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Ecosystem services review of water projects

Edward Hearnshaw* Ross Cullen* Ken Hughey**

Edward.Hearnshaw2@lincolnuni.ac.nz, Ross.Cullen@lincoln.ac.nz, Ken.Hughey@lincoln.ac.nz

*Department of Accounting, Economics and Finance

**Department of Environmental Management

PO Box 84, Lincoln University, New Zealand

Water projects are typically evaluated using benefit cost analysis. Ecosystem services are the direct and indirect benefits that people obtain from ecosystems. Many of these benefits are ignored in benefit cost analysis, because of the absence of markets and the limited information or understanding of how the benefits from ecosystem services are produced. Regional or local government may be interested in learning how the value of ecosystem services associated with projects may change if a project occurs. Ecosystem Service Reviews aim to make ecosystem services explicit and quantifiable so that they can be accounted for in the evaluation of water use projects. Water storage projects can enable land use intensification to occur, and confer environmental benefits in some instances (e.g., flow augmentation) and costs in others (e.g., groundwater contamination and flow-on effects). Water storage projects can have both positive and negative outcomes for the environment. More flow can lead led to better fishing, better clarity, more contaminant dilution and a healthier aquatic ecosystem. It can also result in loss of braided river-bird habitat, and regulated flows can result in nuisance growths of potentially toxic algal species. Irrigation can increase productivity of land within the scheme, with attendant benefits to soil quality and other out-of-river environmental characteristics. This paper reports the methods used to assess the impact of a water storage dam on the flow of ecosystem services in a river system. We review the range of ecosystem services that are available in a river system and examine how the flow of ecosystem services can be altered by water storage and flow augmentation through the construction of a dam. In order to list and quantify ecosystem services an attempt is made to determine a suitable site specific set of ecosystem service indicators for the Opuha-Opihi river system case. We draw inferences about shifts in the value of ecosystem services that might arise from water projects in other contexts.

Keywords: Ecosystem services review, water projects

1.0 Introduction

There is increasing demand from the agricultural sector in New Zealand for abstracting water resources for irrigation. This demand is particularly strong in the Canterbury region. Canterbury region experiences high levels of evaporation through dry summers and yet has the potential for its vast agricultural land to be extensively irrigated. For these reasons, Canterbury has the largest allocation of abstracted water for consumptive use (70% of the national total) and the highest dependency on irrigation in New Zealand (*Figure 1*). Nevertheless, the supply and availability of water is limited making it essential that the sustainable and efficient use of water resources is appropriately considered.

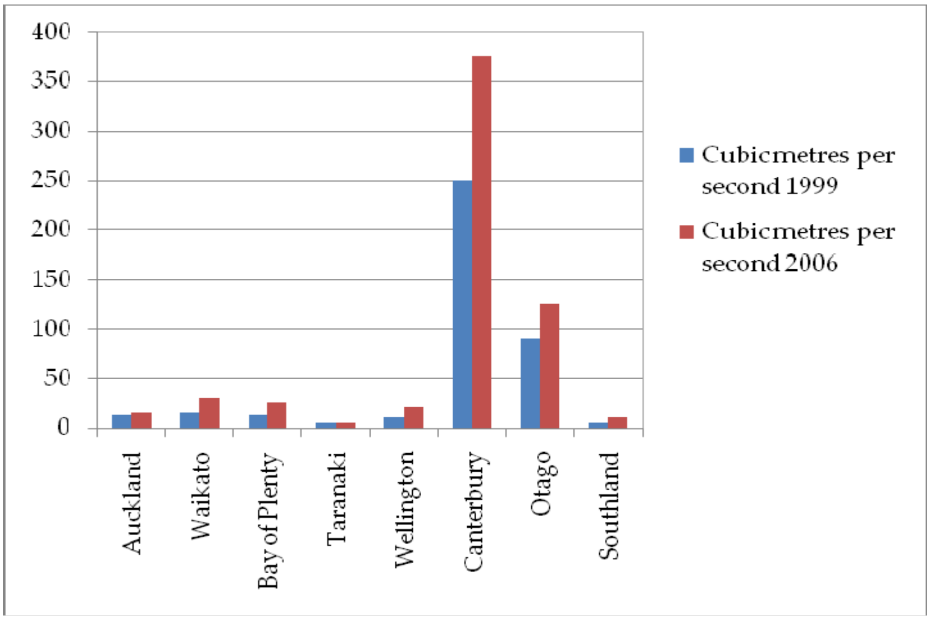

Figure 1: Weekly water allocation by regions within New Zealand for years 1999 and 2006 (adapted from Ministry for the Environment, 2006).

The impact of irrigation enables farmers to substantially intensify their agricultural operations. Irrigated farms can generate three times the household 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 the present land use or a change by farmers towards a higher intensity land use (*e.g*. sheep farming/mixed cropping to dairy farming/vegetable produce). 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). However, to meet ever-increasing demand for irrigation, it is recognized that there is a need 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, 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 exacerbated through climate change. Climatic changes will have both positive and negative impacts on the supply of freshwater and the productivity of agricultural operations.

While much irrigation water in Canterbury is sourced from run-of-river schemes, there is a realization that much of this source has reached maximum allocation limits while maintaining acceptable minimum flows to sustain aquatic health (Canterbury Water Management Strategy, 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. Certainly, as Bryan Jenkins, the chief executive of Environment Canterbury (*i.e*. Canterbury Regional Council), recognizes, "… 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; p. 118). Moreover, 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 their water quality and the ecology of the river through excessive primary production of algae, a process referred to 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.

Given the positive and negative impacts from water abstraction and the impoundment of rivers, water availability and water storage are now critical issues for local and regional government in the Canterbury region (Canterbury Mayoral Forum, 2009). The complexity of the issues has become apparent with a shift in values and concerns to include issues beyond the direct consumptive use of water resources. 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. Thus, evaluations in the viability of water storage projects need to account for all values found with water resources and rivers for them to be politically justifiable. Conservation and spiritual values are no longer seen as supplementary considerations (Canterbury Water Management Strategy, 2009). Rather, these values must be appropriately integrated into the evaluation approach undertaken. However, despite this need to appropriately consider and integrate all values, standard economic approaches have often only considered tangible use values which are easily 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. For all intents and purposes these less tangible values are given an implicit value of zero, so that evaluation inherently neglects the full range of values provided (Loomis *et al*., 2000; Navrud, 2001; Barkmann *et al*., 2008). 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, some 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 provided by ecosystems (Daily, 1997). 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 in 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 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 services that are provided by ecosystems. There have been various classifications of ecosystem services developed, each with arguments to support use of the classification devised (Capistrano *et al*., 2006; Barkmann *et al*., 2008). However, Raymond *et al*. (2009) argue 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 adopted here. Specifically, in the *Millennium Ecosystem Assessment* project, there is a defined taxonomy of four classes of ecosystem services. However, in this paper 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*).

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 derive (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 was found that agricultural systems are the most valuable ecosystems and that freshwater supply and water regulation are the most important ecosystem services provided by rivers. The study concluded that rivers account for 43.3 per cent of the total economic value of ecosystem services in Canterbury whereas the national average is 20.3 percent. However, the study was not ecosystem specific. Moreover, the study estimated the total economic value of ecosystem services for various ecosystem types and not changes to ecosystem services as a result of an 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; p. 394). 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, ecosystem complexity highlights the path dependence of ecosystems (National Research Council, 2005). It may well be the complexity of ecosystems that can best explain why the ecosystem services approach, while popular in general conversation, remains under utilized for evaluations of environmental projects.

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 paper 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 reported attempts to indicate the impact and change of ecosystem services, if any, from a water storage project in Canterbury. In many respects the ecosystem services review here reflects an ecological impact assessment from an ecosystem services perspective.

The review involves a multiple step methodology (*Figure 1*). In the first step (*Section 3*) a general 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 hypotheses being developed as to the impact of the water storage project on each ecosystem service. Finally, we report part of the ecosystem services review completed by the selection of appropriate indicators for ecosystem services (*Section 5*), which attempt to quantify changes in provisioning ecosystem service as a result of the water storage project. The use of indicators is significant as it provides a means to quantify the impact on each ecosystem service from the water storage project, without necessarily requiring each ecosystem service to be quantified in monetary values.

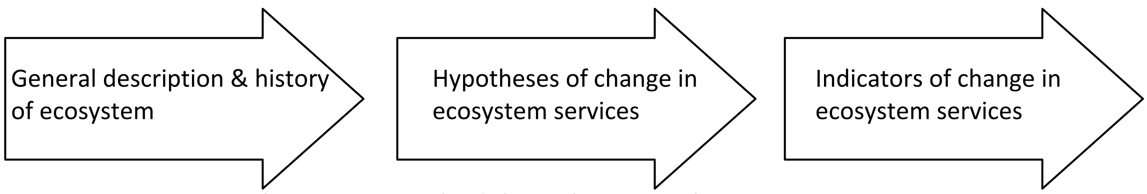

Figure 2: The various methodological steps in the ecosystem services review.

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 Opihi River is investigated. This river has been hydrologically modified by the Opuha Dam, for the purposes of storing water and ensuring a reliable supply of freshwater for irrigation. The ecosystem services review undertaken attempts to provide some much needed visibility as to how the ecosystem services provided by the Opihi River have changed from this water storage project. Young (2005) has observed that *ex-ante* evaluations of water storage projects are overly optimistic when compared with *ex-post* (or review) evaluations. One reason for this over optimism is that these evaluations often neglect the full range of values provided.

3.0 The Opihi River and the Opuha Dam

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. 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 paper is the Opihi River and in particular from the confluence of the Opihi River and the Opuha River to the coast.

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 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 viable 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 irrigated up to 3700 hectares of land 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 in the 1980s (Canterbury Regional Council, 1990).

The result of these dry summer months coupled with the excessive abstraction of water 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 including a supply of freshwater became degraded in the Opihi River. For all intents and purposes when the Opihi River was dry, it was according to Mark Webb, a local Fish and Game officer, “a dead river” (Worrall, 2007; p. 6). However, it is important to recognize that while the Levels Plains Irrigation Scheme has exacerbated the unacceptable minimum river flows in the Opihi River, it has not been the sole cause. Historical records indicate that while water abstraction has increased the frequency in which the Opihi River has dried up, there have been periods in which the river was dry naturally (*e.g*. 1915, 1931-1932) (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 for open 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 mahinga kai (Dacker, 1990; Scarf, 2009; pers. comm.). Mahinga kai, 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 re-considered during the early 1990s. 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 the degraded recreational fishery that was once of national importance. The *ex-ante* impact assessment of a dam to be located on the Opuha River, provided evidence that the proposed Opuha Dam scheme would provide many 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 Opuha Dam scheme beyond increased freshwater supply for irrigation highlighted the multiple purpose nature of the dam.

However, a number of anticipated negative impacts were also anticipated. These included the limited number of flushing flows downstream of the dam resulting 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 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 irrigation and ensuring that the river mouth remained open for extensive periods of time (Canterbury Regional Council, 1995). Hence, given even a return to a natural state was not considered appropriate, dam construction appeared necessary. Consequently, despite 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. Dam construction went ahead, and despite a devastating dam breach during construction after a period of heavy rain in 1997 the dam was fully operational by the end of 1998 (Worrall, 2007).

4.0 Ecosystem Services Hypotheses

In this section the full range of ecosystem services that are provided by the Opihi River are considered. From the study undertaken by MacDonald and Patterson (2008) it was maintained that rivers in Canterbury provide five ecosystem services. These are **Food**, **Freshwater Supply**, **Water Regulation**, **Water Purification** and **Recreational Values**. However, as noted earlier in this report, the complexity of ecosystems often means ecosystems 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. Methods used included: literature reviews, interviews with experts and stakeholders including tāngata whenua, data retrieval from various sources, and site visits. In this section the review will compile a list of ecosystem services provided by the Opihi River and also provide hypotheses as to the possible 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, as 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). This hypothesized impact on water quality may require increased treatment costs before water can be used 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 (Palmer & Sagar, 1990). Most of the native fish species are found in the Opihi Lagoon and are used by local Māori as mahinga kai, especially 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 (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, by 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 and other plant material (*i.e*. mahinga 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 Canterbury (Hudson, 2005). 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

MacDonald and Patterson (2008) 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 may have both positive and negative impacts. Positive impacts include 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 March the 13th 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). These negative impacts include the limited capacity of the river to flush potentially toxic algae and invasive exotic algae such as didymo (*Didymosphenia geminata)* 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 may 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 may 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 (Davies, 1987). 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 lake edge when lake levels on Lake Opuha were low (Canterbury Regional Council, 1995).

Despite claims that the Opuha Dam scheme would improve **Conservation Values** there is information 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 percent 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.) noted 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 connection is particularly important for the Opihi Lagoon, where mahinga kai has been traditionally gathered. 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).

Recreational Values are also provided by the Opihi River through many recreational activities. including 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).

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.

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. The drivers that influence many ecosystem services are interrelated (Capistrano *et al*., 2006). The interrelatedness of ecosystem services highlights why it is important to undertake an ecosystem services review, as it provides greater understanding of how altering on ecosystem service may result in unintended impacts on other ecosystem services.

Ecosystem service class	Ecosystem service	Notes and sub-class of ecosystem service		Hypothesized impact
Provisioning ecosystem services	**Food**	Fisheries	Salmon	+/-
			Trout	+/-
		Mahinga 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			+/-
	Erosion control			+
	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	Perceptive 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) of the Opuha Dam on each ecosystem service.

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 undertaken by Harris Consulting (2006) has provided much evidence that the Opuha Dam has positively impacted the capacity of farmers to irrigate and intensify land use. In the Harris Consulting 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 4*). 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 4: 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 5*). This indicates that the benefits generated from irrigation far exceed those gained from hydroelectricity. This was expected given that the Opuha Dam was not 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 5: 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 *Cryptpsporidium Levels* (Ministry of Health, 2005).

Figure 3 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 making 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 3* it is not evident that the Opuha Dam has impacted on *E. coli* levels in the Opihi River. This is because *E. coli* levels for the Opihi River do not appear to have significantly changed and appear similar to the levels observed for the Opihi River – Confluence. Interestingly, all *E. coli* levels obtained far exceed maximum acceptable levels for human consumption. Water supplied from the Opihi River will require waste treatment prior to human consumption and usage. Accordingly, an appropriate socio-economic indicator that might provide more information to make substantive inferences is *Cost of Water Treatment*.

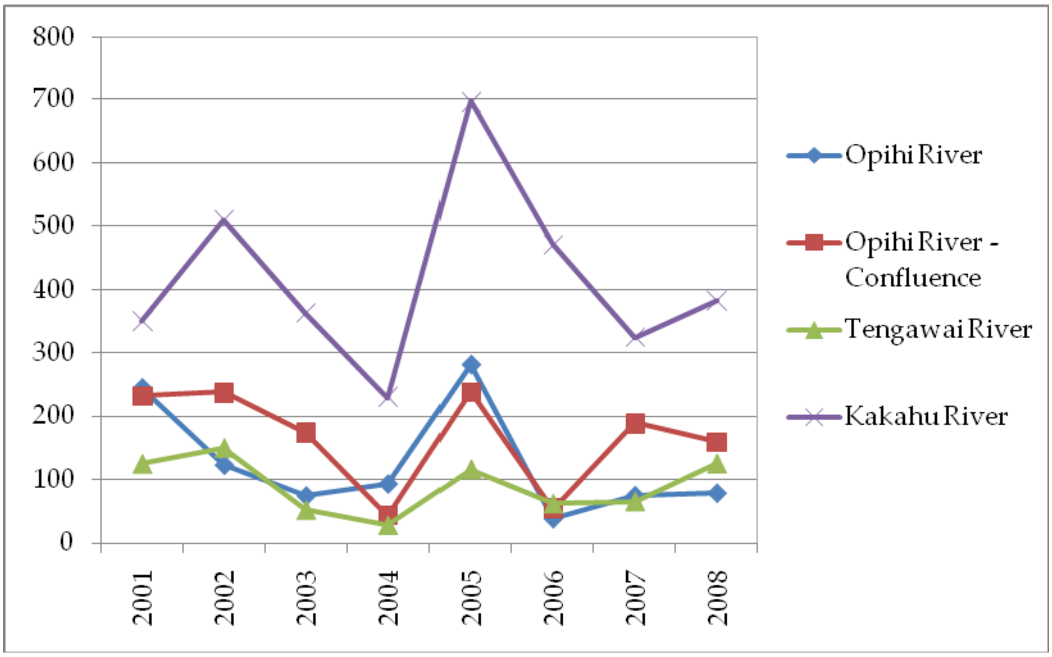

Figure 3: Average annual *E. coli* levels for the Opihi River and its tributaries between 2001 and 2008 (adapted from Environment Canterbury, 2009).

In *Figure 4* 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.

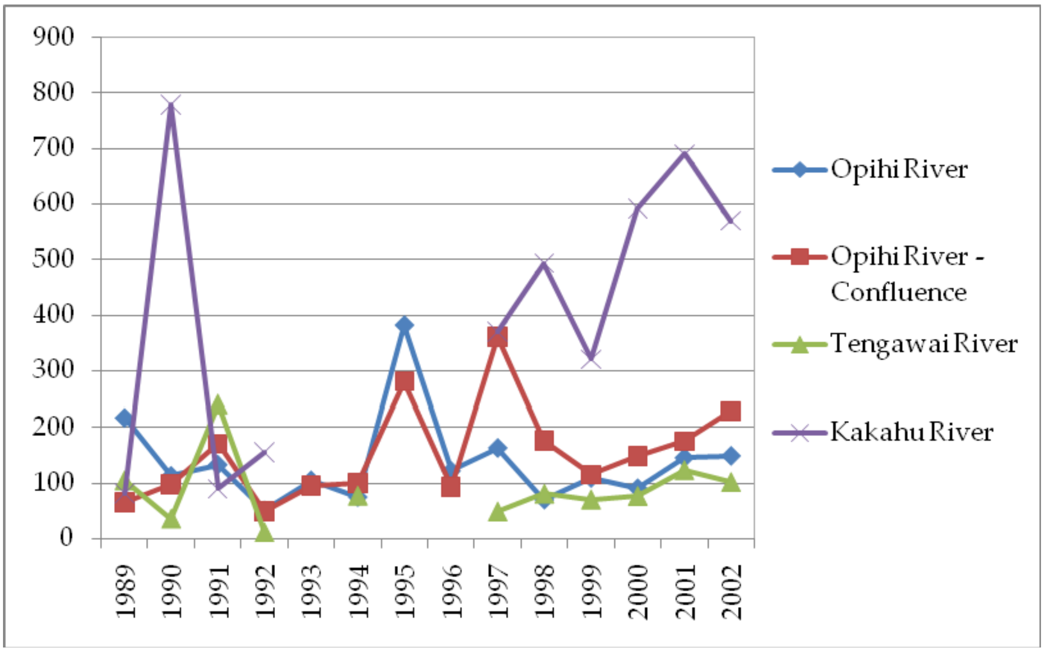

Figure 4: Average annual faecal coliform levels for the Opihi River and its tributaries between 1989 and 2002 (adapted from Environment Canterbury, 2009).

In sum, many biophysical and socio-economic indicators demonstrate that the Opuha Dam has positively impacted various benefits obtained from the ecosystem service **Freshwater Supply**. There are however more indicators required for fully capturing 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.

Apart from increasing freshwater supply, one of the primary purposes of the Opuha Dam scheme was to improve the degraded game and native fishery 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 mahinga kai. Hence, the ecosystem service **Food** was considered to possibly increase or decrease as a result of the Opuha Dam. In addition to the improved minimum river flows (*Table 6*), 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 river mouth of the Opihi River remained open allowing fish migration to the sea.

Monitoring site / Biophysical indicator	Unit	Opihi River: Waipopo		Opihi River - Confluence: Rockwood		Opuha River: Skipton Bridge	
		2007	Trend	2007	Trend	2007	Trend
Minimum River Flows	m^3/s	7.67	+	2.95	0	4.45	+

Table 6: Trends in the average minimum river flows on the Opihi River and its tributaries 1989 - 2007 (Ministry for the Environment, 2009).

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 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.).

Biophysical indicator / Period	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.

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 5* depicts the average spawning numbers of salmon 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 are lower for the Opihi River when compared with the Opihi River – Confluence data.

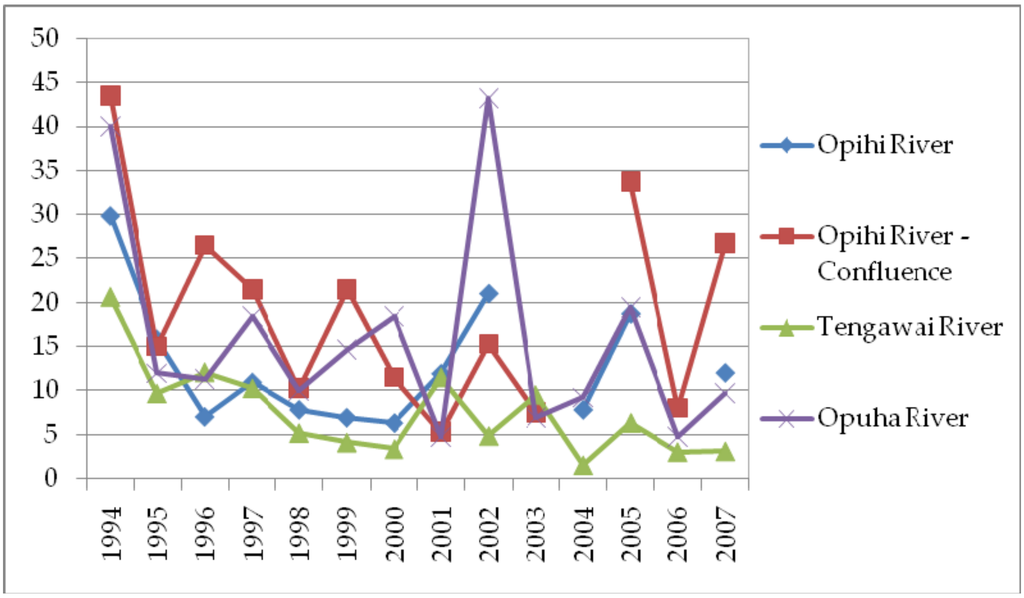

Figure 5: Average annual salmon spawning numbers between 1994 to 2007 for the Opihi River and its tributaries (adapted from Fish and Game, 2009).

Table 8 provides further weight to observations made in *Figure 5*. It is found that average spawning numbers per year have all decreased since the construction of the Opuha Dam. The greatest decrease is found on the Opihi River. It is interesting that decreases in spawning numbers are also found on tributaries not directly affected by the dam. This may indicate that other factors are involved in the decreases in spawning numbers. 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
Opuha River	20	14
Opihi River	16	12
Opihi River – Confluence	27	16
Tengawai River	13	5

Table 8: Average spawning numbers for salmon on 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 6* indicates the water temperature of the Opihi River and its tributaries. It appears that water temperature has decreased on the Opihi River, yet increased on the Opihi River – Confluence, which is the part of the river not directly affected by the dam. Hence, presumably the decrease in water temperature on the Opihi River is the result of minimum river flow augmentation. 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.

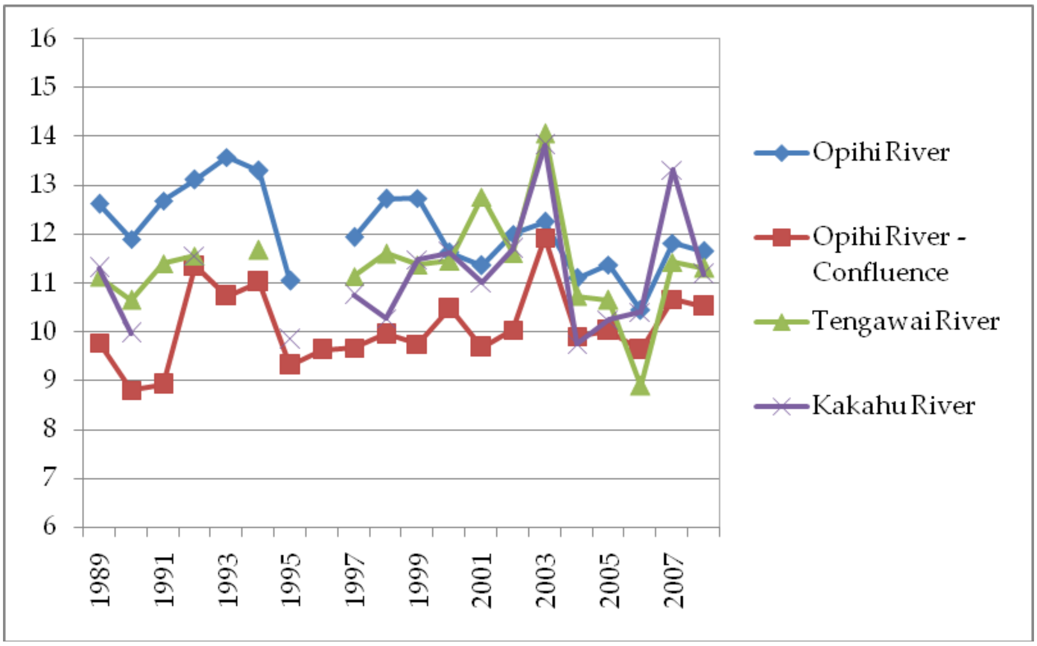

Figure 6: Average annual water temperature for the Opihi River and its tributaries between 1989 and 2008 (adapted from Environment Canterbury, 2009).

Period River	Pre-Opuha Dam	Post-Opuha Dam
Opihi River	12.6	11.7
Opihi River – Confluence	9.9	10.2
Tengawai River	11.3	11.4
Kakahu River	10.7	11.3

Table 9: Average water temperature for 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 7* 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.

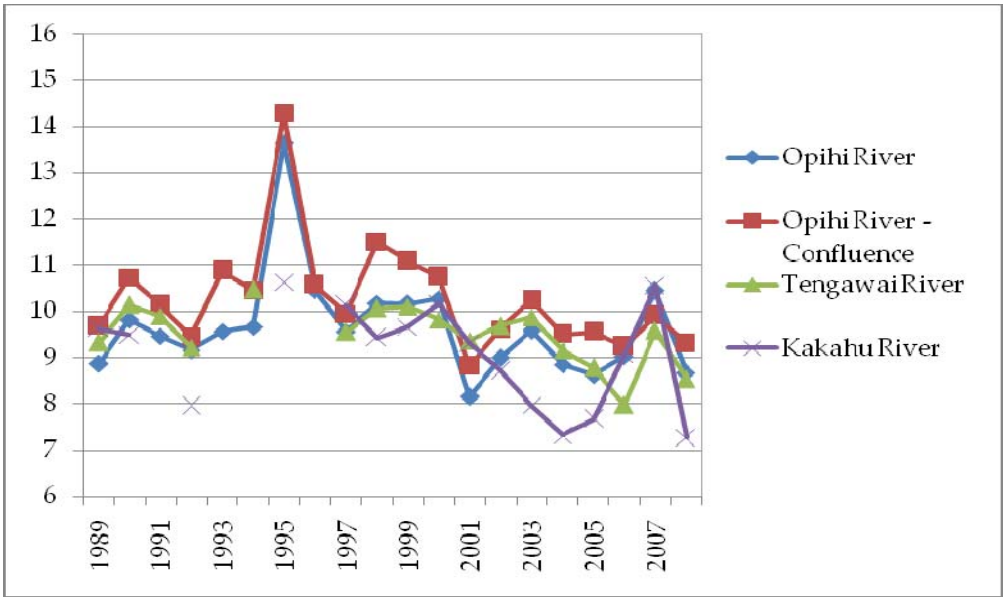

Figure 7: Average annual dissolved oxygen levels for the Opihi River and its tributaries between 1989 and 2008 (adapted from Environment Canterbury, 2009).

Period River	Pre-Opuha Dam	Post-Opuha Dam
Opihi River	10.1	9.4
Opihi River – Confluence	10.8	10.0
Tengawai River	9.8	9.4
Kakahu River	9.4	8.9

Table 10: Average annual dissolved oxygen levels for 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 after 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*. phormidium) (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 Biophysical indicator		Opihi River: Waipopo		Opihi River – Confluence: Rockwood		Opuha River: Skipton Bridge	
		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*. Interestingly, it is understood that various local fishermen have complained about the taste of fish caught from the Opihi River in recent years (Scarf, 2009; pers. comm.). This poor 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 to eat (Fish and Game, 2009).

Finally, a critical set of indicators required to adequately capture the ecosystem service **Food** is to account for the mahinga kai available on the Opihi River. One simple indicator would be the *Number of Mahinga Kai Fish Species Available*. It was indicated previously that there are 18 native fish species found in the Opihi River (Palmer & Sagar, 1990). 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 mahinga kai fish species available from the Opihi River. Hence, to obtain a better reflection of the benefits obtained from mahinga kai there is a need to determine the change in the number of mahinga 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 the use by Māori, 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 mahinga kai is 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.* A CHI assessment for the Opihi River is at present in progress (Waaka-Home, 2010; pers comm.). From these assessments, the general conclusion is that rivers and other 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 Water Management Strategy, 2009).

The ecosystem service **Fibre** is 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 mahinga kai species and can be used for weaving Māori artefacts (*e.g*. kete or traditional flax bags and baskets).

The final provisioning ecosystem service investigated is **Abiotic Products**. The Opihi River provides a supply of gravel that can be extracted from its riverbed. A suitable biophysical indicator available is the *Volume of Gravel Extracted per Year*. The volume of gravel extracted from the Opihi River steadily increased prior to the Opuha Dam scheme and has stabilized since the dam development *Figure 7*. The average gravel extracted per year prior to the dam was approximately 98,000 cubic metres per year. After the dam the average extraction increased to approximately 109,871 cubic metres per year. 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.

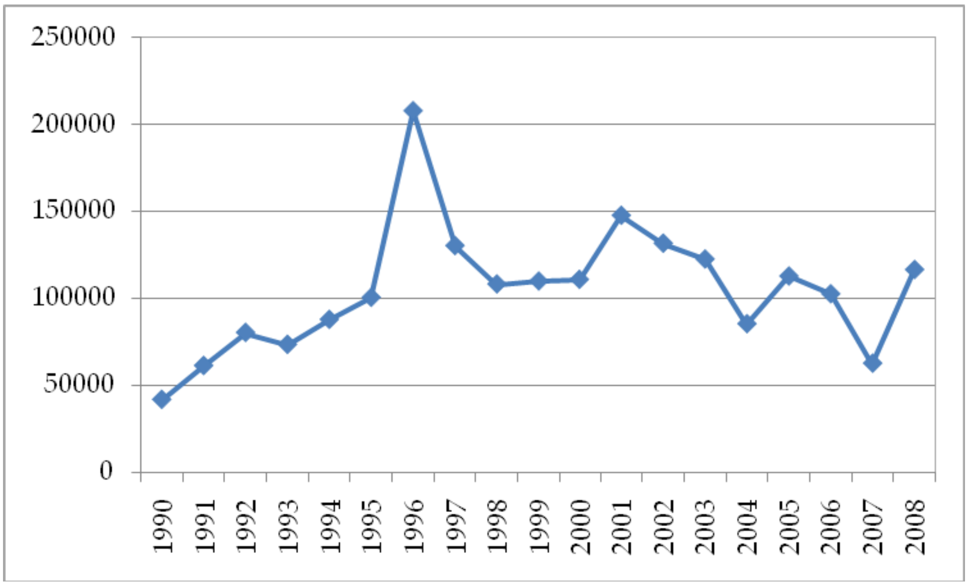

Figure 7: Volume (cubic metres) of gravel extracted per year from the Opihi River (Environment Canterbury, 2009).

6.0 Discussion

The partial ecosystem services review reported provided a means for evaluation of ecosystem services using appropriately selected indicators. However, the use of ecosystem services indicators is underdeveloped. In particular, many ecosystem services do not have a comprehensive set of indicators in which to adequately represent their state. Both biophysical and socio-economic indicators are required for an ecosystem service to be adequately captured. Despite this requirement very few ecosystems services have both biophysical and socio-economic indicators available to capture their state. Only the provisioning ecosystem service **Freshwater Supply** in this study was believed to be adequately captured by multiple indicators in which to provide a comprehensive representation of this ecosystem service. This finding is 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 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.

Previous research has indicated the difficulty of expressing ecosystem services into a monetary metric. 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 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; p. 257)”. However, it is not just data availability that is often limited. It is also the availability of indicators that are limited. Many indicators are collected by different organizations, each with their own protocols and capacities to undertake monitoring. 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. Movement towards a single easily accessible database has occurred for a few NIWA indicators, which are available on Ministry for the Environment (2009) website.

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 12* indicates the various indicators used for the full range of ecosystem services considered for the Opihi River. Twelve indicators are used to determine the state of at least two ecosystem services. 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, but only one of 34 studies on ecosystem services mentions 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 12: 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 13*). 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.

	Criteria/sub-criteria	Data availability (0-3 scale)		Ability to communicate information (0-3 scale)			
Ecosystem service	Indicator	Scale monitoring	Processed	Intuitive	Accepted	Cost (0-3 scale)	Indicator cost-effectiveness
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
	Average Percentage of EPT Taxa	3	2	2	2	2	4.5
	Macroinvertebrate Community Index	3	2	2	2	2	4.5

Table 13: 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.

With the potential to standardize indicators to particular ecosystem services it becomes possible to establish an ecosystem services index, in which future environmental projects can be considered and evaluated. The final part of this paper 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 in the ever-increasing demand for irrigation. Climate change will exacerbate that trend. 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 found in the neighbouring Waitaki catchment to the Opihi River (*Table 14*).

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 m^3/s) with Opuha Dam	?	33,000	15 (96%)	83

Table 14: Proposed water storage projects for increasing water storage and augmenting minimum river flows on the Opihi River (adapted from Canterbury Strategic Water Study, 2006).

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. 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 provisioning and regulating 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.

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 for two reasons, despite being projected to be less costly (Scarf, 2009; pers. comm.). 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. 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**. However, in either of these proposed schemes it is likely 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 could 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 projected indicator scores between 0 and 100 representing each ecosystem service for the proposed schemes. These scores multiplied by preferential weights would provide an index value. This index value divided by the cost of the proposed scheme would allow the determination of the more preferable scheme.

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 shown, so that the ecosystem services approach can be used a means to evaluate future water storage projects in Canterbury.

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