SUSTAINABLE WATER ALLOCATION FOR FAMILIES, FISH AND FARMING: A WICKED PROBLEM OR A WICKED SOLUTION?

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ABSTRACT

This paper describes an example of integrated socio-ecological systems management that is underway in Central Canterbury, New Zealand. Canterbury is New Zealand's largest region comprising approximately 17% of the country's land area. The region currently accounts for approximately 60% of all water allocated for consumptive use in New Zealand and 70% of the nation's irrigated land. The 'wicked' problem greeting researchers in 2004 was a community divided over the sustainable development of its water resources as these resources approached full allocation potential. The context for this situation is resource management legislation (the Resource Management Act 1991) with integrating intent but fragmented and under-resourced implementation until recently, which has inhibited integrated understanding of relevant social, economic, cultural and ecological systems before the pressures escalated in processes to allocate a resource deemed increasingly scarce and valuable.

To add value to recent processes at multiple spatial extents led by the devolved resource management decision maker (the Canterbury Regional Council), a multi-disciplinary group of researchers and stakeholders of place, interest and regulation embarked on a collaborative approach to consider the challenges of sustainable water allocation in Central Canterbury. Significant progress has been made despite participation challenges for those also involved in the continuing adversarial processes and those requiring quick answers to complex questions. Collaboration has occurred via meetings of various scale and focus, written research reports, meeting reports, peer reviewed literature and a website.

A key achievement to date has been the assimilation of a wide variety of knowledge and information for a catchment/watershed-focussed historical information project. One output from this process involves the combination of qualitative and quantitative knowledge on a key intermittent river in the catchment to identify river connection potential prior to the commencement of river flow recording. This extended river connection record was then analysed alongside multiple scales of natural and human drivers to address an information gap relating to the rise and dramatic decline of New Zealand's greatest brown trout fishery. Trout are particularly relevant to water allocation due to a section of the resource management legislation that seeks to protect trout (and salmon) habitat in a sustainable balance between water abstraction and fishable/swimmable water bodies.

The new hydrosystem information was then added to other relevant information and utilised in a system resilience assessment based on the Panarchy framework. This information is currently being structured in a way that enables analysis of interconnections with other relevant socio-ecological systems such as riparian zone functions, the opening regime of a large lake at the base of the catchment, and potential institutional arrangements for increasing the efficiency and effectiveness of currently allocated water. At the same time, all statutory agencies with responsibilities in the catchment are working with a community trust to poll the community on a choice between three potential futures for the lake and its catchment. A long term aim for these processes is the creation and implementation of an integrated catchment management plan which is significantly supported by regulatory agencies and the community. This would indeed be a wicked (in the best sense of the word) solution to a 'wicked' socio-ecological system problem.

Keywords: integrated socio-ecological system; wicked problem; water allocation

INTRODUCTION

Competition for water between ecosystem, economic, cultural and social needs is a daunting task for decision makers in a constantly changing world. Dramatic population changes in a particular species can provide a focus for addressing the wider resource balancing issues. The relationship between historical population changes to the brown trout fishery in the Lake Ellesmere catchment, Central Canterbury, and current water management practices provided such an opportunity for a research programme focused on how to determine sustainable levels of water allocation in New Zealand (Painter & Bright 2006). It also provided an opportunity for a multi-disciplinary group of researchers and stakeholders of place, interest and regulation to collaborate outside adversarial processes that are currently dominating water management in regions such as Canterbury, where allocatable water resources are increasingly scarce and valuable.

This group, the Selwyn Water Allocation Liaison Group (SWALG), adopted a collaborative research approach based on the principals of Participatory Action Research (Whyte et al., 1991). A starting point for collaboration was the collation of a variety of qualitative and quantitative sources of information considered relevant to local water management. The information, from multi-generational river observations by local farmers to daily climate readings, was presented at research meetings and/or by subject matter on a dedicated website. Some of the benefits for utilising this type of approach in the midst of adversarialism can be seen in a recent independent review of SWALG, which concluded that "there appears to be almost universal appeal to the science and to the trustworthiness of the scientists and experts involved" (Ti Kouka, 2008).

A key aspect of sustainable resource management in New Zealand legislation is the achievement of fishable and swimmable waterways. Two introduced fish species singled out are trout and salmon (Resource Management Act Part II, Section 5). Brown trout (Salmo trutta L.) were chosen as a study focus due to their status in the Lake Ellesmere catchment and the mystery of their dramatic spawning population decline. Brown trout were introduced to the Lake Ellesmere catchment in 1868 and by 1935 the lower Selwyn River was considered to contain "the best 3 miles of brown trout fishing in the

Dominion" (NCAS 1935). It was also highly productive as a hatchery and was used to stock other fisheries for many decades (Lamb, 1964).

However, a dramatic decline in the spawning run population up the Selwyn River in the 1970s suggested the fishery was in trouble (NCAS 1883-1989; Glova et al. 1989). Spawning redd surveys in recent decades have provided evidence for further population decline in the Selwyn River and some nearby lowland streams (Taylor and Good 2006). Possible contributing factors were proposed by Hardy (1989) and Taylor (1996) but Millichamp (2007) concluded that there were "still large information gaps that needed to be plugged before the true cause of the observed declines could be identified." Two key information gaps to date have been the effects of highly variable flow permanence and flow volume on the trout population, and the relative contribution of climate and groundwater abstraction to these conditions. Addressing these issues has been hindered by the hydrological complexities of ground and surface water interactions in the catchment, and the lack of suitably long data sets.

The purpose of this paper is therefore to bring together the available evidence for potential contributing factors, with particular focus on brown trout management, predation and competition, food supply, water quantity and habitat, and water quality.

METHODS

Study Area

The Lake Ellesmere catchment (Fig. 1) in New Zealand is a hydrologically complex system with interconnected surface and groundwater components. The catchment can be artificially bounded by the Waimakariri River to the north and Rakaia River to the south, though the underlying groundwater system remains connected further north and south. The western catchment boundary can be taken as the Southern Alps and the eastern boundary is considered to lie to the west of the city of Christchurch and the hills of Banks Peninsula.

The Selwyn River has been of interest as a brown trout fishery due to its spawning potential (particularly in the upper plains) and access to food in the connected river, lake and (sometimes) sea systems. The river rises in the eastern foothills of the Southern Alps, winds through the hills for 35 km, then flows east-southeast across the Central Canterbury Plains for 58 km to coastal Lake Ellesmere. The high permeability of the postglacial fluvial deposits in the upper plains results in high transmission losses from the Selwyn River for approximately 40 km from the foothills-inland plains transition. Downstream of the inland plains-coastal plains boundary, the river gains from the groundwater system until it flows into Lake Ellesmere (Rupp et al., 2007). Lake Ellesmere is subject to a Joint Management Plan (2005) between the Department of Conservation and Te Runanaga o Ngai Tahu. It is mechanically opened to the sea according to criteria set by the Lake Ellesmere Water Conservation Order (1990) and by resource consents under the Resource Management Act (1991).

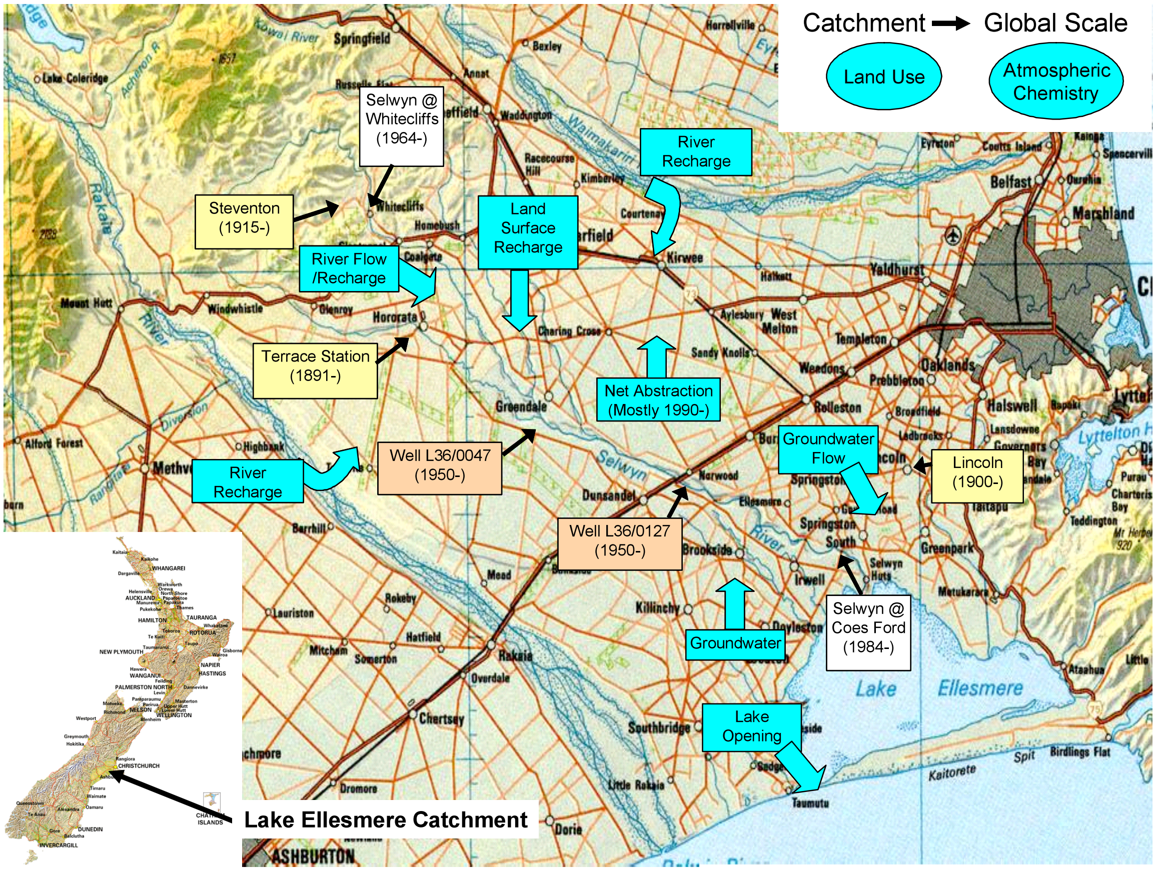

Figure 1. Location of the Lake Ellesmere catchment and hydrological data sources.

Data sources

The main water quantity components of the Lake Ellesmere catchment hydrosystem are highlighted in blue in Figure 1. Potential impacts on hydrosystem quantity and quality from land use and atmospheric chemistry such as greenhouse gas production are also noted to highlight inter-connections with these systems. The catchment hydrosystem is primarily climate-driven through land-surface recharge on the plains and from river recharge. Local climate is connected to other systems such as the El Niño–Southern Oscillation and Interdecadel Pacific Oscillation. River recharge from the Upper Selwyn is believed to be variable (Rupp et al., 2007) while the Rakaia and Waimakariri Rivers are believed to provide a relatively steady but hard-to-measure recharge to groundwater (ECan, 2007a). The key system outputs are groundwater conversion to surface water through springs and seeps, groundwater discharge to Lake Ellesmere, groundwater outflow pressure on sea water and net abstraction (i.e., abstracted volume minus return flow). Long term information of relevance is contained in the rainfall records highlighted in yellow. A key area of missing information is net abstraction from individual water abstractors. Water use telemetry has recently undergone trials (e.g., ECan, 2005) but good water use information from proposed implementation for the catchment as a whole is unlikely to be available until about 2010 or 2011 (Water Governance Forum, 2008).

Recent fora (e.g, ECan, 2007a; SWALG, 2008) and computer modelling (e.g., Rupp et al., 2007) has improved understanding with respect to Lake Ellesmere catchment hydrology, but the lack of river flow records prior to 1964 has been a key hindrance to understanding the contribution of climatic effects to changes in brown trout populations prior to this time. Identification by Rupp et al. (2007) of the combination of Selwyn River flows at the Whitecliffs and Coes Ford recorders that was likely to result in the connection of the upper and lower portions of the Selwyn River led to an investigation of shallow well records in the vicinity of the Selwyn River. Analysis of well records for periods of expected connection resulted in the identification of target well levels for two groundwater well records dating back to 1950. These are highlighted in orange in Figure 1. Further qualitative information relating to climatic and river conditions was extracted from the annual reports of the North Canterbury Acclimatisation Society (NCAS, 1881-1989). This information proved particularly useful in the analysis of the period 1950-64 due to the lack of river flow records (Painter, 2009).

Trout habitat information of relevance includes the status of pools (NCAS, 1881-1989), macrophyte beds (Taylor, 1996), instream/bank cover (Sagar and Glova 1995), the potential for impoundment, and loss of access to suitable spawning gravels (McDowall, 1984). Water quality information include levels of pollution, eutrophication, oxygenation (McDowall, 1984), turbidity (Barrett et al., 1992; James & Graynoth, 2002), and temperature (Elliott, 1994).

With respect to Selwyn brown trout population estimation, a number of methods have been utilised. A key data set is the count through a fish trap during the annual spawning run up the Selwyn River. A total population census was also undertaken in 1941 and 1949 (NCAS, 1881-1989; Fish and Game, 1990-2007). A more recent method is the spawning redd survey, undertaken during the mid 1980s by the North Canterbury Acclimatisation Society and then again in 2005 by Aquatic Ecology (Taylor and Good, 2006).

Relevant trout management information includes artificial re-stocking practices (e.g., Glova, 1996; Hayes, 1988), fish salvage and transfer, and potential levels of recreational harvest (NCAS, 1881-1989; Fish and Game, 1990-2007) and commercial by-catch (Glova and Todd, 1987; Taylor, 1996; Smith, 2008). Predation and competition connections include parasites (Dix, 1967), shag and eel predation (McDowall, 1984), and potential adverse affects on native freshwater fish (Jellyman and Graynoth, 1994). Trout food sources include caddis larva, mayflies, beetles, crayfish, worms, whitebait, other small fish and frogs (McDowall, 1984; Sagar and Glova, 1995).

Data analysis

At a 2007 symposium on Lake Ellesmere, the Canterbury Regional Council CEO proposed the adoption of a panarchic framework for management of Lake Ellesmere as a complex interactive system (Jenkins, 2007). Panarchy is useful for framing discussions regarding how human and ecological processes interact. It is defined as "a nested set of adaptive cycles in a hierarchy of space and time" (Gunderson and Holling, 2002). Key properties of panarchies are:

- Connectedness – the nature and degree of links between processes governing the system;
- Resilience – the ability to adapt to change or the vulnerability to change;
- Potential for resources – any limits on the resources, energy or capability available.

Key characteristics of panarchies are:

- Distinct time and spatial cycles;
- The relationships governing the adaptive cycles;
- The nature of the connections between levels;
- The interactions of processes with different time scales;
- The management decisions needed to match multiple spatial levels and time frames.

Using the brown trout spawning survey statistics for the Selwyn River and lowland stream spawning redd survey statistics as the key system measures, evidence for connectedness with other processes was sought and analysed for vulnerability to changes in these processes. The future potential of the brown trout fishery was then considered with respect to the future potential states of key vulnerabilities. The concept of sustainability within the Lake Ellesmere system can then be considered through an understanding of the sustainability range of the brown trout adaptive cycle in conjunction with other relevant adaptive cycles (Jenkins, 2007; Hughey et al., 2007).

RESULTS

Brown trout population estimation

A variety of data sources have been utilised to understand historical brown trout population changes in the Lake Ellesmere catchment. Key information is presented in Figures 2 and 3. Brown trout stocking of Lake Ellesmere and its catchment started in 1870 and from 1912 the number of brown trout heading up the Selwyn River to high quality spawning grounds were estimated with the aid of a spawning trap (Fig. 2). The first significant increase in spawning statistics occurred in 1930 with a further significant increase in 1941. The spawning trout population remained relatively unchanged until 1969 when a steep decline saw the population fall to the similarly low numbers of the early 1900s.

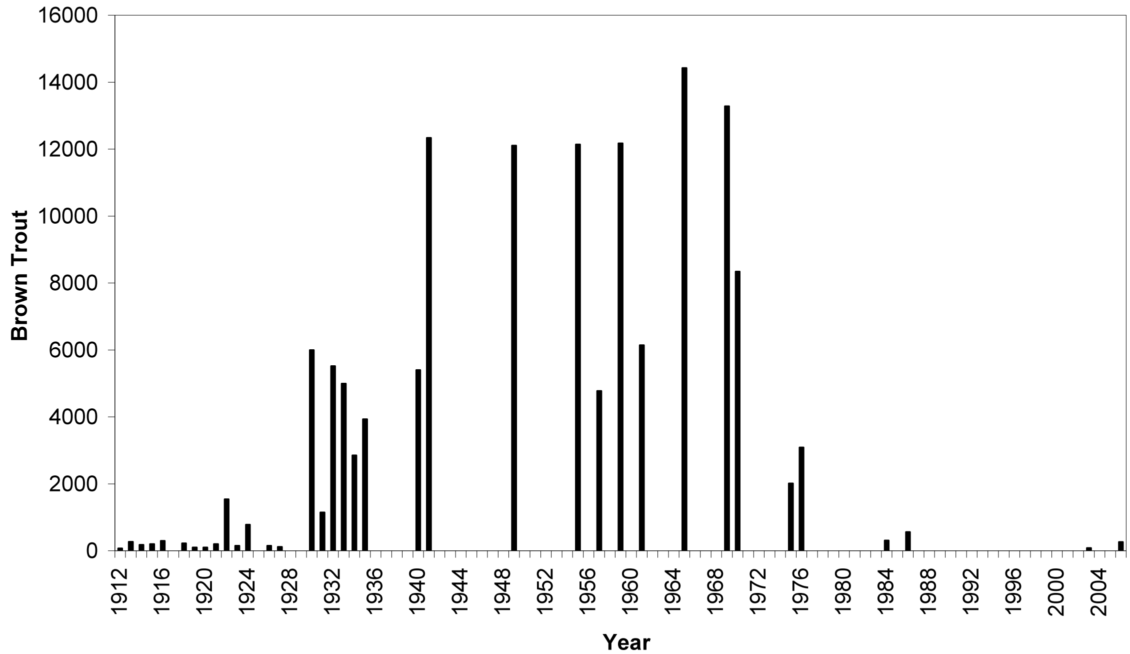

Figure 2. The number of trout through the Selwyn River spawning trap. Data source: North Canterbury Fish and Game Council.

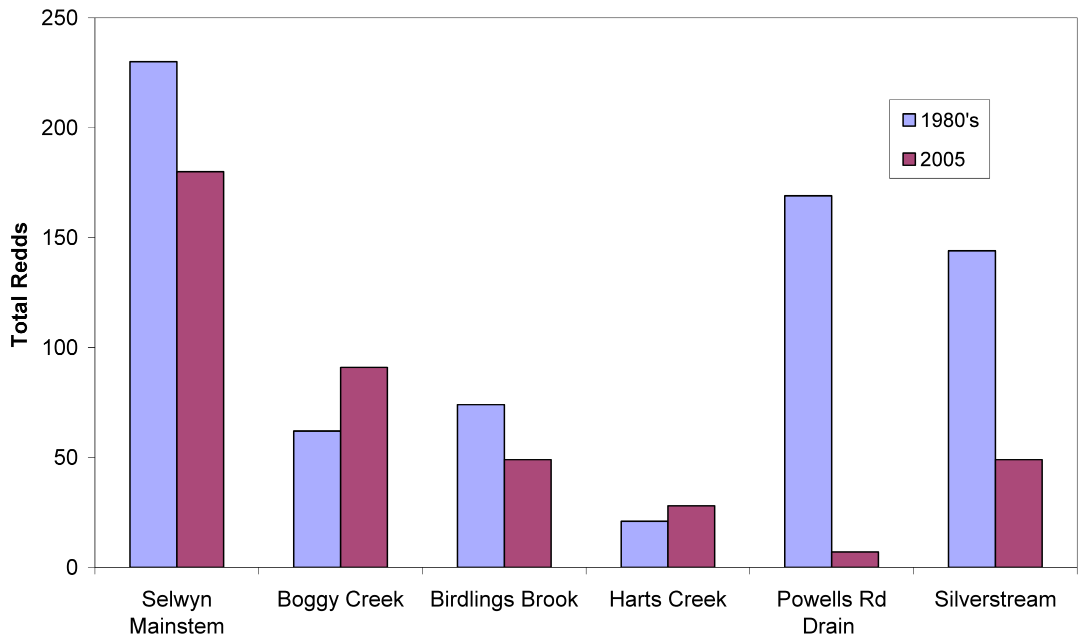

Figure 3. Total Brown Trout Redds found in Spawning Surveys. (Data source: North Canterbury Fish and Game Council & Aquatic Ecology)

The second data source comprised total Lake Ellesmere catchment population surveys in 1941 and 1949, with estimates of 37,000 and 65,000 brown trout respectively. The third data source is the spawning redd surveys (Taylor and Good, 2006), undertaken during the early to mid 1980s and then again in 2005 for the Selwyn River and the lowland streams that feed Lake Ellesmere (Fig. 3). These surveys showed an increase in spawning potential in Boggy Creek and Harts Creek with decreases elsewhere. The conclusions of these studies were that improved riparian management had contributed to the improvements in Boggy Creek and Harts Creek while stock access and siltation of gravel beds in combination with shorter flowing reaches had contributed to the spawning potential decreases elsewhere.

Brown trout management

The release of trout and fry was the primary management focus during the initial decades after trout introduction. From 1900 this process was self regenerating with the stripping of ova and use of nearby hatcheries. Re-stocking practices largely ceased in 1940 and by 1948 it was not considered worthwhile or necessary, particularly using fry (Hobbs, 1948; NCAS, 1948). Low numbers of trout were recaptured after experimental stocking of the Selwyn River in 1996, with predation of the juvenile fish by shags noted for daytime releases (Glova, 1996). High mortality rates and trout disappearance after re-stocking have also been noted in other New Zealand streams (Allen, 1962, Hayes, 1988).

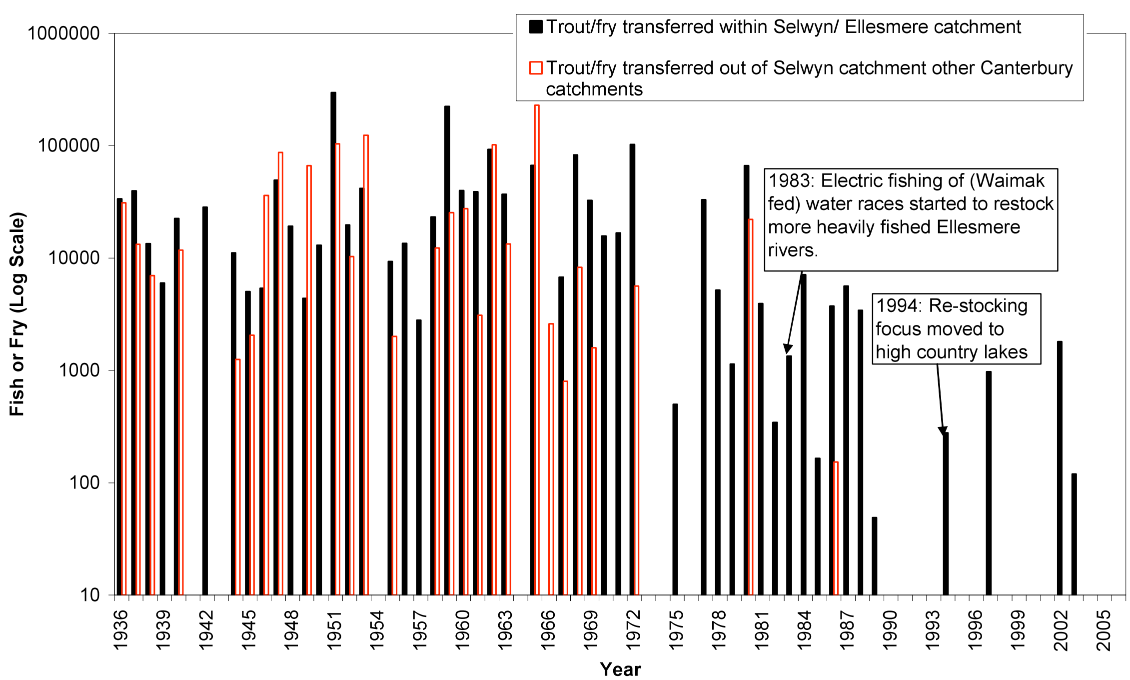

Figure 4. Brown trout and fry transferred within and out of the Lake Ellesmere catchment. Data source: North Canterbury Fish and Game Council.

A second significant management initiative involves salvage and transfer of brown trout. Trout salvage has been required since the extension of the fishery to the upper plains due to the natural drying of the Selwyn River and other nearby waterways. Transfers out of the Lake Ellesmere catchment largely stopped after 1972 but there were still significant internal transfers during the 1970s (Fig. 4). This evidence suggests that many brown trout were still present in the Lake Ellesmere catchment for about a decade after the Selwyn River spawning run decline began in the early 1970s. In 1983, fish transfers included electric fishing of irrigation races fed by the Waimakariri River so that more brown trout could be placed in popular lowland streams. In 1994 the transfer effort shifted to the high country lakes due to increased angler interest there.

The third area of interest for trout management is the recreational fishing pressure and the loss of trout due to commercial fishing by-catch. The potential fishing effort in the Selwyn catchment can be gauged from the number of fishing licences issued by North Canterbury Fish and Game, and angler surveys. A number of angler diary schemes were attempted but suffered from low data collection (Graynoth, 1974). Fishing licence records (NCAS 1883-1989; Fish and Game, 1990-2007) suggest that regional interest reached a peak around 1980 and again in the late 1990s. Hardy (1989) showed that the number of anglers present at the beginning of the 1987 season was still large, but that angling pressure decreased significantly within a few weeks of the season opening. National Angler Surveys by Fish and Game NZ conducted in 1994/95 and 2001/02 show a decline in estimated angler days on the Selwyn mainstem from an average of 6700 to 2130. Fishing licences dropped by over a third in the same period. A decrease in lowland river fishing in most South Island regions was also noted (Unwin and Image, 2003) as fishing attention moved to lakes, reservoirs and canals.

By-catch from commercial fishing in Lake Ellesmere has been suggested as a potential connection affecting trout population (Glova and Todd, 1987; Taylor, 1996) but this issue lacks sufficient evidence for resolution. A long term commercial fisherman on the lake suggests that a significant effect on brown trout populations is unlikely as is no brown trout market for commercial fishermen (they are not legal catch), and evidence of significant by-catch would be very difficult to hide (Smith, 2008).

A vulnerability assessment of trout management connections to population statistics logically suggests that the re-stocking scheme played a part in the rise of the brown trout population and the within catchment transfers helped to reduce losses during dry years. Transfers out of the Lake Ellesmere catchment largely ceased before the dramatic decline in the spawning run during the 1970s and the significant internal transfers in many years from 1977-88 suggest that the overall population may not have declined at the same rate as the Selwyn spawning run in this period. The 1983-89 transfer numbers (Fig. 4) from electric fishing of Waimakariri River-fed water races suggests other habitat areas in the region were still productive for brown trout after the reduction in spawning activity in the Selwyn River. With a variety of habitat quality options in the Lake Ellesmere catchment, further salvage and transfer should be beneficial provided it is economically justifiable. Further investigation of artificial re-stocking potential is also considered justifiable for habitats of sufficient quality. However, the costs of rearing trout before release are considerable, so the timing and management of re-stocking practices requires careful attention (Glova, 1996; Graynoth, 2009).

Significant trout population vulnerability to recreational fishing and commercial by-catch in the Lake Ellesmere catchment is unlikely. Taylor (1996) suggested that the reduction in angling pressure since 1977 should have resulted in increased fish stocks if the population was vulnerable to angling pressure. Improved monitoring of commercial by-catch in Lake Ellesmere has been suggested to clarify the situation, but very low trout numbers found during stock assessments in recent decades (e.g., Glova and Sagar, 2000) suggests this may be a fruitless exercise. Habitat degradation due to the loss of Lake Ellesmere's macrophyte beds in a 1968 storm is more likely to be the principle culprit for this change. This connection will be examined in a subsequent section.

Predation and competition

Lack of information hinders a thorough vulnerability assessment of predation and competition connections, but available information suggests that these connections are unlikely to have a significant effect on Lake Ellesmere catchment brown trout population changes. A 2007 assessment of the Black Shag and Little Shag rated their impact on trout populations in Christchurch/Ellesmere as 'minor' (CCC, 2007) and a decline in Lake Ellesmere water clarity in recent decades (Hughey et al., 2007) would further hinder trout predation potential there. Glova (1996) did however find evidence for shag predation of juvenile trout released during the day in a lowland stream.

The longfin eel (whose diet includes juvenile trout) require long flowing river reaches, as do river-run trout, though the growing cycle of longfin eels is significantly longer. The longfin eel population has declined in recent decades (Hughey et al., 2007), and Selwyn River connection evidence presented later suggests a mutual connection between lack of access to Selwyn River headwaters and the decline of both populations. Conversely, the shortfin eel (whose diet is similar to trout) shows a potential population increase since 1974 (Hughey et al., 2007). However, Jellyman (2008) stated that there is unlikely to be a strong causal link between this rise in shortfin eel numbers and the decline in Selwyn spawning survey trout numbers during the same period.

With respect to parasites, Dix (1967) found that in the decade prior to the spawning decline it appears parasites were unlikely to have been a threat to the Selwyn trout population. With respect to native freshwater fish in headwater trout fisheries in New Zealand, Jellyman and Grynoth (1994, p.8) state "trout have been linked with the reduction in both the range and population size of a number of native species". Some evidence exists for the decline and disappearance of the giant kokopu Lake Ellesmere catchment since to the introduction of the brown trout (Haast, 1872; Stokell, 1949; Taylor, 1996). Giant kokopu and brown trout occupy similar ecological niches, but Main (1988) considers that brown trout are more aggressive.

Food supply

Lack of information also hinders a vulnerability assessment of food supply for Lake Ellesmere catchment brown trout, but available information suggests that these connections are unlikely to have a significant effect on the dramatic population changes. The NCAS annual reports note research and discussion on trout food sources and food source habitat (e.g., encouraging the planting of Willows to support insect populations) back to 1918 with no significant concerns (NCAS, 1883-1989). A comparison of survey information taken at Coes Ford on the Selwyn River in the mid 1980s and again recently shows that there were species present in the first sample that were not present at all in the recent sample. The changes were considered to be primarily associated with temperature and flow, and not of great use in understanding the Selwyn River brown trout spawning population decline (SWALG, 2008). The increase in shortfin eel numbers over recent decades suggests food that trout also prefer is not necessarily in short supply in Lake Ellesmere, though competition between eels and trout for this food may be an issue. More regular monitoring of food sources, particularly for juvenile trout may be beneficial for comparison with studies on other New Zealand streams (e.g., Sagar and Glova, 1995) and to determine conditions that may be conducive to re-stocking initiatives.

Water quantity and habitat

A vulnerability assessment of water quantity and habitat connections produced some very promising evidence for high vulnerability to loss of macrophyte beds in Lake Ellesmere, impoundment through river drying patterns, prolonged reduction in access to suitable spawning gravels, and potential vulnerability to prolonged loss of pools in the Selwyn River. Painter (2009) utilised a combination of qualitative local knowledge, computer modelling results, well records, river flow records and rainfall records to identify Selwyn River connection potential prior to the commencement of river flow recording.

Figure 5 shows many years of good Selwyn River connection between 1950 and 1965 when the trout spawning population was at its peak. In the late 1960s, river connections dropped off significantly, with no connection expected in 1967. In 1968, a severe storm ripped up the *Ruppia megacarpa* and *Potamogeton pectinatus* macrophyte beds around the edges of Lake Ellesmere and deposited them on the north shore of the lake. A long period of low rainfall from 1969 to 1971 produced low likelihood of any river connection and low lake levels. This will have hindered any chance of natural regeneration of the macrophytes beds, as had occurred in previous decades (NCAS, 1883-1989). The macrophytes beds have still not re-grown, despite an attempted re-introduction in 1980, most probably due to a shifting lake bed in a windy and shallow lake (NCAS, 1981).

The macrophyte beds were considered to help maintain water clarity inshore by reducing wind action and provided important habitat for invertebrates and fish. This is where most brown trout were caught prior to 1969 (Hardy 1989). As trout are primarily visual feeders, water clarity has been shown to significantly affect their ability to detect prey and is therefore likely to affect their choice of feeding habitat (Barrett et al., 1992). The loss of this feeding habitat is expected to have been particularly devastating for fry and juvenile trout, for whom daytime visual feeding on aquatic insects associated with the macrophytes beds was considered a key aspect of their early life cycle. This may help explain why there seems to have been a drop in recent decades of fry-to-adult survival rates (Graynoth, 2009).

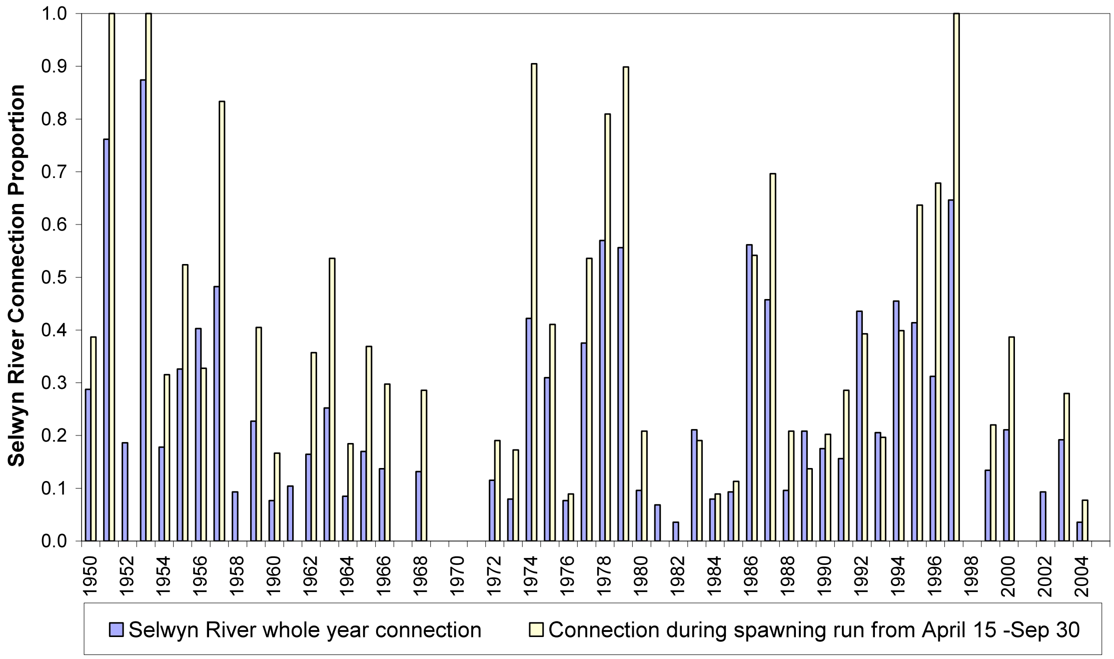

Figure 5. Estimation of the proportion of time the Selwyn River is fully connected, both for the winter spawning run months and the full year (from Painter, 2009).

Two water management decisions implemented during the late 1940s may have increased trout population vulnerability to this loss of connection and habitat. The first was a reduction in lake level by lowering the height at which the lake was artificially opened to the sea. This created more land for farming around the lake edge but probably reduced trout habitat around the lake margins and increased macrophyte vulnerability to wind effects. The potential connection between increased lake openings (but of shorter duration) and trout population changes is not known at this stage. Access to the ocean (particularly over the summer) is considered important for trout recovery from the rigors of spawning as well as transfers with other catchments (Millichamp, 2007), but trout need to be able to sense the opening and make use of it before the opportunity disappears. The second potentially negative management decision was to straighten Selwyn River channels under requirements of the Soil Conservation and Rivers Control Act 1947. A reduction in fish stocks was observed and the reduction of fish hole presence due to channel straightening was considered particularly detrimental for feeding habitat and survival during periods of low flow (NCAS, 1957).

The significant and multi-year loss of river connection is considered to be a key vulnerability connection to the dramatic Selwyn River spawning population decline in the 1970s, despite the installation of a special spawning trap in 1966 (with fish released above the trap when there was suitable length of spawning water available). The loss of the Lake Ellesmere macrophytes beds are considered a key vulnerability connection to dispersal of trout away from the lake, contributing to continuing low Selwyn River spawning populations when periods of good river connection returned from 1977-79, 1986-87 and 1995-97 (Fig. 5). The trout salvage records (Fig. 4) suggest that a significant number of trout remained in the Lake Ellesmere catchment, at least until a further multi-year loss of spawning connection in 1981-82 (Fig. 5).

From 1983, an increasing number of trout were brought into the catchment by electric fishing of waterways not directly connected with the lake. Lowland stream spawning redd surveys in the mid 1980s (Fig. 3) suggested that suitable spawning habitat existed, but survival rates from these redds are not known. Between the mid 1980s and 2005 spawning surveys, two changes in water availability are likely to be connected to the continued low Selwyn River spawning population statistics and the decline in lowland stream spawning redd statistics. The first change was a sub-regional climate shift that has resulted in increasing aridity (the ratio of rainfall to potential evapotranspiration) in the lower catchment but not to the same extent in the upper catchment. The second change was significant increases in water abstraction for irrigation since the early 1990s.

The middle graph in Figure 6 compares rainfall and potential evapotranspiration (PET) for a lower catchment location, with annual totals graphed against their long term (90 year) average. From the mid 1930s to the late 1960s when the Selwyn River spawning population was high, rainfall (in blue) was above average and PET (in red) was below average for most years (top graph in Figure 6). Rainfall dropped significantly during the spawning population decline of the early 1970s while PET continued to increase. After a brief wet phase during the mid 1970s, annual rainfall shows a decreasing trend while PET shows an increasing trend.

Moving out to a wider climatic scale, Figure 6 shows that the rainfall record and trout population changes relate reasonably well to the positive and negative phases of the Interdecadel Pacific Oscillation (IPO). In particular, the height of the Selwyn River spawning run occurred during a negative IPO phase with the dramatic spawning run decline occurring during the transition from a negative to a positive phase. The IPO is a multi-decadal sea surface temperature pattern, which has also been correlated with rainfall variation in New Zealand (Zheng and Thompson, 2007). The IPO is considered to be correlated with the Pacific Decadel Oscillation (e.g., Salinger et al., 2001), which was named by researchers studying salmon production patterns similar to the Selwyn brown trout fishery but in the North Pacific (Mantua et al., 1996).

The Southern Oscillation Index (Fig. 6) also shows some connection to trout population statistics through its effect on local climate. In particular, the two periods of increased spawning run statistics correspond reasonably well with a low incidence of extended El Niño conditions compared with recent decades. In Canterbury, El Niño conditions correspond with increased westerly systems which usually produce rainfall at the top of the catchment but warm, dry and windy conditions in the lower catchment. An analysis of the potential evapotranspiration record at the Lincoln site found that the increasing trend is primarily due to increasing wind and increasing minimum temperature (SWALG, 2008). In addition to evaporation effects, increases in wind around Lake Ellesmere may also contribute to increased turbidity when the lake level is sufficiently low.

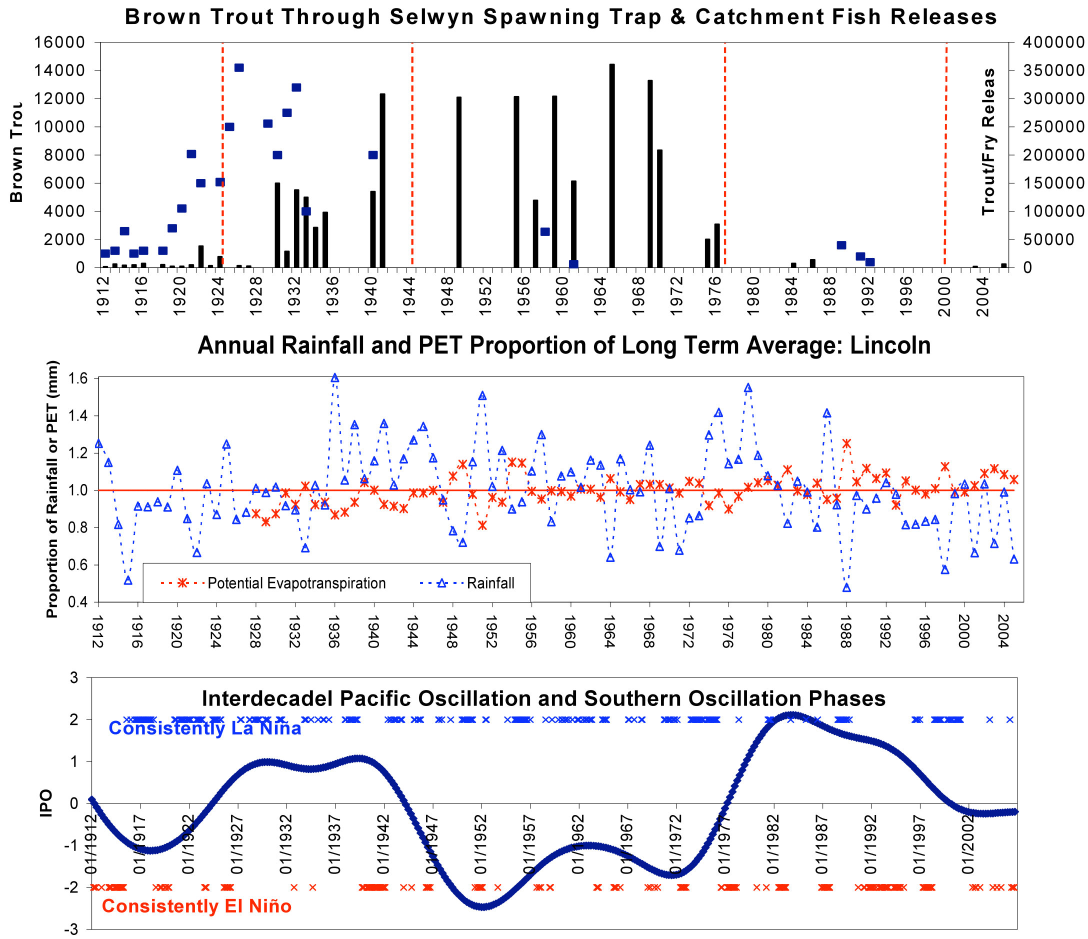

Figure 6. Comparison of Selwyn River spawning statistics, catchment fish releases, lower catchment rainfall and potential evapotranspiration, the Interdecadel Pacific Oscillation and Southern Oscillation phases.

The principal human effect on the Lake Ellesmere hydrosystem is the abstraction of water, primarily for irrigation. Significant increases have occurred since 1990, first in the coastal plains and then further inland. The low level of abstraction in the 1970s and 80s suggests that abstraction was not connected to the dramatic brown trout population decline during that time period, but McKerchar and Schmidt (2007) show that more recent abstraction increases could be contributing to a decline in Selwyn River minimum annual wetted length of approximately 320m per year over the last 20 years. The context for this trend is an average wetted length between 6 and 40km short of the full river length. Abstraction management alone is unlikely to control future Selwyn River connection but abstraction management of shallow wells with good hydraulic connection to lowland stream may benefit spawning potential and habitat quality.

Water quality

Surface and ground water quality in the Lake Ellesmere catchment is the final area for vulnerability assessment. Historical information is covered extensively in Environment Canterbury reports[1] and further information is presented on the Selwyn Catchment Information Centre website[2]. Water quality in the catchment has gradually declined since the clearing of the catchment in the mid 1800s for farming but there is no evidence that critical thresholds were reached in the early 1970s with respect to the trout spawning statistics. Trout spawning potential in the lowland stream and juvenile trout survival do however show potential vulnerability to recent conditions.

For Lake Ellesmere, total nutrient conditions are considered to be largely caused by sediment re-suspension, with inorganic nitrogen and dissolved reactive phosphorus considered the immediately available nutrients. The lake is nutrient rich and phytoplankton growth is generally considered limited by light availability rather than nutrient availability. However, some studies have indicated that nitrogen may be a limiting nutrient at times. Lowland streams currently exhibit a range of nitrate concentrations. Overall they tend to have concentrations above the guidelines for the prevention of nuisance algae but generally below the aquatic toxicity thresholds.

A key riparian management issue in the Lake Ellesmere catchment is the lack of waterway fencing to exclude animals from introducing sediment through bankside disturbance and direct pollution of the water. While a strong connection with the trout spawning population decline is highly unlikely, connection with spawning redd potential in lowland streams is very likely (Taylor and Good, 2006) and lakeside habitat decline is also reported (Environment Court, 2005).

SUSTAINABILITY POTENTIAL FOR FAMILIES, FISH AND FARMING

Climate predictions out to 2030 for Canterbury (ECan 2007b) suggest continuing aridity with increasing mean temperature (except perhaps in summer) and reducing rainfall on the plains (particularly in autumn and winter), although the Interdecadel Pacific Oscillation signals the potential for increasing rainfall in the headwaters of the alpine rivers after 2018. As winter rainfall is the largest contributor to groundwater recharge, these predictions are likely to induce lower overall recharge and lower groundwater levels.

The frequency of droughts, variation in temperature and intensity of extreme rainfall events are also expected to increase by 2030 on the Canterbury Plains. This combination of climatic effects is not expected to be positive for the Lake Ellesmere catchment brown trout population, both in terms of water quantity and quality. Increasing evapotranspiration is expected to reduce water quality in rivers and affect the contamination assimilation capacity of streams. Heavy precipitation events (particularly

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[1] see http://www.ecan.govt.nz/Plans+and+Reports/Water

[2] see http://www.selwyninfo.org/selwyn-historic-information-project.php

after a period of low recharge) are expected to have an adverse effect on water quality by increasing nutrient run-off, sedimentation, river erosion and turbidity.

Despite a discouraging climatic outlook, initiatives at a number of levels are creating the potential for more integrated and collaborative resource management within the confines of current legislation. The demise of a trout fishery of international standing was a stand-out feature in state-of-the-lake reporting during the 2007 Waihora/Ellesmere Living Lake Symposium (Millichamp, 2007; Hughey et al., 2007). The research presented in this paper and in Painter (2009) is included in the Selwyn Water Allocation Liaison Group collaborative as well as feeding into the 2009 symposium through a panarchical Lake Ellesmere system framework (Jenkins, 2007) and community consultation regarding future management scenarios for the lake and its catchment[3]. One of the drivers for this initiative is the consent for the lake opening regime, which is up for renewal in 2011. Direction is sought on future lake levels, catchment land use, waterway fencing, and water quality and quantity imperatives. The Lake Ellesmere catchment has also been a focus catchment for research to enhance the potential of Integrated Catchment Management (ICM) planning in New Zealand (Painter et al., 2008).

At the sub-catchment level, the Canterbury Regional Council have been supporting a number of Living Streams programmes that are designed to improve the health of waterways in partnership with local people[4]. The Waihora Ellesmere Trust are also leading a variety of relevant initiatives such as riparian planting[5]. In 2007, the Canterbury Regional Council launched the Restorative Programme for Lowland Streams to ensure environmental flows that will preserve the intrinsic values of lowland aquatic ecosystems. This was followed in 2008 by the formation of sub-catchment and catchment level cluster groups of water consent holders to improve water user/regional council collaboration on issues such as water meter implementation, adaptive management and audited self-management[6]. At the regional level the Canterbury Mayoral Forum is currently co-ordinating community engagement for Stage 4 of the Canterbury Strategic Water Study[7]. This stage focuses on strategic resource management direction and will be followed by a focus on integration of land use and water management in Stage 5.

Such a multi-pronged approach to a complex socio-ecological system problem provides hope for the implementation of integrated solutions that will stand the test of time. In colloquial New Zealand English, that would be a ‘wicked’ (excellent) result!

SUMMARY

In the Lake Ellesmere catchment of Canterbury, New Zealand an integrated approach is making positive progress towards a sustainable solution for water and land management that addresses social, economic, environmental and cultural value sets. This paper

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[3] See http://www.wet.org.nz/
[4] See http://www.crc.govt.nz/Our+Environment/Water/LivingStreams/
[5] See http://www.wet.org.nz/
[6] See http://www.ecan.govt.nz/Our+Environment/Water/Rivers/LowlandStreams.htm
[7] See http://www.canterburywater.org.nz

focuses on research to collate and organise brown trout information in a panarchical framework so that the future potential of the brown trout fishery can be considered with respect to the future potential states of other adaptive cycles it is vulnerable to. Using the brown trout spawning survey statistics for the Selwyn River and lowland stream spawning redd survey statistics as the key system measures, evidence for connectedness with other processes was identified and a vulnerability assessment completed.

The key trout vulnerabilities are considered to be:

- Significant climatic effects on flow volume and presence, recently decorated by cumulative abstraction effects.
- Degradation of river and lake habitat through human and natural processes.
- Discontinuation of re-stocking to counter losses in dry periods.
- Negative effects of sedimentation and poor water quality.

Recommendations to maximise the future potential of the trout fishery include:

- Prioritise further riparian fencing and enhancement, and efforts to address non-point-source pollution and sedimentation.
- Research Ruppia weed bed re-establishment in combination with lake opening regime.
- Research future climatic and dynamic water allocation implications on spawning reach, Selwyn River connection and the optimal implementation of artificial re-stocking programmes.

The framing of all relevant adaptive cycles in the Lake Ellesmere catchment in a similar manner enables an integrated sustainability analysis to be undertaken with consideration of all value sets. Management interventions can then be planned with confidence and adaptive cycles updated as new information is identified.

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