opihi Lagoon from the Milford Huts.

4.0 Ecosystem Services Hypotheses

In this section the full range of ecosystem services that are provided by the Opihi River are considered. It was noted earlier that the complexity of ecosystems often means they provide a unique set of ecosystem services. Hence, in an effort to investigate all ecosystem services that are provided by the Opihi River, a thorough review of ecosystem services for the Opihi River is undertaken. In this section the review will compile a list of ecosystem services provided by the Opihi River and also give reasoned hypotheses as to the potential impact the Opuha Dam scheme may have on each of these ecosystem services. These hypotheses are developed from the *ex-ante* evaluation of the dam and from relevant literature of the possible impact dams may have on ecosystem services.

4.1 Hypotheses for Provisioning Ecosystem Services

In this sub-section the provisioning ecosystem services provided by the Opihi River are reviewed. It is found that the provisioning ecosystem services provided are extensive. They include **Freshwater Supply**, **Food**, **Fibre** and **Abiotic Products**. Only the ecosystem service **Biological Products** are not obviously provided. But, even this ecosystem service may have some quasi-option value, in the sense that future technological and scientific progress may attribute value in biological products derived from various species that inhabit the Opihi River.

A primary purpose for the construction of the Opuha Dam was to increase the ecosystem service **Freshwater Supply**, which allows for the provision of numerous benefits. Indeed, through the construction of the Opuha Dam, minimum river flows have increased to an average of six cubic metres per second and there is water storage of up to 91 million cubic metres created through Lake Opuha (though the active storage of water is estimated to be 83 million cubic metres) (Worrall, 2007; Canterbury Mayoral Forum, 2009). This freshwater supply allows for an increased amount of irrigated area in the Opihi River catchment from that provided by the Levels Plains Irrigation Scheme and the greater capacity for land use intensification. The Opuha Dam also provides provision for hydroelectric production through a 7.6 megawatt turbine housed in the Opuha Dam. In addition, the increased freshwater supply provides benefits as a consumptive supply of water for stock, industrial

and municipal uses. For example, the Timaru District Council supplements its main supply of freshwater from the Pareora River with water from the Opihi River, while the Smithfield freezing works uses water from the Opihi River for industrial processing purposes. However, despite these numerous benefits from the ecosystem service **Freshwater Supply**, it is hypothesized that there could be negative impacts on this ecosystem service as a result of the Opuha Dam scheme. These negative impacts include the degradation of water quality through the increased intensification of land use (Environment Canterbury, 2000), which in turn may result in increased water treatment costs before water is suitable for consumptive use (*e.g.* drinking).

The ecosystem service **Food** is provided from the Opihi River through the game fisheries of salmon and trout as well as native fisheries. There are a total 18 native fish species that can be found in the Opihi River. Most of the native fish species are found in the Opihi Lagoon and are used by local Māori as mahika kai, especially long and short-finned eel (*i.e.* tuna), whitebait (*i.e.* inanga), lamprey (*i.e.* kanakana) and flounder (*i.e.* patiki). It is hypothesized that the **Food** ecosystem service will be positively impacted from the Opuha Dam. One reason for this positive impact is that aquatic and fish habitat is expected to improve with augmented minimum river flows as water quality problems associated with low flows should be alleviated (Canterbury Regional Council, 1995). Another reason for an improved game and native fishery is that the higher river flows allow improved fish passage downstream of the dam and maintain the opening of the river mouth for fish to migrate out to the sea. Nevertheless, despite augmented minimum river flows allowing improved fish migration, there will be limited fish passage upstream of the dam. This limitation of fish passage may not be significant to fish stock, but it is known that dams have negatively impacted fish stocks in other rivers. For example, on the Columbia River in the United States, dams have prevented the migration of fish throughout the river resulting in the rapid decline of fish stocks (Schaller *et al.*, 1999). Other hypothesized negative impacts that may affect the abundance of fish stocks include the possible increased sedimentation of the riverbed downstream resulting in poor fish habitat for spawning and the increased pollutants in the Opihi River from land use intensification. In particular, the hypothesized increase in pollutants may increase the growth and proliferation of algae, which may become toxic and adversely affect fish populations and fish taste (Biggs, 2000; Environment Canterbury, 2000; Harris Consulting, 2006).

The ecosystem service **Fibre** is, in contrast to the ecosystem services **Freshwater Supply** and **Food,** an ecosystem service of limited value. However, the ecosystem service is still provided through driftwood from collapsed willows and from flax (*i.e.* harakeke) and other plant material (*i.e.* mahika kai) that can be used for ornamental purposes. It is hypothesized that the regulated and stable river flows along the Opihi River resultant from the Opuha Dam may increase the encroachment of non-native willow species that are widespread along the river margin of the Opihi River. Hence, with the greater number of willows it is foreseen that there will be greater amount of driftwood available that can be used for fuelwood.

The Opihi River also provides for the ecosystem service **Abiotic Products** through gravel that can be extracted from the riverbed. The Opihi River is a key source of gravel in South Canterbury (Hudson, 2005). It is understood that approximately 116,000 cubic metres of gravel was removed from the Opihi River in 2008. It is hypothesized that the impact of the

Opuha Dam will have a negligible impact on the supply and extraction of gravel on the Opihi River. However, it is recognized that gravel extraction can be a cause for both positive and negative impacts on the ecology of the Opihi River. For example, gravel extraction can improve flood mitigation through widening the river channel, while it can degrade sensitive braided river habitat used by native bird species (Kelly *et al.*, 2005).

4.2 Hypotheses for Regulating Ecosystem Services

In this sub-section the regulating ecosystem services provided by the Opihi River are reviewed. In the work of MacDonald and Patterson (2008) it was estimated that the main ecosystem services provided by rivers in Canterbury are the regulating ecosystem services of **Water Regulation** and **Water Purification**. However, from the review undertaken here it is recognized that the Opihi River provides for many other regulating ecosystem services including **Natural Hazard Regulation**, **Disease Regulation**, **Pest Regulation** and **Erosion Control**. The only regulating ecosystem service that was not considered to be provided by the Opihi River is **Climate Regulation.** For the most part, ecosystems that provide for the ecosystem service **Climate Regulation** are those with a large carbon sink such as forest ecosystems.

The Opuha Dam regulates hydrological flows. Hence, the Opuha Dam impacts the ecosystem service **Water Regulation**. However, while the Opuha Dam ensures a regular and stable flow of water, it has limited the capacity to vary river flows so as to simulate flushing and flood flows (Meredith, 2009; pers. comm.). This reduced capacity to vary flow rates is generally undesirable though it may have some positive impacts including that the dam would through limiting flood flows provide some flood mitigation (Canterbury Regional Council, 1995). In fact, the improved protection against floods and the increased capacity for irrigation indicates that the Opuha Dam scheme is hypothesized to positively impact the ecosystem service **Natural Hazard Regulation**. This hypothesized improvement to **Natural Hazard Regulation** is likely to be significant as not only is the Opihi River catchment drought prone, but it has also been severely impacted by various flood events. For example, on 13 March 1986 a devastating flood event on the Opihi River caused considerable damage to infrastructure, agriculture and also resulted in the loss of one human life (Scarf, 1987). However, the lack of flushing and flood flows is also hypothesized to have negative impacts on the ecology of the Opihi River (Canterbury Mayoral Forum, 2009). Indeed, Dyson *et al.* (2003) have argued that the over-regulation of river flows will have considerable adverse impacts in the long-term. These negative impacts may include the limited capacity of the river to flush potentially toxic algae from the ecosystem and the inability to turnover gravels in the riverbed. The limited gravel disturbance may adversely affect fish stocks, which rely on gravels for spawning, and therefore the ecosystem service **Food**.

It is hypothesized that the Opuha Dam scheme will have both positive and negative impacts on the ecosystem service **Water Purification**. Positive impacts may result from a dilution effect, where pollutant assimilation may be increased as concentrations presumably will decrease with augmented minimum river flows (Canterbury Regional Council, 1990; 1995). However, negative impacts include the greater likelihood of pollutants being put into the Opihi River as a result of increased land use intensification. The greater level of pollutants coupled with the hypothesized decrease in flushing flows may, as indicated previously, increase the growth and proliferation of algae. The possibility of increased algae may

negatively impact the ecosystem service **Disease Regulation**, as the algae could become toxic. This problem of nutrient-rich water resulting in toxic algal growths is of particular concern in Lake Opuha (Meredith, 1999). This is because it is well known that inundated vegetation and soil organic matter releases many nutrients into the water of newly formed reservoirs (Petts, 1984; Scudder, 2005). The increased nutrient loads increase the likelihood of excessive primary production in the reservoir and the susceptibility of toxic algal blooms occurring, which can result in fish kills through reduced dissolved oxygen levels.

As indicated previously, the regular and stable river flows resultant from the Opuha Dam is hypothesized to increase the encroachment of willows found along the river margins of the Opihi River. The encroachment of willows is hypothesized to positively impact the ecosystem service **Erosion Control**. This is because willows can stabilize river banks. In fact, willows are often planted by river engineers for this very reason. However, willows are also considered a pest by conservation groups as by stabilizing river banks they alter the naturally unstable character of braided rivers (Hughey & Warren, 1997). Hence, the Opuha Dam is hypothesized to negatively impact the ecosystem service **Pest Regulation** on the Opihi River.

4.3 Hypotheses for Cultural Ecosystem Services
In this sub-section the cultural ecosystem services provided by the Opihi River are reviewed. It is found that all cultural ecosystem services are provided by the Opihi River including the ecosystem services **Conservation Values**, **Educational Values**, **Aesthetic Values**, **Spiritual Values** and **Recreational Values**.

The **Conservation Values** obtained from the Opihi River include native biodiversity, the presence of endangered native species and the existence of significant ecological landscapes. Native biodiversity includes species of fish, birds, macroinvertebrates and plants. One area where native plants are found, which is also a wetland landscape of ecological significance is the Opihi Lagoon (Environment Canterbury, 2000). This lagoon provides breeding and nursery habitat for many native fish (*e.g.* whitebait) and has remnant stands of native vegetation including raupo, ribbonwood, flax and sedges. Various native bird species (*e.g.* banded dotterel, black-backed gull, white-winged black tern, black-fronted dotterel, South Island pied oystercatcher, black-billed gull and the black-fronted tern), some of which are endangered, also breed and feed around the lagoon and other parts of the Opihi River (de Joux, 1982; Hughey, 2009; pers. comm.). In addition, to bird and fish species, Fowles (1972) found a total of 43 invertebrate species that inhabit the Opihi River. It is hypothesized that the Opihi Lagoon would become healthier with the construction of the dam, as the mouth of the river would be open for extensive periods allowing improved water quality and habitat for various fish and bird species. Furthermore, it was maintained that habitat for birds could increase with the Opuha Dam scheme through the development of a 200 hectare wetland around the lake edge when the water levels on Lake Opuha were low (Canterbury Regional Council, 1995).

Despite claims that the Opuha Dam scheme would improve **Conservation Values** there is also information available to suggest that dams negatively impact conservation and river ecology. Various researchers have argued that the regulation and stabilization of river flows from the hydrologic modification of rivers can threaten native biodiversity (Canterbury

Regional Council, 1990; Dudgeon *et al*., 2006). For example, many native bird species that have adapted specifically to the constantly changing environment of braided rivers can become threatened from the changes in river ecology from hydrologic modification and associated land use intensification (O'Donnell & Moore, 1983; Woolmore & Sanders, 2005). For example, the invasive encroachment of non-native willows as a result of limited flood flows in dammed rivers can exacerbate the loss of braided river habitat by covering gravels and limiting the availability of suitable breeding habitat (Hoeinghaus *et al*., 2008). This problem is of particular concern with the banded dotterel, the black-fronted tern and the black-billed gull, where over 60 per cent of suitable nesting sites on riverbeds have been degraded from invasive encroachment of non-native vegetation (*e.g.* willows) (O'Donnell, 1992; Hughey & Warren, 1997; Maloney *et al*., 1999).

Braided rivers found in Canterbury are themselves important ecological landscapes (Canterbury Regional Council, 1990). These ecosystem types are rare globally, and are only found in Canterbury, North Otago and a few parts of North America and Europe (O'Donnell & Moore, 1983). However, dams stabilize and regulate river flows, which prevent the naturally unstable character of braided rivers that are represented by multiple channels and gravel islands continuously appearing and disappearing (Ward *et al*., 2002; Young *et al*., 2004). This stabilization of the braided river characteristics of the Opihi River as a result of the Opuha Dam is hypothesized to negatively impact the river being used as a source of knowledge about the functioning and structure of these complex ecosystem types. However, the Opuha Dam scheme is hypothesized to also positively impact knowledge systems and therefore the ecosystem service **Educational Values** through the improved understanding of how dams affect the ecology and dynamics of rivers. Indeed, Meredith (2009; pers. comm.) iterated that the effects of the Opuha Dam on the Opihi River has provided important understanding on how future water storage projects may influence river ecosystems. Importantly, the Opihi River also provides **Educational Values** through the existence of various historical and archaeological sites. These significant sites include the Milford Māori pa site and burial ground near the Opihi Lagoon and the Raincliff Historic Reserve, which is where Māori rock drawings and shelter sites are found. It is hypothesized that the Opuha Dam scheme will not significantly affect these historical and archaeological sites.

Like most ecosystems used for cultural purposes, **Aesthetic Values** are likely to be of some importance on the Opihi River. It is hypothesized that the Opuha Dam would have both positive and negative impacts on aesthetics. Positive impacts that have been hypothesized include the transformation of agricultural land into an artificial lake and the augmented minimum river flows preventing the unattractive occurrence of a river that is dried up. However, negative impacts include the potential unsightly nature of the dam construction itself, the increased growth and proliferation of unattractive algae in the Opihi and Opuha Rivers and Lake Opuha, and the increased likelihood of dust storms when the lake level is low (Canterbury Regional Council, 1995).

The ecosystem service **Spiritual Values** focuses predominantly on those relating to Māori, as Māori are said to have an essential and integral connection with water and the Opihi River (Ministry for the Environment, 2009). This spiritual connection is critical to Māori, and is particularly important for the Opihi Lagoon, where mahika kai has been traditionally gathered (Waaka-Home, 2010; pers. comm.). In order for these spiritual values to be

maintained local Māori have expressed the desire for the restoration of the perceived natural character and the life supporting capacity (or mauri) of the river to be maintained and not degraded. It has already been hypothesized that the natural character of the river will be negatively impacted as a result of the Opuha Dam (Environment Canterbury, 2000). However, it is also hypothesized that the life supporting capacity of the river will improve as augmented minimum river flows is hypothesized to increase the abundance of aquatic life that can be supported by the Opihi River (Canterbury Mayoral Forum, 2009).

Finally, **Recreational Values** are also provided by the Opihi River through the many recreational activities that can be participated in. These recreational activities that are supported by the Opihi River include swimming, boating, picnicking, hunting, fishing and walking (*e.g.* the Opihi walkway). With the creation of Lake Opuha and the augmentation of minimum river flows it has been hypothesized that the **Recreational Values** provided by the Opihi River will be improved (Canterbury Regional Council, 1995). However, through increased land use intensification, it is recognized that the Opihi River and Lake Opuha may be impacted by the growth and proliferation of algae, which can be a severe nuisance for many recreational activities and especially recreational fishing and boating (Biggs, 2000; Environment Canterbury, 2000). They may also be negatively impacted by land use intensification leading to degraded water quality.

In summary, this section considered the potential impacts of the Opuha Dam on the full range of ecosystem services provided by the Opihi River. In undertaking this task, it is recognized that the Opihi River provides many ecosystem services. Only two ecosystem services as classified in *Table 1* are not provided. Hence, there are many more ecosystem services than the five generic ecosystem services detailed by MacDonald and Patterson (2008) for rivers in Canterbury. This reiterates the need to undertake an ecosystem services review for each ecosystem that is evaluated.

From the hypotheses developed for the impacts of the Opuha Dam on each ecosystem service provided it is recognized that many ecosystem services may have both positive and negative impacts. The hypothesized impacts from the Opuha Dam scheme on each ecosystem service are summarized in *Table 3*. Many of the reasons for the hypothesized impacts on the ecosystem services provided are the same for several ecosystem services. For example, the potential growth and proliferation of algae was reasoned to impact at least five different ecosystem services. This highlights that the causal drivers that influence many ecosystem services are interrelated (Capistrano *et al.*, 2006). The causal interrelatedness of ecosystem services highlights why it is important to undertake an ecosystem services review, as it provides greater understanding on how policies that target a particular ecosystem service may result in unintended impacts on other ecosystem services. This causal interrelatedness is evident in *Figure 6*.
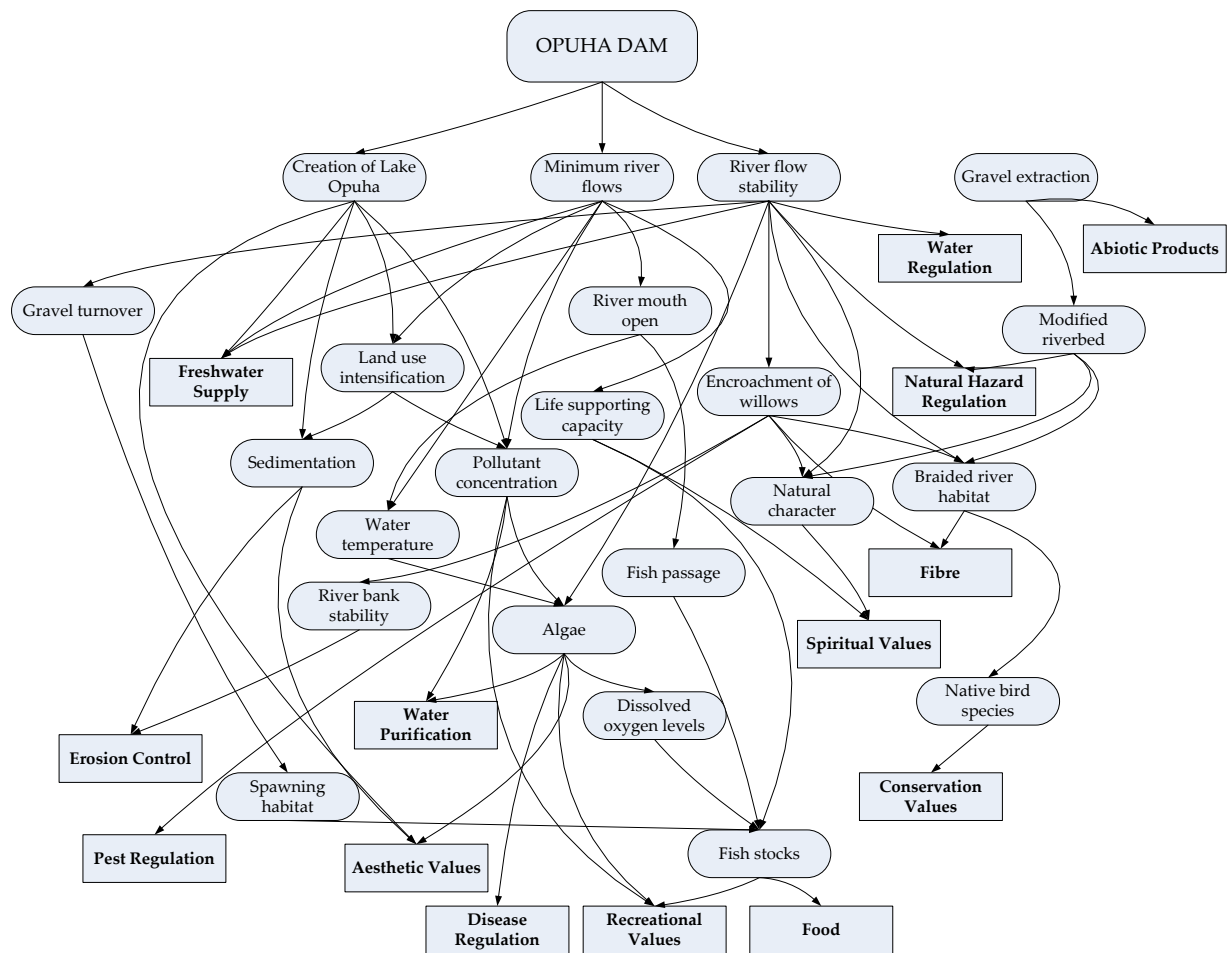
Figure 6: A causal diagram indicating the causal reasoning from the development of Opuha Dam and its impact on ecosystem services provided by the Opihi River. Note that **Educational Values** are not indicated in the above diagram.

Ecosystem service class	Ecosystem service	Notes and sub-class of ecosystem service			Hypothesized impact
Provisioning ecosystem services	**Food**	Fisheries	Salmon		+/-
			Trout		+/-
		Mahika kai (*e.g.* eel, whitebait, flounder)			+/-
	Fibre	Flax, driftwood			+
	Freshwater supply	Irrigation			+
		Hydroelectric production			+
		Municipal water supply			+
		Industrial water supply			+
		Stock water supply			+
	Biological products	Not applicable			Na
	Abiotic products	Gravel extraction for road chip and concrete			0
Regulating ecosystem services	**Climate regulation**	Not applicable			Na
	Disease regulation	Parasite and toxic algae regulation			-
	Water regulation	Hydrological flow regulation (*e.g.* minimum river flows, flushing flows)			+/-
	Water purification	Removal of pollutants			+/-
	Erosion control	Stabilization of river banks			+
	Pest regulation	Invasive non-native species (*e.g.* algae, willows, gorse, broom)			-
	Natural hazard regulation	Flood and drought protection			+
Cultural ecosystem services	**Conservation values**	Native biodiversity and habitat			-
		Endangered native species			-
		Ecological landscapes of significance			+/-
	Educational values	Historical/archaeological values			0
		Knowledge systems			+/-
	Aesthetic values	Perceived beauty			+/-
	Spiritual values	Māori values	Natural character		-
			Life supporting capacity or mauri		+
	Recreational values	Boating (*e.g.* sailing, rowing, kayaking)			+
		Fishing			+/-
		Hunting (*e.g.* duck hunting)			+
		Picnicking			+
		Swimming			+/-
		Walking			0

Table 3: The ecosystem services provided by the Opihi River and the hypothesized impacts (*i.e.* positive '+'; negative '-'; no change '0'; not applicable 'Na') of the Opuha Dam on each ecosystem service.

5.0 Ecosystem Services Indicators

In the previous section, the ecosystem services review developed reasoned hypotheses for the impacts of the Opuha Dam on each ecosystem service provided by the Opihi River. In order to complete the ecosystem services review there is a need to test the validity of these hypotheses. We judge they can be tested by investigating indicators which provide empirical evidence of the change in ecosystem services resultant from the hydrologic modification of the Opihi River from the Opuha Dam. The use of indicators allows policy makers to be informed, as indicators can communicate long-term trends in the supply of many ecosystem services (Meyerson *et al.*, 2005). This is in part because indicators are able to "summarize complex information of value to the observer. They condense … complexity to a manageable amount of meaningful information … informing ... and directing our [policy] actions" (Bossel, 1999). Hence, monitored indicators can provide a general sign to policy makers about the impact on ecosystem services from environmental projects. However, in spite of the potential of indicators for ascertaining the change in ecosystem services and allowing the approach to become evaluative and inform policy making, it remains underdeveloped.

At present, the development of ecosystem services indicators is still in its infancy and is a critically needed area of research (Layke, 2009). There are no indicators that are fully agreed upon for the monitoring of each ecosystem service. The final report of the *Millennium Ecosystem Assessment* project included similar sentiments. In particular, it was stated that there are "no widely accepted indicators to measure trends in [many] ecosystem services, much less indicators that measure the effect of changes on human well-being" (Capistrano *et al.*, 2006). One reason why no well-defined set of indicators have been established for the full range of ecosystem services is that ecosystem services can be difficult to capture by indicators (Layke, 2009). This difficulty of equating a single indicator for each ecosystem service is, in part, because while an indicator makes understanding an ecosystem service more manageable, it also often leads to overly reductionistic interpretations. The result of this is that the ecosystem service provided is poorly captured and that policies are directed towards positively influencing the chosen indicator, thereby potentially negatively influencing other aspects of the ecosystem service that is ignored by the chosen indicator (Functowicz *et al.*, 2001).

One approach to capture an adequate description of an ecosystem service from the viewpoints of the 'ecosystem' and its relationship with people is to use multiple indicators from both biophysical and socio-economic perspectives. Hence, ideally each ecosystem service would be determined by multiple biophysical and socio-economic indicators, which when all indicators are considered together provide sufficient information to ascertain long-term trends for the particular ecosystem service investigated. Naturally, this method of using both biophysical and socio-economic indicators where available has much broader appeal than using only a single biophysical or socio-economic indicator, which can easily lead to inferences made from an overly reductionistic perspective. Indeed, by gathering both biophysical and socio-economic indicators the objective ecosystem dimension and subjective value dimension of an ecosystem service can be considered together. This is significant as a monetary metric often used in economic valuations fails to reveal information about the actual status of the river, while considering an evaluation by biophysical units alone ignores the preferences of human agents (Straton, 2006; Winkler, 2006) Previously, ecosystem services have been evaluated only by either a subjective and anthropocentric perspective

through methods of economic valuation (Costanza *et al.*, 1997) or by an objective and biocentric perspective through attaching services to the abundance of various species considered to be ecosystem service 'providers' (Kremen, 2005).

It has been argued herein that both biophysical and socio-economic indicators where available should be used to capture the long-term trends of each ecosystem service. Accordingly, this approach to ecosystem services indicators is used in this report in an effort to capture the impact of the Opuha Dam on each ecosystem service provided by the Opihi River. But, even with both biophysical and socio-economic indicators available there is still a need to have a suitably rich and long time-series of data available, which is obtained from multiple periods in a year and from multiple monitoring sites along the Opihi River and its tributaries. Indicators that attempt to make inferences from a single monitoring site or from only an inadequate or short time-series are, of course, limited in capturing accurate trends. For instance in regards to the Opuha Dam and its impact on the Opihi River, there is a need for indicators to have a time-series that extends well before the beginning of dam construction in 1996.

Fortunately, the need for multiple monitoring sites and a long and rich time-series is well-recognized. Of the data used in this report four organizations provided the bulk of the information used. These organizations were the National Institute of Water and Atmospheric Research (NIWA), the Ministry for the Environment, Environment Canterbury and Fish and Game (Central South Island). From the data collected for the various indicators it was evident that there is much variability. This can be explained, in part, by the complexity of ecosystems, where there are many factors that influence any indicator. Variability makes it difficult to make definitive inferences about trends. However, NIWA in conjunction with the Ministry for the Environment have collected data on the Opihi River and its tributaries and have subsequently calculated trends between 1989 to 2007 showing whether the indicator has increased (+), decreased (-), or remain unchanged (0). Where data was available that had not had trends inferred, then trend analysis was applied in an attempt to determine trends in the ecosystem services indicators firsthand. In using trend analysis for indicating the impact of the Opuha Dam on the ecosystem services provided by the Opihi River it is recognized that the complexity of ecosystems limits the capacity to causal infer without doubt the relationship between the dam scheme and each ecosystem service. Accordingly, actual impacts are determined not through statistical significance, but rather by the weight of evidence available.

With regards to the indicators collected by NIWA, three monitoring sites have data readily available for the Opihi River (Ministry for the Environment, 2009). These sites are Waipopo located on the Opihi River near the coast, Skipton Bridge located on the Opuha River downstream of the Opuha Dam, and Rockwood located on the Opihi River before the confluence with the Opuha River. This part of the Opihi River before the confluence with the Opuha River is referred to here as 'Opihi River – Confluence'. The collection of data from the Opihi River – Confluence and other tributaries (*e.g.* Tengawai, Kakahu Rivers) are significant, as these sites are not directly affected by the Opuha Dam scheme. As such, data from these areas provide a comparative control when forming trends about the actual impact of the Opuha Dam on the ecosystem services of the Opihi River. For example, the usefulness of the Rockwood monitoring site is indicated in *Table 4*, which indicates data available for the

biophysical indicator *Minimum River Flows*. Here the impact of the Opuha Dam on minimum river flows is confirmed. This is because Waipopo and Skipton Bridge minimum river flows have increased during the period between 1989 and 2007, while Rockwood minimum river flows have remained unchanged.

Monitoring site	Unit	Opihi River: Waipopo		Opihi River - Confluence: Rockwood		Opuha River: Skipton Bridge	
Biophysical indicator		2007	Trend	2007	Trend	2007	Trend
Minimum River Flows	m³/s	7.67	+	2.95	0	4.45	+

Table 4: Trends in the average minimum river flows (cubic metres per second) in the Opihi River and its tributaries between 1989 to 2007 (Ministry for the Environment, 2009).

5.1 Indicators for Provisioning Ecosystem Services

In this sub-section the impact of the Opuha Dam on the provisioning ecosystem services provided by the Opihi River are investigated by selected ecosystem services indicators. The first ecosystem service investigated is **Freshwater Supply**, which is expected to be positively impacted from the Opuha Dam. As indicated previously, there are numerous benefits that can be obtained from freshwater obtained from the Opihi River. These benefits include irrigation, hydroelectric generation and industrial, municipal and stock water supply. Where possible each of these benefits is investigated with indicators.

In the case of irrigation, a study by Harris Consulting (2006) has provided evidence that the Opuha Dam has positively impacted the capacity of farmers to irrigate and intensify land use. In this study the biophysical indicator *Irrigated Area* for the Opihi River catchment was found to have increased from less than 4000 hectares to approximately 16,000 hectares. On this irrigated area, the biophysical indicator *Agricultural Production* increased 2.4 times over non-irrigated agricultural land. This increased agricultural production is also indicated by the indicator *Nitrogen Fertilizer Application* increasing from 37 kilograms nitrogen per hectare on non-irrigated agricultural land to 86 kilograms nitrogen per hectare on irrigated agricultural land within the Opihi River catchment (Harris Consulting, 2006). The increased agricultural production indicated in the above biophysical indicators is also found in the socio-economic indicator *Economic Impact over Irrigated Area*, where it was found that $12,000,000 in surplus per year for farmers is generated from irrigation as a result of the Opuha Dam scheme (*Table 5*). The increased surplus per year generated from irrigation and land use intensification was estimated to provide over $123,000,000 per year in total economic benefits to the local economy within the catchment area. This socio-economic indicator of *Total Economic Benefits* indicating the positive impact of the Opuha Dam is also observed with the indicator *Full Time Employment* (FTEs). Specifically, it was estimated that the increased capacity to irrigate and intensify land use in the catchment area as a result of the Opuha Dam scheme has generated 480 jobs (Harris Consulting, 2006).

Socio-economic indicator	Indicator calculation	Unit	Revenue	Expenses	Surplus
Farm Level Impact of Irrigation	$/ha irrigated farms - $/ha non-irrigated farms	$/ha	$1211	$849	$362
Irrigation Impact per Hectare	Irrigation impact/proportion of area irrigated (0.493)	$/ha	$2457	$1722	$735
Economic Impact over Irrigation Area	Irrigation impact per ha × irrigation area (16,000)	$/year	$39,740,000	$27,850,000	$11,890,000

Table 5: Economic benefits from reliable and increased freshwater supply for irrigation (adapted from Harris Consulting, 2006).

The construction of the Opuha Dam and the storage of water in Lake Opuha provides the capacity for hydroelectric production. The biophysical indicator *Hydroelectric Hours Produced per Year* indicates that 30 gigawatt hours per year of hydroelectricity is generated through the 7.6 megawatt turbines of the Opuha Dam. In addition to this biophysical indicator, it has been estimated that the socio-economic indicator *Total Economic Benefits* to the catchment from the hydroelectric generation is $1.22 million per year (Harris Consulting, 2006). Moreover, the socio-economic indicator *Full Time Employment* estimates that four jobs have been established as a result of the hydroelectric production (*Table 6*). This indicates that the benefits generated from irrigation far exceed those gained from hydroelectricity. This was expected given that the Opuha Dam was not specifically designed to maximize returns from hydroelectric production (Worrall, 2007).

Socio-economic indicator	Unit	Irrigation	Hydroelectric production
Total Economic Benefits	($/catchment/year)	$123,200,000	$1,220,000
Full Time Employment	(FTEs/catchment)	480	4

Table 6: Impact of irrigation and hydroelectric generation in catchment area (adapted from Harris Consulting, 2006).

Previously, it was hypothesized that the increased storage of water as a result of the Opuha Dam scheme would improve the quantity of stock, municipal and industrial water supply obtained from the Opihi River. Evidence of this improvement is not available for this study, but could be obtained from various biophysical indicators including *Total Rate of Water Abstraction* for the purposes of stock, municipal and industrial uses. But, for this water to be consumed it is required to be of sufficient quality for drinking. Presently, the maximum acceptable level for the safe human consumption of water in New Zealand is water with one *Escherichia coli* (a common gut bacterium) colony forming unit per 100 millilitres (Ministry of Health, 2005). Hence, a suitable biophysical indicator for the human consumption of water is *E. coli Levels*. Other biophysical indicators that could also be useful for inferring the quality of water for consumption include *Cryptosporidium Levels* (Ministry of Health, 2005).

Figure 6 indicates annual average *E. coli* levels for the Opihi River and its tributaries. Ideally, the time-series available would extend before the construction of the Opuha Dam for purposes of forming adequate inferences. However, the data available only extends back to 2001, as prior to 2001 the biophysical indicator *Faecal Coliform Levels* was used rather than *E. coli Levels* (Meredith, 2009; pers. comm.). From the data indicated in *Figure 7* it is not evident

that the Opuha Dam has directly impacted on *E. coli* levels in the Opihi River. This is because *E. coli* levels for the Opihi River do not appear to be markedly different from those levels observed for the Opihi River – Confluence. However, there is some evidence indicating a decline in overall *E. coli* levels in both parts of the Opihi River. Interestingly, from *Figure 7* it is found that *E. coli* levels in the Opihi River and its tributaries far exceed maximum acceptable levels for human consumption. This is significant as water from the Opihi River was once consumed by local people (Waaka-Home, 2010; pers. comm.). Given the present undrinkability of the water, it will require costly water treatment prior to human consumption. Accordingly, an appropriate socio-economic indicator that might provide more information to make substantive inferences is *Cost of Water Treatment*.
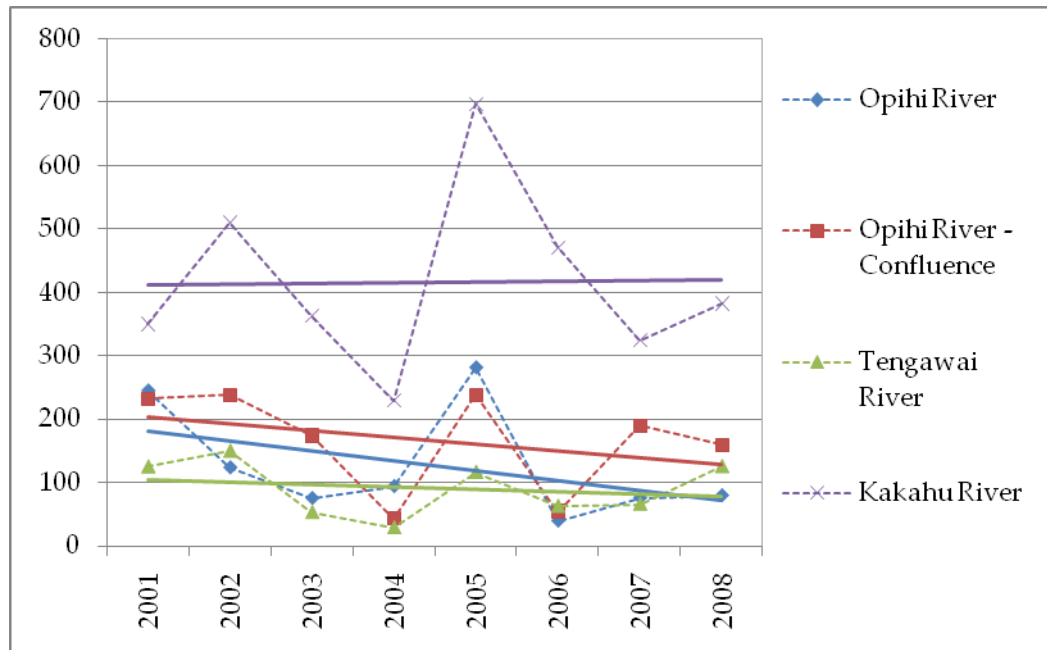

Figure 7: Actual data points and linear trendlines for the average annual *E. coli* levels (*E. coli* per 100 millilitres) in the Opihi River and its tributaries between 2001 and 2008 (adapted from Environment Canterbury, 2009).

In *Figure 8* the biophysical indicator *Faecal Coliform Levels* are reported in an effort to investigate if there are substantial differences between the Opihi River and its tributaries with this indicator. It appears that similar findings to that observed with *E. coli* levels is found with faecal coliform levels for the Opihi River.

In sum, many biophysical and socio-economic indicators show that the Opuha Dam has positively impacted various benefits obtained from the ecosystem service **Freshwater Supply**. However, more indicators are required to fully capture this ecosystem service. In particular, more evidence of the impact the Opuha Dam has on industrial, municipal and stock water supply needs to be considered.
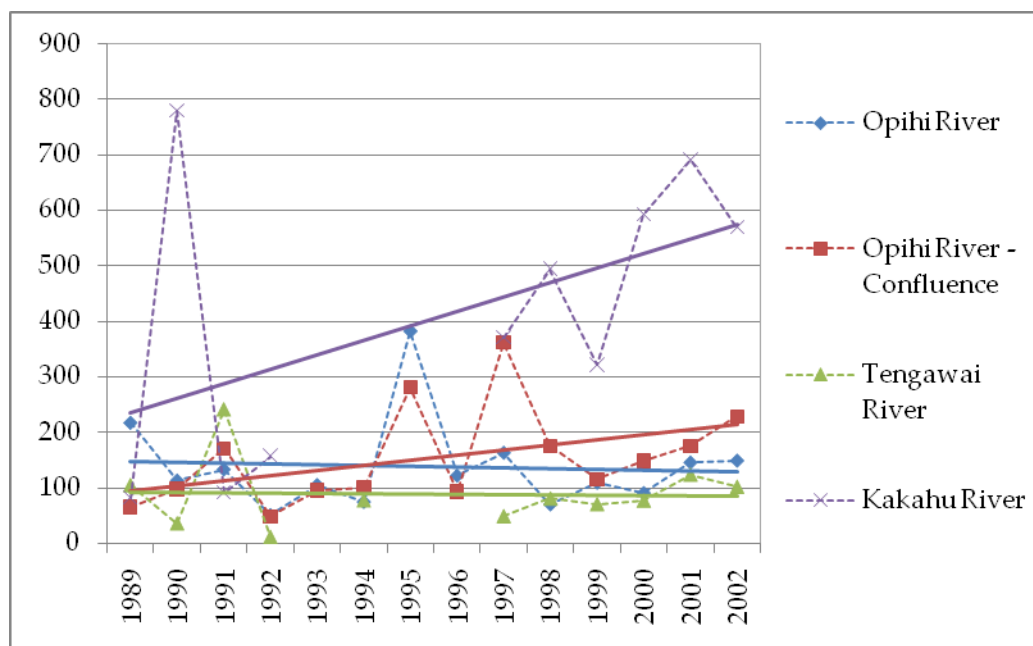
Figure 8: Actual data points and linear trendlines for the average annual faecal coliform levels (faecal coliforms per 100 millilitres) in the Opihi River and its tributaries between 1989 and 2002 (adapted from Environment Canterbury, 2009).

Apart from increasing freshwater supply, one of the primary purposes of the Opuha Dam scheme was to improve the degraded fisheries through augmenting minimum river flows. However, it was hypothesized that the Opuha Dam would have both positive and negative impacts on fish stocks. Fish stocks are consumed as food or mahika kai. Hence, the ecosystem service **Food**, it was conjectured, could increase or decrease as a result of the Opuha Dam. In addition to the improved minimum river flows (*Table 4*), another hypothesized reason that the game and native fishery of the Opihi River would be positively impacted is that the continuous river flow would ensure that the mouth of the Opihi River remained open allowing fish migration to the sea. For this reason, one suitable biophysical indicator for the ecosystem service **Food** is *Number of Days River Mouth Closed*. *Table 7* depicts the data for the biophysical indicator *Number of Days River Mouth Closed*. It is found that the Opuha Dam has significantly increased river mouth openings. However, of interest despite river mouth closings occurring much less frequently there have been some reports from locals that flounder stocks have decreased in recent years. One possible cause for this perceived decrease is that the Opihi Lagoon is becoming less saline despite the improvements to the opening of the river mouth to the sea. This is because the river mouth with the continuous flow resultant from the Opuha Dam has moved further up the coastline (Meredith, 2009; pers. comm.).

Period Biophysical indicator	Pre-Opuha Dam	Post-Opuha Dam
Number of Days River Mouth Closed	100+	4-5

Table 7: The average annual number of days the mouth of the Opihi River is closed (Worrall, 2007).

In an effort to substantiate the indication of a positive impact on fish populations the biophysical indicator *Spawning Numbers* was investigated. Importantly, this indicator

measures the spawning numbers of salmon and not trout, which is more difficult to discern (Webb, 2009; pers. comm.). *Figure 9* depicts the average spawning numbers for the Opihi River and its tributaries. It is difficult to infer any definitive trend from this data because of its variability. However, it does appear that spawning numbers have decreased slightly in the Opihi River, but less so that than other tributaries. This may indicate that the dam has alleviated the ongoing loss of spawning numbers in the Opihi River.
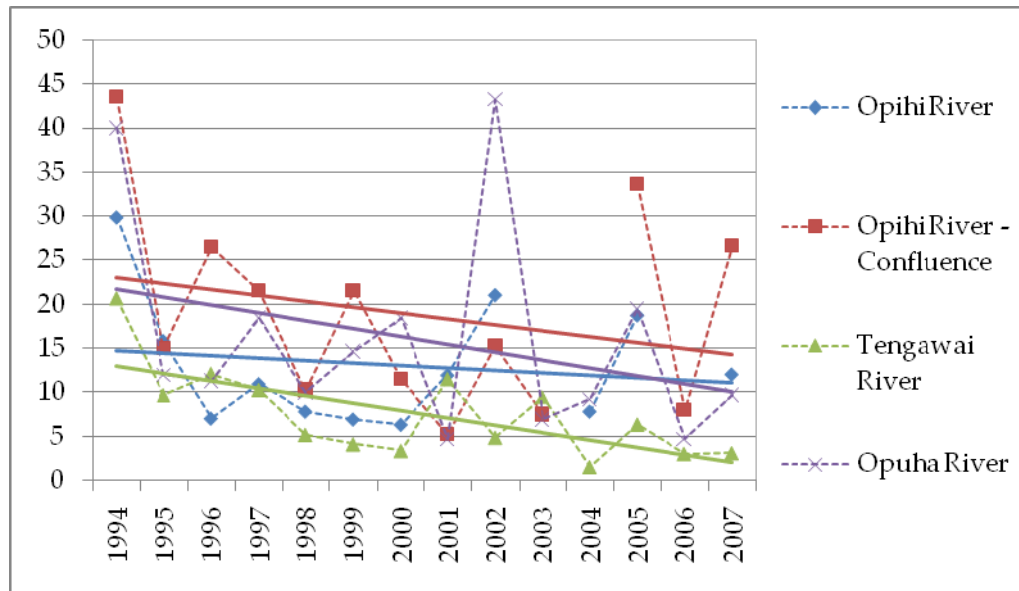

Figure 9: Actual data points and linear trendlines for the average annual spawning numbers of salmon between 1994 to 2007 in the Opihi River and its tributaries (adapted from Fish and Game, 2009).

Table 8 provides further weight to observations and inferences made in *Figure 9*. It is found that average salmon spawning numbers per year have all decreased since the construction of the Opuha Dam. The greatest percentage decrease is found on the Tengawai River and the least on the Opihi River and the Opuha River, which are directly impacted by the dam scheme. The fact that spawning numbers have decreased in the tributary rivers may indicate that other factors are involved. These additional factors could include the impact of increased land use intensification as a result of the increased irrigation from the Opuha Dam.

River	Period Pre-Opuha Dam	Post-Opuha Dam	Percentage change (%)
Opuha River	20	14	-30
Opihi River	16	12	-25
Opihi River – Confluence	27	16	-41
Tengawai River	13	5	-62

Table 8: Average spawning numbers for salmon in the Opihi River and its tributaries before and after the Opuha Dam scheme (adapted from Fish and Game, 2009).

In an effort to further investigate the fishery of the Opihi River the biophysical indicators *Water Temperature* and *Dissolved Oxygen Levels* are considered. These indicators are useful, as water temperature and dissolved oxygen are important factors affecting the health of fish stocks (Jellyman, 2009; pers. comm.). For example, water temperature affects fish stocks

because fish are ectotherms, where their body temperature is dependent on the temperature of their environment (*i.e.* water). *Figure 10* indicates the water temperature of the Opihi River and its tributaries. It appears that water temperature has decreased on the Opihi River, yet increased or remain unchanged on the Opihi River – Confluence and other tributaries. Hence, presumably the decrease in water temperature on the Opihi River is the result of the dam because of the augmentation of minimum river flows. This decrease in water temperature is further indicated in *Table 9*. Significantly, a decrease in water temperature is likely to impact positively on the fishery of the Opihi River.
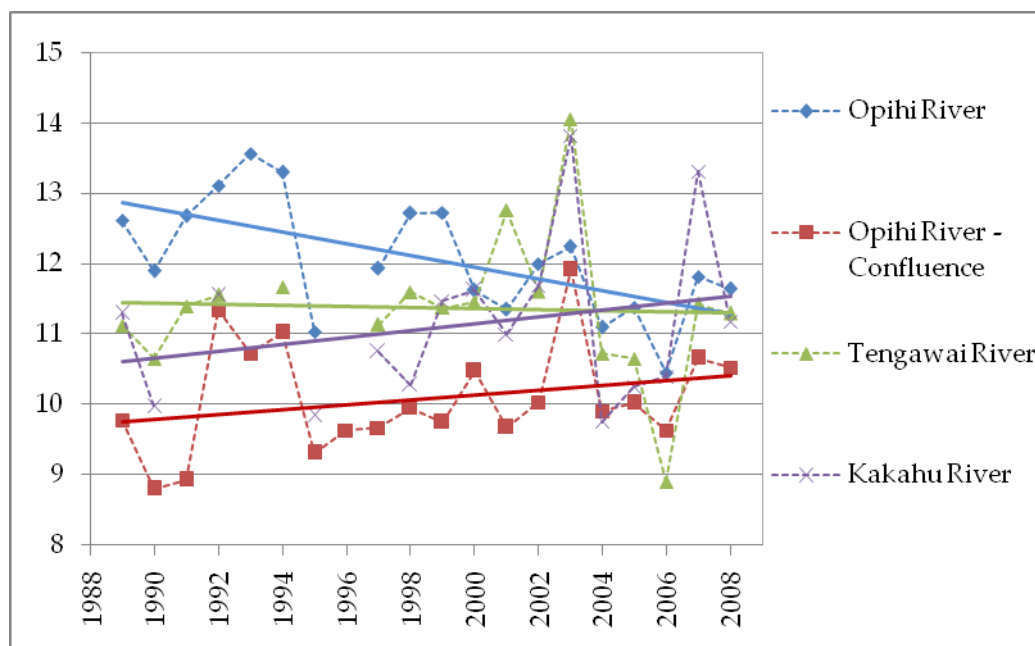

Figure 10: Actual data points and linear trendlines for the average annual water temperature (degrees Celcius) in the Opihi River and its tributaries between 1989 and 2008 (adapted from Environment Canterbury, 2009).

River	Period Pre-Opuha Dam	Post-Opuha Dam	Percentage change (%)
Opihi River	12.6	11.7	-7
Opihi River – Confluence	9.9	10.2	3
Tengawai River	11.3	11.4	1
Kakahu River	10.7	11.3	6

Table 9: Average water temperature (degrees Celsius) in the Opihi River and its tributaries before and after the Opuha Dam scheme (adapted from Environment Canterbury, 2009).

It is known that the solubility of oxygen in water increases as water temperature reduces. Hence, given that water temperature appears to have decreased on the Opihi River it might be expected that the biophysical indicator *Dissolved Oxygen Levels* would show an increased level during the same period. However, in *Figure 11* it appears that dissolved oxygen levels for the Opihi River and its tributaries have decreased since the construction of the Opuha Dam. *Table 10* also indicates that a decrease in dissolved oxygen levels have occurred since the construction of the Opuha Dam. Given that dissolved oxygen levels appear to have

decreased for the Opihi River and all its tributaries considered suggests that the decline may be the result of increased land use intensification.
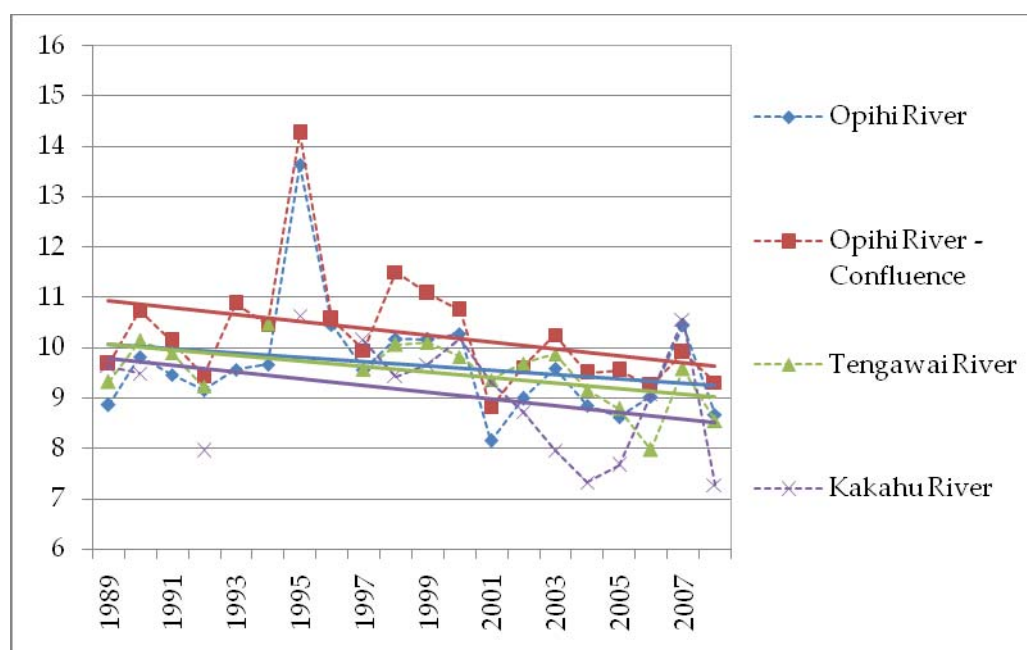

Figure 11: Actual data points and linear trendlines for the average annual dissolved oxygen levels (millilitres per litre) in the Opihi River and its tributaries between 1989 and 2008 (adapted from Environment Canterbury, 2009).

Period River	Pre-Opuha Dam	Post-Opuha Dam	Percentage change (%)
Opihi River	10.1	9.4	-7
Opihi River – Confluence	10.8	10.0	-7
Tengawai River	9.8	9.4	-4
Kakahu River	9.4	8.9	-5

Table 10: Average annual dissolved oxygen levels (millilitres per litre) in the Opihi River and its tributaries before and after the Opuha Dam scheme (adapted from Environment Canterbury, 2009).

It has been previously reported that the trout fishery on the Opihi River has declined after initially doing well following the construction of the Opuha Dam scheme because of the increased growth and proliferation of algae in the river (Harris Consulting, 2006). One type of algae that is extensively monitored in many rivers of New Zealand including Opihi River is periphyton. *Table 11* reports the trends of the biophysical indicators *Annual Mean Periphyton Cover* and *Annual Maximum Periphyton Cover*. Trends in the type of periphyton - a long filamentous growth or a thick mat - are also reported. The indication of the type of periphyton present can be informative as greater mat cover may indicate an increased likelihood of algae that is toxic to fish species (*e.g.* phoridium) (Meredith, 2009; pers. comm.). Despite the reported decline in trout from the increased presence of algae this is not evident from the data available. Rather, it is found that the trends for periphyton cover are either decreasing or stable. However, while these biophysical indicators considered are useful measures of algal content in rivers, they do not consider all types of algae.

	Monitoring site	Opihi River: Waipopo		Opihi River – Confluence: Rockwood		Opuha River: Skipton Bridge	
Biophysical indicator		2006	Trend	2006	Trend	2006	Trend
Annual mean periphyton cover	Total	10	-	7	0	18	0
	Filamentous		-		-		0
	Mats		0		0		+
Annual maximum periphyton cover	Total	37	-	37	0	50	0
	Filamentous		-		-		0
	Mats		0		0		0

Table 11: Trends in periphyton cover in the Opihi River and its tributaries between 1990 and 2006 (adapted from the Ministry for the Environment, 2009; NIWA, 2009).

In sum, from the indicators evaluated there is evidence that the Opuha Dam has positively and negatively impacted fish stocks on the Opihi River. Given that both positive and negative impacts appear to have occurred it is difficult to draw substantive inferences as to the net impact of the Opuha Dam on the ecosystem service **Food**. Accordingly, it would be prudent to consider additional indicators. Other biophysical indicators that could further illuminate the impact of the Opuha Dam on the fishery include *Sedimentation Levels*, as sediment can damage riverbed habitat that is used for fish spawning (Davies-Colloy *et al*., 2003). There is also a need to consider socio-economic indicators, such as *Commercial Fishery Employment* and *Fish Taste*. Presently, it is understood that nine commercial fishermen fish the Opihi River for long and short-finned eel. In regards to fish taste, it has been reported by local fishermen and Māori alike, that the taste of both the game fish and mahika kai caught from the Opihi River in recent years is poor tasting relative to what it once was (Scarf, 2009; pers. comm.; Waaka-Home, 2010; pers. comm.). The poorer tasting fish may be the result of (toxic) algae, which can cause off-flavours (Biggs 2000). Despite these complaints there are also recent reports highlighting that the fish from parts of the Opihi River and Lake Opuha are excellent eating (Fish and Game, 2009).

Finally, to adequately capture the ecosystem service **Food** a critical set of indicators is required to account for the mahika kai available on the Opihi River. One simple indicator would be the *Number of Mahika Kai Fish Species Available*. It was indicated previously that there are 18 native fish species found in the Opihi River. However, it is not known whether this number has changed since the construction of the dam. But, even if numbers were known, the above indicator does not provide any indication about the quality or volume of mahika kai fish species available from the Opihi River. Hence, to obtain a better reflection of the benefits obtained from mahika kai there is a need to determine the change in the number of mahika kai fish species, the success of catching fish using traditional methods, and whether the fish are culturally fit for consumption by local Māori. One indicator available that has been developed by Māori for their own use, which captures broadly these attributes, is the *Cultural Health Index*. Specifically, this index considers: one, the present food resources available on the river in comparison with what mahika kai was traditionally sourced from the river; and two, the likelihood of Māori returning to the river; and three, the accessibility of river. It is understood that over 100 freshwater sites in the South Island have been assessed by Māori using the *Cultural Health Index*. At present, an assessment with the index is

in progress for the Opihi River (Waaka-Home, 2010; pers. comm.). Hence, while results are not yet available, it is known that the access to mahika kai has continued to deteriorate since the 1960s. Moreover, the success rates of catching native fish species have deteriorated and the size of the fish (especially eel) has notably been reduced. The cause of this loss is believed to be the result of overfishing from commercial fishermen (Waaka-Home, 2010; pers. comm.). Despite the lack of data from a cultural health assessment of the Opihi River, other assessments throughout the South Island concluded that rivers and other significant water bodies are in a moderate to poor state of cultural health. A major reason for this poor state of cultural health in rivers is considered to be the result of increased land use intensification (Canterbury Mayoral Forum, 2009). Importantly, land use intensification and limited riparian management around creeks and streams that flow into the Opihi River have been blamed for the loss of edible water cress that once was abundant in streams and waterways (Waaka-Home, 2010; pers. comm.).

The ecosystem service **Fibre** is certainly a minor ecosystem service provided by the Opihi River when compared with the ecosystem services of **Freshwater Supply** and **Food**. A consequence of this is that no quantitative information is collected that considers the amount of fibre that is removed from the river and its margins. Hence, indicators for this ecosystem service need further development. However, in the interim the best available indicator for the ecosystem service **Fibre** appears to be the *Number of Fibrous Species Available*. There are two known species that can be used for its fibre. These species are willow, which can be used for fuelwood and flax found in the Opihi Lagoon, which is a mahika kai species and has been used, amongst other things, for constructing woven Māori artefacts (*e.g.* kete or traditional flax bags and baskets).

The final provisioning ecosystem service investigated is **Abiotic Products**. Previously, it was recognized that the Opihi River provides a supply of gravel that can be extracted from its riverbed. A suitable biophysical indicator available to indicate the amount of gravel extracted is the *Volume of Gravel Extracted per Year*. *Figure 12* reports the volume of gravel extracted from the Opihi River. It is observed that the volume of gravel extracted from the Opihi River steadily increased prior to the Opuha Dam scheme and has gradually stabilized since dam development. The average gravel extracted per year prior to the dam was approximately 98,000 cubic metres per year (this amount would have been lower if the 1996 gravel extraction spike is removed). After the dam the average extraction increased to approximately 109,871 cubic metres per year. The current amount of gravel removed from Opihi River is believed to be unsustainable according to Maori (Waaka-Home, 2010; pers. comm.). Importantly, in order to gain further information about gravel extraction the socio-economic indicator *Profitability of Gravel Resource* could prove to be informative. However, from the information obtained it suggests that gravel extraction in recent years may be impacting on the ecology of the river. This potential impact makes it more difficult to infer affects on the ecology of the Opihi River as a result of the Opuha Dam scheme.
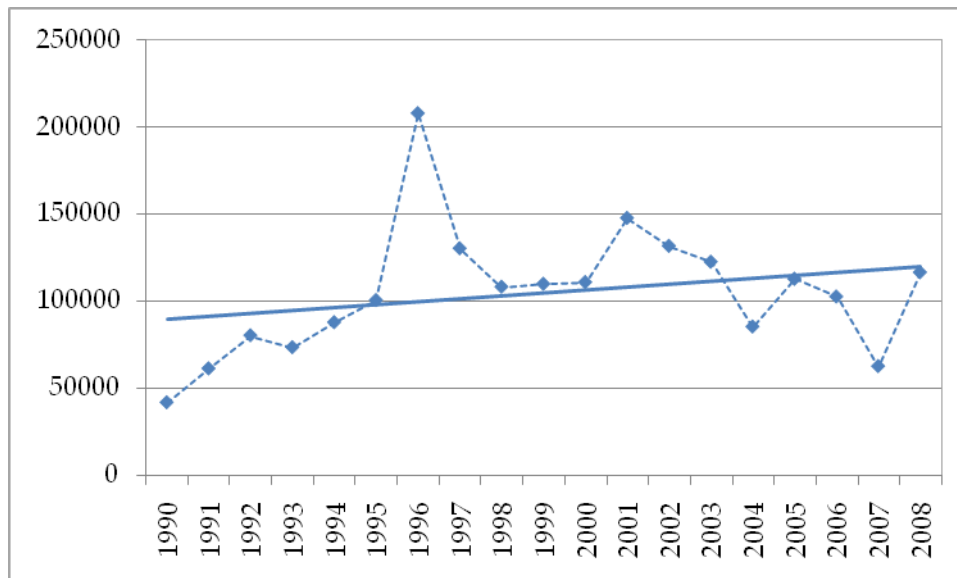
Figure 12: Actual data points and linear trendline for the volume (cubic metres) of gravel extracted per year from the Opihi River (Environment Canterbury, 2009).

5.2 Indicators for Regulating Ecosystem Services

In this sub-section the impact of the Opuha Dam scheme on the various regulating ecosystem services is investigated. The first regulating ecosystem service investigated is **Water Regulation** or the capacity of the river to regulate hydrological flows. Suitable biophysical indicators for the ecosystem service **Water Regulation** involve river flows and include the indicators *Minimum River Flows* and *Number of Days River Mouth Closed*, which have been previously considered. It has been indicated that the Opuha Dam has augmented minimum river flows on the Opihi River (*Table 4*) and has substantially decreased the number of days the river mouth is closed per year (*Table 7*). In addition, to augmenting minimum river flows, the dam stabilizes the variability of minimum river flows throughout the year. However, some variability in minimum river flows is maintained for the consideration of aquatic health. *Figure 13* depicts the biophysical indicator *Variability of Minimum River Flows* for the two regimes set for the Opihi River. It is found that minimum river flows vary between three and nine cubic metres per second depending on the regime used. The determination as to which regime is employed depends on the lake level of Lake Opuha.
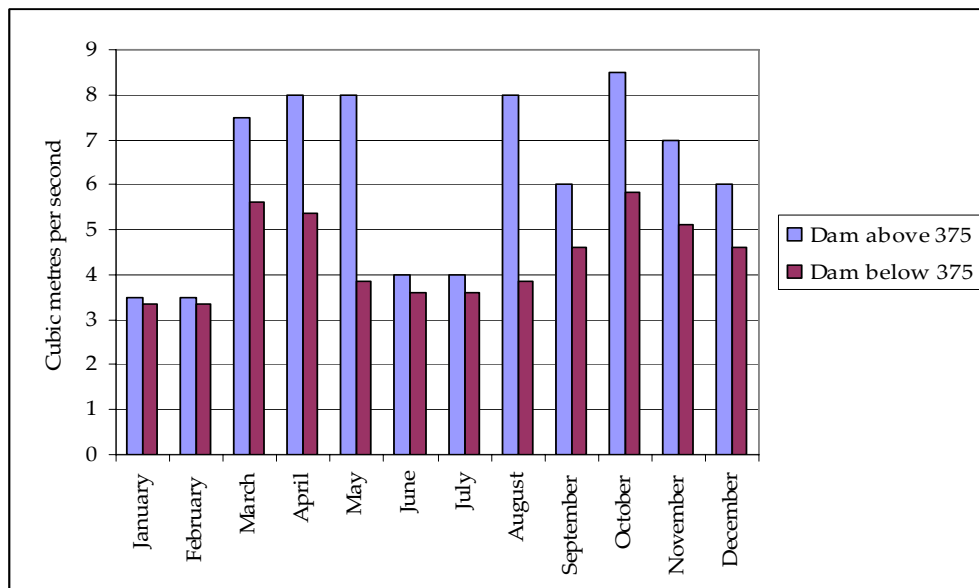
Figure 13: The two flow regimes set (cubic metres per second) for the Opihi River. These flow regimes depend on the lake level of Lake Opuha behind the dam (above or below 375 metres).

From *Figure 13* it is observed that minimum river flows in the Opihi River vary between three and nine cubic metres per second. Importantly, the capacity of the Opuha Dam to allow further variance in river flows is limited. Hence, the Opuha Dam cannot easily regulate flows to allow for flushing flows (*i.e.* approximately 20-30 cubic metres per second), let alone flood flows (*i.e.* greater than 100 cubic metres per second). Various biophysical indicators could depict the flushing and flood flows, such as the indicators *Number of Flushing Flows* and *Number of Flood Flows*. However, in *Figure 14* the biophysical indicator *Instantaneous Annual Flood Peaks* for the period 1936 to 1980 is shown for the Opihi and Opuha rivers.
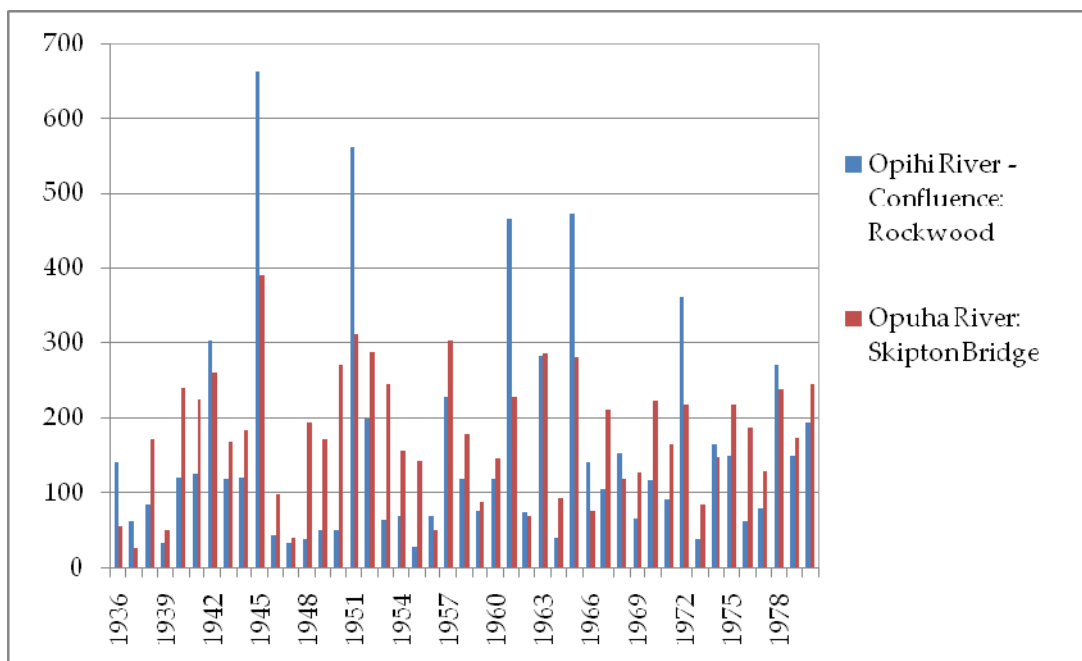

Figure 14: Instantaneous annual flood peaks (cubic metres per second) in the Opihi and Opuha rivers (adapted from de Joux, 1982).

The considerable length of time-series data found in *Figure 14* highlights that much river flow data is available for the Opihi River. This data can be recorded in various ways to provide some interesting biophysical indicators. While not shown, it is known that the number of flushing flows and flood events occurring on the Opihi River has reduced considerably, with the construction of the Opuha Dam, as compared to data observed in *Figure 14*. In fact, only two notable river flow events have occurred in the last decade when the dam was overtopped (Lambie, 2009; pers. comm.; Meredith, 2009; pers. comm.).

It has been indicated how the Opuha Dam scheme has impacted and regulated the hydrological flows of the Opihi River. These altered river flows were hypothesized to positively impact the ecosystem service **Natural Hazard Regulation**, as it was anticipated to reduce both flood and drought events. In the case of flood events, the biophysical indicator *Number of Flood Flows* has indicated that floods flows have decreased on the Opihi River since the construction of the Opuha Dam. Other indicators that could capture the impact of flood events include the socio-economic indicators *Total Economic Cost of Flood Event* and *Number of Fatalities from Flood Event*. In the case of the major flood event that occurred on the Opihi River on 13 March 1986, the cost to infrastructure and agriculture was estimated at $60 million, while the flood also resulted in the loss of one human life (Scarf, 1987).

Another indicator useful for accounting for the ecosystem service **Natural Hazard Regulation**, which has also been previously considered, is *Irrigated Area*. It was shown that the Opuha Dam scheme has allowed irrigation to be increased from less than 4,000 hectares with the Levels Plains Irrigation Scheme to approximately 16,000 hectares. Hence, the increased irrigation indicates a decreased likelihood of drought conditions in the catchment area for 12,000 hectares of agricultural land. This conclusion was also iterated by Scarf (2009, pers. comm.), who maintained that during the summers of 2001/2002 and 2003/2004 drought conditions could have occurred in parts of the Opihi River catchment. However, as a result of the increased irrigation the socio-economic impacts of these potential drought conditions were not brought to bear on farmers or the local economy. Hence, in addition to biophysical indicators *Mean Summer/Annual Rainfall* and *Mean Summer Air Temperature*, the socio-economic indicator *Total Economic Cost of Drought Event* would provide useful inferences on the impact of the Opuha Dam on the ecosystem service **Natural Hazard Regulation**.

It was hypothesized that the Opuha Dam would positively and negatively impact the ecosystem service **Water Purification**. Positive impacts were considered possible through a dilution effect obtained through augmented minimum river flows. Negative impacts were considered possible through increased land use intensification causing increased pollutant runoff into the Opihi River. Hence, the determination of the ecosystem service **Water Purification** can be partially captured by pollutant levels (*i.e.* nitrogen and phosphorus) in the Opihi River by the biophysical indicators *Total Nitrogen Concentration*, *Total Phosphorus Concentration*, *Nitrate Concentration* and *Dissolved Reactive Phosphorus Concentration*. *Figure 15* depicts the total nitrogen concentration in the Opihi River and its tributaries. It is shown that the total nitrogen concentration is increasing in the Opihi River and all the tributaries considered. This suggests that despite a dilution effect likely to be occurring as a result of augmented minimum river flows that land use intensification has markedly increased in the catchment area. This conclusion is consistent with the indicator *Nitrogen Fertilizer Application*,

which has reported to have increased by 132 per cent since the development of the Opuha Dam (Harris Consulting, 2006).
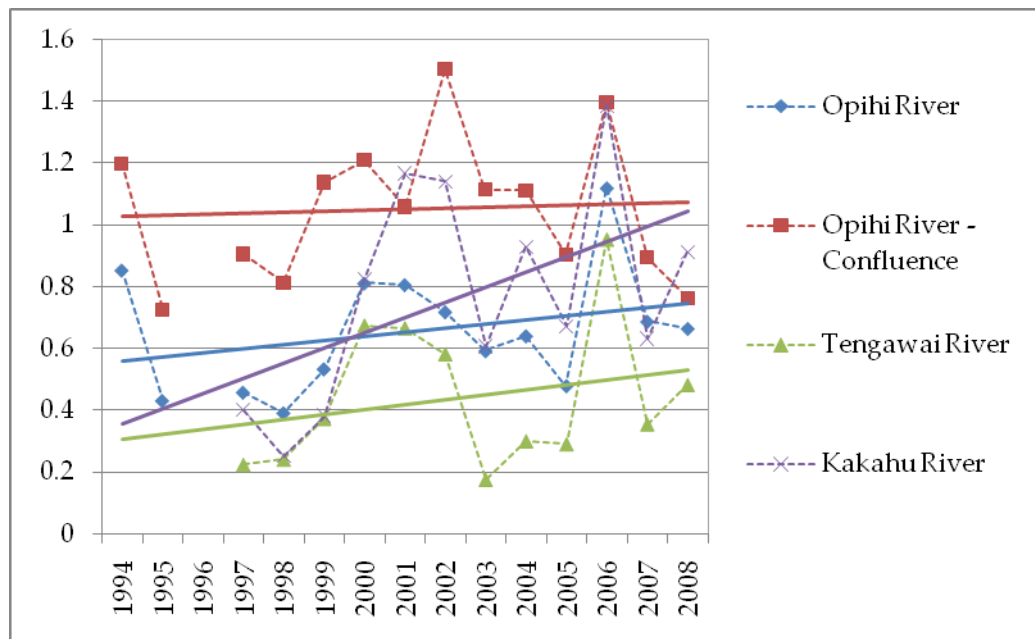

Figure 15: Actual data points and linear trendlines for the average annual total nitrogen concentration (milligrams per litre) in the Opihi River and its tributaries between 1994 and 2008 (adapted from Environment Canterbury, 2009).

Figure 16 depicts the total phosphorus concentration in the Opihi River and its tributaries. It is shown that total phosphorus concentrations are, unlike total nitrogen concentrations, decreasing in the Opihi River and all the tributaries considered.
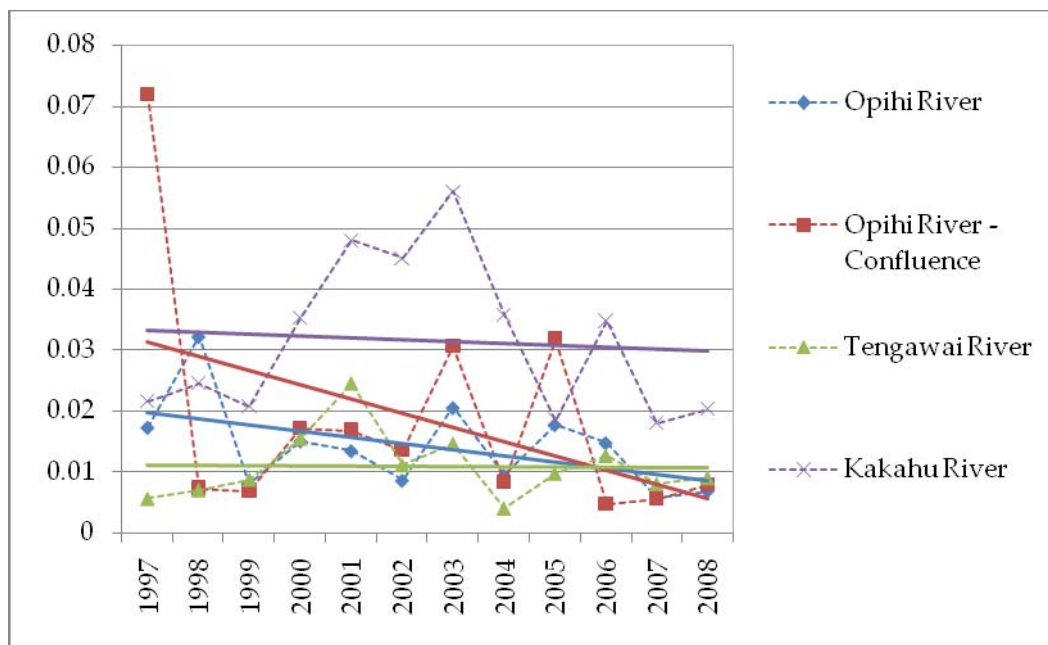

Figure 16: Actual data points and linear trendlines for the average annual total phosphorus concentration (milligrams per litre) in the Opihi River and its tributaries between 1997 and 2008 (adapted from Environment Canterbury, 2009).

In order to further investigate pollutant concentrations, *Table 12* reports the trends of nitrogen and phosphorus indicators from NIWA. Consistent with findings reported previously, it is found that nitrogen concentrations have increased. Furthermore, while trends are less conclusive with indicators of phosphorus concentrations, they are decreasing or stable in the Opihi River as indicated in *Figure 16*. However, contradictory to *Figure 16*, phosphorus concentrations in *Table 12* have increased at the Rockwood monitoring site. Despite this contradiction, which can be explained by differences in data collection (Meredith, 2009; pers. comm.), it is found that nitrogen concentrations have increased indicating that the ecosystem service **Water Purification** has been negatively impacted by the Opuha Dam scheme.

Monitoring site	Unit	Opihi River: Waipopo		Opihi River – Confluence: Rockwood		Opuha River: Skipton Bridge	
Biophysical indicator		2007	Trend	2007	Trend	2007	Trend
Nitrate Conc.	mg/L	0.396	+	1.009	+	0.235	+
Total Nitrogen Conc.	mg/L	0.527	+	1.159	+	0.372	+
Dissolved Reactive Phos. Conc.	mg/L	0.0026	-	0.0038	+	0.0014	0
Total Phosphorus Conc.	mg/L	0.005	0	0.007	+	0.007	+

Table 12: Trends in nitrogen and phosphorus concentrations in the Opihi River and its tributaries between 1989 and 2007 (adapted from the Ministry for the Environment, 2009).

In order to further illuminate the impact of pollutant concentrations on the ecosystem service **Water Purification** the biophysical indicator *pH Levels* is considered. This indicator may be revealing as pollutants can increase water acidity (Davies-Colloy *et al.*, 2003). *Figure 17* indicates the pH levels of the Opihi River and its tributaries. In general, it appears that pH levels have increased for the Opihi River and the tributaries considered. This finding supports trends observed with nitrogen concentrations.
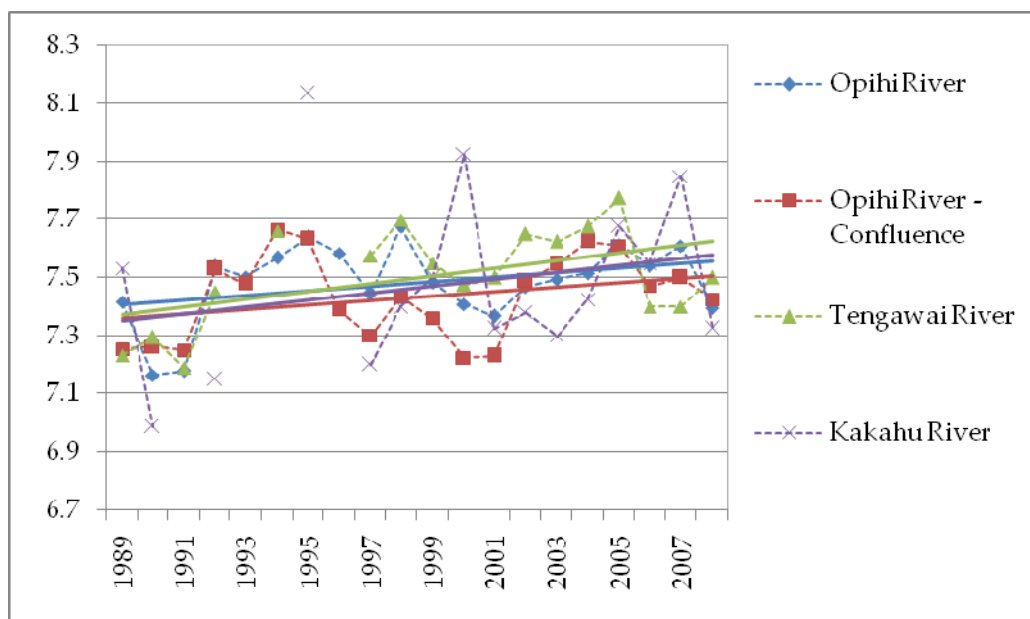

Figure 17: Actual data points and linear trendlines for the average annual pH levels in the Opihi River and its tributaries between 1989 and 2008 (adapted from Environment Canterbury, 2009).

	Pre-Opuha Dam	Post-Opuha Dam	Percentage change (%)
Opihi River	7.4	7.5	1
Opihi River – Confluence	7.4	7.4	0
Tengawai River	---	7.6	---
Kakahu River	---	7.5	---

Table 13: Average annual pH levels in the Opihi River and its tributaries before and after the Opuha Dam scheme (adapted from Environment Canterbury, 2009).

An alternative approach to measuring chemical attributes of river water (*i.e.* pollutant concentrations, pH levels) is the use of indicators that determine the presence and abundance of species that are pollution sensitive. One set of species particularly sensitive to pollutants is algae and therefore can be used to indicate the level of pollutants and aquatic health of the Opihi River (Biggs, 2000; Quinn & Raaphurst, 2009). It was previously found from the biophysical indicator *Annual Periphyton Cover* that there is little evidence of increased periphyton cover in the Opihi River (*Table 11*). This would suggest that the increased pollutant concentrations observed in the Opihi River have not been detrimental to aquatic health and therefore to the ecosystem service **Water Purification**. However, despite this conclusion it is also recognized that algal growth is controlled by a number of other factors besides pollutant levels (*e.g.* water temperature, river flows).

Another set of species that are sensitive to pollutants are macroinvertebrates, such as insects, snails and worms (Arimoro & Ikomi, 2009). There are two well developed indicators of macroinvertebrates available and monitored on the Opihi River. These are the biophysical indicators *Macroinvertebrate Community Index* (MCI) and the *Percentage of the Total Abundance comprising Ephemeroptera, Plecoptera, and Trichoptera Taxa* (%EPT) (*i.e.* mayflies, stoneflies and caddisflies). Specifically, MCI measures the entire macroinvertebrate population. A MCI score that is greater than 119 indicates a high number of macroinvertebrates present and a therefore a low impact on macroinvertebrates from pollutants. However, a MCI score less than 80 indicates a low number of macroinvertebrates and therefore a high impact on macroinvertebrates from pollutants. The %EPT score reflects those macroinvertebrates that are particularly sensitive to pollutants. Hence, a low %EPT indicates a river with a high level of pollutants (Ministry for the Environment, 2009).

Table 14 reports trends in MCI and %EPT scores for various monitoring sites along the Opihi River between 2005 and 2007. It indicates that there is a decreasing trend in the MCI score at Waipopo and an increasing trend in the %EPT score at Rockwood. There was no evidence of change in other monitoring sites. Hence, this data suggests that the populations of macroinvertebrates have been somewhat adversely affected by the Opuha Dam scheme. However, given the small time-series available it is difficult to make any substantive inferences. Nevertheless, it is recognized that the level of macroinvertebrates in the Opihi River and its tributaries is low in comparison with rivers found in other catchments in New Zealand (Ministry for the Environment, 2009).

Monitoring site	Unit	Opihi River: Waipopo		Opihi River – Confluence: Rockwood		Opuha River: Skipton Bridge	
Biophysical indicator		2007	Trend	2007	Trend	2007	Trend
Macroinvertebrate Community Index	Index	97	-	109	0	98	0
Percentage of *Ephemeroptera, Plecopetera* and *Trichoptera* taxa	%EPT	73	0	83	+	10	0

Table 14: Trends in macroinvertebrate community index and percentage of *Ephemeroptera*, *Plecopetera* and *Trichoptera* for the Opihi River and its tributaries between 2005 and 2007 (adapted from the Ministry for the Environment, 2009).

In sum, various biophysical indicators have been identified for the purposes of indicating the impact of the Opuha Dam on the Opihi River for the ecosystem service **Water Purification**. From the various indicators considered it was difficult to draw any substantive inferences as to the impact on this ecosystem service as some indicators showed a negative impact (*e.g. Total Nitrogen Concentration*), while others indicated no change (*e.g.* %EPT) or even a marginal positive impact (*e.g. Annual Periphyton Cover*). Therefore, while it appears that a negative impact is most likely additional indicators are needed to further clarify the impact of the Opuha Dam on the ecosystem service **Water Purification**. In addition, the biophysical indicator *Trophic State Index* of Lake Opuha could be informative.

The limited flushing flows on the Opihi River since the construction of the Opuha Dam lead to the hypothesis that the dam would increase the likelihood of toxic algal blooms in the river and Lake Opuha. It was expected therefore that the ecosystem service **Disease Regulation** may be negatively impacted. However, it has been identified previously using the biophysical indicator *Annual Periphyton Cover*, and mat periphyton cover in particular, that algal growth that may lead to toxic algal growths has not increased in the Opihi River (*Table 11*). Other indicators that may be useful for the ecosystem service **Disease Regulation** include the *Number of Fish Kills*.

However, while the indicator of *Annual Periphyton Cover* revealed no substantial increase in algae, it does not consider the impact of all types of algae, such as the non-toxic didymo. Given that didymo is not toxic, it is not an agent of disease, but it remains a significant pest species in many rivers in New Zealand. From observations it has been indicated that didymo is present in the Opihi River (Lambie, 2009; pers. comm.). However, there is no biophysical indicator currently available that aptly quantifies the level of didymo established to measure the level of didymo present in the Opihi River.

In addition, to the presence of didymo the regular and stable river flows resultant from the Opuha Dam is hypothesized to result in the increased encroachment of non-native vegetation (*e.g.* willows, gorse, broom and lupins). This anticipated increase in non-native vegetation was hypothesized to negatively impact the ecosystem service **Pest Regulation**, while positively impacting the ecosystem service **Erosion Control**. While there are no known indicators available to determine the level of encroachment of non-native vegetation, it has been suggested that vegetation encroachment has become a greater problem since the Opuha

Dam scheme (Meredith, 2009; pers. comm.). Indeed, local Māori suggest that willow encroachment is reducing the amount of native raupo present around the Opihi Lagoon (Waaka-Home, 2010; pers. comm.). However, in an effort to capture this impact, a proposed biophysical indicator that could be applied is the *Area Covered by Non-Native Vegetation*. This indicator could be inferred from satellite imagery. Given that river engineers have planted willow in the past along the Opihi River for the purposes of erosion control, a socio-economic indicator that could be used is *Cost of Willow Planting*. Finally, surface runoff as a result of erosion can cause increased sedimentation. Various biophysical indicators can be measured to indicate this erosion impact. These include *Sedimentation Levels*, *Total Suspended Solids* and *Turbidity*. *Table 15* indicates that total suspended solids have increased in the Opihi River, but have decreased amongst its tributaries. This increase in suspended solids suggests that the ecosystem service **Erosion Control** has been negatively impacted by the Opuha Dam scheme.

Period River	Pre-Opuha Dam	Post-Opuha Dam	Percentage change (%)
Opihi River	4.5	5.8	29
Opihi River – Confluence	9.1	6.9	-24
Tengawai River	8.8	3.6	-59
Kakahu River	3.8	3.2	-15

Table 15: Annual average total suspended solids (milligrams per litre) in the Opihi River and its tributaries before and after the Opuha Dam scheme.

Figure 18 depicts the biophysical indicator *Turbidity* for the Opihi River. It is indicated that a decreasing turbidity is found with the Opihi River and the tributaries considered. While these results differ from *Total Suspended Solids* (*Table 15*), it is recognized that the degree to which turbidity has decreased on the Opihi River is marginal relative to the tributaries considered.
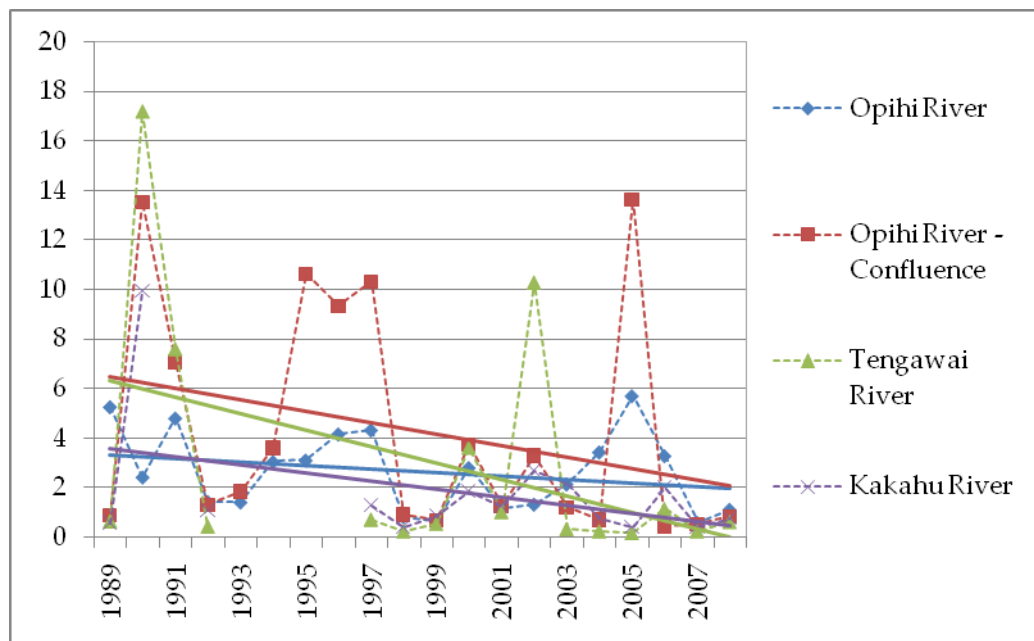

Figure 18: Turbidity (NTU) in the Opihi River and its tributaries between 1989 and 2008 (adapted from Environment Canterbury, 2009).

5.3 Indicators for Cultural Ecosystem Services

In this sub-section the impact of the Opuha Dam scheme on the cultural ecosystem services provided by the Opihi River are investigated. It was hypothesized that the ecosystem service **Conservation Values** would be adversely affected by the Opuha Dam. This is because the stable and regular river flows would alter the natural braided character of the river which may result in the loss of native biodiversity and habitat. There are then various indicators that can account for the **Conservation Values**. Ideally, one indicator would be *Native Biodiversity*. However, while it is known that there are 18 native fish species, one native long-tailed bat, 43 macroinvertebrate species, various native plant species and at least ten native bird species that inhabit the Opihi River, the exact total of native species remains unknown. While it is likely that an estimate can be determined for native biodiversity, a useful alternative measure may be to consider the biophysical indicator *Macroinvertebtate Community Index*. If this indicator is used, it reveals that the ecosystem service **Conservation Values** may be adversely affected by the Opuha Dam scheme.

Another biophysical indicator suitable for ascertaining the impact of the Opuha Dam on **Conservation Values** is the *Number of Endangered Native Bird Species* that inhabit the Opihi River. In accordance with the threat classification system developed by the Department of Conservation (Molloy *et al.*, 2002), there are at least six threatened bird species that inhabit the Opihi River. These are Australasian bittern, black-fronted tern, black-billed gull, banded dotterel, white-winged black tern and the black-fronted dotterel. The impact of the Opuha Dam on the abundance of these threatened bird species is unknown. However, a recent study investigating the trends of various bird species between 1994 and 2003 has however indicated that the banded dotterel population in Canterbury has markedly declined (Southey, 2009). Similarly, in 2005 the threatened status of black-billed gulls increased in recognition that the number of breeding gulls had declined significantly in Canterbury (Birdlife International, 2005). Another indicator that captures the ecosystem service **Conservation Values** is the *Status of Ecological Landscapes of Importance*. It is understood that the Opihi Lagoon has been an ecological landscape of regional importance (Canterbury Regional Council, 1995). It is not known whether the status of the Opihi Lagoon has changed since the construction of the Opuha Dam. However, it is understood that the lagoon has been reduced significantly in size since intensive land practices were adopted by neighbouring farmers. The likely reason for this reduction is because spring-fed waterways that once flowed into the Opihi River and Opihi Lagoon are now extracted and used for irrigation (Waaka-Home, 2010; pers. comm.).

The impact of the Opuha Dam scheme on the ecosystem service **Educational Values** was hypothesized to have both positive and negative impacts to knowledge systems. The negative impact on knowledge systems was the potential loss of braided river ecosystems through the stabilization and regulation of river flows through river impoundment. This potential loss of Educational Values could be evaluated using the socio-economic indicator *Number of Studies Undertaken on the Natural River Ecology of the Opihi River*. A hypothesized positive impact of the dam on knowledge systems is a better understanding of how river impoundment affects river ecology. A socio-economic indicator that could be used to account for this impact is the *Number of Publications about the Opuha Dam*, when future water storage projects are considered. Neither of these indicators has been quantified in this

ecosystem services review, though it is known that a book has been written about the development and construction of the Opuha Dam (*i.e. A Dream Fulfilled* by Worrall (2007)).

The impact of the Opuha Dam scheme on the ecosystem service **Spiritual Values** was hypothesized to have a negative impact on the natural character and taonga species of the Opihi River, but a positive impact on the river's mauri or life supporting capacity. In an effort to indicate the impact of the Opuha Dam on the natural character and taonga species of the Opihi River the *Cultural Health Index* could be used. In addition, to indicating the level of mahika kai resources suitable for use and harvest by local Māori, the index provides information about the health of taonga species and the natural character of the river from the perspective of local Māori (Harmsworth & Tipa, 2006). The *Cultural Health Index* is significant as it recognizes the importance of the Māori perspective in the management of rivers. Indeed, "the spiritual and cultural significance of a freshwater resource of Māori can only be determined by the Tangata Whenua who have traditional rights over the river" (Ministry for the Environment, 1997). However, as indicated previously, an assessment of the Opihi River in which to determine its *Cultural Health Index* is not yet complete, though presently underway. Significantly, despite the capacity of the *Cultural Health Index* to cover a wide range of aspects of **Spiritual Values** for Māori it does not account for the life supporting capacity or mauri of the river. This is because it is considered to be difficult to measure and possibly inappropriate to quantify (Harmsworth & Tipa, 2006). However, a proxy indicator may be *Native Biodiversity* or the *Macroinvertebrate Community Index*. The application of MCI would suggest that the Opuha Dam has negatively impacted on the life supporting capacity of the Opihi River, and therefore negatively impacted **Spiritual Values**.

The Opuha Dam scheme on the ecosystem service **Aesthetic Values** was hypothesized to have both a positive and negative impact. Positive impacts include the augmented minimum river flows allow the river to flow and not dry up (*Table 4*), which is aesthetically displeasing. Negative impacts include the growth and proliferation of algae, which can be unattractive. However, *Table 11* has indicated that certain types of algae have not increased significantly with the Opuha Dam. It is known that algal blooms have occurred in Lake Opuha, which resulted in intolerable pungent odours when the algae decomposed (Meredith, 1999). These algal blooms on the lake have become less noticeable since an aerating sparge system was put in place (Worrall, 2007). Nonetheless, it is stressed that the biophysical indicator *Annual Periphyton Cover* does not account for the presence and abundance of the algae didymo, which has been observed in the Opihi River.

Another useful indicator for determining **Aesthetic Values** is *Clarity*. *Table 16* reports that there has been little change in the clarity at Waipopo and Skipton Bridge sites. However, clarity has decreased at Rockwood. Usually, downstream areas are less clear than upstream areas (Ministry for the Environment, 2009). However, the data indicates the reverse on the Opihi River. Nonetheless, overall the data suggests that the clarity of the Opihi River has not been impacted by the Opuha Dam. This finding contradicts observational reports. Māori and local fishermen believe that the presence of didymo in the river has reduced river water clarity (Waaka-Home, 2010; pers. comm.). For example, it used to be possible to see eels in the river, but given the reduction in clarity the sighting of eels is much more difficult today.

Monitoring site	Unit	Opihi River: Waipopo		Opihi River – Confluence: Rockwood		Opuha River: Skipton Bridge	
Biophysical indicator		2007	Trend	2007	Trend	2007	Trend
Clarity	m	4.07	0	3.55	-	2.91	0

Table 16: Trends in the clarity of the Opihi River and its tributaries between 1989 and 2007 (Ministry for the Environment, 2009).

A suitable socio-economic indicator for **Aesthetic Values** is the use of hedonic analysis and in particular the *Willingness to Pay for Property*. Recently, hedonic property analysis has been applied to the Kennedec River in the United States. It was found that the value of homes near or at the river's edge increased markedly after the dam that was once found on the river was removed (Lewis *et al.*, 2008). One reason for this increase in value with dam removal was that rivers that flow naturally and are therefore unobstructed by dams are becoming rarer and are often considered to be more aesthetically pleasing than modified river flows. With this finding in mind, it becomes difficult to infer the impact of the Opuha Dam on the **Aesthetic Values** of the Opihi River. However, it does appear that while variable river flows are aesthetically preferred to stable river flows (*i.e.* flat lining), it is also acknowledged that augmented minimum river flows resultant from the Opuha Dam are more attractive than when the Opihi River is dry for extensive periods of time (Scarf, 2009; pers. comm.; Waaka-Home, 2010; pers. comm.).

Previously, it was found that the ecosystem service **Recreational Values** comprises of many recreational activities. These include swimming, boating, picnicking, fishing, hunting and walking. The impacts on these recreational activities from the Opuha Dam were anticipated to have predominantly a beneficial effect. One reason for the anticipated positive impact of the Opuha Dam on **Recreational Values** were because of the augmented minimum river flows allowing use of the river throughout the year (*Table 4*) and through the creation of a new 710 hectare recreational resource in Lake Opuha. This anticipated positive impact appears supported by various discussions, as it has been maintained that public perception of the Opihi River as a recreational resource has improved since the construction of the Opuha Dam (Lambie, 2009; pers. comm.; Scarf, 2009; pers. comm.). One factor that will negatively impact recreational activities is the presence of algae (Biggs, 2000). Previously, it has been established by the biophysical indicator *Annual Periphyton Cover* that algae has not increased since the construction of the Opuha Dam (*Table 11*). This conclusion is supported by Fish and Game (2009), who have stated that finding evidence for the growth and proliferation of algae is difficult and when algae is present it has rarely caused problems for recreational activities. However, the guideline for the maximum acceptable level of total periphyton in rivers is 40 per cent for recreational activities (Ministry for the Environment, 2009). This level in 2007 alone was breached at Skipton Bridge, where its total maximum percentage of periphyton reached 50 per cent.

In order to further understand the impacts of the Opuha Dam on the ecosystem service **Recreational Values**, the impact on swimming and recreational fishing are considered. Other recreational activities are not investigated as there is little information available about them. Ideally for swimming the socio-economic indicator *Number of Swimmers in River* should be used. However, while there is some data available for this indicator (Environment

Canterbury, 2009), the record collection is poor. Instead Environment Canterbury uses the biophysical indicator *E. coli Levels* to monitor various popular swimming sites along the Opihi River during the summer months. The present requirement for a particular swimming site to be deemed safe for swimming is that 85 per cent of all samples must not exceed the limit of 550 *E. coli* units per 100 millilitres. *Figure 19* reports the degree of compliance of *E. coli* samples taken over the past decade at a number of monitored swimming sites along the Opihi River. It is indicated that only two sites have complied consistently with the minimum safe swimming conditions. Moreover, of these two one of them only marginally complied with minimum safe swimming conditions. However, it was expected that while Lake Opuha would initially be unsuitable for swimming it would improve in its suitability for swimming as vegetation and soil organic matter fully decomposed. This improvement in swimming appears to have occurred as all sites are increasing in their compliance with the safe swimming requirements.
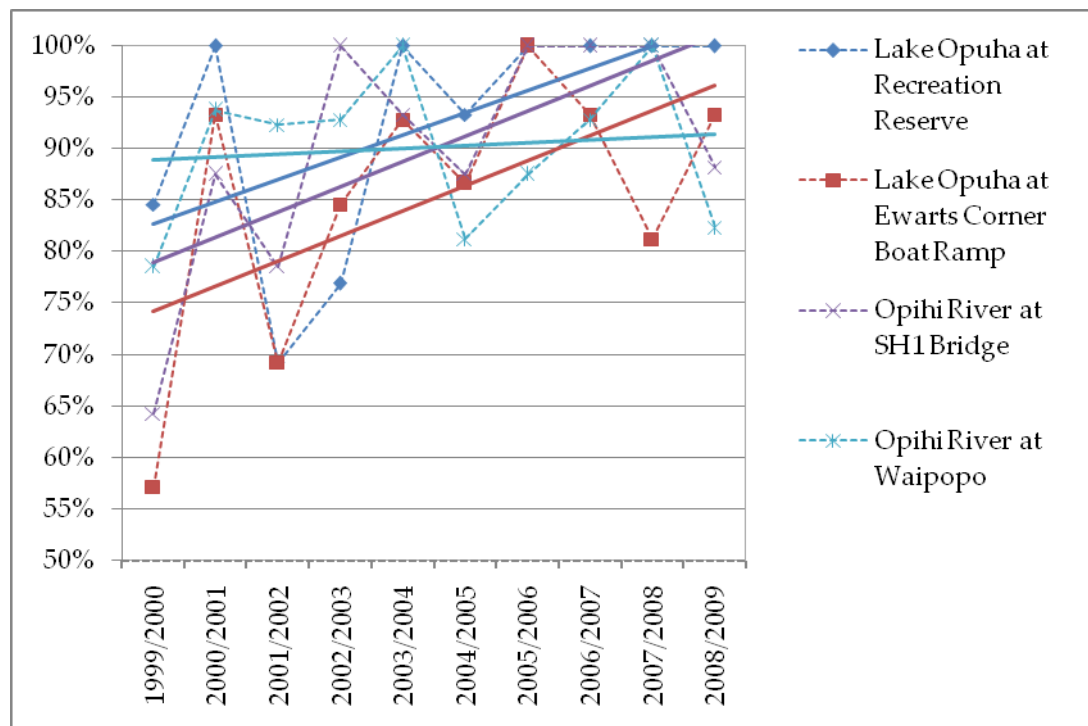

Figure 19: Actual data points and linear trendlines for the percentage of *E. coli* samples that do not exceed 550 units per 100 millilitres in the Opihi River and Lake Opuha (Environment Canterbury, 2009).

The suitability of rivers for swimming can also be indicated by the clarity and suspended sediment in the water (Davies-Colloy *et al.*, 2003; Ministry for the Environment, 2009). In particular, a reduction in clarity can adversely affect swimming conditions. For this reason, the biophysical indicator *Clarity* is investigated for this recreational activity. Previously, it has been shown that clarity in the Opihi River has not significantly changed (*Table 16*).

The Opihi River has historically been considered a river of national importance for recreational fishing. A primary purpose of the Opuha Dam was to help restore the degraded fishery in the Opihi River by augmenting minimum river flows and allowing the river mouth to remain open for extensive periods of time. Both of these impacts have occurred

47

with the construction of the Opuha Dam (*Table 4*; *Table 7*). Hence, the expectation is that the Opihi River has been fully restored as a fishery. However, evidence obtained about the fishery when investigating the ecosystem service **Food** have indicated that some indicators (*e.g. Spawning Numbers*, *Dissolved Oxygen Levels*) decreased since the construction of the Opuha Dam (*Table 8*; *Table 10*). Despite this the most recent trends from the socio-economic indicator *Total Angler Days per Season* indicate an increase of nearly 6000 anglers (*i.e.* 29 per cent) when compared to data available prior to the construction of the Opuha Dam (*Table 17*).

Period	Pre-Opuha Dam	Post-Opuha Dam	
	Year 1994/95	Year 2001/2002	Year 2007/2008
Socio-economic indicator			
Total Angler Days Per Season	20040	18260	25840

Table 17: Total number of angler days on the Opihi River and its tributaries between 1994 and 2008 (adapted from Fish and Game, 2009).

Figure 20 depicts the indicator *Total Angler Days per Season* by river. It is found that the Opihi River has increased in angler days since the construction of the Opuha Dam. Despite this increase it is noted that during the 2001/2002 season the number of angler days decreased markedly before recovering in the 2007/2008 season. The most evident change from *Figure 20* is the increase in angler days on Lake Opuha. In fact, approximately 85 per cent of the increase in angler numbers can be attributed to the creation of Lake Opuha. The expectation would be that Lake Opuha is an excellent recreational fishery. However, reports have indicated that Lake Opuha, in spite of being regularly inundated with salmon, is not as yet a particularly successful fishery (Harris Consulting, 2006). One possible explanation for the high participation in recreational fishing on Lake Opuha relative to the quality of its fishery is that various events including a children's fishing day are held at the lake (Fish and Game, 2009; Scarf, 2009; pers. comm.).
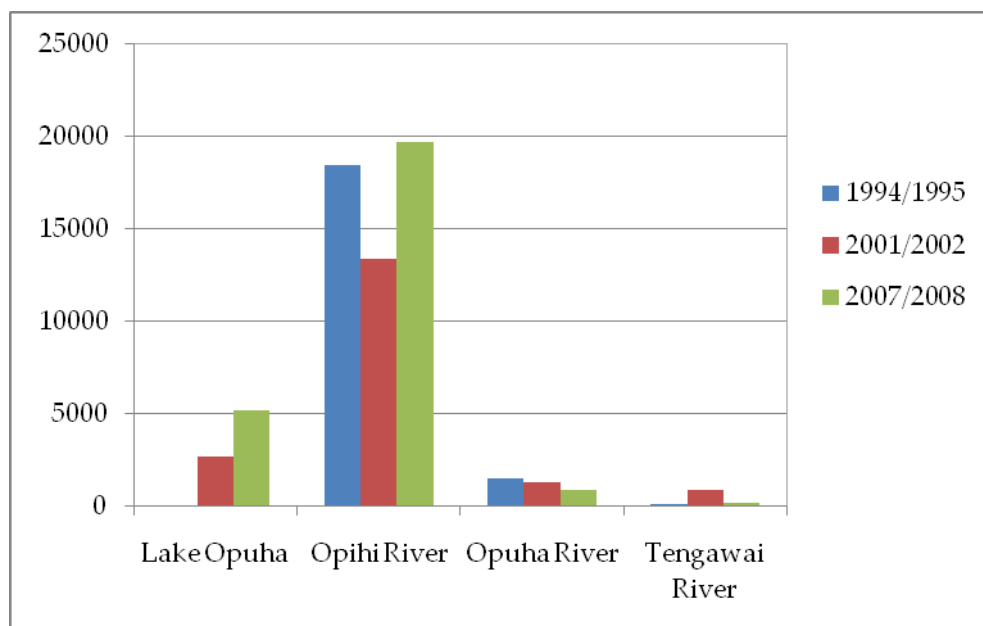

Figure 20: Number of angler days on the Opihi River and its tributaries between 1994 and 2008 (adapted from Fish and Game, 2009).

The fall in angler days in the 2001/2002 season followed by a marked recovery in the 2007/2008 season (*Table 17 & Figure 20*) is also indicated in *Figure 21*. In this figure the socio-economic indicator *Number of Anglers* and the biophysical indicator *Number of Salmon Caught* are plotted together. From *Figure 21* it is found that prior to the construction of the Opuha Dam anglers caught more than one fish per angler. However, since the construction of the Opuha Dam anglers caught less than one fish per angler. The exception to this trend is the 2004/2005 season, where anglers caught nearly 1.5 fish per angler. Hence, despite one outstanding season the recreational fishery on the Opihi River appears to have been negatively impacted with the construction of the Opuha Dam.
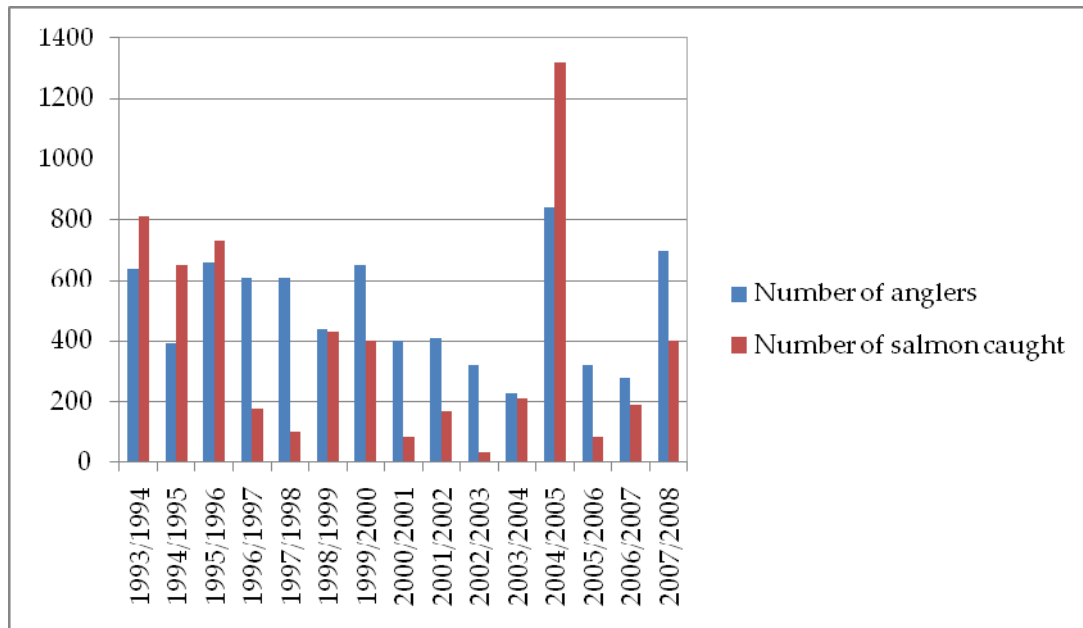

Figure 21: The number of anglers and salmon caught in the Opihi River between 1993 and 2008 (Fish and Game, 2009).

In sum, it has been found that there is no concrete evidence to suggest that swimming has been negatively impacted as a result of the Opuha Dam. Moreover, it is likely that swimming overall has improved within the Opihi River catchment through the augmented minimum river flows ensuring guaranteed swimming throughout the summer period and through the increased swimming area with the creation of Lake Opuha. The creation of Lake Opuha also appears to have benefited recreational fishing as indicated by the increased number of angler days in the 2007/2008 season. However, despite this improvement it also appears that recreational fishing on the Opihi River has been adversely affected by the Opuha Dam. Hence, overall the ecosystem service **Recreational Values** on the Opihi River appears to have been both positively and negatively impacted by the Opuha Dam.

6.0 Discussion

In this report an ecosystem services review was performed for the Opihi River located in Canterbury. The Opihi River was chosen for investigation as this river has been hydrologically modified by the Opuha Dam scheme. The dam was originally commissioned to store water for ensuring a reliable supply of freshwater for irrigation and augment minimum river flows in order to restore the degraded game and native fishery. By

investigating the impact the Opuha Dam has on the ecosystem services provided by the Opihi River this ecosystem services review establishes a template for further investigations using the ecosystem services approach for evaluating environmental projects, and especially water storage projects.

The ecosystem services review provided a means for evaluation of ecosystem services using appropriately selected indicators. However, it is recognized that the use of ecosystem services indicators are underdeveloped. In particular, it was recognized that many ecosystem services do not have a comprehensive set of indicators in which to adequately represent their state. Previously, it was argued that both biophysical and socio-economic indicators are required for an ecosystem service to be adequately captured. Despite this requirement very few ecosystems services were shown to have both biophysical and socio-economic indicators available to capture their state. Only the provisioning ecosystem service **Freshwater Supply** is judged to be adequately captured by multiple indicators with which to provide a comprehensive representation of this ecosystem service. For the ecosystem service **Freshwater Supply** there is conclusive evidence that a positive impact has resulted from the Opuha Dam scheme. The impact on other ecosystem services is in general uncertain, inconclusive or mixed. This finding was similar to that observed in the recent study undertaken by Layke (2009). Layke (2009) observed that indicators available for capturing regulating and cultural ecosystem services lag well behind that of provisioning ecosystem services. In this study it was also observed that regulating and cultural ecosystem services are mainly captured only by biophysical indicators. Hence, a critical research requirement for the ecosystem services approach is the development of scientifically sound (socio-economic) indicators for the multitude of regulating and cultural ecosystem services. Nevertheless, no matter the quality of indicators used, it is likely that the capacity to fully capture an ecosystem service is difficult given that ecosystem services are, in themselves, complex phenomena.

Despite these problems in adequately depicting the various ecosystem services with available indicators various inferences have been made about the actual impact of the Opuha Sam scheme on some ecosystem services. *Table 18* depicts a summary table of the perceived actual impacts of the Opuha Dam scheme on the various ecosystem services provided by the Opihi River. For ease of comparison *Table 18* also shows the hypothesized impacts of the dam (*Table 3*). It is observed from *Table 18* that much uncertainty exists as to the actual impacts of the Opuha Dam on many ecosystem services. Most of the uncertainty lies with the regulating and cultural ecosystem services.

Ecosystem service class	Ecosystem service	Notes and sub-class of ecosystem service			Hypothesized impact	Actual Impact
Provisioning ecosystem services	**Food**	Fisheries	Salmon		+/-	+/-
			Trout		+/-	+/-
		Mahika kai (*e.g.* eel, whitebait, flounder)			+/-	+/-?
	Fibre	Flax, driftwood			+	?
	Freshwater supply	Irrigation			+	+
		Hydroelectric production			+	+
		Municipal water supply			+	+
		Industrial water supply			+	+
		Stock water supply			+	+
	Biological products	Not applicable			Na	Na
	Abiotic products	Gravel extraction for road chip and concrete			0	0
Regulating ecosystem services	**Climate regulation**	Not applicable			Na	Na
	Disease regulation	Parasite and toxic algae regulation			-	?
	Water regulation	Hydrological flow regulation (*e.g.* minimum river flows, flushing flows)			+/-	+/-
	Water purification	Removal of pollutants			+/-	-?
	Erosion control	Stabilization of river banks			+	-?
	Pest regulation	Invasive non-native species (*e.g.* algae, willows, gorse, broom)			-	-?
	Natural hazard regulation	Flood and drought protection			+	+
Cultural ecosystem services	**Conservation values**	Native biodiversity and habitat			-	-?
		Endangered native species			-	-?
		Ecological landscapes of significance			+/-	?
	Educational values	Historical/archaeological values			0	?
		Knowledge systems			+/-	?
	Aesthetic values	Perceived beauty			+/-	0?
	Spiritual values	Māori values	Natural character		-	?
			Life supporting capacity or mauri		+	-?
	Recreational values	Boating (*e.g.* sailing, rowing, kayaking)			+	+?
		Fishing			+/-	+/-?
		Hunting (*e.g.* duck hunting)			+	?
		Picnicking			+	?
		Swimming			+/-	?
		Walking			0	?

Table 18: The ecosystem services provided by the Opihi River and the hypothesized and actual impacts of the Opuha Dam on each ecosystem service. Note that '?' indicates uncertainty as to the impact on the particular ecosystem service.

6.1 Ecosystem Services Index Construction

Previous research has indicated the difficulty of expressing ecosystem services into a monetary metric (*e.g.* Ackerman *et al.*, 2007). This work highlights that ecosystem services are difficult to quantify in terms of any objective measurement. However, it is also recognized that with both biophysical and socio-economic indicators it is possible to capture the long-term trends of an ecosystem service. Accordingly, efforts are needed to generate a comprehensive set of biophysical and socio-economic indicators for each ecosystem service. If this can be attained, then an aggregated ecosystem services index suitable for evaluating environmental projects and informing policy makers can in turn be established (Boyd & Banzhaf, 2007). The benefits of an ecosystem services index would not only provide more accurate detail of *ex-post* evaluations, but provide information about the net impact on ecosystem services. This is important as it has been shown in the ecosystem services review that many ecosystem services appeared to be both positively and negatively impacted from the Opuha Dam scheme. An ecosystem services index would allow net impacts to be quantified providing a better assessment of environment projects.

The development of an ecosystem services index from the indicators can be achieved through three steps. First, there is a need to normalize each indicator on to a 1-100 scale, where 1 and 100 would represent the historical minimum and maximum values observed for that indicator either for the ecosystem investigated or, where comparisons are to be made between them, for a number of ecosystems of a similar type (*i.e.* braided rivers). Evidently, those indicators with a considerable time-series of data will provide more accurate historical minimum and maximum values as the trends and extremities of the data are likely to be known with some certainty. Nevertheless, over time it is possible that these values initially developed are inaccurate and may need readjusting. If so, then all previous scores should also be readjusted accordingly so that previous assessments are measured with current scaling parameters. Secondly, from the established 1-100 scale, the present state of the ecosystem for that indicator can be appropriately quantified. Finally, ecosystem services and class of ecosystem service (*i.e.* cultural ecosystem services) require weights, which reflect their societal preference. These preferences can be generated through a sample population of all stakeholders or through a diverse expert panel, which is representative of these stakeholders.

The preferential weights for each ecosystem service can be estimated using the analytical hierarchy process (Saaty, 1995). Briefly, the analytical hierarchy process is a multi-criteria analytical method, which forms a hierarchical structure of an evaluation problem (*Figure 22*). From this structure developed, pairwise comparisons between ecosystem services and classes of ecosystem services can be made on a one-to-nine scale allowing preferential weights to be estimated. With preferential weights for ecosystem services quantified, an aggregated ecosystem services index can be estimated by multiplying weights with the normalized scores for each indicator. These products of weights and scores then can be multiplied to form a product as an ecosystem services index (*Equation 1*).

$$\text{Ecosystem services index} = \Pi w_n s_n$$

Equation 1: The ecosystem services index.
Here w_n is the preferential weight for ecosystem service n; and
s_n is the normalized score for ecosystem service n.

The capacity of establishing an informative ecosystem services index will depend on resolving a number of problems including the establishment of a comprehensive set of indicators for each ecosystem service. For example, there is a need to ensure that sufficient data is available for each indicator and that the sampling methods used to collect the data are scientifically defensible (Ehrlich, 1996). The lack of sufficient data in several indicators to infer useful trends was apparent in the ecosystem services review undertaken. Yet, despite the need for a long time-series of data the reality is that "despite advances in monitoring technology, the lack of uninterrupted time series of sufficient length to reflect social-ecological dynamics is a major problem" (Carpenter *et al.*, 2006). However, it is not just data availability that is often limited. It is also the availability of indicators that are limited. In this study it was noted that many indicators are collected by different organizations, each with their own protocols and capacities to undertake monitoring. In order to ensure a standardized approach to ecosystem services indicators there is a need for all indicators relevant for an ecosystem to be available on a single database. The movement towards a single easily accessible database has occurred for a few NIWA indicators, which are available in some capacity on the Ministry for the Environment (2009) website.
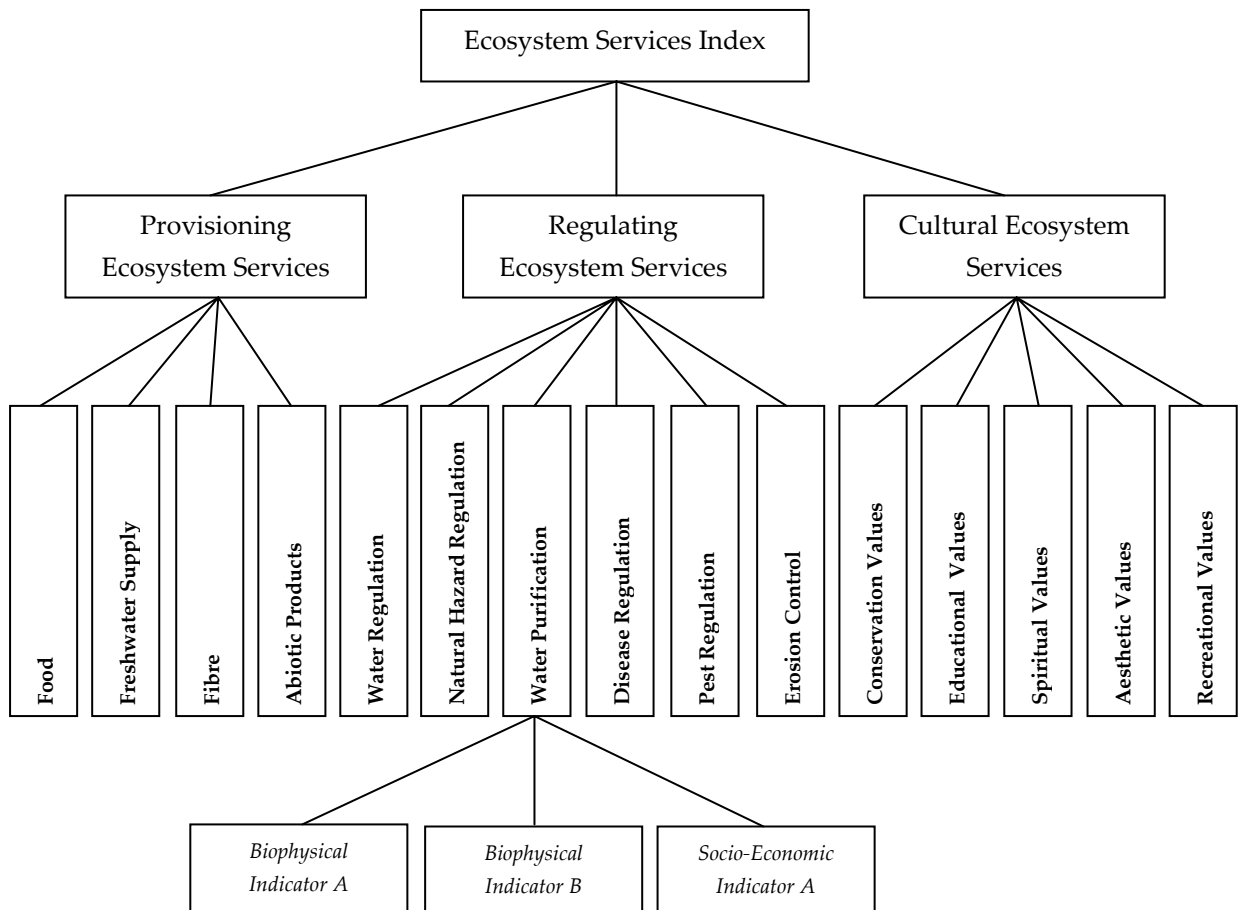

Figure 22: The hierarchal structure developed to represent the evaluation problem of forming an aggregated ecosystem services index from indicators.

A further problem recognized with the use of indicators and the formation of an ecosystem services index is that many indicators are used to determine trends for multiple ecosystem

services. For example, the indicator *Macroinvertebrate Community Index* can capture components of various ecosystem services including **Water Purification**, **Conservation Values** and **Spiritual Values**. *Table 19* indicates the various indicators used for the full range of ecosystem services considered for the Opihi River. It is found that 12 indicators are used to determine the state of at least two ecosystem services. This finding highlights the interrelatedness of ecosystem services (Capistrano *et al.*, 2006). While this interrelatedness of ecosystem services might not appear to be a problem, it is for the formation of an ecosystem services index (Boyd & Banzhaf, 2007). This is because the use of indicators for determining trends and scores for multiple ecosystem services results in the problem of double counting. Double counting is a fundamental issue, yet surprisingly only one of 34 studies on ecosystem services has mentioned the problem of double counting (Fisher *et al.*, 2009).

Indicator — Ecosystem service	Annual Periphyton Cover	Clarity	Cultural Health Index	E. coli Levels	Irrigated Area	Macroinvertebrate Community Index	Native Biodiversity	Number of Days River Mouth Closed	Number of Flood Flows	Number of Salmon Caught	Total Suspended Sediment	Turbidity
Freshwater Supply				×	×							
Food	×		×			×		×		×		
Fibre												
Abiotic Products												
Water Regulation						×			×			
Natural Hazard Regulation					×				×			
Water Purification	×				×							×
Disease Regulation	×											
Pest Regulation												
Erosion Control											×	×
Conservation Values					×		×					
Educational Values												
Aesthetic Values	×	×									×	
Spiritual Values		×	×		×		×					
Recreational Values	×	×		×					×	×		
Total	5	3	2	2	5	2	2	2	2	2	2	2

Table 19: Indicators that were used to indicate the state of multiple ecosystem services.

In an effort to resolve the problem of double counting there is a need to standardize the various indicators to particular ecosystem services. To undertake this standardization an evaluation of the indicators is required in order to determine which indicators most appropriately communicate trends for each ecosystem service. For example, it is likely that

the biophysical indicator *Macroinvertebrate Community Index* is better at communicating trends about the ecosystem service **Water Purification** than the ecosystem service **Spiritual Values**. This is because the use of the indicator was only a proxy attempt to measure and quantify the mauri of an ecosystem. Hence, in this evaluation of indicators various criteria need to be established. Recently, Layke (2009) suggested various criteria to evaluate indicators based on work developed by Boswell (1999). These criteria were the availability of data for the indicator and the ability the indicator has in communicating information and summarizing trends about the ecosystem service. These criteria were placed into various sub-criteria. For example for data availability a sub-criterion was whether the data is collected at an appropriate spatial and temporal scale. However, it is recognized here that an additional criterion is required. This criterion is the cost of monitoring for the indicator. These criteria and sub-criteria in this study were scored on a zero-to-three scale (where three is high) by an expert for the **Water Purification** ecosystem service to indicate how the evaluation might proceed (*Table 20*). The scores given by the expert were summed and divided by the cost score given providing a measure of the cost-effectiveness of the indicator for the particular ecosystem service. Accordingly, where one indicator is initially selected to two or more ecosystem services, the ecosystem service that provides the highest cost-effectiveness score for that indicator should be assigned to that ecosystem service.

Ecosystem service	Indicator	Data availability (0-3 scale)		Ability to communicate information (0-3 scale)		Cost (0-3 scale)	Indicator cost-effectiveness
		Scale monitoring	Processed	Intuitive	Accepted		
Water Purification	*Total Nitrogen Concentration*	3	3	2	3	2	5.5
	Total Phosphorus Concentration	3	3	2	3	2	5.5
	pH Levels	3	3	1	3	2	5
	Annual Periphyton Cover	3	2	2	2	1	9
	Percentage of EPT Taxa	3	2	2	2	2	4.5
	Macroinvertebrate Community Index	3	2	2	2	2	4.5

Table 20: Expert scores for various evaluation criteria of several indicators representing the ecosystem service **Water Purification**. Sub-criteria for the criteria availability of data and ability to communicate information are:
1. Multiple scales: Data gathered at appropriate spatial and temporal scales;
2. Processed: Data processed into indicators that are widely used;
3. Intuitive: Indicator communicates information about ecosystem service in an obvious way that limits ambiguity, so that the mind can perceive a clear agreement between the indicator and the ecosystem service; and
4. Accepted: Indicator adheres to scientific principles and methods.

Despite the detailed account of an ecosystem services index, its formation could be critiqued as the unit-less index has no natural anchor, lacks meaning and may be perceived to provide little benefit to policy makers (Kirk & Gilbert, 1999). However, the ecosystem services index can model progress towards long-term sustainability, if sustainability is defined as welfare aggregated from environmental and socio-economic dimensions that are non-declining over a period of time (Pearce *et al.*, 1990). Hence, if the index is non-declining over the long-term then the ecosystem is considered not 'unsustainable'. This definition of sustainability is considered 'weak' because it assumes that all indicators can be compensated and traded-off with each other. For example, the ecosystem services index implies that a high scoring **Recreational Values** can compensate a low scoring **Water Regulation**. In allowing for compensation, the ecosystem services index is not able to consider 'strong' definitions of sustainability where various ecosystem services would be considered non-compensatory in trade-offs with other ecosystem services (Faucheux & O'Connor, 1998). One might reason that in a world with endless wants and needs and with numerous conflicting interests involving multiple stakeholders, trade-offs and thus, substitutability are not only inevitable, but warranted. However, where strong definitions of sustainability are sought for reasons of ensuring that a safe minimum standard for various ecosystem services is achieved, then an alternative approach to an aggregated ecosystem services index could be employed. A suitable alternative approach would be to avoid the weighting and aggregation of ecosystem services. Instead each ecosystem service could be given a specific safe minimum standard to be achieved, which would be transformed on to a normalized 1-100 scale. Sustainability would be observed, then, not through a non-declining index over time, but where all standards (or as many as possible) have been met.

6.2 Future Water Storage Projects

With the potential to standardize indicators to particular ecosystem services it becomes possible to evaluate future water storage projects. In recognizing the potential of the ecosystem services approach, the final part of this report considers future schemes to further improve water storage in the Opihi River catchment. The need to continue to find water storage solutions in the Opihi River catchment is recognized from the seemingly ever-increasing demand for irrigation. This is especially the case with the realization of climate change. Some research indicates that the catchment area could experience severe drought conditions, where irrigation would have to be restricted for at least three months in one year in order to maintain adequate minimum river flows to sustain the aquatic health of the Opihi River (Canterbury Strategic Water Study, 2006). Accordingly, there is a need to consider alternative water storage projects in the Opihi River catchment to further increase the freshwater supply available to farmers. From the Canterbury Strategic Water Study (2006) two schemes have been considered 'feasible'. Both schemes were considered to provide at least the same amount of irrigated land as the present Opuha Dam (*i.e.* 16,000 hectares). Hence, the total irrigated land area has been suggested to be around 33,000 hectares if either of these additional schemes went ahead. One scheme, the Opihi Dam scheme, is to construct another dam upstream from the Opihi Gorge. The other scheme is to channel and transfer water from Lake Tekapo in the neighbouring Waitaki catchment to the Opihi River (*Table 21*).

Scheme	Cost (NZ$)	Irrigated area (ha)	Reliability	Active storage (Mm3)
Opuha Dam (present)	---	16,000	28 (92%)	83
Opuha Dam and Opihi Dam	$33 million for dam and $57 million for water distribution system	33,000	22 (93%)	240
Water from Lake Tekapo (10 m³/s) with Opuha Dam	?	33,000	15 (96%)	83

Table 21: Proposed water storage projects for increasing water storage and augmenting minimum river flows on the Opihi River (adapted from Canterbury Strategic Water Study, 2006).

The chief instigator of the Opuha Dam, Tom Henderson, considers "stored water as the future" and he believes that the scheme which uses water from Lake Tekapo should be the source of future freshwater supply for the catchment (Worrall, 2007). Despite this belief there are concerns over this proposed scheme. One concern is the mixing of waters from different catchment areas, which is hypothesized to negatively impact the ecosystem service **Spiritual Values**, as Māori do not accept the transfer and displacement of water from one catchment to another (Waaka-Home, 2010; pers. comm.). It is also unclear whether the mixing of water from different catchments, one glacial and turbid and the other 'warm' and clear would have ecological impacts that may affect other ecosystem services. In addition, there are other issues with this proposed scheme relating to legal and planning barriers. In particular, it may be insurmountably difficult obtaining appropriate resource consents because the water is presently used for hydroelectric production, which would be compromised with the development of the proposed scheme. Indeed, the Lake Tekapo scheme has been considered "a one in million chance" of going ahead (Lambie, 2009; pers. comm.). In foreseeing the loss of hydroelectric productivity from Lake Tekapo from this proposed scheme, it is also recognized that in using water from Lake Tekapo that an ecosystem services (pre)review or an *ex-ante* ecological impact assessment from an ecosystem services perspective would be required that considers two catchments and not just the Opihi River catchment.

The alternative scheme to channelling water from Lake Tekapo is to construct the Opihi Dam upstream of the Opihi Gorge on the Opihi River. This scheme is presently less favoured, despite being projected to be less costly (Scarf, 2009; pers. comm.). The limited preference for this scheme may be for two reasons. First, the Opihi Dam while improving irrigated area does not improve gains in reliability for irrigation. Secondly, some scientists are against this scheme as it would result both in the Opuha and Opihi Rivers being impounded. Presently, with the Opuha Dam scheme there is some variability of flow through the Opihi River and unimpeded access for fish passage. However, constructing the Opihi Dam would further limit fish passage and is further reduce the variability of river flows (Canterbury Strategic Water Study, 2006). Accordingly, these changes may negatively impact on various ecosystem services including **Water Regulation**, **Recreational Values** and **Food**. However, there would be positive impacts from the Opihi Dam including the creation of a 1000 hectare reservoir

(*i.e.* Lake Opihi), which may improve the ecosystem services **Recreational Values** and **Conservation Values** through providing a resource for recreationalists and birdlife. However, in either of these proposed schemes it is a matter of course that land use intensification will increase. This increased intensification of land use will see greater amounts of fertilizers being applied in the catchment leading to increased surface runoff of pollutants into the Opihi River. The hypothesized impact of this land use intensification is the decrease in the ecosystem services **Water Purification** and **Pest Regulation**.

With these impacts on various ecosystem services in mind, it is evident that there is a need to consider all costs and values for an appropriate scheme to be chosen for construction. The basis of this evaluation should follow the methodology established for an ecosystem services review demonstrated for the Opuha Dam scheme on the ecosystem services provided for the Opihi River. In addition, experts could provide probabilities for different scenario outcomes for each water storage project and projected indicator scores between 1 and 100 representing each ecosystem service for the proposed scenario outcomes. Where an ecosystem services index is employed, then these scores could be multiplied by preferential weights generating an index value. This index value could then be multiplied by the associated probability of that outcome and summed across all outcomes for the proposed water storage project. Finally, the probability-adjusted index could be discounted and divided by the cost of the proposed scheme to allow the determination of the most efficient scheme in accordance with the method of cost utility analysis (Cullen *et al.*, 2001).

In conclusion, it has been shown how an ecosystem services review can be undertaken using ecosystem services indicators. In undertaking this ecosystem services review it was recognized that several issues remain in allowing an aggregated ecosystem services index to be formed from various indicators, which were selected to capture the trends and state of the ecosystem services provided. However, in this final section a means of resolving these issues has been sketched, so that the ecosystem services approach can be used a means to evaluate future water storage projects in Canterbury.

7.0 Acknowledgements

8.0 References

Ackerman, F., Heinzerling, L. and Massey, R. I., 2007. Wrong in retrospect: Cost-benefit analysis of past successes. *In* Erickson, J. D. and Gowdy, J. M. (*eds.*). *Frontiers in Ecological Economic Theory and Application.* Edward Elgar: Cheltenham.

Arimoro, F. O. and Ikomi, R. B., 2009. Ecological integrity of upper Warri River, Niger Delta using aquatic insects as bioindicators. *Ecological Indicators, 9*, 455–461.

Ballantine, D. J. and Davies-Colloy, R. J., 2009. Water quality trends in National River Water Quality Network sites for 1989 to 2007. Ministry for the Environment: Wellington.

Barkmann, J., Glenk, K., Keil, A., Leemhuis, C., Dietrich, N., Gerold, G. and Marggraf, R., 2008. Confronting unfamiliarity with ecosystem functions: The case of ecosystem services approach to environmental valuation with stated preference methods. *Ecological Economics*, 65: 48-62.

Baskaran, R., Cullen, R. and Colombo, S., 2010. Testing different types of benefit transfer in valuation of ecosystem services: New Zealand winegrowing case studies. *Ecological Economics*, 69: 1010-1022.

Biggs, B. J. F., 2000. New Zealand periphyton guideline: Detecting, monitoring and managing enrichment of streams. Ministry for the Environment: Wellington.

Birdlife International, 2005. www.birdlife.org/datazone/species/index.html.

Bossel, H., 1999. *Indicators for Sustainable Development*: *Theory, Methods, Applications*. International Institute for Sustainable Development: Winnipeg.

Boyd, J. and Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, 63: 616-626.

Boyd, J. and Wainger, L., 2002. Landscape indicators of ecosystem service benefits. *American Journal of Agricultural Economics*, 84: 1371-1378.

Canterbury Mayoral Forum, 2009. Canterbury water management strategy. Environment Canterbury: Christchurch. www.canterburywater.org.nz

Canterbury Regional Council, 1990. Opihi-Temuka River and Catchment: Issues and Options. Canterbury Regional Council: Christchurch.

Canterbury Regional Council, 1995. Opihi River Augmentation. Canterbury Regional Council: Christchurch.

Canterbury Strategic Water Study, 2006. www.canterburywater.org.nz

Canterbury Water Management Strategy, 2009. Canterbury Water Management Allocation Zone 2009. Orari-Opihi-Pareora Zone.

Capistrano, D., Samper, C. K., Lee, M. J. and Raudsepp-Hearne, C. (*eds.*). 2006. *Ecosystems and Human Well-bring. Findings of the Sub-Global Assessments Working Group for the Millennium Ecosystem Assessment*. Island Press: Washington.

Carpenter, S. R., DeFries, R., Dietz, T., Mooney, Polasky, Reid & Scholes, 2006. Millennium Ecosystem Assessment: Research needs. *Science*, 314: 257-258

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R. G., Sutton, P. and van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387: 253-260.

Cullen, R., Fairburn, G. A. and Hughey, K. F. D., 2001. Measuring the productivity of threatened species programs. *Ecological Economics*, 39: 53-66.

Curtis, I. A., 2004. Valuing ecosystem goods and services: A new approach using a surrogate market and the combination of multiple criteria analysis and a Delphi panel to assign weights to the attributes. *Ecological Economics*, 50: 163-194.

Dacker, W., 1990. Belonging here/Toi Taketake. The People and the Place: Mahika Kai. New Zealand Commission: Wellington.

Daily, G. C., 1997. *Nature's Services*: *Societal Dependence on Natural Ecosystems*. Island Press: Washington.

Davies-Colloy, R., Cameron, K., Francis, G., Bidwell, V., Ball, A. and Pang, L., 2003. Effects of rural land use on water quality. NIWA report, NIWA: Hamilton.

De Groot, R. S., Wilson, M. A. and Boumans, R. M. J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41: 393-408.

De Joux, R. T., 1982. The water resources of the Opihi and Temuka Rivers. South Canterbury Catchment Board and Regional Water Board: Timaru.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A. H., Soto, D., Stiassny, M. L. J. and Sullivan, C. A., 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Conservation Biology*, 81: 163–182.

Dyson, M., Bergkamp, G. and Scanlon, J., 2003. *Flow*: *The Essentials of Environmental Flows*. IUCN: Gland.

Ehrlich, P. R., 1996. Conservation in temperate forests: What do we need to know and do. *Forest Ecology and Management*, 85: 9-19.

Environment Canterbury, 2000. Opihi River Regional Plan Report R00/16. Environment Canterbury: Christchurch.

Environment Canterbury, 2006. Regional gravel management report. Report R06/1. Environment Canterbury: Christchurch.

Environment Canterbury, 2009. Data supplied to Edward Hearnshaw for various indicators taken on the Opihi River catchment by Environment Canterbury.

Farber, S. C., Costanza, R., Childers, D. L., Erickson, J., Gross, K., Grove, M., Hopkinson, C. S., Kahn, J., Pincetl, S., Troy, A., Warren, P. and Wilson, M., 2006. Linking ecology and economics in ecosystem management. *BioScience*, 56: 121-132.

Faucheux, S. and O'Connor, M., 1998. Weak and strong sustainability. *In* Faucheux, S. and O'Connor, M. (*eds*.). *Valuation for Sustainable Development*: *Methods and Policy Indicators*. Edward Elgar: Cheltenham.

Fish and Game, 2009. http://www.fishandgame.org.nz/

Fisher, B., Turner, R. K. and Morling, P., 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics*, 68: 643-653.

Fowles, C. R., 1972. Some effects of low flow conditions on the invertebrate fauna of the Opihi River, South Canterbury. University of Canterbury: Christchurch.

Frame, B. and Russell, S., 2009. Water allocation: Canterbury's wicked problem. *In* Frame, B., Gordon, R. and Mortimer, C. (*eds*.). *Hatched*: *The Capacity for Sustainable Development*, Landcare Research: Lincoln.

Funtowicz, S. O., Martinez-Alier, J., Munda, G. and Ravetz, J., 2001. Multicriteria-based environmental policy. *In* Abaza, H. and Branazini, A. (*eds*.). *Implementing Sustainable Development*: Integrated *Assessment and Participatory Decision-Making Processes*. Edward Elgar: Cheltenham.

Graynoth, E. and Skrzynski, W., 1973. The South Canterbury trout and salmon fishery. Fisheries Technical Report, Ministry of Agriculture and Fisheries: Wellington.

Hanson, C., Ranganathan, J., Iceland, C. and Finisdore, J., 2008. The corporate ecosystem services review: Guidelines for identifying business risks and opportunities arising from ecosystem change. World Resources Institute: Washington DC.

Harmsworth G. R. and Tipa, G., 2006. Māori environmental monitoring in New Zealand: Progress, concepts and future direction. Report for the ICM website: http://www.landcareresearch.co.nz/research/sustainablesoc/social/indigenous_index.asp

Harris Consulting, 2006. The Opuha Dam: An *ex-post* study of its impacts on the provincial economy and community.

Harris Consulting, 2009. Modelling the Canterbury Water Management Strategy area: Draft report prepared for Environment Canterbury. Environment Canterbury: Christchurch.

Hawes, I. and Spigel, B., 1999. Report on water quality in the Opuha Dam. NIWA report: Christchurch.

Hazel, S., 1999. Canada vs The Environment. Canadian Environmental Defence Fund:

Toronto.

Hoeinghaus, D. J., Winemiller, K. O. and Agostinho, A. A., 2008. Hydrogeomorphology and river impoundment affect food-chain length in diverse Neotropical food webs. *Oikos*, 117: 984-995.

Hoeinghaus, D. J., Agostinho, A. G., Gomes, L. C., Pelicice, F. M., Okada, E. K., Latini, J. D., Kashiwaqui, E. A. L. and Winemiller, K. O., 2009. Effects of river impoundment on ecosystem services of large tropical rivers: Embodied energy and market value of artisanal fisheries. *Conservation Biology*, 23: 1222-1231.

Hudson, H. R., 2005. Opihi and Tengawai Rivers: Status of gravel resources and management implications. ECan report U05/31.

Hughey, K. F. D. and Warren, A. 1997. Habitat restoration for wildlife nesting on degraded braided riverbeds in New Zealand. *In* Hale, P. and Lamb, D. (*eds*). *Conservation Outside Nature Reserves*. Centre for Conservation Biology, The University of Queensland: Brisbane.

Kelly, D., McKerchar, A. and Hicks, M., 2005. Making concrete: Ecological implications of gravel extraction in New Zealand rivers. *Water and Atmosphere*, 13: 20-21.

Kuik O. J. and Gilbert, A. J., 1999. Indicators of sustainable development. *In* Van den Bergh, J. C. J. M (*ed*.). *Handbook of Environmental and Resource Economics*. Edward Elgar: Northampton.

Kremen, C. 2005. Managing ecosystem services: What do we need to know about their ecology? *Ecology Letters*, 8: 468-4d79.

Layke, C., 2009. Measuring nature's benefits: A preliminary roadmap for improving ecosystem service indicators. World Resources Institute: Washington.

Lewis, L. Y., Bohlen, C. and Wilson, S., 2008. Dams, dam removal and river restoration: A hedonic property value analysis. *Contemporary Economic Policy*, 26: 175-186.

Loomis, J., Kent, P., Strange, L., Fausch, K. and Covich, A., 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation study. *Ecological Economics*, 33: 103-117.

MacDonald, G. and Patterson, M., 2008. Canterbury region's 'hidden' economy: Assessing the value of the region's ecosystem services and biodiversity. New Zealand Centre of Ecological Economics: Palmerston North.

Maloney, R. F., Keedwell, R. J., Wells, N. J., Rebergen, A. L. and Nilsson, R. J., 1999. Effect of willow removal on habitat use by five birds of braided rivers, MacKenzie Basin, New Zealand. *New Zealand Journal of Ecology* 23: 53-60.

Meredith, A. S., 1999. Water quality of Lake Opuha: Limnological issues in a newly formed lake. Technical report, Environment Canterbury: Christchurch.

Meyerson, L. A., Baron, J., Melillo, J. M., Naiman, R. J., O'Malley, R. I., Orians, G., Palmer, M. A., Pfaff, A. S. P., Running, S. W., Sala, O. E., 2005. Aggregate measures of ecosystem services: Can we take the pulse of nature? *Frontiers in Ecology and Environment*, 3: 56-59.

Minca, E. L., Petz, K.. and Werners, S., 2007. An ecosystem services approach in the Tisza River Basin. *Tiscia*, 36: 35-40.

Ministry for the Environment, 1997. *Environmental Performance Indicators: Proposals for Air, Freshwater and Land*. Ministry for the Environment: Wellington.

Ministry for the Environment, 2006. Snapshot of water allocation in New Zealand. Ministry for the Environment: Wellington.

Ministry for the Environment, 2007. Environment New Zealand 2007. Ministry for the Environment: Wellington.

Ministry for the Environment, 2009. http://www.mfe.govt.nz/issues/water/

Ministry of Health, 2005. Drinking water standards for New Zealand 2005. Ministry of Health: Wellington.

Molloy, J., Bell, B., Clout, M., de Lange, P., Gibbs, G., Given, D., Norton, D., Smith, N. and Stephens, T., 2002. Classifying species according to threat of extinction: A system for New Zealand. Threatened Species Occasional Publication No. 22, Department of Conservation: Wellington.

National Research Council, 2005. *Valuing Ecosystem Services*: *Toward Better Environmental*

Decision-Making. National Academy Press: Washington.

Navrud, S., 2001. Economic valuation of inland recreational fisheries: empirical studies and their policy use in Norway. *Fisheries Management and Ecology*, 8: 369-382.

O'Donnell, C. F. J. 1992. Birdlife of the Ashburton River, Canterbury, New Zealand. Department of Conservation Technical Report, Department of Conservation: Christchurch.

O'Donnell, C. F. J. and Moore, S. G. M., 1983. The wildlife and conservation of braided river systems in Canterbury. Fauna Survey Unit Report. New Zealand Wildlife Service: Christchurch.

Parkyn, S. M. and Wilcock, R. J., 2004. Impacts of agricultural land use. *In* Harding, J. S., Mosley, M. P., Pearson, C. P. and Sorrell, B. K. (*eds*.). *Freshwaters of New Zealand*. New Zealand Hydrological Society and New Zealand Limnological Society: Christchurch.

Pearce, D. W., Barbier, E. and Markandya, A., 1990. *Sustainable Development*: *Economics and Environment in the Third World*. Edward Elgar: Aldershot.

Petts, G. S., 1984. *Impounded Rivers*: *Perspectives for Ecological Management*. Wiley & Sons: London.

Quinn, J. and Meleason, M. A., 2005. Trends in nuisance periphyton at National River Water Quality Network Sites 1989-2001. www.niwascience.co.nz/ncwr/nrwqn

Quinn, J. and Raaphurst, E., 2009. Trends in nuisance periphyton cover at New Zealand National River Water quality Network sites 1990-2006. NIWA report: Hamilton.

Raymond, C. M., Bryan, B. A., Hatton MacDonald, D., Cast, A., Strathearn, S., Grandgirard, A. and Kalivas, T., 2009. Mapping community values for natural capital and ecosystem services. *Ecological Economics*, 68: 1301-1315.

Rayner, S., 2006. Wicked problems: Clumsy solutions.www.martininstitute.ox.ac.uk

Saaty, T. L., 1995. *Decision Making for Leaders*: *The Analytic Hierarchy Process in a Complex World*. RWS Publications: New York.

Scarf, F., Waugh, J. R. and Swete, K. N., 1984. Opihi River Water Management Plan 1984-1990. South Canterbury Catchment and Regional Water Board: Timaru.

Scarf, F., Keys, R. S., Connell, R. J., Cuff, J. R. I. and Waugh, J. R., 1987. Report on Flood 13th March 1986. South Canterbury Catchment and Regional Water Board: Timaru.

Schaller, H. A, Petrosky, C. E. and Langness, O. P., 1999. Contrasting patterns of productivity and survival rates for stream-type chinook salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia rivers. *Canadian Journal of Fish Aquatic Science*, 56: 1-15.

Scudder, T., 2005. *The Future of Large Dams*: *Dealing with Social, Environmental, Institutional and Political Costs*. Earthscan: London.

Shaw, W. D., 2005. *Water Resource Economics and Policy*: *An Introduction*. Edward Elgar: Cheltenham.

Southey, I., 2009. Number of waders in New Zealand 1994-2003. Department of Conservation: Wellington.

Straton, A., 2006. A complex systems approach to the value of ecological resources. *Ecological Economics*, 56: 402-411.

Taylor, G. A., 2000. Action plan for seabird conservation in New Zealand: Threatened seabirds. Threatened species occasional publication No. 16, Department of Conservation: Wellington.

Tipa, G. and Teirney, L., 2003. A cultural health index for streams and waterways: For recognizing and expressing Māori values. Ministry for the Environment: Wellington.

Ward J. V., Tockner K., Arscott D. B., Claret C., 2002. Riverine landscape diversity. *Freshwater Biology*, 47: 517–539.

Winkler, R., 2006. Valuation of ecosystem goods and services. Part 1: An integrated dynamic approach. *Ecological Economics*, 59: 82-93.

Woolmore, C. and Sanders, M., 2005. Project River Recovery: Strategic plan 2006-2012. Department of Conservation: Twizel.

Worrall, J., 2007. *A Dream Fulfilled – The Story of the Opuha Dam*. Opuha Dam Limited: Timaru.

Young, R. A., Smart, G. and Harding, J., 2004. Impacts of hydro-dams, irrigation schemes and river control works. *In* Harding, J. S., Mosley P., Pearson, C., Sorrell, B. (*ed*). *Freshwaters of New*

Zealand. New Zealand Hydrological Society and New Zealand Limnological Society: Christchurch.

Young, R. A., 2005. Economic criteria for water allocation and valuation. *In* Brouwer, R. and Pearce, D. (*eds*.). *Cost-benefit Analysis and Water Resources Management*. Edward Elgar: Cheltenham.