The proceedings of

The Way Forward on Weirs.

Presented on

18th - 19th August 2000

at the Centenary Lecture Theatre,

Royal North Shore Hospital, St Leonards, NSW

Published by

INLAND RIVERS NETWORK

June 2001

Acknowledgements

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The Sponsors: World Wide Fund for Nature
Department of Land and Water Conservation
NSW Fisheries
Murray-Darling Basin Commission
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The Steering Committee would like to thank all chairs, speakers and presenters of posters for their contributions of time and knowledge.

Thanks to the following people who volunteered their time to make things run smoothly: Craig Woodfield, Jen Guice, Katryna Dawson, Imogen Schoots, Lawrence Backer, Amy Hankinson, Josie Walker, Norm Lenehan

Printed on Xerox Document Centre 551 at the Nature Conservation Council of NSW, using Xerox Green Wrap environmentally friendly paper supplied by Fuji Xerox.
Cover printed and bound by Premium Recycled Supplies, Matraville, NSW.

Published in Sydney, 2001, by the Inland Rivers Network.

National Library of Australia

Cataloguing-in-publication data

The Way Forward on Weirs Conference Proceedings

ISBN 0 949257 32 X

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Foreword — Managing Weirs, Managing Rivers

River management and water resources policy have changed markedly in the past decade. The Council of Australian Government's Water Reform Framework in 1994 led to reform of water policy and legislation across the States, whilst the Murray-Darling Basin Ministerial Council's cap on diversions at 1993/94 levels of development heralded a more responsible era in managing water in the Basin.

Yet weirs have largely been overlooked in the reforms. There are approximately 4,000 weirs in the Murray-Darling Basin, and as many as 20,000 across the south east of the continent. Weirs come in a variety of shapes and sizes. In dry areas weirs are used to provide secure water supplies for stock and domestic uses and for irrigation. They can be a couple of feet high on a small upland creek or higher than a house on a large lowland river, and range from simple earthen banks to large concrete and steel gated structures. In coastal areas floodgates have been built to keep saline water from grazing and cropping areas and provide flood mitigation.

Much smaller than their big cousins – dams – weirs can nevertheless have significant impacts on the ecology and geomorphology of rivers, floodplains and estuaries. The effects of weirs are numerous, and include amongst others changes to flow patterns, drowning of riparian and floodplain areas, reduced flow variability, salinisation of adjacent floodplains, riverbank erosion and sediment capture, obstruction of passage by fish and other aquatic biota, and benefiting carp and blue-green algae.

Importantly, the impacts of weirs have been listed as one of the factors which have led to the demise of native fish in the southern Murray-Darling Basin. Consequently the fish communities of the River Murray and its tributaries have been or are in the process of being listed as threatened in Victoria and New South Wales.

Many rivers have been transformed into a series of stepped lakes, with weirs constructed at the upstream end of a weir pool. Hence, whole river systems, such as the lower Murray River or the upper Nepean River near Sydney, have lost much of their natural flow patterns.

The Way Forward on Weirs was the first conference to address the ecological, engineering, economic and social aspects of reducing the environmental impacts of weirs in Australia. Hosted by the Inland Rivers Network on 18 and 19 August 2000 in Sydney, it was the first large-scale gathering of stakeholders to address the issue. The papers presented here arose from the Conference and address four key themes:

What are the effects of weirs on the environment?

How can weir operations be altered to reduce environmental impacts?

How can weirs be removed or modified? and,

Thinking laterally about water supply options and management.

Together the 28 papers provide a balanced and insightful view into how the environmental impacts of weirs can be reduced whilst ensuring that the legitimate water supply needs of landholders, domestic users and others are met. Papers are provided by the broad range of stakeholders with interests in weirs, such as ecologists, engineers, irrigators, academics, fish biologists, indigenous people, fishers, weir operators, floodplain managers and others.

So what is the way forward on weirs? Many are obsolete and should be removed as a matter of priority. Each State needs to audit its weirs and assess their need for removal, the addition of a fishway, or alterations to their structure or operation. In New South Wales alone the State Weir Review Committee has found almost 88 licensed weirs which are unnecessary and can be removed, whilst another 135 require the construction of a fishway. Thousands of unlicensed weirs remain to be assessed. The Murray-

Darling Basin Commission's *Native Fish Management Strategy* has prioritised the facilitation of fish passage throughout the Basin's rivers, which will necessitate all of the weir management options listed above to be addressed in a coordinated fashion.

On behalf of the Conference Organising Committee I commend this book to you in your endeavour to reduce the environmental impacts of weirs.

Dr Stuart Blanch
Convenor, *The Way Forward on Weirs* Conference
and Healthy Rivers Campaign Coordinator,
Australian Conservation Foundation
(formerly Coordinator, Inland Rivers Network).

The Inland Rivers Network: A Decade of Campaigning for Inland Rivers

The Inland Rivers Network seeks to improve the management of rivers in the Murray-Darling Basin through the protection of ecosystem processes and conservation of biological diversity. IRN is a network of organisations and individuals which shares information and concerns about the degradation of our wonderful rivers, floodplains and wetlands. Established in 1991, IRN is committed to working with rural communities, landholders, concerned individuals and governments to ensure that water resources policies and river and catchment management practices conserve and rehabilitate inland river systems.

IRN campaigns across a wide range of issues, including the delivery of environmental flows, capping irrigation extractions, floodplain management, weirs, cold water pollution, irrigation management, pesticides, salinity and more. The Network comprises mainly volunteers and works with any group or individual keen to improve the management of inland rivers.

For more information or to place an order for this book, please contact the

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A River Transformed: The Effects of Weirs on the River Murray

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Abstract

The 830km River Murray below the Darling junction is impounded by 10 weirs built originally (1922-37) to aid navigation but now operated mainly as pools for irrigation. The weirs are 3m high, with pools 29-88km long. Flow regulation generally has reduced the natural winter-spring peak and decreased the variability of mid-range flows, and discharge at the Murray mouth now is about 21% of the natural average. The weirs maintain steady pools except during over-bank flows. Immediately below each weir, however, there are daily rises and falls in the river level, diminishing downstream toward the next weir, where the sequence is reset. The fluctuations affect littoral plants and animals. The weirs may promote development of algal blooms by impeding flow. Their hydraulic effects also contribute significant amounts of salt to the river. Channel changes in response to weir construction are continuing, and the river is progressively developing a stepped gradient through deposition upstream of each weir and erosion downstream.

Regulation has increased the numbers of permanent wetlands but decreased those subject to occasional drying, and those affected may no longer produce the characteristic pulse of organisms associated with re-flooding. The vigour and regenerative capacity of the floodplain vegetation also are flood-related. In the river channel, water level changes may have promoted the growth of algae at the expense of bacteria, and reduced the nutritional value of biofilms for grazing animals, notably snails. Although about 18 snail species were present before weir construction only two remain in significant numbers. The banks of the unregulated river typically were bare, but the pool margins have been invaded by emergent plants (e.g. Phragmites, Typha*) and introduced willows (*Salix *spp.), and the distributions of crayfish, freshwater mussels and other animals also have changed. One native fish that probably has benefited from impoundment is the bony herring* Nematalosa erebi *which, like the introduced carp* Cyprinus carpio, *thrives in the pools.*

There is limited scope for modifications of weir structures and operations, particularly if these would increase saline inflows and prejudice agricultural and urban development on the floodplain. Options for weir manipulations to improve instream habitat are now being examined by the Murray-Darling Basin Commission and the South Australia Department of Water Resources.

Introduction

The River Murray below the Darling junction is ecologically different from its parent rivers, and is a discrete “environmental unit” for research and management (Walker 1992, Crabb 1997). The regional climate is semi-arid, with annual rainfall 200-500mm and evaporation 1,500-2,400mm, and the soils generally are derived from calcareous marine sediments. Irrigated agriculture and grazing are the main forms of land use, and most towns have populations <10,000. Much of the area lies within South Australia so that it is also, for the most part, a separate political unit.

These regional features are reflected in the physical nature of the river. The 830km ‘Lower Murray’ has no significant tributaries and its hydrologic behaviour normally is governed by flows from the middle and upper Murray (inflows from the Darling are highly variable, but usually low). Immediately below the Darling junction, the geomorphic character of the Murray is like that of the middle reaches, including a broad 5-20km floodplain with many wetlands and woodlands (Gill 1973) and regional landforms that are shaped by the prevailing wind. Below Overland Corner, however, the river enters a 30m limestone gorge where marine, tectonic and fluvial factors have dominated (Twidale *et al.* 1978, Walker & Thoms 1993). The floodplain is constrained to 2-3km and the typical riparian wetlands are "channel margin swales" rather than cut-off meanders (oxbows) (Pressey 1986).

These differences are compounded by the effects of 10 regulating weirs located between the Murray-Darling confluence and Blanchetown, 274km from the sea (Fig. 1). Thus, the 'river' is a series of cascading pools and, as the lowermost reaches are controlled by barrages along the seaward margins of Lake Alexandrina, virtually no part of it is unaffected by impoundments. Just as the weirs have changed the physical environment, there have been corresponding changes in the biological nature of the river and its floodplain communities. This paper outlines these physical and biological changes, and considers ways to offset them in the interests of restoring and maintaining communities of native flora and fauna.

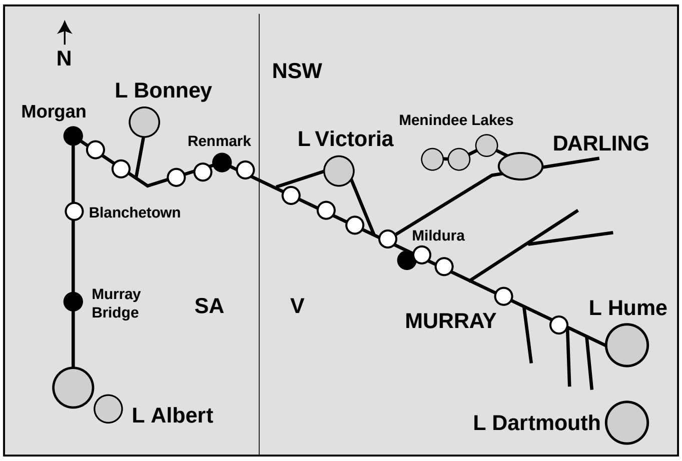

Figure 1: *Schematic map of the Lower River Murray showing the 10 weirs below the Murray-Darling junction (NSW: New South Wales; SA: South Australia; V: Victoria).*

Hydrology

Flows to the Lower Murray are governed by climate, and by control through storages and diversions. The natural regime is inherently variable at seasonal, annual and inter-annual scales, reflecting the Basin's small contributing sector (<5% of the total area, 1,061, 469km^2) and its vulnerability to climatic changes. The variability is due partly to the El Niño Southern Oscillation (ENSO) and other atmospheric circulation phenomena, and to evaporation and other processes implicated in the conversion of rainfall to runoff (McMahon *et al.* 1992, Simpson *et al.* 1993, Greenwood 2000). Drought- or flood-dominated regimes may persist for several years, demonstrating hydrological 'persistence' (Greenwood 2000, Puckridge *et al.* 2000).

Table 1 indicates long-term patterns of annual discharge at stations above and below the Murray-Darling junction. The variability of data for the Darling is striking, reflecting an arid catchment and a headwaters sector subject to erratic summer (monsoonal) rainfall. The data give an inflated impression of the Darling's contribution to the Lower Murray, however, as the longer term average inflow is only about 12% of the total. For comparison, the annual discharge of the Lower Murray in 1894-1993 ranged from 1,626 to 54,168GL, with mean 10, 090GL and median 8,489GL (Walker *et al.* 1995).

The behaviour of the river system changed markedly with the regulation of mainstem flows, beginning in 1922 and intensifying sharply after 1950 (Close 1990; Maheshwari *et al.* 1993, 1995). The effects of upstream reservoirs, mainly on tributaries to the Murray, are

River	Station	Record	Minimum	Mean	Maximum
Murray (a)	Euston	1941-89	235	8,593	110,826
Darling (a)	Menindee	1941-89	0	2,886	58,441
Murray (b)	Blanchetown	1950-80	634	10,084	49,531

Table 1: *Long-term records of annual discharge (GL) at gauging stations (a) above and (b) below the Murray-Darling confluence (Walker & Thoms 1993).*

supplemented by the weirs (1922-1937) and barrages (1940), and storages at Lake Victoria on the Lower Murray (680GL, 1928) and Menindee Lakes on the Darling (1,682GL, 1968). The Darling is much less intensively regulated than the Murray, although diversions have proliferated with the expansion of cotton irrigation in recent years. In dry periods, as in the ENSO-dominated regime of the late 1980s, Darling water may be stored in Lake Victoria for release to the Murray during the irrigation season (Mackay *et al.* 1988, Walker *et al.* 1992). Regardless of climate, the operating rules for the system guarantee a minimum annual 'entitlement flow' of 1,850GL to South Australia, although average flows are well above this level. In 1995, basin-wide diversions were "capped" by the Murray-Darling Basin Commission (MDBC), nominally at levels that prevailed in 1993-1994.

The hydrologic effects of regulation are broadly as follows (Close 1990, Thomson 1992, Walker & Thoms 1993, Maheshwari *et al.* 1995, MDBMC 1995, Walker *et al.* 1995):

- average annual and monthly flows are substantially lower than they were under natural conditions. Annual diversions from the Murray-Darling Basin (excluding Queensland) increased from 3,000 to 11,000GL in 1930-1991. In 1994, when the 'Cap' was determined, the flow at the Murray mouth was a mere 21% of the natural annual median. The median annual natural flow (11,883GL) now is exceeded only 8% of the time, compared to 50% of the time under natural conditions;

- regulation has reduced the variability of mid-range flows, leaving a regime dominated by low flows and occasional high flows. Low flows (<5,000GL) occur 66% of the time under regulation, but would have occurred 7% of the time under natural conditions. Ninety-five percent of regulated annual flows are 0-15,000GL, compared to 2,500-20,000GL for natural flows. Big floods (recurrence 20+ years) are little affected; and

- the seasonal extremes of monthly flows have changed in areas immediately downstream of the bigger reservoirs, but are little affected in the Lower Murray where, despite intensive irrigation, the pattern still tends to a natural summer-autumn minimum and winter-spring maximum. The magnitude of the seasonal peak, however, has decreased markedly, limiting the frequency and extent of floodplain inundation.

Variability is the hallmark of dryland rivers like the Murray, evident in flow records, the geomorphic configuration of the channel and the ecological and evolutionary character of the native flora and fauna (Walker *et al.* 1995). Regulation, however, has redistributed the inherent variability across different temporal and spatial scales. At annual and seasonal scales flows are relatively stable, but there are localised daily water level changes associated with weir operations (see below) so that, depending on the observer's view-point, regulation has both increased and decreased variability. The significance of spatial scale is seen by contrasting gross hydrologic changes with smaller-scale hydraulic changes. Apart from fluctuations in 'stage' (water level), these local effects are reflected in patterns of sediment erosion and deposition, and in the presence of snags and water plants (cf. Blanch *et al.* 1999).

Geomorphology

The Murray and Darling rivers are drainage remnants of a basin that originated by subsidence in the Tertiary. The sea occupied the basin at various times until 2 million years ago, when the river junction was inundated by a large freshwater lake (Bungunnia) that left extensive clay deposits (Gill 1973, Stephenson 1986, Walker 1986). When the impounding barrier was breached, less than a million years ago, the lake drained and the river began to incise a gorge through marine limestone, flowing to the sea at the edge of the continental shelf (Twidale *et al.* 1978). Since then the landscape has been exposed to weathering as the climate has oscillated between wet and dry conditions.

The present channel of the Lower Murray has four geomorphic sections (Pressey 1986, Walker & Thoms 1993):

1. **Valley:** From the Murray-Darling confluence to Overland Corner, including Locks 3-10, the river meanders over a broad floodplain with terraces formed by prior water and sediment regimes. There are many riparian wetlands including anabranches, billabongs (oxbows), deflation basins and Lake Victoria.

2. **Gorge:** From Overland Corner to Mannum, including Locks 1-2, the Murray flows within

a relatively narrow limestone gorge. The channel includes long, straight reaches aligned by geological faults, but retains some inclination to meander. The diversity of wetlands is much less than in the Valley Section.

3. **Swamplands:** From Mannum to Wellington the river flows through a section flanked by swamplands that have been reclaimed for crops and pasture. Earthen levees, stabilised by planted willows (*Salix babylonica*, *S. fragilis*), protect the reclaimed areas. There are no weirs, but the region is affected by river-mouth barrages (e.g. Webster *et al.* 1997) that exclude sea water and maintain a 450-600mm increase in the river level below Lock 1.

4. **Lakes:** At Wellington the Murray enters Lake Alexandrina (2,015GL), where the water is contained by the barrages before entering the sea near Goolwa.

The major division is that between the Valley and Gorge Sections. In the Valley the bank sediments are easily-eroded sandy clays, whereas those in the Gorge are heavy, cohesive clays with less sand. Otherwise, the lower river is characterised by low bed slope (mean 5.5cm.km^{-1}), sinuosity and power. Each is implicated in the processes of channel adjustment invoked by weir construction (Thoms & Walker 1989, 1992a).

Remarkably, the processes of channel change in the Murray are still underway after nearly 80 years, prolonged by the river's low energy, cohesive bank material and limited sediment supply (Thoms & Walker 1992a,b, 1993). The processes involve changes in the shape and slope of the channel. Their extent varies with the sequential position of the weir and the time of its construction, and with local variations in the width of the floodplain and the composition of the bank material. They have involved re-distributions of sediment rather than changes in the overall sediment budget. In effect, the channel is developing a stepped gradient, with deposition above each weir and erosion downstream. Remnant internal benches of the un-regulated river, formed by prolonged low flows and rare high-discharge events, have been eroded in the upper pools and buried to depths of >2m in the lower pools. In the middle reaches they are intact and provide gently shelving banks.

The extent of channel adjustments differs in the Valley and Gorge Sections, reflecting constraints imposed by the limestone matrix (Thoms & Walker 1992a). In Pool 3, in the Valley Section, erosion has increased the channel width-depth ratio by 32% but in Pool 2, in the Gorge Section, deposition has decreased the ratio by 22%. Flow variations will ensure that the channel is never completely stable, but the bed slope is likely to reach a quasi-equilibrium in perhaps 40 years. Weir pools in the Valley are likely to stabilise before those in the Gorge.

Bank erosion has been a conspicuous problem in some areas. In 1988-1989 about 1.8M tonnes of bank material was lost over the 153km reach occupied by Pools 2-3 (Thoms & Walker 1989). Erosion on this scale is associated with rapid drawdown following high flows, and is promoted by changes in water level associated with routine weir operations (Lee *et al.* 1998) and, in some areas, by backwash from boats (Munday *et al.* 1998).

Sediments in the weir pools generally are well-mixed, but cores do show an abrupt transition from unregulated to regulated conditions. The sediments prior to regulation were predominantly coarse sand, and now are fine silts and clays (Thoms & Walker 1992a,b). As the finest particles tend to accumulate in the pools immediately above the weirs, sediments there contain the highest levels of complexed heavy metals derived from agricultural and urban sources (Thoms & Walker unpubl.).

Diminished flow across the Murray mouth barrages caused by upstream diversions (cf. Maheshwari *et al.* 1995) has promoted local erosion and sedimentation, and there have been many prolonged periods when no flow has entered the river mouth (Bourman & Barnett 1995, Jensen *et al.* 2000 and papers therein). The likelihood of mouth closures, and the general deterioration of the adjacent Coorong lagoon as a bird sanctuary and fishery has lead to a reappraisal of options for regulating flows in the lower lakes (Jensen *et al.* 2000). One option now under consideration is to remove the barrages and construct a new weir on the Murray at Wellington, near the river's embouchure to Lake Alexandrina. The environmental implications of this proposal need close scrutiny.

Weirs

Configuration

The Lower Murray has 10 locked weirs, built originally (1922-1937) to promote year-round river-boat transport but now used mainly to preserve stable levels for irrigation pumps. They are commonly referred to as numbered "locks" (thus, Lock 1 at Blanchetown, Lock 10 at Wentworth), although the weir and lock chambers are separate. Figure 2 illustrates the terms used for weirs ("navigation dams") on the Mississippi. The 3-5km reach below each weir is the tailwater, leading successively to upper, middle and lower pools. Each pool is identified by the number of the impounding weir (Walker *et al.* 1994). For example, Pool 3 is impounded by Lock 3; the water immediately above Lock 3 is the lower part of Pool 3, and the Lock 3 tailwater is the upper part of Pool 2.

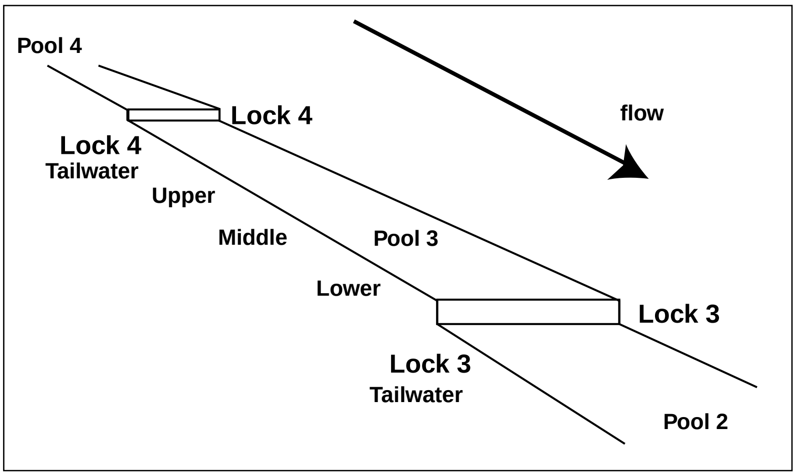

Figure 2: *Terms for weir impoundments (Walker et al. 1994).*

The weirs all are a similar Boulé design. They are 3m high, variously 84,169m long, excluding the lock chamber, with pools 29-88km long and capacities 13-74GL (Table 2). Each weir incorporates a navigable pass, with 1.25m^2 Boulé panels supported by needle beams and trestles, and a sluice section with bays of 300-400mm prismatic pre-stressed concrete "stop logs" (Jacobs 1990). During high flows the panels and stop logs are removed using a mobile crane, and in floods the trestles are folded against the base of the weir. At other times the weir keeper manipulates the panels and stop logs to keep the water level near the target "pool level". The degree of control increases downstream towards Lock 1, as variations are damped by successive weirs.

Stage Variation

As noted, the Lower Murray weirs affect river water-levels ('stage'), but have little effect on flow. Since the 1920s South Australia (SA) Water has maintained daily records of river stage immediately above and below each weir, and has used these to estimate discharge for purposes of management (cf. Jacobs 1990). Records for Locks 1-6 were transferred to a computer database as part of hydrological investigations (Maheshwari *et al.* 1993, 1995), and have been subsequently updated by SA Water. They have a variety of real and potential applications in environmental management (e.g. Blanch *et al.* 1999).

Table 2: *Features of weirs on the Lower River Murray (Murray-Darling Basin Commission data).*

Lock	Name	Distance (km)	Pool level (m AHD)	Pool length (km)	Weir length (m)	Capacity (GL)	Removed at (ML d^{-1})	Completed
1	Blanchetown	274	3.30	…	169	63.7	68,000	1922
2	Waikerie	362	6.10	88	138	44.3	54,000	1928
3	Overland Corner	431	9.80	69	123	74.4	63,000	1925
4	Bookpurnong	516	13.20	85	125	45.3	63,000	1929
5	Renmark	562	16.30	46	125	62.8	67,000	1927
6	Murtho	620	19.25	58	87	43.4	60,000	1930
7	Rufus River	697	22.10	77	84	12.9	29,000	1934
8	Wangumma	726	24.60	29	119	21.4	45,000	1935
9	Kulnine	765	27.40	39	94	42.5	53,000	1926
10	Wentworth	825	30.80	60	117	44.3	…	1929

The general effect of weir operations is to maintain a steady pool level except when flows exceed storage capacity. The mere physical presence of a weir causes the amplitude of stage fluctuations in the tailwater to be nearly four times that upstream, and the downstream profile therefore depends largely on incoming discharge (Lee *et al.* 1998). Some features of the changed regime are shown below (Walker *et al.* 1992, 1995):

- Figure 3 shows daily level changes above and below Lock 3 (Overland Corner) in 1980-1989. In the tailwater there were frequent rises and falls of ±200mm, and changes of more than ±500mm occurred about once annually;

- Figure 4 shows river levels at stations along Pool 3 in 1983-1986. Fluctuations below Lock 4 are transferred down river but progressively diminished in the approach to Lock 3, where the sequence is reset to begin a new progression towards Lock 2. Thus, there are gradients in the magnitude of water level changes between the weirs. The changes at sites along the pool are reasonably well-approximated by simple interpolation (e.g. Blanch *et al.* 1999);

- Figure 5 shows river levels at Lock 3 in 1921-1929. The weir was commissioned in 1926, indicated by the separation of pool levels. From the prior data it appears that the river now is subject to more short-term variation than it was prior to regulation. In the unregulated river the magnitudes of rises and falls were greater, and the changes more sustained, than now (Maheshwari *et al.* 1993, 1995);

- Figure 6 compares three dissimilar flood pulses at Lock 6. Each is represented by actual stage records and natural flows estimated by the MDBC Monthly Simulation Model. During a big, unregulated flood (Fig. 6a), the river moves continually over the banks and the floodplain. A moderate pulse (6b) shows more prolonged stable levels, and for smaller, in-channel pulses (6c), regulation has eliminated any water level response. In general, regulation has decreased the amplitudes of the rises and falls and prolonged periods of stability.

Modelling studies of the weirs show that stage fluctuations in the tailwater depend largely on incoming discharge, and that there is only a small margin to alter the weir configuration (e.g. crest height, upper pool tolerance, numbers of stop logs and Boulé panels) to offset those changes (Lee *et al.* 1998). Weir operations are necessary, however, to maintain the tolerance for upstream stage variations, nominally set to ±50mm.

Another hydraulic effect of the weirs is to slow the passage of water and increase the water renewal time in pools and backwaters. This is significant for the development of algal blooms, and has received considerable attention from researchers (e.g. Bormans *et al.* 1997; Webster *et al.* 1997; Bormans & Webster 1999; Maier *et al.* 1998, 2000; Baker *et al.* 2000). The high turbidity of the river may constrain algal growth, but when the water is warm and retained for long periods the turbidity is likely to decrease through settling of particulate matter and flocculation caused by increased salinity (Grace *et al.* 1997). The perception that the lower river contains an abundant nutrient supply needs to be reviewed, as there is evidence that nitrate-nitrogen may limit algal growth (e.g. Baker *et al.* 2000).

The effects of the weirs on the Murray are modified by inflows from the Darling River (Mackay *et al.* 1988, Walker *et al.* 1992). In the dry years of the late 1980s, Darling water was stored in Lake Victoria for release in summer and autumn, and most of the water in the Lower Murray then came from the Darling. As water from the Darling generally is turbid, the Lower Murray also was turbid (about three times the level in the Murray above the confluence). The consequences of high turbidity were compounded because water levels in parts of the weir pools were fluctuating daily through a range comparable to the extent of the photic zone (hence the limit for growth of aquatic plants). After diversions from the Darling were suspended with the return of higher Murray flows in 1990, there were remarkable increases in the abundance of riverine plants and animals (e.g. Walker *et al.* 1994).

Salinity

Groundwater in the Murray Valley is rendered saline by underlying marine sediments, and inadequate irrigation methods, excessive vegetation clearance and river regulation have contributed to widespread salinisation of land and water resources (MDBMC 1987, 1999; Allison *et al.* 1991, Jolly 1996, GR Walker *et al.* 1996, Crabb 1997). Salinity is responsible for the deterioration of floodplain vegetation (e.g. Jolly *et al.* 1996, Slavich *et al.* 1999) and wetlands in some areas (e.g. Suter *et al.* 1993, Skinner *et al.* 2001). Recently, there has been public concern over the projected future quality of urban water supplies for Adelaide (MDBMC 1999).

It has been estimated that the weirs are responsible for about one quarter of the salt load entering the Lower Murray (EWS 1978). Saline groundwater is pushed downward locally by the hydraulic head associated with the impounded water, but forced nearer the surface in the downstream reach, so that salt is entrained by flow in the river. In salinity mitigation works designed for the floodplain at Chowilla (near Renmark), the options for lowering or removing Lock 6 were considered but ultimately rejected because of indications that flushing the accumulated salt could take many years and would incur short-term increases in river salinity (NEC 1988). In principle, it should be possible to lower a weir pool slowly to control the rate of flushing of stored salt. In this context, the role of the weirs has attracted surprisingly little attention, and clearly it is a priority for future research.

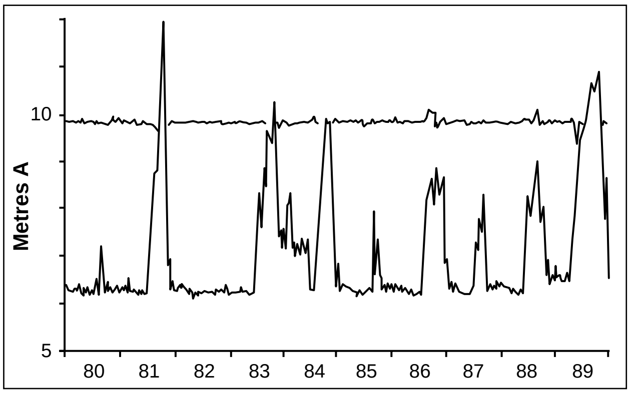

Figure 3: *River levels immediately above (topmost) and below (lowermost) Lock 3 in 1980-1989.*

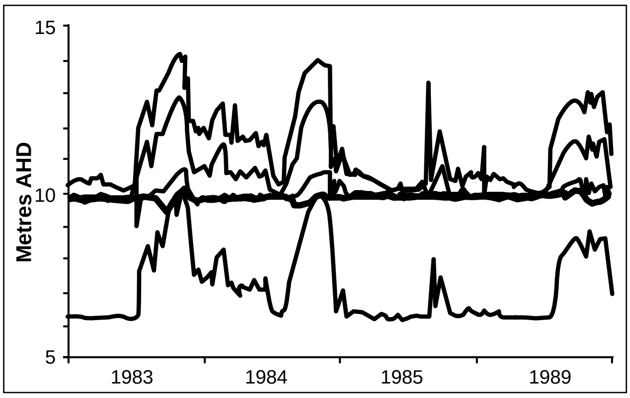

Figure 4: *From top, river levels below Lock 4, at Loxton, Cobdogla and above and below Lock 3, 1983-1986.*

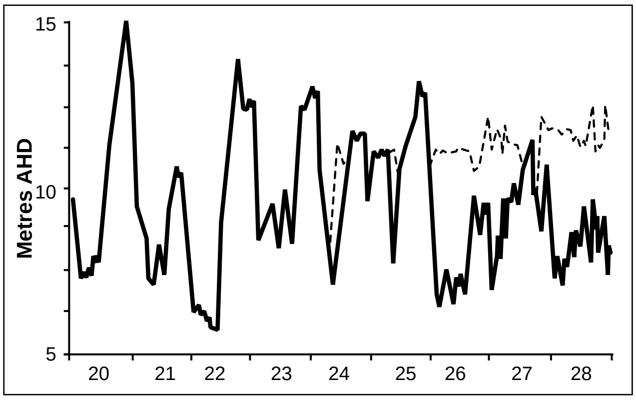

Figure 5: *River stage at Lock 3 in 1920-1929. Final closure of the weir in 1925 is signalled by separation of the pools.*

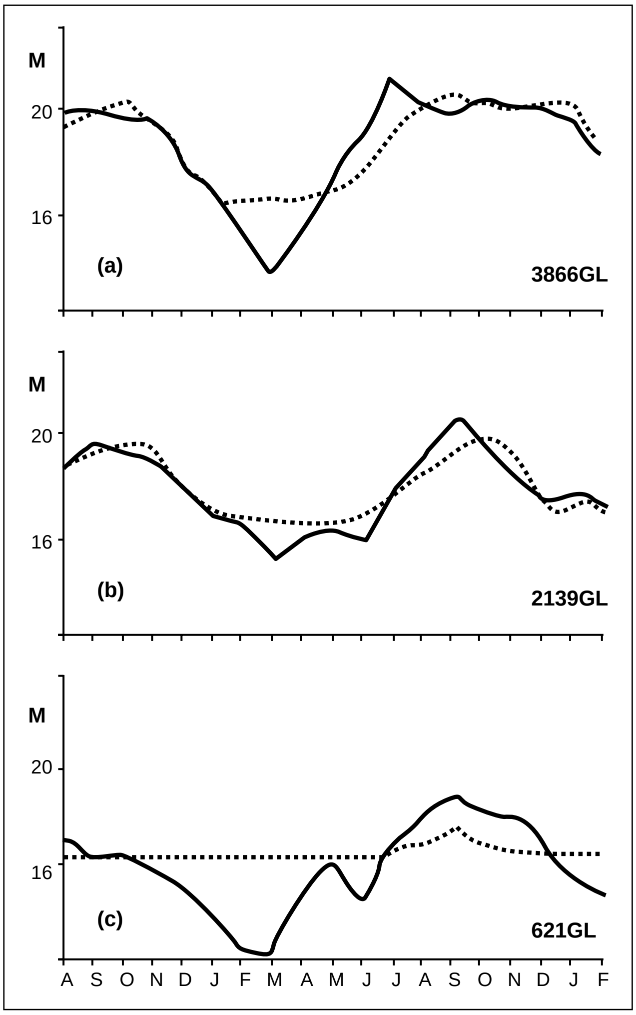

Figure 6: *Comparison of flood pulses at Lock 6 (Walker et al. 1995, after F Sheldon). Each panel shows simulated (unregulated) river stage (solid lines) superimposed on actual records (broken lines) for floods in 1952 (a), 1936 (b) and 1945 (c). Peak monthly flows (GL) are inset.*

Ecosystem Processes

Floodplain

Surface water 'connectivity' is a prerequisite for maintenance of floodplain-river ecosystems, but is prejudiced by flow regulation (cf. Amoros 1991, Ward & Stanford 1995, Ward *et al.* 1999). In the Lower Murray, as in other systems, the floodplain wetlands depend on the river for replenishment, and the riverine biota depend no less on the wetlands for food, breeding sites and refuges. The effect of regulation, particularly by weirs, has been to isolate the river and floodplain for longer periods than would have prevailed under natural conditions. At an ecosystem level the effects are seen, for example, in changed patterns in the storage and flux of carbon (Robertson *et al.* 1999). Regulation has also extended the area of permanently flooded wetlands, so that about 70% of Lower Murray wetlands (backwaters, 'side-arms', anabranches, lakes, billabongs) are now connected to the river at pool level (Pressey 1986). Many of these wetlands were formerly subject to larger, more frequent water level changes, and some would have dried periodically. Further information is provided by O'Malley & Sheldon (1990), Boulton & Lloyd (1991, 1992), Roberts & Ludwig (1991), Suter *et al.* (1993), Sharley & Huggan (1995), Sheldon & Walker (1998) and Janssen & Walker (1999).

A consequence of prolonged inundation is that affected wetlands may no longer exhibit the pulse of plant and animal growth associated with a flood following a dry period. Similarly, wetlands subjected to drying for too long may not produce a strong pulse of productivity when floods occur. In this way, disruption of the natural drying and wetting cycle affects the capacity of the river-floodplain ecosystem to benefit from floods. This idea (e.g. Briggs & Maher 1985) has not been rigorously tested, but enjoys wide credibility, and the reinstatement of wetting-drying cycles is actively encouraged in restoration projects on Lower Murray wetlands (e.g. Jensen 1998).

The drying-wetting sequence is as significant for habitats in the river channel as it for the wider floodplain. Indeed, the term 'flood' is usefully applied to all increases in river stage rather than merely overbank flows (Puckridge *et al.* 1998). Rises and falls in the water level in the channel stimulate corresponding responses in the growth of biofilms (algae, bacteria and fungi growing on sediments, rocks and wood) that provide food for some fish, and for snails and other grazing invertebrates. The in-channel water-level changes suggested by Figure 5 may have promoted the growth of algae, at the expense of bacteria, and thereby reduced the nutritional value of the biofilms for grazing animals (Sheldon & Walker 1993, 1997; Burns & Walker 2000a,b) (see further below).

Lower Murray wetlands have been mapped and assigned to geomorphic and hydrological categories (Pressey 1986), but more work is needed to confirm that these categories are ecologically significant and appropriate for environmental management. Notwithstanding some important agency and community initiatives (e.g. Sharley & Huggan 1994, 1995; Jensen 1998), wetland management still is more *ad hoc* than strategic in nature.

Declines in the vigour of floodplain woodlands are linked to river regulation, as the growth and regeneration of river red gums, black box, lignum and other plants is encouraged by flooding (e.g. Craig *et al.* 1991, Thorburn *et al.* 1994, Jolly & GR Walker 1996, Jolly 1996, Jolly *et al.* 1996, Akeroyd *et al.* 1998, Neumann 2000). As noted, extensive studies have been made of the relationships between eucalypts and groundwater hydrology and salinity in the Chowilla region (e.g. GR Walker *et al.* 1996).

Riverine Littoral Zone

The open river channel is characterised by strong currents, unstable sediments, a shallow photic zone and other conditions that represent a harsh environment for many organisms. In the littoral zone, however, there is a narrow band of emergent and submerged plants (e.g. *Cyperus gymnocaulos*, *Phragmites australis*, *Potamogeton crispus*, *Typha domingensis*, *Vallisneria americana*) that is a refuge for many terrestrial and aquatic animals. The distributions of these plants are correlated with the frequency of flooding and exposure (Walker *et al.* 1992, 1994; Blanch & Walker 1998; Blanch *et al.* 1998, 1999a,b, 2000), and there may be corresponding zonation in the distributions of invertebrates.

It is not widely realised that the stands of littoral plants are an artefact of weir construction (Blanch *et al.* 2000). Historical photographs show that the banks of the unregulated river were largely devoid of vegetation (Walker *et al.* 1992, 1994), whereas the weir pools and changed flow regime have allowed numerous wetland plants (and animals) to invade the channel. With the decline of wetlands, the riverine littoral has become a vital refuge for many species, and warrants special consideration in conservation and management. It would be adversely affected, however, if natural flow patterns were restored. Any initiatives to restore instream habitats need to be developed in parallel with restoration of wetlands and, of course, restored connections between river and floodplain.

Willows (Salicaceae), widely used for ornament and bank stabilisation, were introduced to the Lower Murray in the 19th century. Weeping willow (*S. babylonica*) and crack willow (*S. fragilis*) were planted mainly to stabilise levees protecting reclaimed riparian swamp-lands, and in some regions the former species now rivals the native river red gum (*Eucalyptus camaldulensis*) as a dominant riparian tree (Kennedy *et al.* 2000). Attempts to remove or control the willows have met with strong community opposition, but there is similar opposition to leaving them unchecked, and the debate is poorly supported by scientific evidence. The presumed adverse effect of willows on littoral invertebrate assemblages is unconfirmed (Schulze & Walker 1997), but it does seem likely that the willows consume considerably more water than the native eucalypts, and this may prove to be a decisive factor as accounting for water becomes more intense. S. fragilis occurs mainly downstream of Murray Bridge, below Lock 1, but *S. babylonica* dominates to Blanchetown and thereafter is commonest in the lower weir pools, where water levels are stable. The latter trees are exclusively females and therefore dependent on vegetative reproduction, but there is concern that so-called 'New Zealand hybrids' (e.g. *S. matsudana* x *alba*) introduced to eastern Australia have the capacity to fertilise *S. babylonica* and could initiate seeding (Cremer *et al.* 1995, pers. comm.).

Fish

The regulated river is a stressful environment for many native fish species, particularly those with opportunistic, flow-dependent breeding cycles and those needing access via instream and offstream regulating structures (e.g. Gehrke *et al.* 1995, Thorncraft & Harris 2000). Most native fish have declined in range and abundance (e.g. Harris & Gehrke 1997) in favour of introduced species, like the common carp (*Cyprinus carpio*), that account for about one quarter of the species in the present Murray-Darling fish fauna. The decline arguably is most advanced in the Lower Murray (Lloyd & Walker 1986). One of few native species to have increased in numbers in this region is the bony herring (*Nematalosa erebi*), which thrives in the weir pools (Puckridge & Walker 1990) and rivals the carp as a dominant species.

Not all native fish have breeding cycles directly linked to flooding, although recruitment in most, if not all, species is enhanced by high flows (cf. Harris & Gehrke 1994, Gehrke *et al.* 1995, Humphries *et al.* 1999). This may be mediated by access to and from floodplain wetlands, or by increased abundance of food for young fish, exported from the floodplain. Conceivably, the reduced frequency of smaller floods limits low-level 'bridging' recruitment in longer-lived species, like Murray cod (*Maccullochella peelii*), so that stocks are depleted and unable to respond to big floods.

Weirs and other regulating structures are significant obstacles to fish migrations throughout the Murray-Darling Basin, and removal of barriers or installation of fishways are a prerequisite for restoration and conservation of native species (Thorncraft & Harris 2000). Among the Lower Murray weirs only Lock 6 includes a fishway, but investigations on the structurally similar fishway at Lock 15 (Euston) suggest that the design is inappropriate for most native fish (Mallen-Cooper 1996).

Invertebrates

A striking feature of the lower Murray is the scarcity of freshwater snails. About 18 species were present before weir construction, but there have been sporadic records of only 6 over the past decade and now only the ancylid *Ferrissia* sp. and the introduced physid *Physa acuta* reported in field collections (e.g. Sheldon & Walker 1993, 1997). The latter is easily confused with the native planorbid *Glyptophysa gibbosa*, however, and the status of these two species needs clarification.

Irrigation pipelines fed from the river are a refuge for some aquatic snails, notably *Thiara balonnensis* (Thiaridae) and *Notopala sublineata hanleyi* (Viviparidae). In some years *Notopala* has developed large numbers, becoming a major nuisance for irrigators, and efforts have been made to poison them. As the species is presently known from only one area on the Lower Murray, and apparently is extinct in the river, it is justifiably regarded as an endangered species (cf. Sheldon & Walker 1993, Walker 1996a). The species is declared 'endangered' in New South Wales, but such a designation is not possible for invertebrate animals in South Australia. The Barmera-Moorook Branch of the SA Field and Game Association has a program underway to re-establish *Notopala* in local wetlands (B. Weir, Barmera, pers. comm.).

Three broad factors are implicated in the decline of the snails (Sheldon & Walker 1997, Burns & Walker 2000a). One is the alienation of river and wetland snail habitats, promoted by weir operations. Second is the likelihood of predation by the introduced carp, which is abundant in riverine and wetland habitats. Third, it is possible that the water level changes associated with weir operations are responsible for changes in the composition of biofilms that provide food to snails and other grazing animals. Frequent, rapid short-term variations in water level encourage the growth of algae at the expense of bacteria, and thereby reduces the nutritional value of the biofilms. The populations of snails in some pipelines do have access to bacterial biofilms, as there is no light to sustain algal growth. The presumed connections between weir operations, the nature of the biofilms and the fate of the snails admittedly are speculative, but the evidence is sufficient to warrant further field and laboratory studies.

Freshwater mussels (Hyriidae) are common throughout the Murray (Walker 1981, Walker *et al.* 2000). The range of the obligate riverine species *Alathyria jacksoni* has contracted since construction of weirs and *Velesunio ambiguus*, a species typical of floodplain wetlands, has invaded the weir pools and the sheltered margins of the main channel. It appears that *A. jacksoni* may be excluded from floodplain wetlands because it is unable to tolerate low oxygen levels and dehydration, whereas the physiologically more tolerant *V. ambiguus* may be excluded from the faster-flowing sections of the river by its relatively weak burrowing ability (Sheldon & Walker 1989).

A similar re-distribution has occurred among the crayfish (Parastacidae) (Walker 1986). The yabbie (*Cherax destructor*) is typical of still-water floodplain habitats, but now is common also in weir pools and along the margins of the lower river. The Murray crayfish (*Euastacus armatus*) is a riverine species and virtually extinct in the lower river, although still common in New South Wales. The decline of the Murray crayfish in the lower river is circumstantially related to the construction of weirs, and there is evidence that re-stocking may be feasible (Geddes *et al.* 1993).

Ecosystem Linkages

The Lower Murray weirs supplement the effects of regulation through headwater storages and diversions, and contribute new effects. Processes active in the rising and falling phases of the flood pulse have been disrupted, and those active in periods of stable water have been reinforced. Regulation has reduced the frequency, amplitude and duration of floods and increased the frequency of short-term water level fluctuations, disrupting connections between the river and its floodplain. It has stabilised the river level at a seasonal scale, by maintaining near-bankfull capacities, and introduced daily level fluctuations in reaches immediately below the weirs. The general effect has been to weaken the longitudinal linkages within the river channel environment, and to weaken the lateral linkages between the river and its floodplain. These need to be restored and maintained if the integrity of the system is to be maintained.

Management

This paper outlines environmental changes in the Lower Murray and illustrates some of the ways that the weirs have contributed to those changes. The nature of these changes is broadly recognised by managers, and the authorities are developing a stronger commitment to environmental flow management. This is reflected, for example, in establishment by the Murray-Darling Basin Commission of advisory groups on environmental flow issues. Much of the stimulus for this commitment has come from community groups, led by organisations like the Bookmark Biosphere Trust, Landcare, Wetland Care Australia and the Inland Rivers Network (Australian Conservation Foundation).

There are two major obstacles to progress. One is that our philosophical commitment to environmental management is pluralistic. Many different, often contradictory, perceptions of the goals of management are abroad, and are seen, for example, in divergent meanings of the term 'conservation' (Walker 1996b). Do we seek to manage the environment, or our impact on the environment? Do we wish to preserve native flora and fauna, or to maximise the benefits to human industry? It is a truism to say that we cannot manage well without knowing what we are managing for, but it seems that few are prepared to declare a 'vision' for the future.

A second obstacle is that the technology to support environmental flow management is still primitive. Most initiatives undertaken by authorities and advisory panels necessarily are based on *ad hoc* judgements. It is not enough to recognise that the natural flow regime is the key to river restoration (e.g. Poff *et al.* 1997) because, in the absence of a natural regime and any reasonable likelihood that it can be restored, the greater challenge is to manage the meagre residual supply to good effect. Given a flow allocation of 50ML, how should it be used to benefit the environment?

South Australia's dependency on the Lower Murray is absolute, and in that regard the state faces an uncertain future (e.g. Walker 2000). There is wide acknowledgment that the river environment has deteriorated to a point where its future utility as a human resource is prejudiced. This is most apparent in the spread of salinisation, whether its effects are measured against environmental, agricultural or urban water quality standards. Many other effects are at play, most of them related, directly or indirectly, to flow regulation. If excessive regulation is the fundamental cause of problems, it follows that the solution is to return water to the river. It makes neither ecological nor economic sense to expect a river ecosystem to operate on only a small fraction of its natural discharge.

On one hand, South Australia's future depends upon the capacity of all four states, and the federal government, to work together for the common good. Since 1983 the Murray-Darling Basin Ministerial Council has implemented major reforms, but these are limited by sectional interests because sovereignty over water resources is vested in the states. Water sharing is influenced by the Murray-Darling Basin Agreement, but even so allocations are based on considerations of water supply (particularly irrigation needs) rather than the environment. Management is further constrained by a deeply ingrained attitude that sees the environment as a competitor for resources rather than as a guarantor. A new 'entitlement' flow is required, in which environmental needs are given due priority.

On the other hand, South Australia should not be seen as a hapless victim. The state is obliged to manage its own circumstances, albeit within limits set by upstream diversions, and much could be done to restore and maintain the environment in what is arguably the most highly modified tract of the Murray. In particular, it is time to review the structure, placement and operation of the weirs, with regard to their effects on salinity and the wider environment, and to consider whether some, if not all, are more a liability than an asset.

Prior investigations of options for changed weir operations include an investigation by the Engineering and Water Supply Department (Ohlmeyer 1991), a review for the Department of Environment and Heritage (Jensen *et al.* 2000) and an unpublished modelling study (Lee *et al.* 1998). Ohlmeyer (1991) considered the feasibility of manipulating Locks 1-10 to increase the area of temporary wetlands. Although this could be achieved by lowering/raising pool levels for flows up to 50,000ML d^{-1}, and by introducing more flexible operations at Lake Victoria, Ohlmeyer concluded that the options were limited, and this view is supported by the two other investigations cited above. He recommended that, given its relative isolation from population centres, Pool 8 could be raised or lowered on a trial basis. This lead to a partly successful experiment (Blanch *et al.* 1996). Recently, high flows in South Australia have been augmented by releases from Lake Victoria and manipulations at Locks 4-5. These trials are a step toward more sustainable management, but occasional, *ad hoc* manipulations are bound to be less effective than programmed sequences of manipulations. Restoration of a more natural flow regime would require successive floods in appropriate seasons, with sufficient magnitude and frequency and appropriate rates of rise and fall to promote effective biological responses. From there, we may trust in the oft-repeated dictum to "let nature do the work".

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Biography

Keith Walker is an Associate Professor in the Department of Environmental Biology at Adelaide University, and a member of the Cooperative Research Centre for Freshwater Ecology. His research concerns the environmental effects of flow regulation on the River Murray in South Australia.

In 1975 he joined Adelaide University and began exploratory investigations of two species of freshwater mussels, one adapted to still (impounded) water and the other to flowing water. This was a nucleus for other more wide-ranging studies that have explored the biological and physical effects of flow regulation, particularly through weirs, on the Murray and its floodplain environment.

In 1992 he received the Hilary Jolly Award for research from the Australian Society for Limnology, and in 2000 received a similar award from Australian Science Communicators.

Coastal Weirs:
A Review of Environmental Effects

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Abstract

This paper examines the following issues in relation to coastal weirs.

Weirs of all sorts – including dams, weirs, floodgates, headworks, culverts and the like are ubiquitous on coastal waterways in many parts of Australia.

The range of environmental effects of these structures is similar in many ways to their counterparts on the inland rivers. Some effects include blockages to fish passage, alteration of flow regimes and creation of habitats suitable for pests and weeds.

In tidal areas alterations to flow regimes include tidal access as well as downstream freshwater flows. Wetland drainage and the exposure of acid sulfate soils are also associated with many floodgates and headworks.

There is little doubt that coastal weirs are having an unacceptable effect on coastal fish and wildlife. Widespread evidence of the effects of acid sulfate soils runoff has been detailed in recent years and impacts of structures on migratory fish such as Australian bass are well known. Wetland loss has been implicated in the decline of many species of coastal water birds.

Types of Structures

A wide variety of structures on coastal waterways interfere with the movement of fish and / or water. For the purposes of this presentation, unless otherwise identified, all will be called weirs. Some examples include (modified from Williams & Watford 1997):

a) Floodgates: structures which are placed on either natural waterways or artificial drains for the purpose of preventing tidal waters from entering onto land and to lower the water table in order to dry out a wetland. There are over 1,000 floodgates in New South Wales of which about 630 are located on the North Coast (Williams & Watford 1997).

b) Barrages: are large scale tide control structures designed to prevent tidal penetration upstream. An example is the barrages at the entrance to the Murray River, South Australia.

c) Dams: there are a number of water supply dams on the coast ranging in size from relatively small structures such as Brogo Dam which supplies water to Bega in southern New South Wales to large structures such as Warragamba Dam which supplies drinking water to Sydney.

d) Weirs: are commonly found at the region where brackish and freshwater mix and commonly define the junction of these two types of water bodies. In some areas the freshwater reach is used for town water supply whilst in others it is used for stock watering. There are just under 100 weirs in the area below the 10m contour in coastal New South Wales (Williams & Watford 1997). Harris (1984) found 293 dams and weirs in South Eastern Australia in the region that coincided with the range of the Australian bass.

e) Road crossings: fords, culverts, causeways and bridges are designed to facilitate access across waterways. They number in the tens of thousands (over 3,000 in New South Wales alone, Williams & Watford 1997) and in most cases have been built without taking into account the needs of migratory fish.

f) Miscellaneous barriers: in specific circumstances other types of barriers may also be imposed on waterways. One example is the kilometres of levees used to create ponded pastures in central Queensland and the Northern Territory.

Harris (1985) makes a distinction between weirs according to height (high weirs being 3-7m high) and labels dams as being any structure greater than 7m in height.

State-by-state inventories of the numbers of barriers are generally not available, although New South Wales has conducted a survey of all those below the 10m contour on the coast (Williams & Watford 1997), and a statewide review of the status of weirs and dams is currently underway (see Copeland, these proceedings). As stated by Cappo *et al.* (1998) “The nature of the barriers will also vary from State to State. In New South Wales the major issues are floodgates on the northern floodplains, in South Australia the barrages at the Murray Mouth are a high priority and in Queensland there have been no systematic studies in lower catchments, although problems with weirs, levees and floodgates are certainly present.”

Physical Effects of Coastal Weirs

All the above-mentioned structures create a barrier to water movement. In all cases the flow of water is impeded to a greater or lesser degree and there may be a pooling of water on the upstream side, especially in the case of water supply structures.

Coastal weirs located at the fresh/brackish interface prevent the movement of the tide. In waterways without weirs there is commonly a freshwater tidal area caused by the tide backing up the freshwater inflows without changing the salinity. Freshwater tidal habitats are poorly studied and their ecological value unknown.

Tidal barriers commonly increase the amount of freshwater habitat at the expense of estuarine habitat. Given the extent of barrier installation in some river systems the extent of habitat conversion can be significant. Downstream of the Fitzroy River barrage in central Queensland reduced flushing has been recorded which has concomitant changes in water quality (see below) (Connell *et al.* 1981).

As is the case with inland weirs, coastal weirs, depending on size, can influence the size and frequency of floods and freshes. In general the smaller freshes are removed and the overall frequency of freshes is reduced by dams and weirs, especially if they have been constructed for flood mitigation purposes. In the case of water supply and inter-basin transfer dams (such as that on the Barnard River) the removal of water from the estuary can cause major changes to flushing regimes and also the supply of fresh water offshore.

Scour pools are recorded downstream of major weirs (and dams) and also occur naturally (Turner & Erskine 1997). Depending on depth, stratification of the water column occurs resulting in de-oxygenation and changes in water chemistry (see below).

Culverts can cause ponding of water (Streever *et al.* 1996) and, according to Cappo *et al.* (1999), the dispersal of masses of forage fish such as carp, gudgeons and bony bream in North Queensland may be prevented by the “hydrodynamic barriers” caused by flow velocities associated with small culverts. Cappo *et al.* (1999) states that thousands of hectares of barramundi habitat has been alienated by levees constructed to create ponded pasture.

According to Pollard & Hannan (1994) floodgates were generally ineffective in preventing saline intrusion. Salinities differed only slightly between gated/ungated tributaries at similar distances from the sea, except during some winters and springs when salinities were lower above some of the gates. The ‘leakiness’ (i.e. inefficiency) of floodgates may provide some avenues for mitigating their effects on fish even though there are wider effects on other ecosystem components (see below).

Effects of Weirs on Water Quality

Weirs can affect both the chemical and physical attributes of water, with not only implications for aquatic flora and fauna but human users as well.

In the case of larger structures like dams the water released from the reservoir may have different qualities to the water downstream. For example, the water may be significantly colder, contain lower concentrations of dissolved oxygen and have elevated levels of ammonia and / or sulfides and heavy metals. In the case of Tallowa Dam there are also elevated concentrations of some heavy metals such as manganese (HRC 1999).

In the weirs on the Nepean River, anoxic conditions result in the mobilisation of phosphates from the sediments, which has implications for pollution modeling. This is especially the case in nutrient stressed systems such as the Hawkesbury / Nepean (Turner & Erskine 1997). In the case of the Fitzroy barrage (Connell *et al.* 1981) depressed oxygen concentrations are linked to elevated biological oxygen demand and high nutrient levels.

Floodgates, headworks and associated structures, such as drains, are involved in the production and transport of acid water to coastal waterways if the structures either intersect acid sulfate soils (ASS) or lower the water table in ASS areas (White 1999). Water with pH values of less than 2 has been recorded in some coastal waterways and high acidity also creates elevated concentrations of some heavy metals such as iron and aluminium. The chemical reactions associated with the oxidation of acid sulfate soils can also result in lowered oxygen concentrations.

Floodgates and headworks have also been associated with major de-oxygenation events on some coastal floodplains (Richardson 1980). It is believed that the drainage of wetlands results in the proliferation of flood intolerant vegetation. If inundated during a flood the vegetation dies and rots, resulting in very low dissolved oxygen concentrations (SPCC 1978).

Water quality problems may create chemical barriers to fish movement and, in the case of acid water in northern New South Wales, barriers to fish movement are believed to be a major problem for fish moving between estuarine and fresh waters (Sammut *et al.* 1994).

Ecological Effects of Coastal Weirs

The effects of weirs can be experienced at all levels of biological organisation and can be either direct or indirect. There are commonly multiple sources of impacts associated with both weirs and related structures and land uses.

In addition to the changes in water quality and flow patterns, weirs also present a major barrier for migratory species, such as fish. Harris (1984, 1985) and Pethebridge *et al.* (1998) note that the ability of species to traverse a barrier is highly variable. Eels are well known for their ability to migrate across high dams, but young Australian bass (30mm) were unable to pass over a small (15cm barrier). Even if small structures are ‘drowned out’ during periods of high flows, the ability of fish to traverse the barrier may be affected by the availability of areas of low flows.

According to Cappo *et al.* (1999), barriers to movement have four main effects in lower catchments, namely:

- “prevention of tidal access that transports eggs and larvae upstream into shallow, sheltered habitats of lower salinity;
- concentration below barriers of adult fishes attempting to disperse upstream during rainfall events – these concentrations become ‘predation gauntlets’ and a focus for poaching. Harris (1985) notes that bass become easy targets for anglers when gathered below weirs such as that on the Georges River and below Tallowa Dam;
- maintenance of poor water quality, weeds, pests and reduced habitat diversity upstream – in the extreme this may comprise acidic water (pH down to 2.5) – and trapped fish die; and
- pulse release of poor quality water during flood events that inundate barriers – acid and the production of dissolved metals has killed all gilled life in rivers in the short-term and resulted in longer terms of chronic ‘red-ulcer’ disease.”

A number of species of primarily marine fish can also enter freshwater habitats during their lifecycle. For example the sea mullet enters freshwater wetlands as juveniles and then moves to the estuary in preparation for spawning out on the ocean beaches. Australian bass migrate from freshwater to brackish water to spawn and the young then migrate back upstream. Not only are the spawning areas potentially affected by acidity but the dispersal of juveniles back upstream is prevented by weirs of all kinds. The Tallowa Dam is thought to have been responsible for the demise of the Australian grayling, a fish with similar migratory habits, from the Shoalhaven River system.

Fish kills are but one of the many direct impacts of acid water on estuarine systems. Kills commonly occur following minor flooding after a dry period, when the land has dried out and exposed more acid sulfate soils to the air. Many other organisms are affected as well. For example, Roach (1998) recorded both long and short term changes to benthic infauna in areas affected by acidity whilst Wilson & Hyne (1997) have documented the negative effects of acidity on the settlement of oyster larvae and the hatching success of Australian bass eggs (Hyne & Wilson 1997). In short, acid water can affect the growth and reproduction of individuals within species, affect some species more than others and thus change ecological communities and also remove entire communities of organisms.

A large number of coastal wetlands have been affected by drainage works, primarily to assist grazing and agriculture, but also to protect properties and lives during times of flood. The most significant impacts have been on wet meadows and related freshwater wetlands, which were once directly connected to estuarine systems but generally beyond the reach of most tides (Goodrick 1970). Floodgates and headworks have reduced water tables and thus limited the area suitable for supporting wetland plants. As previously mentioned, these plants have been replaced by non-wetland species.

Pollard (1993) quantified water quality parameters, and the nature of submerged, emergent and riparian vegetation, land-use and fish community structure at 18 sites in northern New South Wales river floodplains.

The major findings were:

- floodgates were very effective in preventing recruitment and establishment of fringing mangroves;
- floodgates were very effective in severely restricting passage of juveniles of estuarine / marine fishes and Australian bass;
- floodgates generally degraded the overall quality of habitat, by excluding mangroves in estuarine areas and also reducing overhanging Melaleucas in freshwater areas. Overhanging riparian vegetation is replaced by rushes and grasses;
- depauperate freshwater fish communities were found above floodgates, in habitats dominated by freshwater and terrestrial vegetation;
- below the floodgates estuarine / marine communities dominated with the highest diversity and abundance of fishes, and highest proportions of economically important species;
- number and diversity of both total and economically important species declined with both distance from the sea and decreasing salinity;
- adults of the euryhaline sea mullet dominated the gillnet samples in floodgated sites in terms of abundance and biomass, but juveniles were not abundant there.

Similar types of results can also be found for other types of structures. For example, water supply weirs change free flowing streams into a series of quiet pools, habitats which favour some fish over others. Rises and falls in the level of the weir pool affects fringing vegetation and can exacerbate erosion.

It needs to be stressed that weirs and other structures are generally part of a wider system of waterway alteration and thus need to be viewed in context, especially when impact mitigation options are being considered. For example flood mitigation works commonly consist of not only barriers to water movement but also channelisation and the removal of fringing vegetation, both of which also have their own impacts on fish and other aquatic organisms. This is not to say that such areas do not support fish but species diversity may be reduced and ecological processes impaired. For example, channelised, ungated, tributaries have been shown to support sea mullet, Australian bass, dusky flathead, estuary perch, mulloway, mud crabs and school and greasyback prawns on a tributary of the Richmond River (Pollard 1993). Gibbs *et al.* (1999) found that gates that allow fish passage can result in relatively healthy fish communities upstream of the gate. Thus, enhancement of fish passage should help rehabilitate fisheries production in “gated” habitats, providing that water quality is satisfactory.

Although partial floodgate openings have been suggested as a mechanism for ameliorating the impacts of floodgates, (Pollard 1993) found that several predominantly estuarine-marine species (dusky flathead, mulloway, tarwhine and luderick) were found below, but not above, partially open floodgates on a tributary of the Hunter River. The open floodgates permitted a 15% tidal exchange, but there were limited improvements in the movement of juvenile fishes upstream and the communities above the gates remained depauperate.

In some cases the creation of artificial habitats (such as drains) creates suitable conditions for weed species to dominate, generating a need for management action, such as the spraying of herbicides (SPCC 1978). Over-drained wetlands commonly support weeds of concern (such as smart weed) which reduce even further the habitat value of these once productive habitats (Smith 1989).

Modifications to water flows have been found to have a substantial impact on the production of many valued fish and shellfish, especially prawns. In Australia, Loneragan and Bunn (1999), Glaister (1978) and Ruello (1973) have all found close links between the catch of some species of fish and prawns and river flows. This pattern follows similar results overseas where there have also been studies demonstrating collapses in the catches of many marine and estuarine species following the construction of dams and/or inter basin transfers. The relationship between rises in rivers and the triggering of breeding is well known for many freshwater fish and Harris (1985) expresses the view that for coastal freshwater fish the increasing regulation of flows may also be affecting breeding cues.

Where to From Here?

Although there is still much research to be undertaken, there is sufficient information available to demonstrate that coastal weirs are affecting aquatic communities on very large spatial scales. Indeed it is testimony to the resilience of many species that there are not more species that can be classified under threatened species legislation.

Research needs have been put forward by both Cappo *et al.* (1999) and Webb (1996). Webb notes the need for integrated programs that evaluate both the land and water components of areas affected by coastal weirs. Furthermore, it has also been accepted that both research and remediation programs need to be backed up by careful documentation so that knowledge can be transferred from one region to another and thus speed up the rate of remediation, which is currently at a glacial pace overall.

However, we should not wait until species reach an endangered state before action is taken. The experience from North America and inland New South Wales is that when species reach critically low levels the first reaction of agencies, especially fisheries agencies is to shoot the victims, namely fishermen and others not responsible for destroying the affected waterways in the first place. A second reaction is to artificially stock the waterways to keep anglers happy, thus further reducing pressure to solve the fundamental problems. The reason I mention this is that this is exactly what is happening in coastal New South Wales where habitat destruction is the worst in Australia and politically expedient solutions are at their most destructive.

What we need is legislation that mandates action before species are placed on an endangered list. Legislation is needed to drive the rehabilitation of productive habitats irrespective of whether species are at risk. At the moment legislation only provides for habitat remediation when a development of one sort another has been proposed or habitat has been damaged.

Finally, there needs to be some serious funding allocated to habitat remediation. We can conduct study after study of the ecological and economic impacts of weirs but at the end of the day communities, industries and governments are foregoing the benefits of healthier aquatic habitats in the absence of focused, sustained and adequate funding.

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Biography

Duncan Leadbitter is the former executive director of Ocean Watch Australia and deputy chair of the Australian Seafood Industry Council. He has had long involvement in habitat protection, management and rehabilitation with a special focus on coastal floodplains.

Physical Impacts of Weirs on the Burnett, Kolan and Pioneer Rivers, Queensland

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Abstract

The Burnett, Kolan and Pioneer Rivers are all situated on the east coast of Queensland. There are five major weirs and a tidal barrage on the Burnett River, one major weir and a tidal barrage on the Kolan River, and three weirs on the Pioneer River. There is also other water resource development in these catchments, and the weirs are used in conjunction with other major infrastructure. This paper outlines the physical impacts of the weirs. Upstream effects include loss of fast-water habitat, increase in pool habitat, increased likelihood of thermal and chemical stratification, unnatural water level regimes in the weir pondages, increased extent of water in the landscape, reduction in the extent of the riparian zone, and sediment entrapment. Barrier effects include impediment of bedload transport and fish passage. Downstream effects include altered flow regimes, reduced sediment inputs, reduced bedload inputs and, particularly in the case of tidal barrages, changes in estuary hydrodynamics.

Introduction

Water Resource Plans (WRPs) are being developed across Queensland. Environmental, social and economic considerations are taken into account by government in the development of the WRPs, which specify environmental flow objectives as well as water allocation security objectives. Environmental investigations are undertaken as part of the planning process by panels of independent specialists, and include assessments of current environmental conditions and impacts of existing water resource development, development of environmental flow performance measures, and assessment of environmental implications of possible future water resource management scenarios.

In order to carry out the environmental investigations most effectively, a consolidated knowledge base regarding the impacts of water resource management is required. Most of the published case studies in the scientific literature focus on the relatively spectacular impacts of major dams, and relatively few look at weirs. Examples of studies where the impacts of weirs have been examined include Thoms and Walker (1993) and Walker and Thoms (1993).

This paper presents a summary of the physical impacts of weirs on the Burnett, Kolan and Pioneer Rivers. It is based on information from the Griffith University research project "Environment Flow Guidelines for Queensland Rivers", as well as environmental investigations funded by the Department of Natural Resources, Queensland (DNR) for the Burnett Basin and Pioneer Valley WRPs. A companion paper (Arthington *et a*l. these proceedings) examines the ecological impacts of weirs on the Pioneer River.

Description of the Weirs

The Burnett, Kolan and Pioneer Rivers are all situated on the east coast of Queensland. The Burnett and Kolan Rivers discharge to the sea near Bundaberg, while the Pioneer River discharges to the sea at Mackay. The Burnett has a catchment area of approximately 33,000km^2, the Kolan 2,600km^2, and the Pioneer 1,500km^2.

Table 1 lists the major weirs on the Burnett, Kolan and Pioneer Rivers. In each case, they are listed in downstream order. There are five major weirs and a tidal barrage on the Burnett River, one major weir and a tidal barrage on the Kolan River, and three weirs on the Pioneer River. All except the Ben Anderson Barrage are fixed-crest structures. The Ben Anderson Barrage has shutters. Three of the weirs (Claude Wharton, Mirani and Dumbleton) have inflatable fabri-dams which are used to increase capacity above the fixed crest level. There are also some stream gauging weirs on the Burnett and Kolan Rivers which are not listed in Table 1. These are very small structures which have only localised effects.

Table 1: *Weirs on the Burnett, Kolan and Pioneer Rivers*

River	Weir Name	Type of Structure	Capacity (ML)
Burnett	John Goleby	fixed-crest	1,690
	Jones	fixed-crest	3,720
	Claude Wharton	fixed-crest with inflatable fabri-dam	11,900
	Walla	fixed-crest	29,500
	Bingera	fixed-crest	6,030
	Ben Anderson Barrage	tidal barrage - fixed crest with shutters	27,600*
Kolan	Bucca		11,605
	Kolan Barrage	tidal barrage - fixed crest	3,810
Pioneer	Mirani	fixed-crest with inflatable fabri-dam	5,800
	Marian	fixed-crest	3,800
	Dumbleton	fixed-crest with inflatable fabri-dam	8,260

Based on Brizga *et al.* (2000) and GHD *et al.* (1996). The capacity of Dumbleton Weir has been updated based on recent advice from DNR. * The capacity of Ben Anderson Barrage includes 6,030ML upstream of Bingera Weir.

The weirs and tidal barrages are used conjunctively with other major water infrastructure.

- Bucca, Walla and Bingera Weirs and the Kolan and Ben Anderson Barrages are all part of the Bundaberg Irrigation Area, which supplies water for irrigation, water supply for the City of Bundaberg, and town water supplies. Fred Haigh Dam on the Kolan River is the main source of water supply. The weirs and barrages provide additional storage and regulating capacity.

- John Goleby, Jones and Claude Wharton Weirs are part of the Upper Burnett Irrigation Project, which supplies water for irrigation and town water supply purposes along the Burnett River. Wuruma Dam on the Nogo River is the main storage in this project, and water is delivered by regulating flows in the Nogo and Burnett Rivers downstream of the dam. The weirs provide additional storage and regulating capacity.

- Mirani, Marian and Dumbleton Weirs are operated in conjunction with other major water infrastructure, including Teemburra and Kinchant Dams. The water is used for irrigation, town water supply, and water supply for the City of Mackay.

Other water resource use and development also affects flows in the rivers. In the Burnett catchment, there are three other major developments (Three Moon Creek Irrigation Project, Boyne River Irrigation Project and Barker-Barambah Irrigation Project) as well unregulated abstraction. Unregulated abstraction also occurs in the Kolan and Pioneer catchments.

Impacts

The physical impacts of weirs can be grouped into three categories: 1) upstream impacts, 2) barrier effects, and 3) downstream impacts (Table 2). Further details regarding each type of impact are provided below.

Table 2: *Summary of the Physical Effects of Weirs*

Category	Impact Type
Upstream Effects	• loss of fast-water habitat
	• increase in pool habitat
	• increased likelihood of thermal and chemical stratification
	• unnatural water level regimes
	• increased extent of water in the landscape
	• reduction in the extent of the riparian zone
	• sediment entrapment
Barrier Effects	• bedload transport impediment
	• fish passage impediment
Downstream Effects	• altered flow regime
	• reduced sediment inputs
	• reduced bedload inputs
	• changes in estuary hydrodynamics

Upstream Impacts

Dams, weirs and tidal barrages cause upstream ponding of water. Ponding leads to a loss of lotic (flowing-water) habitat and an increase in lentic (still-water) habitat, which has water quality and ecological implications. Water level regimes in weir pondages may be quite different from water level regimes in natural pools. The riparian zone is reduced in extent. The ponded area is a preferential sediment deposition zone, and this in turn may lead to changes in morphology and substrate, which in turn have further ecological implications.

The degree of upstream impact of a weir depends on a range of factors including the length of the ponded reach, the relative proportion of riffles or other shallow and/or fast-water habitats versus pools within the ponded reach under pre-impoundment conditions, the depth of inundation, the nature and extent of changes in water level regimes resulting from storage operation, the extent to which ponding persists under high flow conditions, and the width and depth of ponding in relation to the extent of the riparian zone.

Loss of Fast-Water Habitat

The river reaches in the study area which have been impounded by weirs typically featured a combination of pools and shallow fast-water habitats such as riffles, rock bars and sandy glides prior to impoundment. Shallow fast-water habitats have been drowned and lost as a result of the weir pondages, whereas pool habitats have been increased in extent and depth (Figure 1).

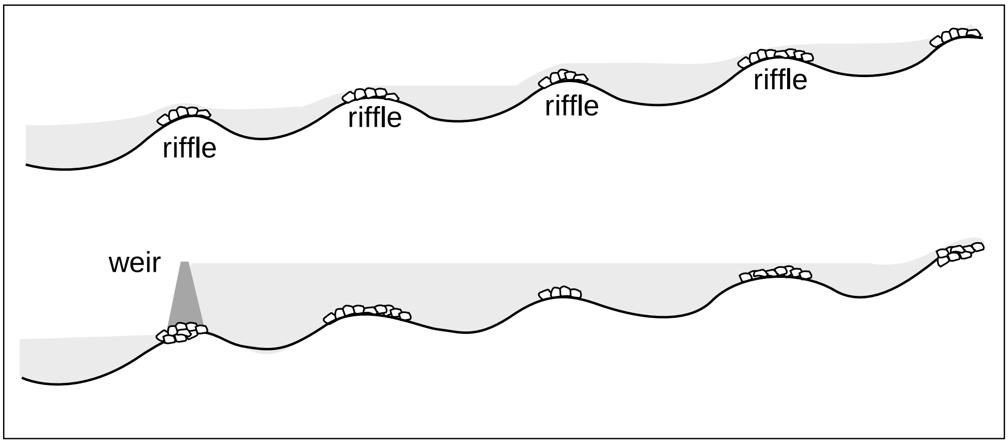


Figure 1: *Impact of a weir on lotic habitat. The upper plot shows the original longitudinal profile with alternating riffles and pools. The lower plot shows the longitudinal profile with the weir, showing drowning of the riffles and the creation of a large pool (from Brizga* et al. *2000).*

The loss of shallow fast-water habitats leads to a loss of habitat diversity. The greater the original extent of shallow fast-water habitats in the impounded reach, the greater the ecological implications are likely to be. Many types of macroinvertebrates and microscopic organisms are confined to riffles, and these are highly productive areas serving as a food supply for other components of the aquatic system.

Increase in Pool Habitat

The pondages behind dams function as lakes rather than river pools, as, even in large floods, flows through the ponded areas occur only at low velocity. However, in the case of weirs, high velocity flows may still occur during floods. For example, hydraulic modelling by the Queensland Government Hydraulics Laboratory (1994) indicates that mean flow velocities in excess of 1.5m/s occur in the Ben Anderson Barrage pondage during major floods.

The weir pondages in the study area are larger than natural pools, and therefore more susceptible to thermal and chemical stratification. Walla and Bucca Weirs are both known to stratify, and have multiple-level offtakes (Brizga *et al.* 2000).

Unnatural Water Level Regimes

There can be significant differences between natural pools and weir pondages in terms of their water level regimes. In natural pools, water levels remain relatively constant during baseflow periods, but are subject to rapid rise and fall during floods. Water levels may fall below the control level during cease-to-flow periods, as a result of water abstraction or evaporation. In weirs, ambient water levels may be subject to a greater degree of variation than baseflow water levels in natural pools, as a result of water abstraction and/or downstream releases. These effects are greatest at the downstream end of the storage, where the difference between full supply level and the bottom of the storage is greatest, and they decrease upstream as the weir pool merges with the river channel.

Figure 2 shows time series plots of water levels for three weir pondages. Figure 2a shows water levels in Marian Weir (Pioneer River), where water level fluctuations for much of the time are similar to those that would be expected in a natural pool; that is, limited variation in baseflow water levels, and short, sharp rises and falls during flood events. However, unlike in the natural pools in this river, drawdown by up to 1m occurs periodically. Figure 2b shows water levels in Bucca Weir (Kolan River), which are regularly drawn down by up to 4m below crest level as a result of normal operations, leading to major fluctuations in baseflow water levels. Flood events still lead to sharp, short rises and falls, though the starting elevation is variable depending on storage levels. Figure 2c shows water levels in Mirani Weir (Pioneer River), when baseflow water levels are variable as a result of operational drawdown, but flood peaks are largely suppressed by the operation of the fabri-dam (Craigie 2001).

The water level regimes in weirs have important ecological implications. For example, large variations in water levels under baseflow conditions preclude the establishment of stable littoral vegetation communities (Mackay *et al.*, these proceedings).

Increased Extent of Water in the Landscape

The storage of water in weirs has increased the extent of water in the landscape in the study area. This has implications for populations of species such as waterbirds.

Reduction in Extent of Riparian Zone

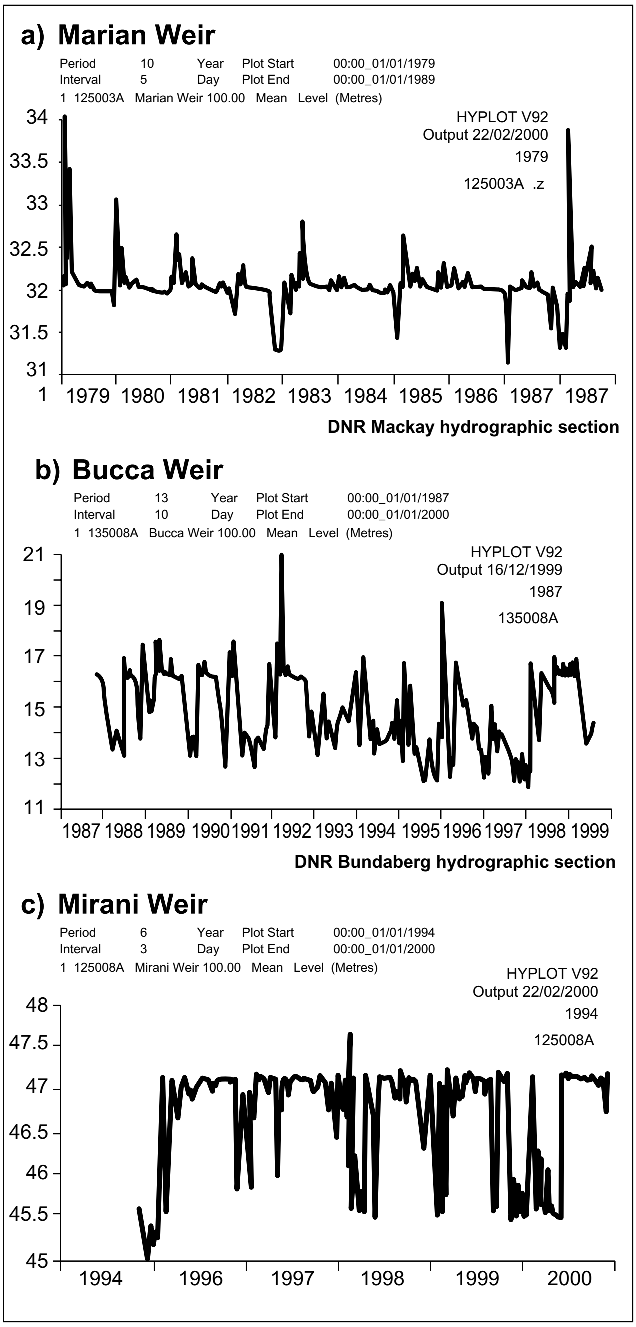
The extent of the riparian zone is reduced in the ponded area upstream of a weir (Figure 3). The toe of the riparian zone is elevated, but flood levels are not elevated to the same degree. The degree of impact decreases in an upstream direction, away from the structure. Trees are killed by waterlogging or drowning.

Sediment Trapping

River systems play a key role in geochemical cycles by transporting erosion and weathering products (solutes and sediments) from the various parts of a catchment to the catchment outlet. The river and stream channels act as conveyor belts for sediment. Weir pondages disrupt natural sediment transport processes by acting as partial sediment traps. The reduction in flow velocity as it enters the ponded area leads to the deposition of sediment. Weirs may also directly impede bedload transport, as discussed below under the heading of “Barrier Effects”.

Trap efficiency calculations using Brune’s (1953) method indicate that the weirs in the study area have trap efficiencies ranging from approximately 20% to 65% of all incoming sediment. The actual quantities of sediment trapped in a weir pondage and rates of accumulation vary, depending on a range of factors including sediment size, flood history and flow velocities through the weir pondage.

Figure 2: *Time series plots of water levels in three weir pondages. Based on DNR data.*



Sedimentation surveys have been carried out by DNR in the weir pondages in the study area. The highest rates of sedimentation apparent from the surveys occurred in Mirani Weir, where 1.2 million cubic metres of aggradation occurred over the period September 1988 to May 1991. The delivery of such large quantities of sediment was enabled by the two major floods that occurred over this period. Mirani Weir is situated at the confluence of the Pioneer River and Cattle Creek, and the majority of the sedimentation occurred in the Pioneer River arm. The Pioneer River has a sand bed in this area, while Cattle Creek has a gravel bed. The greater mobility of sand compared to gravel is likely to be a factor in the more rapid sedimentation rates in the Pioneer arm.

Barrier Effects

Weirs act as physical barriers to sediment transport and also impede the movement of fish and other instream biota. Tidal barrages also have chemical barrier effects, resulting from the sharp contrast between the fresh water in the pondage and the salty or brackish water in the estuary below.

Bedload Transport Impediment

Rivers transport the finer part of their sediment load in suspension in the water column, and the coarser fraction as bed load which is rolled or saltated downstream. Weirs are physical barriers to the downstream transport of bedload, as they block the movement of sediment along the river bed (Figure 4). Bedload can only be transported past weirs if they have gates which are kept open in floods, or if the bed has aggraded to the level of the weir crest. All the weirs in the study area have fixed-crest spillways, except for Ben Anderson Barrage, which has shutters.

Fish Passage Impediment

The weirs in the study area impede fish passage to varying degrees. A number have fishways, as follows:

- Jones Weir – stepladder fishway (dysfunctional);
- Walla Weir – fish lock;

Figure 3: *The impact of a weir on the extent of the riparian zone. The original cross-section is shown above, and the effects of the weir are shown below. From Brizga* et al. *(2000)*

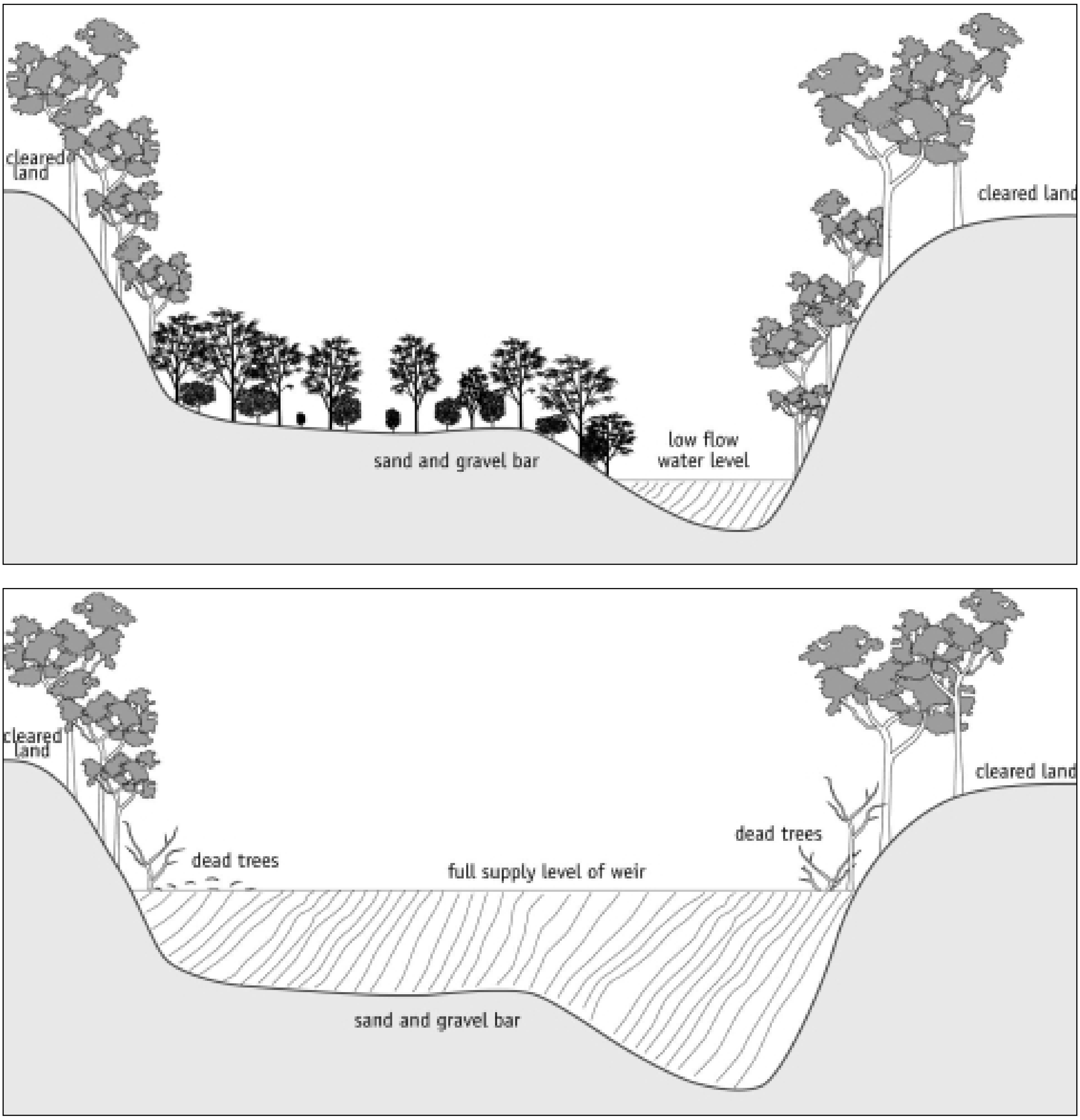
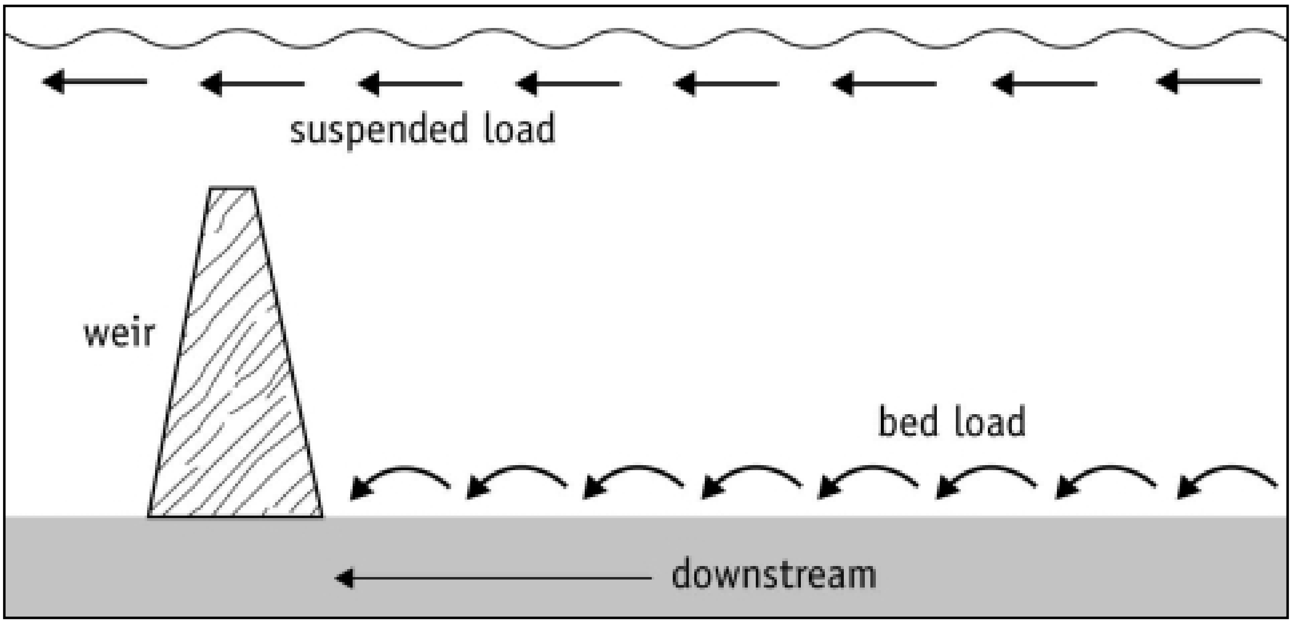


Figure 4: *Barrier effect of a weir in relation to bedload transport. From Brizga* et al. *(2000)*



- Bingera Weir – stepladder fishway (dysfunctional but usually inundated by backwater from the Ben Anderson Barrage);
- Ben Anderson Barrage – modified vertical slot fish ladder;
- Kolan River Barrage – modified vertical slot fish ladder;
- Marian Weir – fish ladder (dysfunctional);
- Dumbleton Weir – fish lock.

Some fish species will survive downstream movement over weirs during overtopping, but the presence of water at the toe of the weir is important for their survival (Brizga *et al.* 2000). Fish can be stranded on weir footings when flows over a weir suddenly stop, and strandings may also occur in lateral habitats that become dewatered or disconnected from the main channel. In the case of tidal barrages, freshwater fish that get washed over the barrage may die due to high salinities downstream.

Opportunities for upstream and downstream movement of fish may be created under drownout conditions. The majority of weirs in the study area are periodically drowned out, at least in the largest of floods (Maynard 2000, Brizga *et al.* in press). Mirani and Dumbleton Weirs on the Pioneer River are exceptions. From the viewpoint of fish passage, three points need to be made about drownout conditions (Brizga *et al.* 2000). Firstly, they occur infrequently and therefore may significantly reduce the frequency of passage events compared to natural conditions. Secondly, only some species move under high flow conditions and, of these species, only large and/or mature fish may move. Thirdly, drownouts need to occur at seasonally appropriate times to allow passage relevant to life history processes. Therefore, even if weirs are periodically drowned out, they may still act as significant impediments to fish passage.

In addition to physical barrier effects, the Ben Anderson and Kolan Barrages also have chemical barrier effects, resulting in a sharp break between freshwater conditions upstream of the barrage and saltwater conditions below the barrage. This is in contrast to the natural situation where there is generally a transition zone. The sharp change in water chemistry has implications for the movement of aquatic biota, including fish (Brizga *et al.* 2000).

The distributions of fish species in the Burnett, Kolan and Pioneer catchments has been significantly altered from natural as a result of the presence of weirs. Detailed discussions of this issue can be found in Kennard (2000) and Pusey (in press).

Downstream Impacts

The downstream physical impacts of weirs can be grouped into three categories: flow regime change, reduced sediment and bedload supply and changes in tidal hydrodynamics (particularly in the case of tidal barrages).

Change in Flow Regime

Large dams have the potential to alter flow regimes across the full range of flows – low, medium and high. However, weirs generally affect only low and medium flows, and have limited ability to alter high flows. The actual impact of a specific weir on downstream flow regimes depends on its size and how it is operated. For example, Dumbleton Weir, Ben Anderson Barrage and Kolan Barrage are all used primarily to store water for abstraction or diversion, leading to reduced flows downstream. In contrast, Bucca Weir is used to regulate flows in the Kolan River, leading to elevated and more sustained baseflows (Brizga 2000).

In the study area, flow regimes are also affected by other water infrastructure and usage apart from the weirs. Flows in the Burnett River are affected by four major dams and associated water supply schemes on its tributaries, as well as unregulated abstraction. The hydrological impacts of the weirs are superimposed upon an already altered flow regime. The Kolan River is regulated by Fred Haigh Dam and Bucca Weir, which are operated conjunctively. Flows in the Pioneer River are affected by Teemburra Dam and unregulated abstraction, as well as the weirs.

Changes in flow regime resulting from weirs have geomorphological and ecological implications. Only physical implications are discussed here, with particular reference to hydraulic habitat and sediment transport processes.

Hydraulic habitat conditions are determined by channel morphology and flow at any given point in time. Different hydrogeomorphic units vary in terms of their sensitivity to variations in flow. Riffles and other hydrogeomorphic units which act as low flow controls are subject to considerable changes in flow depth, velocity and wetted area as a result of variations in flow rates and are de-watered when flows cease. Therefore they are directly altered by flow regime change. Pool habitats change less in response to variations in flow, and (in the study area) retain water even after flows cease.

Sediment transport processes can be affected by flow regime change in two ways: impacts on sediment transport capacity, and impacts on sediment mobility. Flow is a key determinant of sediment transport capacity. Sand can be transported across the full range of flows, while coarse sediments such as gravel are generally only moved under high flow conditions. As the weirs in the study area generally have little, if any, effect on flood flows, they have limited implications for the transport of coarse sediments. However, sand transport processes may be affected.

The mobility of sediments stored in the riverbed, banks and bars is influenced by vegetation cover, which is susceptible to change as a result of flow regime modification. For example, in the reaches of the Burnett River where low flows have become elevated and more sustained as a result of regulation, dense beds of aquatic macrophytes have become established in riffle areas. The changes in flow regime in this instance are partly related to weirs, but also strongly influenced by Wuruma Dam on the Nogo River, a tributary of the Burnett, which is a key source of the water which is further regulated by the weirs. The dense aquatic vegetation cover reduces the mobility of the riffle sediments, except in major floods when the vegetation is scoured out.

As well as changes in overall flow regimes, operational procedures may also have downstream ecological implications. For example, sudden falls in water levels such as caused by the inflation of fabri-dams can cause fish stranding on and below spillways (Brizga *et al.* 2000).

Change in Sediment Supply

Sediment is intercepted by weirs as a result of their ponding and barrier effects, as discussed earlier in this paper. The weirs in the study area trap varying proportions of the incoming sediment load, leading to varying degrees of reduction in downstream sediment supply. The sediment load which passes a fixed-crest weir is likely be finer than it would have been in the absence of the weir, due to the impedance of bedload transport.

However, this is not necessarily the case for gated structures. For example, anecdotal evidence indicates that relatively coarse sediments, including gravels, are transported past the Ben Anderson Barrage, which has shutters, and deposited immediately downstream in floods.

A relative absence of sediment deposits in the rocky reach of the Pioneer River immediately downstream of Mirani Weir suggests clearwater erosion. Evidence of clearwater erosion, including bed armouring, has been observed by the author downstream of other large fixed-crest weirs (e.g. Brizga *et al.* 1999).

Changes in Estuary Hydrodynamics

Estuary hydrodynamics are affected by changes in flow regime, as well as the physical presence of tidal barrages. Relatively detailed investigations have been carried out in relation to the effects on the Ben Anderson Barrage on the Burnett River, which have been summarised by Brizga et al. (2000). A brief précis is given here.

The natural limit of tidal penetration in the Burnett River extended 56km inland from the coast. Ben Anderson Barrage limits tidal penetration to 25.9km inland from the coast. It has led to a reduction in the total tidal prism of the estuary by some 23% (Department of Harbours and Marine 1985). It has also caused amplification of the tidal range; that is, high tide levels are higher than they would naturally be, while low tide levels are lower (QGHL 1994). The degree of amplification is greatest at the barrage, and decreases downstream. Reduction in water depths in the estuary has been reported in recent years, which is likely to be partly due to tidal amplification (QGHL 1994). However, there has also been conspicuous deposition, particularly of fine sediments (silts, muds). The deposition of these materials in estuaries is determined by flocculation processes, which are related to saline water intrusion, chemical reactions at the interface between fresh and saline water, and mixing of fresh and saline water. These factors can be affected by changes in estuary hydrodynamics and freshwater inputs.

Conclusions

This paper provides an overview of the physical impacts of weirs on the Burnett, Kolan and Pioneer Rivers. Weirs are not the only form of water resource development in these catchments, and water resource management is only one of many factors affecting the condition of these rivers. Other influences on river condition include catchment land use, riparian zone management, and instream modifications. An understanding of how human activities (in this case, weirs) affect the environment is a necessary basis for improved environmental and resource management.

Acknowledgements

This paper draws on research carried out as part of the Griffith University research project “Environment Flow Guidelines for Queensland Rivers”, as well as environmental investigations funded by the DNR for the Burnett Basin and Pioneer Valley WRPs. The views expressed in this paper are not university or government policy. I would like to thank all of the people involved in the abovementioned studies, for numerous stimulating discussions which have influenced the ideas presented in this paper, especially Professor Angela Arthington, Mr Neil Craigie and Mr Ray Maynard.

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Biography

Sandra Brizga holds a PhD in Fluvial Geomorphology. From 1990-94 she worked as a Research Fellow and then Lecturer at the University of Melbourne, and since then has held an honorary appointment as an academic associate of the Department of Geography and Environmental Studies. In 1995, she commenced full time practice as a consultant in the fields of geomorphology and waterway management. She has carried out numerous studies in Victoria, Queensland, New South Wales and South Australia. In recent years, Sandra has undertaken extensive work in the field of environmental flows and management of regulated streams. She is currently the scientific coordinator of the environmental flow studies for the Barron, Burnett, Logan and Pioneer Water Allocation and Management Plans (WAMPs) in Queensland, and is involved in related research projects being carried out at the Centre for Catchment and In-stream Research at Griffith University.

Ecological Impacts of Weirs in the Pioneer Catchment, Queensland

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Abstract

This paper describes the effects of weirs on aquatic macrophyte and riparian vegetation communities of the Pioneer River, central Queensland. Flows in the Pioneer River are regulated by three weirs located at Mirani, Marian and Dumbleton Rocks. Collectively, these weirs inundate 30km of river channel, representing one-quarter of the total length of the Pioneer River. Alterations to the natural flow regime of the Pioneer River resulting from weir construction and operation include aseasonal fluctuations in water levels, vertical drawdowns in water levels that are more rapid than natural and prolonged periods of unnaturally elevated and stable water levels. Sudden changes in water levels in Mirani and Dumbleton weir pools occur through the use of fabridams mounted on weir crests and operated in relation to stream discharge. Whereas the magnitude of water level fluctuations in weir pools and unregulated reaches of the Pioneer River are comparable, rates of water level change are not.

Aquatic macrophyte and riparian vegetation communities associated with weir pools are substantially different to those communities found in unregulated areas of the Pioneer River. Aquatic macrophyte communities found in weir pools are dominated by exotic, semi-aquatic grasses that form dense stands in the littoral zones of weir pools. Macrophyte biomass is concentrated into a narrow band along weir littorals. In comparison, less impacted reaches of the Pioneer River are characterised by low aquatic macrophyte biomass, patchy growth and very low occurrence of exotic species.

*The lower Pioneer catchment originally supported predominantly medium to low open sclerophyll woodland comprising ironbark (*Eucalyptus crebra*), forest bluegum (*E. tereticornis*), bloodwood (*Corymbia intermedia, C. clarksoniana*), poplar gum (*E. platyphylla*), swamp mahogany (*Lophostemon suaveolens*) and paperbark woodland (*Melaleuca *spp.). The threatened eucalypt* Eucalyptus raveretiana *is found within the riparian zone of Blacks Creek and the Pioneer River. In drier parts, more open communities, with or without mesic (moisture-loving) elements in the sub-canopy and/or understorey feature river she-oak (*Casuarina cunninghamiana*), weeping bottlebrush (*Callistemon viminalis*) and weeping paperbark (*Melaleuca leucadendra*). Weir construction has resulted in the inundation of established riparian forests as evidenced by standing dead spars and of in-stream rock and sand bar communities. Exotic species are advantaged by such disturbances and have proliferated in degraded remnants.*

The impacts of weir construction and operation are confounded by land use practices, degradation of the riparian zone and the active spread and promotion of ponded pasture species. Restoration of riparian and in-stream vegetation communities of weir pools can have environmental, economic and social benefits but requires an holistic or integrated approach to manage the myriad of factors that structure vegetation communities of weir pools.

Introduction

The ecological effects of weirs can be divided into three types of impact: upstream effects resulting from the ponding of water above the structure, barrier effects arising from the presence of the structure, and downstream effects. Each class of impact involves change in flow and sediment regime, with implications for stream morphology and substrate characteristics (Walker & Thoms 1993). Water quality changes may also be involved depending upon the particular weir and how it is operated. These changes in turn alter the diversity and structure of aquatic communities as well as ecological processes normally operating in the free-flowing river (Walker & Thoms 1993).

This paper is concerned with the ecological impacts of weirs in the Pioneer catchment, Queensland, with particular reference to aquatic and riparian vegetation in weir pools. It forms part of a research project (“Guidelines for Environmental Flow Management in Queensland Rivers”) funded by the Queensland Department of Natural Resources.

Water resource development within the Pioneer catchment has been undertaken primarily to guarantee irrigation and urban supplies (Irrigation and Water Supply Commission 1975, Water Resources Division 1993). The Pioneer catchment is one of Australia’s premier sugarcane (*Saccharum officinarum*) growing districts, with about one-third of Queensland’s total sugar crop produced within the Pioneer system (Higham, W. 1999, pers. comm.). The city of Mackay (population 44,880, Australian Bureau of Statistics 1996 Census) is located at the mouth of the Pioneer River and population growth in Mackay and adjacent shires is expected to maintain pressure on surface water supplies in the catchment (Water Resources Division 1993).

At present five major water storages are located within the Pioneer catchment: Mirani, Marian and Dumbleton Weirs, located on the Pioneer River, and Kinchant and Teemburra Dams (Fig. 1). Kinchant Dam is part of the Eton Irrigation Project and receives “surplus” flows pumped from Mirani Weir via a diversion channel. Mirani Weir facilitates the delivery of water to Kinchant Dam by reducing pumping head (Irrigation and Water Supply Commission 1975). Kinchant Dam and the three weirs are operated as a single system to supply water for agricultural, industrial and domestic usage (Water Resources Division 1993). Teemburra Dam, on Teemburra Creek, is the most recent water infrastructure development within the Pioneer catchment. Water stored by Teemburra Dam is used primarily for sugarcane irrigation and is delivered to users via tributaries of the Pioneer River. At present, the Teemburra irrigation scheme is not fully operational and the flow regimes of the affected tributaries are not substantially altered.

This paper describes the condition of aquatic macrophyte and riparian vegetation communities of the Mirani, Marian and Dumbleton weir pools on the lower Pioneer River. We outline our methods of vegetation assessment and present data on weir pool vegetation in the form of data summaries and conceptual diagrammatic models. These models are designed to summarise our present understanding of the impacts of water infrastructure development on aquatic macrophyte and riparian vegetation communities of the Pioneer River, and to identify the ecological factors and processes affecting the composition and structure of these communities in weir pools. We suggest that several confounding factors are operating to structure vegetation communities of weir pools (e.g. flow regulation, land use, fire regime and invasions by exotic species), and propose an integrated approach to restoration of vegetation communities. The environmental, economic and social benefits of vegetation restoration are outlined.

Study Area and Methods

Study Area

The Pioneer catchment (including the adjacent Sandy and Bakers Creeks) is a small catchment of approximately 2,350km^2 located on the central coast of Queensland (Fig. 1). The Pioneer River sub-catchment has an area of approximately 1,490 km^2 and a mean annual discharge of 994,000ML per annum, representing 66% of the mean annual discharge of the entire catchment (Water Resources Division 1993). Headwater tributaries of the Pioneer River (including Teemburra Creek, Blacks Creek, Stockyard Creek and Black Waterhole Creek) originate in the Clarke and Connors Ranges (elevation 1,100-1,800m) within 80km of the Queensland coast (Gourlay & Hacker 1986; Water Resources Division 1993; Fig. 1).

Despite the relatively small catchment area, climatic conditions within the catchment are quite variable (Oliver 1973). The climate is generally described as tropical but the catchment lies astride the boundary of two Köppen climatic classification categories, Cfa (Mackay-Whitsunday Coast) and Cwa (Inland) (Linacre & Hobbs 1977). The former category is characterised by minimum temperatures exceeding 18^{o}C in the coolest month compared with minimum temperatures of –3 to 18^{o}C in the coolest month for the latter category (Linacre & Hobbs 1977). Both categories experience maximum temperatures exceeding 22ºC in the warmest month. Rainfall is highly seasonal, falling mostly between December and April, but inter- and intra-annual variability is relatively high (Water Resources Division 1993). Variations in rainfall within the catchment are in part attributable to topography and distance from the coast (Oliver 1973; Gourlay & Hacker 1986).

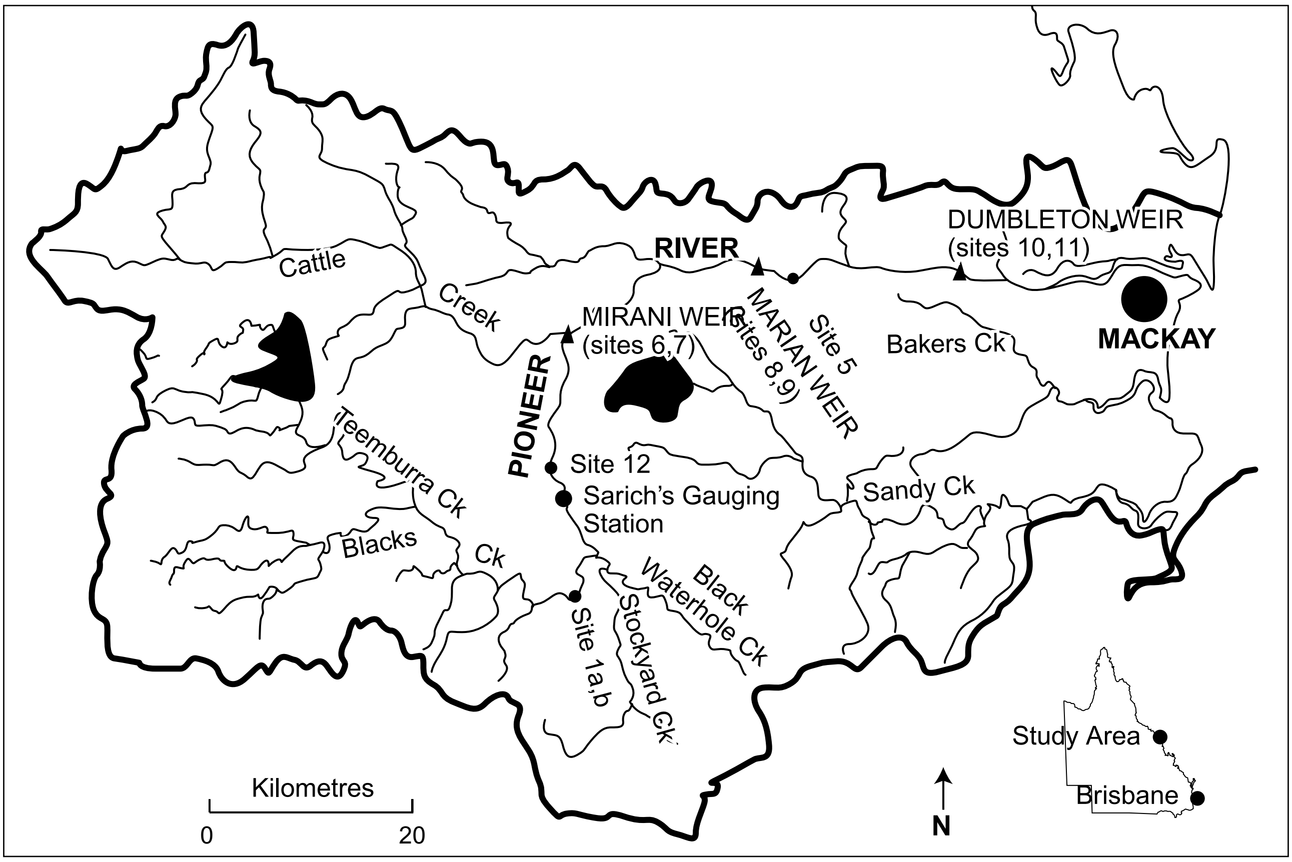
Geomorphology and Hydrology

Bedrock outcrops are a prominent feature of the Pioneer River and Gourlay and Hacker (1986) suggest that since much of the riverbed is scoured rock the river is actively degrading its bed. Although essentially a bedrock controlled river the channel is typically sandy and alluvial in nature because large volumes of sediment are produced from weathering in headwater tributaries (Gutteridge Haskens & Davey 1997). Sediment transport downstream has been interrupted by weir construction. Bank slumping is evident in the lower Pioneer River but this is not necessarily the result of weir construction (Gutteridge Haskens & Davey 1997). Approximately 30km of river channel have been inundated by Mirani, Marian and Dumbleton Weirs (Table 1), representing one quarter of the total length of the Pioneer River (Gourlay & Hacker 1986). This represents a substantial loss of natural in-stream habitat and its replacement by large bodies of standing water.

Water level fluctuations recorded at Sarich's gauging station (see Fig. 1), located in an unregulated reach of the Pioneer River are presented in Figure 2a. From the hydrograph it can be seen that river discharge, as shown by increases in water levels, is highest during spring–autumn and winter is generally a period of low flows. Increases in water levels associated with floods and spates are rapid but declines in water levels following flood recession are gradual, occurring over several days (Fig. 2a).

Substantial alterations to the flow regime of the Pioneer River have been brought about by Mirani, Marian and Dumbleton Weirs but each weir is operated in a different fashion (Figs. 2b-d; Table 1). Alterations to the flow regime of the Pioneer River can be summarised as aseasonal variations in water levels, aseasonal periods of flow stability and reduced frequency of high and low flows (Table 1). Water levels in Mirani Weir seldom exceed the control level. Vertical drawdowns of

Figure 1: Location of the Pioneer catchment and study sites on which conceptual models are based.



approximately 1.5m occur frequently, followed by refilling to the control level (Fig. 2b). Vertical drawdowns are interspersed with periods of stable water levels (e.g. see water levels for 1999, Fig. 2b). Vertical drawdowns in Dumbleton Weir are of a greater magnitude (2-5m) than Mirani Weir but Dumbleton Weir tends to dampen out water level fluctuations to a greater extent than Mirani Weir (Fig. 2b,c). Water level fluctuations in Mirani and Dumbleton Weirs are exacerbated by the use of “fabridams”, which are inflatable rubber structures attached along weir crests; they are used to increase weir height and are activated by river discharge (Table 1). Thus the control level of Dumbleton Weir varies between 14 and 16m (see Fig. 2c).

Water levels in Marian Weir are very stable and some degree of seasonality is retained, with greater fluctuations in water levels occurring in summer (Fig. 2d). Vertical drawdowns are typically 0.5-1m but water levels remain unnaturally stable for long periods of time (Fig. 2d). Marian Weir does not have a fabridam and frequently overspills the weir crest. Water level recessions in Marian Weir occur at a similar rate to natural water level recessions (Figs. 2a,d).

Figure 2: *Stage hydrographs for the Pioneer River at (a) Sarich’s gauging station, (b) Mirani Weir, (c) Dumbleton Weir and (d) Marian Weir. Marian Weir gauge decommissioned in 1988.*

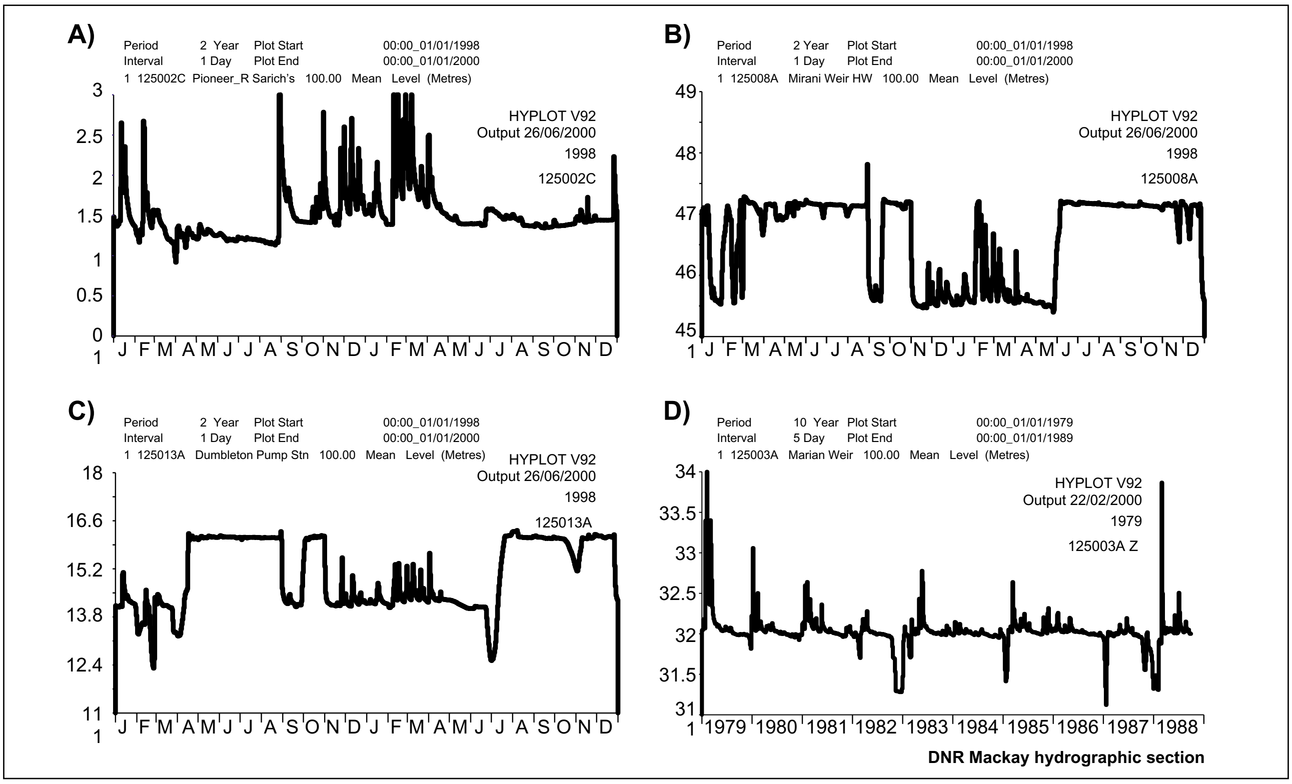


Table 1: *Characteristics of Mirani, Marian and Dumbleton Weirs. Sources: Gourlay & Hacker (1986); Water Resources Division (1993); Craigie (in press). See Brizga (2001, these proceedings) for more information on weir operating procedures and characteristics.*

	Mirani Weir	**Marian Weir**	**Dumbleton Weir (Stage III)**
Capacity (ML)	5,850	3,830	8,330
Purpose	Irrigation	Irrigation, industrial, urban	Irrigation, industrial, urban
Length of channel inundated	12km	7.5km	10.5km
Fabridam	Yes	No	Yes
Drownout	No	Yes	No
High flow frequency	Minor reduction	Minor reduction	Minor reduction
Low flow frequency	Moderate reduction	Moderate reduction	Minor reduction

Conceptual Model Development and Vegetation Surveys

Conceptual models were developed to describe reference (unregulated) condition and the impacts of channel inundation by weirs. The reference condition model was developed for comparison with the weirs model and describes the structure of aquatic macrophyte and riparian communities found in the middle to lower Pioneer River prior to weir construction. Conceptual models are based on data collected in August 1999 from unregulated reaches of the Pioneer catchment and weir pools as part of a research project "Guidelines for Environmental Flow Management in Queensland Rivers" (Arthington *et al.* in progress) funded by the Queensland Department of Natural Resources.

Sites were surveyed using rapid assessment and semi-quantitative methods to satisfy the dual purposes of this project, namely (i) comparison of rapid assessment techniques for stream condition assessment and (ii) assessment of the impacts of flow regulation in the Pioneer River. The latter was required as an input to the Pioneer WAMP program (Mackay 2000, Werren 2000). Sites in weir pools were surveyed using rapid assessment techniques whereas unregulated sites were surveyed using rapid assessment and semi-quantitative methods.

Conceptual models describing the upstream impacts of weirs (i.e. ponding) on aquatic macrophytes and riparian vegetation are based on data collected from four sites in each of the three weir pools (12 sites total) (Table 2). Within each weir pool two sites were surveyed in an "upstream" reach (left and right bank) and a "downstream" reach (left and right bank) (see Fig. 3 for terminology used to describe sites in weir pools). The reference condition model was based on data collected from Blacks Creek and the Pioneer River which were unimpacted by flow regulation (sites 1a,b and 12, see Fig. 1). Additional information regarding reference condition was obtained from one site surveyed between Marian and Dumbleton Weirs (Table 2).

Aquatic macrophyte communities were visually surveyed by wading, snorkelling or observation from a boat (Mackay 2000). Sites located in weir pools consisted of 100m of shoreline and all aquatic macrophytes occurring from the waterline to a distance of 3m from the bank were recorded.

Table 2: *Sites surveyed in the Pioneer catchment as part of the project "Guidelines for Environmental Flow Management in Queensland Rivers" (Arthington et al. in progress). LB = left bank looking downstream, RB = right bank looking downstream. Site locations are shown in Figure 1 and terminology used to describe weir pool sites is described in Figure 3.*

Site No.	Location	Description	Site Length
	Unregulated sites		
1a	Blacks Creek	Pool	100m
1b	Blacks Creek	Riffle	80m
12	Pioneer R @ Bustard Creek junction	Riffle-run sequence	100m
	Impacted sites (weir pools)		
6a	Pioneer R @ Mirani Weir	Upper Pool (RB)	100m
6b	Pioneer R @ Mirani Weir	Upper Pool (LB)	100m
7a	Pioneer R @ Mirani Weir	Lower Pool (RB)	100m
7b	Pioneer R @ Mirani Weir	Lower Pool (LB)	100m
8a	Pioneer R @ Marian Weir	Upper Pool (RB)	100m
8b	Pioneer R @ Marian Weir	Upper Pool (LB)	100m
9a	Pioneer R @ Marian Weir	Lower Pool (RB)	100m
9b	Pioneer R @ Marian Weir	Lower Pool (LB)	100m
10a	Pioneer R @ Dumbleton Weir	Lower Pool (RB)	100m
10b	Pioneer R @ Dumbleton Weir	Lower Pool (LB)	100m
11a	Pioneer R @ Dumbleton Weir	Upper Pool (RB)	100m
11b	Pioneer R @ Dumbleton Weir	Upper Pool (LB)	100m
	Between weir pools		
5	Pioneer R @ Marian	Pool	100m

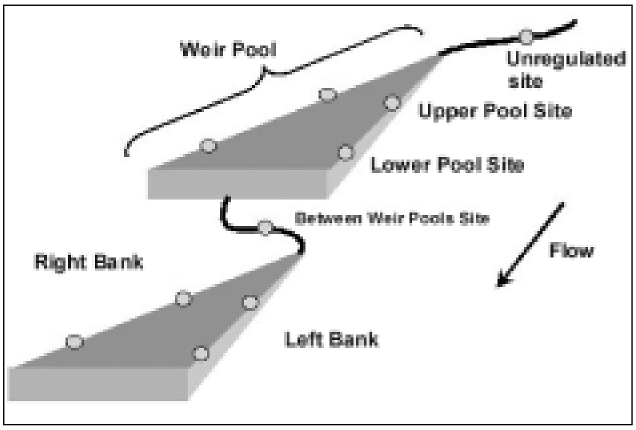


Figure 3: *Terminology used to describe sites located in weir pools.*

Sites in unregulated reaches and those downstream of weir pools consisted of 100m of river channel and all aquatic macrophytes occurring within the wetted perimeter of the channel were included in the survey (except site 5, where only the left bank was surveyed due to channel width). At all sites percent cover of individual species was estimated as a proportion of the total site area surveyed, using the Braun-Blanquet cover/sociability scale (Küchler 1967; Table 3). Sociability describes how individual species are distributed within the area surveyed and is estimated using a five-point scale (Table 3).

Riparian vegetation bordering weir pools was surveyed along 100m transects located parallel to the river channel (Werren 2000). Species presence/absence, relative abundance and structural configuration (presence of dead trees, canopy cover) were recorded at five points spaced at 25m intervals along each transect. Bank vegetation profiles were sketched at each inspection point. Detailed surveys carried out at reference sites and sites downstream of weir pools were performed along 10m wide transects perpendicular to the stream channel extending from the stream verge (channel edge) to a point just beyond the lip of the high bank. Transects were divided into three segments – bank verge (that section immediately adjacent to the channel), the flank, and the lip (high bank). A sketch of the bank configuration was made and details of soil type, aspect and gradient were recorded. Broad structural features such as the height and degree of stratification of the vegetation and structural type (Specht 1981) and extent of canopy cover (spherical densiometer, Lemmon 1956) were recorded at mid-points along verge, flank and lip of the bank. Indications of impacts not apparently related to flow (e.g. fire damage, stock trampling) were also noted.

Relative abundance of individual riparian species was recorded according to the DAFOR system (Table 3) within each subordinate stratum (i.e. understorey, groundcover, and 'other' to provide for vines, epiphytes, etc.) for each transect segment (verge, flank, lip). Woody vegetation with stem sizes ≥ 10cm GBH (girth at breast height i.e. 1.2m) was noted within a 5m swathe either side of a tape measure aligned along the centre of the transect, with species identity, stem girth, height and stem/crown condition recorded on a standard pro forma. This allowed subsequent calculation of stem density and basal area for the various bank segments and a broad appraisal of proportion of damaged or dead stems.

Results of Surveys

For the purposes of constructing conceptual models we present preliminary results from the aquatic macrophyte and riparian vegetation surveys carried out in the Pioneer catchment. More comprehensive analyses will be presented in a separate publication.

Table 3: *The Braun-Blanquet (Küchler 1967) and DAFOR scales for estimating plant cover and sociability.*

Class	Braun-Blanquet Cover	Braun-Blanquet Sociability	DAFOR
5	76-100% of the area	1 = Growing singly	(D)ominant = 5
4	51-75% of the area	2 = Growing in tufts	(A)bundant = 4
3	26-50% of the area	3 = Growing in small groups	(F)requent = 3
2	6-25% of the area	4 = Growing in larger groups	(O)ccasional = 2
1	1-5% of the area	5 = Growing in extensive groups	(R)are = 1
+	Less than 1% of the area		Rare
r	Extremely small area; usually only 1 specimen		Rare

Aquatic macrophyte and riparian species recorded from Pioneer catchment sites are listed in Appendices 1 and 2 respectively. Thirty (30) aquatic macrophyte taxa and 135 riparian taxa were recorded. Aquatic macrophytes were predominantly submerged and emergent taxa (Appendix 1) and many of these species have wide distributions within Queensland (Orchard 1985, Sainty and Jacobs 1994). The number of aquatic macrophyte taxa recorded per site varied from 3-12 for unregulated sites, and between 2-9 for sites in weir pools (Appendix 1). Exotic aquatic macrophytes were not recorded from unregulated reaches but in some cases comprised a large proportion of the species recorded from weir pools (Fig. 4; Appendix 1). The number of riparian taxa varied considerably between sites, but in general more taxa were recorded from weir pools (Appendix 2). Exotic species comprised a large proportion of the total riparian species recorded, even in unregulated reaches of the Pioneer River (Fig. 4).

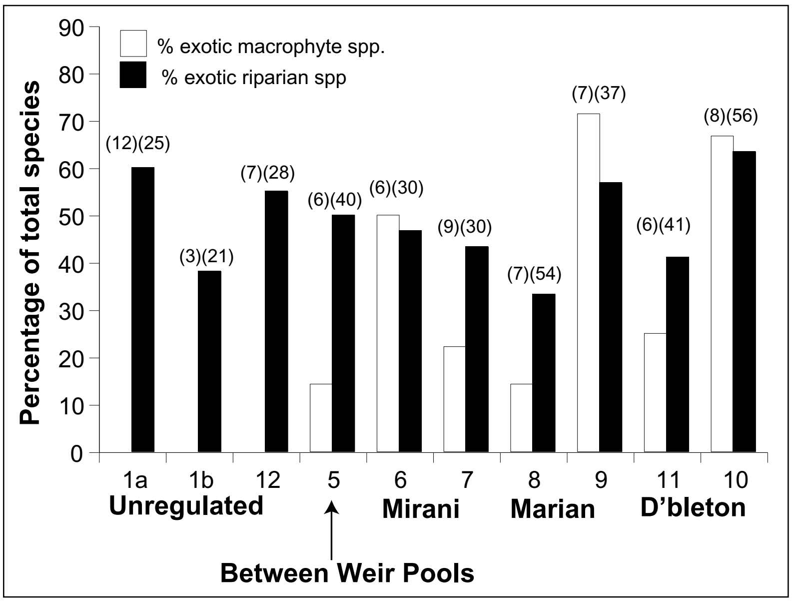


Figure 4: *Percentage of native and exotic macrophyte and riparian species recorded from Pioneer River sites. Figures in brackets are the total number of macrophyte and riparian species recorded from each site.*

Conceptual Models

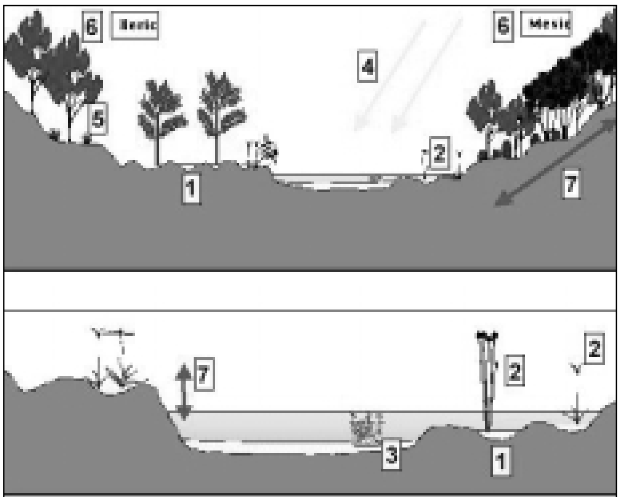
Reference Condition Model

In unregulated river reaches of the Pioneer River, aquatic macrophyte abundance is generally low and sociability scores indicate that aquatic macrophytes generally occur in small clumps, i.e. extensive beds of vegetation are rare (Appendix 1). This pattern of plant growth is represented in a conceptual model of reference condition in Figure 5.

The primary factor limiting aquatic macrophyte growth in the Pioneer River is the suitability of substrates for colonisation and establishment, and substrate stability, which influences the ability of aquatic macrophytes to resist scouring. The substrate of the lower Pioneer River features bedrock outcrops and sandy, unstable substrates, with smaller amounts of coarser materials. Finer alluvial sediments accumulate in depressions in the bedrock and aquatic macrophytes of varying growth forms (i.e. submerged, floating and emergent species) colonise these accumulations. However, accumulations of finer sediments are easily entrained by higher flows, thus aquatic macrophytes (including below-ground parts) are easily scoured during high flow events. Coarser, more consolidated substrates are not as easily entrained and prevent below ground parts from being scoured during spates. This permits relatively rapid regeneration or recolonisation following flow disturbance. An example is the species diversity of site 1a, Blacks Creek (Appendix 1). The relatively high species diversity of this site is due in part to the presence of a narrow strip of coarse substrate (cobbles) which was extensively colonised by a variety of submerged macrophyte species, including *Hydrilla verticillata*, *Ottelia alismoides*, *Potamogeton javanicus* and *P. crispus*. Aquatic macrophyte abundance on surrounding sandy substrates was found to be lower than on cobble substrates.

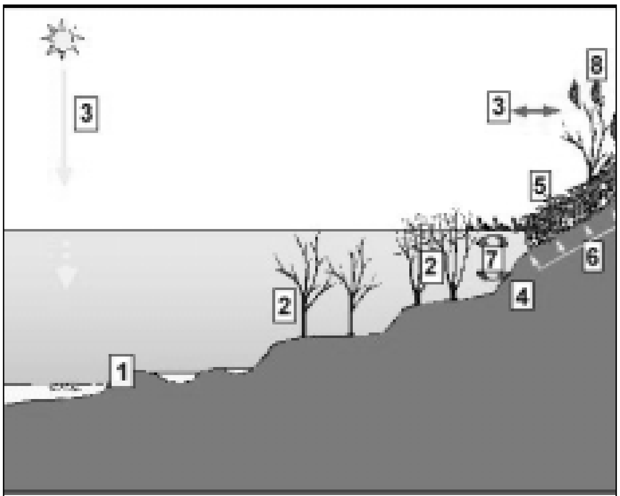
The lower Pioneer catchment originally supported predominantly medium to low open sclerophyll woodland comprising ironbark (*Eucalyptus crebra*), forest bluegum (*E. tereticornis*), bloodwood (*Corymbia intermedia*, *C. clarksoniana*), poplar gum (*E. platyphylla*), swamp mahogany (*Lophostemon suaveolens*) and paperbark woodland (*Melaleuca* spp.) (Werren 2000). The threatened eucalypt *Eucalyptus raveretiana* is found within the riparian zone of Blacks Creek and the Pioneer River (Werren 2000). In drier parts more open communities, with or without mesic (moisture-loving) elements in the sub-canopy and/or

Figure 5: *Conceptual model of reference condition for aquatic macrophyte and riparian vegetation communities of the Pioneer River.*



1. *Substrate typically rocky with finer sediments accumulating in depressions -finer substrates colonised by aquatic macrophytes.* ***2.*** *Aquatic macrophyte assemblages characterised by low abundance and high structural diversity (i.e. submerged, floating and emergent species).* ***3.*** *Coarser sediments that resist entrainment may support higher aquatic macrophyte assemblages with higher abundances and greater species diversity.* ***4.*** *Aquatic macrophyte growth not light-limited, since channel width is high and shading by riparian vegetation is minimal.* ***5.*** *Riparian assemblages structurally diverse, with distinct layering of vegetation (i.e. trees, shrubs, grasses) and few if any exotic species.* ***6.*** *Bank aspect (position relative to sun) may influence structure of riparian assemblages, with xeric (drought tolerant) species in exposed locations and mesic (moisture-loving) species in sheltered areas.* ***7.*** *Water level fluctuations influence species composition of vegetation assemblages: species tolerant of periodic inundation/exposure found near waterline, whereas purely terrestrial species are found in areas rarely or never flooded. Fluctuations in water levels may also be important reproductive or flowering triggers.*

Figure 6: *Conceptual model describing aquatic and riparian vegetation communities found in lower weir pools of the Pioneer River.*



1. *In-stream habitat (e.g. bedrock outcrops, sand bars) lost through flooding.* ***2.*** *Death of trees and other vegetation intolerant of flooding and increased illumination.* ***3.*** *Aquatic vegetation restricted to narrow littoral zone as sunlight cannot penetrate to substrate in deeper parts of the pondage.* ***4.*** *The new littorals are characterised by steep gradients and are therefore difficult for native macrophyte species to colonise.* ***5.*** *Degraded riparian zone and increased moisture availability promotes prolific growth of exotic semi-aquatic grasses such as para grass and floating species e.g. Eichhornia crassipes that smother native submerged species. Loss of native aquatic and riparian species. Structural diversity low.* ***6.*** *Para grass, being a "clonal" plant, can share resources (e.g. nutrients) amongst stems sharing a common root system. This allows persistence in variable habitats such as weir littorals that are prone to desiccation and inundation.* ***7.*** *Excessive aquatic macrophyte growth causes diurnal fluctuations in dissolved oxygen concentrations and may lead to death of aquatic fauna e.g. fish. 8. Increased growth of exotic grasses increases fire-proneness of near-stream community.*

understorey depending upon bank aspect (Fig. 4), feature river she-oak (*Casuarina cunninghamiana*), weeping bottlebrush (*Callistemon viminalis*) and weeping paperbark (*Melaleuca leucadendra*).

Conceptual Model for Lower Weir Pools

Aquatic Macrophytes

Aquatic macrophyte communities of the Mirani, Marian and Dumbleton Weir pools are quite distinct from communities found in unregulated or less impacted areas of the Pioneer catchment (Appendix 1; Fig. 6). All three weir pools are dominated by exotic, semi-aquatic grasses such as para grass (*Urochloa mutica*), wild cane (*Saccharum spontaneum*) and cow cane (*Pennisetum purpureum*). Beds formed by these species are extensive and native species, especially submerged species, are relatively low in abundance (Appendix 1). The free-floating exotic *Eichhornia crassipes* (water hyacinth) is also prevalent in some weir pools, particularly in lower weir pools. The more common native species in weir pools are semi-aquatic taxa such as Polygonaceae (e.g. *Persicaria* spp.) or free-floating species such as *Azolla* spp. and *Lemna* spp. (Appendix 1). Species recorded from weir pools also included typically terrestrial species such as *Pandanus* sp., *Lantana camara* (lantana) and *Ageratum conyzoides* (blue top) which are periodically inundated by changes in water levels.

There are several interacting factors influencing the structure of aquatic macrophyte communities in weir pools. Ponding by the weirs results in flooding of the channel and in the case of Mirani, Marian and Dumbleton Weirs, reduced in-stream habitat diversity, e.g. in-stream bedrock outcrops and sand and gravel bars are lost due to inundation (Fig. 6). Weir pools have made much of the channel uninhabitable due to increased water depths and reduced light penetration in deep areas, thereby restricting plant growth to a zone of approximately 3-5m extending out from the shoreline of the weir pool (Fig. 6). In addition, the new littoral zones created by the weir pools are characterised by steep banks (especially in lower pool areas) which are not easily colonised by submerged macrophytes (Duarte & Kalff 1986) (Fig. 6).

Establishment of para grass and other exotic grasses in weir pools is aided by disturbance to the riparian zone (see below). The growth of exotic species such as para grass may be reduced (but not necessarily completely suppressed) by riparian shading (Bunn *et al.* 1998). In the absence of weir pools, an intact riparian zone in the lower Pioneer River may not have completely shaded out aquatic macrophytes (due to channel width) but may have partially reduced aquatic macrophyte cover in littoral areas and hindered the growth of exotic species (e.g. Bunn *et al.* 1998).

In upper weir pools the impacts of weirs are somewhat ameliorated as river depths become shallower, light penetration increases, bank gradients decrease and water level fluctuations are more similar to natural fluctuations. Submerged species may occur in areas where para grass is absent or in low abundance (see Appendix 1).

Riparian Vegetation

Increases in locally available surface water and wetted perimeter as a result of ponding prompts increased growth of mesic (moisture-loving) riparian plants, possibly at the expense of more xeric (drought-tolerant) local species. Additional moisture availability may also promote increased vigour and height of the fringing vegetation. This scenario can also initiate interaction with factors unrelated to water resource development by increasing the opportunity for invasion of exotic species that require moist conditions for establishment. These plants include a suite of introduced pasture species such as molasses grass (*Melinus minutiflora*) and guinea grass (*Panicum maximum*) that cure during drier times of the year to produce highly flammable fuel loads, increasing the fire-proneness of the near-stream community (Wallmer 1994). Should flows be elevated to levels that inundate lateral terraces, opportunities for invasion by exotic ponded pasture species such as para grass (*Urochloa mutica*) will be greatly increased.

Weir ponding may result in the death of woody vegetation, which is often sensitive to flooding or inundation (Hill & Keddy 1992). Dead spars of formerly middle-bank riparian trees are testimony to the impacts of water resource development. These are prominent immediately in and around all weir pools on the Pioneer River, particularly where banks are comparatively steep. Where trees have been drowned and the canopy consequently opened, exotic weed species have proliferated, adding a factor reinforcement dimension to the direct impact of impoundment.

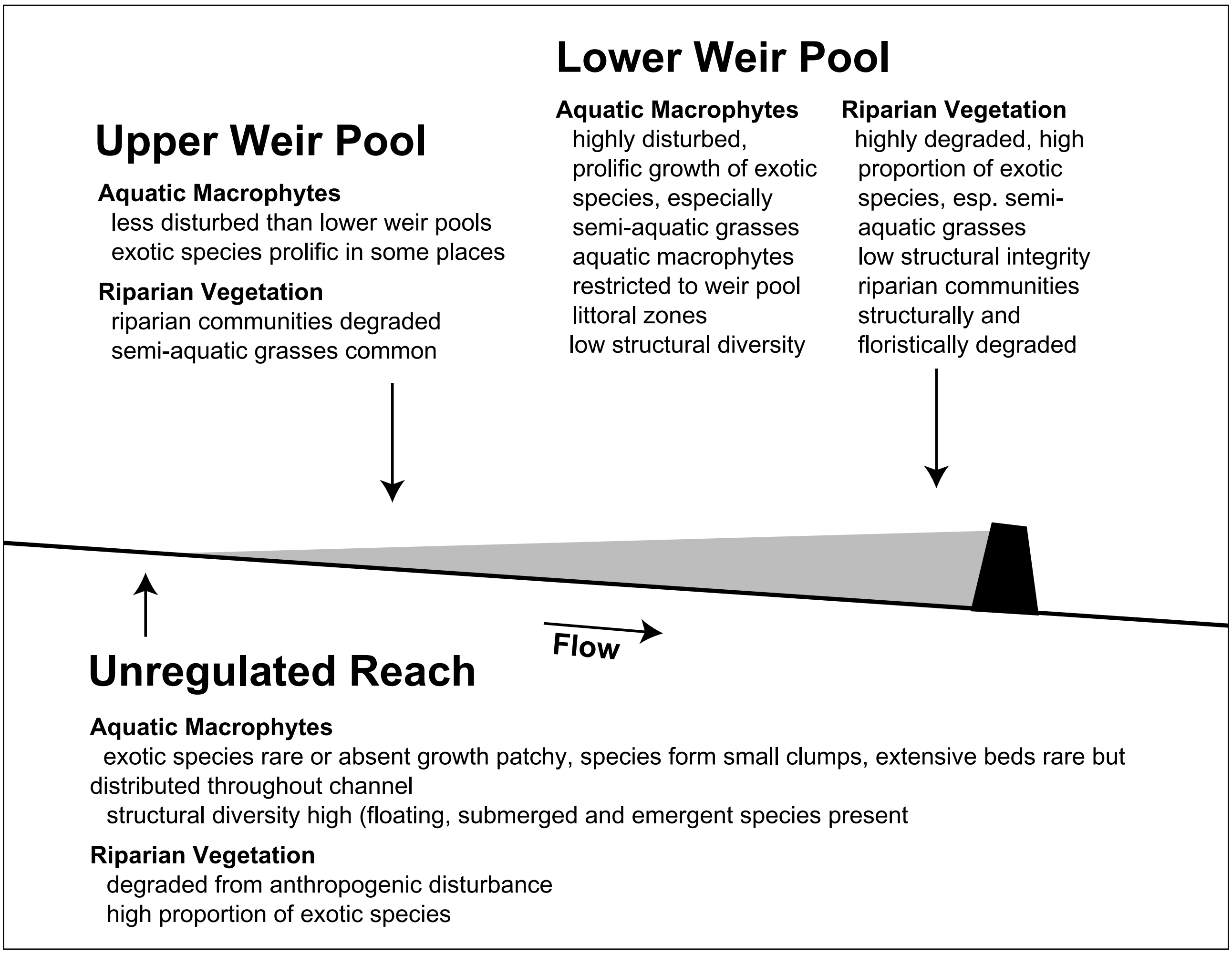
Discussion

Effects of Water Resource Development

Aquatic macrophyte and riparian communities associated with Mirani, Marian and Dumbleton Weirs are substantially different from those communities found in unregulated reaches of the Pioneer River. Plant communities associated with lower weir pools are highly disturbed systems dominated by emergent, semi-aquatic grasses. Aquatic macrophyte biomass is concentrated into narrow littoral zones, biomass is high and structural diversity is low, with communities dominated by exotic species. Riparian zones are also dominated by exotic ponded pasture species and similarly, the structural diversity of the riparian zone is reduced. The characteristics of these plant communities are summarised in Figure 7.

Several processes are interacting to structure aquatic macrophyte and riparian communities associated with weir pools. The effects of flow regime changes (in particular, water level fluctuations) are difficult to assess but are

Figure 7: *Summary model of characteristics of aquatic and riparian vegetation communities of the Pioneer River.*



essentially related to the effects of disturbance (Grime 1977, Biggs 1996). Fluctuations in water levels associated with weir operation, while potentially not as large as natural seasonal fluctuations, are aseasonal and vertical drawdowns may involve greater rates of decrease than occur naturally (see Fig. 2). It is likely that many native aquatic and riparian species do not tolerate the relatively rapid changes in water level associated with weir operation. In a natural system aquatic and riparian vegetation communities establish in relation to a flow disturbance gradient, i.e. species tolerant of frequent inundation are found lower on the gradient or closer to the waterline than those species intolerant of inundation (e.g. Brock & Casanova 1997). Species tolerant of inundation and desiccation (e.g. *Myriophyllum* spp.) possess life history attributes such as variable leaf morphology that allow persistence in habitats where falls in water levels occur over several days (Brock 1991, Brock & Casanova 1997). Some submerged species such as *Vallisneria* (ribbonweed) and *Potamogeton* spp. (pondweeds) may not survive desiccation if exposed to direct sunlight (Sainty & Jacobs 1981, Blanch & Walker 1998).

In weir pools, the natural disturbance gradient is replaced by a "moving littoral" (Ward & Stanford 1995) representing a zone of continued (but irregular) phases of disturbance, i.e. inundation and desiccation with little opportunity for mature vegetation communities to develop. This can be interpreted as a change from physical flow disturbance (e.g. scouring) in unregulated reaches to more subtle disturbance via water level fluctuations along weir pools (e.g. Roberts &

Ludwig 1991, Blanch & Walker 1998). Vegetation communities adjacent to weir pools are characterised by opportunistic "weedy" species (Werren 2000), especially ruderal species that possess life history attributes enabling persistence in these environments. These ruderal species are typically efficient dispersers and recover rapidly from disturbance through vegetative reproduction (see Blanch and Walker 1998).

The introduced para grass (*Urochloa mutica*) is a successful exploiter of disturbed aquatic habitats (e.g. Arthington, Milton & McKay 1983, Bunn, Davies & Kellaway 1997). Para grass is a robust, fast growing species reaching 2m in height, usually found in moist environments (Sainty & Jacobs 1981). In aquatic habitats para grass grows as an emergent in shallow water or as floating mats in deeper water (Sainty & Jacobs 1981). Para grass spreads mainly vegetatively, producing "clones" or ramets connected by stolons up to 5m long. Effectively, a stand of para grass may consist of a number of individual ramets sharing a common root system. The advantage of such a method of reproduction and dispersal is that resources can be shared amongst ramets connected by stolons (Stuefer, During & Schieving 1998), especially in spatially and temporally heterogeneous and variable environments such as weir pools. It should be noted, however, that many native species possess similar attributes (reproduce vegetatively, are efficient dispersers), suggesting that other factors such as interspecific competition may also influence plant community structure in weir pools (Biggs 1996).

Other components of water resource development that further disrupt the riparian zone can be more difficult to distinguish from the myriad of factors exerting influence on that zone. These can operate indirectly and/or reinforce or countervail other factors that are operating. Two examples of this are riparian clearing and the introduction of exotic species. Approximately 65% of the region's vegetation has been cleared for agricultural and urban development (Clear 2000), often to the stream margin (Werren 2000). Increased light availability through reduced riparian shading promotes the growth of weedy species such as para grass (Bunn, Davies & Kellaway 1997). Pesticides draining from agricultural areas into the riparian zone and waterways can cause direct damage to riparian plants, either through direct death or sub-lethal effects that reduce vigour to a point where native species are out-competed by exotics or fail to reproduce successfully (Werren 2000). Nutrients leached from crops can, in the context of the comparatively poor soils of the district (Werren 2000), advantage exotic species not pre-adapted to low nutrient environments and produce eutrophic conditions along stream verges and within waterways. This frequently prompts vigorous growth of moisture-loving terrestrial plants, incursion of semi-aquatic grasses into riparian communities and algal blooms (Arthington *et al.* 1997, Werren 2000).

Because riparian zones are often the most environmentally equable parts of the landscape, there is likely to be a prevalence of weedy species within these systems. A considerable proportion of the region's flora is comprised of exotic species, particularly introduced pasture grasses and legumes (Anderson *et al.* 1983). Around Mackay, Batianoff & Franks (1998) recorded 310 species of naturalised exotics with 12 considered significant. The region has been the staging point for several species that have become significant environmental weeds elsewhere. It is notable that most of these problem plants have arisen from deliberate introductions for pasture "improvement" or stock fodder (e.g. the aggressive lucaena, *Lucaena leucocephala* that now dominates much of the riparian verge of the lower catchment). Additional exotic pest species of note are the vines *Macfadyena unguis-cati* (cats-claw creeper), *Anredera cordifolia*, pasture legume vines such as *Glycine* spp., siratro (*Macroptilium atropurpureum*) and pasture grasses such as cow cane (*Pennisetum purpureum*) and wild cane (*Saccharum spontaneum*). All are prevalent within the riparian zone, and, with regard to the giant grasses, can grow within the stream itself. The type and abundance of weed infestation can have significant consequences for the integrity of the remaining riparian verge, particularly with regard to fire proneness (Wallmer 1994) and is likely to inhibit any natural recovery in the absence of further clearing (Werren 2000).

An even more aggressive recently introduced ponded pasture species is Hymenachne (*Hymenachne amplexicaulis*). This South American species, along with a native congener (*H. acutigluma*, from the Gulf of Carpentaria and the Northern Territory), pose considerable threats to the district's waterways and wetlands. Infestations of both grasses occur in the Sandringham Lagoons (Sandy Creek sub-catchment) and reportedly occur elsewhere within the study area (Dunn C., 2000, pers. comm.; Paterson G., 1999, pers. comm.). Being robust species they can be expected to constitute an even greater problem than that which para grass already poses.

Stock itself is an alien introduction that can wreak major impacts on the riparian zone both through destruction of ground cover and understorey plants by grazing and through trampling, compaction and erosion (Jansen & Robertson, in press). Stock excrement can also provide nutrients at levels far in excess of natural levels within the riparian zone, particularly at watering access points. This can significantly modify the floristics and structure of the riparian community. It can distinctly advantage exotic species at the expense of native riparian constituents and, when transported into the stream, will have adverse impacts on water quality and implications for aquatic community composition, structure and functioning (Werren 2000).

Implications of Degraded Vegetation Communities

Aquatic macrophyte and riparian vegetation communities are recognised as integral components of natural aquatic ecosystems. They increase habitat heterogeneity, directly modify aquatic habitats and provide food, cover, and spawning and nesting sites for aquatic and semi-aquatic biota (Carpenter & Lodge 1986, Catterall 1993, Cummins 1993, Carr, Duthie & Taylor 1997, Scott 1997, Lynch & Catterall 1999). Disturbance to aquatic macrophyte and riparian vegetation communities may have effects on other aquatic biota (invertebrates, fish and turtles) or terrestrial biota reliant on aquatic systems for food, shelter or nesting sites (Arthington *et al.* 1997, Lynch & Catterall 1999). Excessive aquatic macrophyte growth may interfere with recreational activities (Mitchell 1978) and produce large diurnal fluctuations in dissolved oxygen (DO) which may lead to fish kills (Brooker, Morris & Hemsworth 1977, Mitchell 1978, Henriques 1987). Riparian vegetation is an important source of carbon for in-stream communities. Para grass, however, contributes little carbon to in-stream food webs (Bunn, Davies & Kellaway 1997). Moreover, para grass beds reduce stream flow, increase fine sediment deposition, reduce channel capacity and consequently increase flood risk to sugarcane farmers (Arthington *et al.* 1997, Bunn, Davies & Kellaway 1997, Bunn *et al.* 1998). The role of riparian zones in buffering streams and rivers against sediment and nutrient runoff has been well documented (Lowrance *et al.* 1984, Ryan 1991, Campbell 1993).

Disturbed vegetation communities often provide habitat for exotic fauna. Para grass provides habitat for exotic fish species such as tilapia (*Oreochromis mozambicus*, *Tilapia mariae*), guppy (*Poecilia reticulata*), swordtail (*Xiphophorus maculata*) and mosquito fish (*Gambusia holbrooki*), and protects the smaller species from the full force of flood waters (Arthington, Milton & McKay 1983). The cane rat (*Rattus sordidus*), which causes damage to sugarcane, can be controlled by establishing closed canopy vegetation in riparian zones (Tucker & Brodie 1996, Arthington *et al.* 1997).

Conservation and/or restoration of native in-stream and near-stream vegetation communities should ensure the maintenance of faunal biodiversity and minimise the economic and ecological impacts of exotic flora and fauna and habitat degradation (Pusey, Arthington & Read 1993, Humphries 1996, Lynch & Catterall 1999). Vegetation restoration would also improve the amenity and recreational value of weir pools for fishing and other water-based activities.

Management Options for Weir Pools

The conceptual models presented in this paper summarise our present understanding of the impacts of water infrastructure development on aquatic macrophyte and riparian communities of the Pioneer River and we have identified several hypothetical, causal mechanisms to explain the composition and structure of these communities. More intensive seasonal surveys will be required to capture temporal variations in vegetation structure, and to improve our understanding of these causal mechanisms. Nevertheless, it is clear that several confounding factors are operating to structure vegetation communities of weir pools (e.g. flow regulation, land use, fire regime and invasions by exotic species), suggesting that an integrated holistic approach to vegetation management is desirable.

Walker and Thoms (1993), in discussing management options for the Murray River, state

"Given the requirements of irrigators and other water consumers, and the political and economic constraints that abound, it is doubtful whether proposals to restore a more nearly natural distribution of flows ... would be seriously regarded, although this may be the only option for restoration of some elements of the natural ecosystem." This is equally true of the Pioneer system. Sugarcane production in the Mackay region requires water for irrigation (Irrigation and Water Supply Commission 1975) and increasing urbanisation in the local shires will increase demands on surface water supplies. However, this does not mean that alleviating the impacts of weir pools is a futile exercise. Restoration of riparian and in-stream vegetation communities of weir pools can have environmental, economic and social benefits (Section 5.2). How can vegetation restoration be achieved in a river such as the Pioneer?

It is often stated that mimicking the natural flow regime as far as possible will produce ecological benefits in regulated rivers (Poff & Ward 1990, Walker 1993, Richter *et al.* 1997). In the case of the Pioneer River, simply reducing flow regulation impacts (e.g. water level fluctuations) may have relatively little effect in ameliorating degradation of aquatic macrophyte and riparian communities in weir pools. We suggest that several management approaches must be integrated for successful vegetation restoration. Firstly, maintaining as much natural flow variability as possible to weir pools will restore the flow disturbance gradient, seasonal flow-related triggers of life history processes and competitive interactions. Adjustments of the flow regime and weir pool water level fluctuations should be combined with restoration of riparian zones. (The latter will increase shading, aid in reducing the abundance of exotic species and produce detritus and energy inputs to river food webs) (e.g. Bunn *et al.* 1998). Restoring natural flow variability entails natural rates of rise and fall in water levels, maintaining seasonality in water level fluctuations as much as possible (i.e. greater variability during spring-summer) and reducing periods of unnaturally stable water levels. The use of fabridams should be minimised or discouraged since these structures exacerbate water level fluctuations in weir pools. Restoration of riparian zones should help to maintain rare and endangered plant species and regional ecosystems while minimising spread of exotic species such as para grass and Hymenachne.

Acknowledgements

We thank Dr Thorsten Mosisch (CCISR) for assistance with designing conceptual models, DNR for provision of hydrological data and Dr Sandra Brizga (Brizga and Associates) for assistance in the interpretation of these data. This project was funded by the Queensland Department of Natural Resources' WIPDIP initiative.

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Angela's chief research interest is the ecology and flow requirements of freshwater fishes. She and her team are currently working on a book on the biology and flow requirements of the freshwater fishes of Queensland. Her recent research has produced a series of protocols for determining, providing and monitoring environmental flows. Angela has promoted a whole of system approach to the issue of environmental flows, and is the author of four LWRRDC Occasional Papers on this theme.

Impacts of Weirs on Fish

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Abstract

Fish are one of the key components of biodiversity which are affected by weirs. Fish are also one of the key indicators with which the public can identify and judge the success of river management. As our native freshwater fish species have suffered substantial declines and now contain many threatened species, this judgment would suggest that our management has not been very sustainable. Many of the threats to fish populations arise from the use of water for non-environmental purposes, including the installation and management of weirs.

The impacts of weirs on fish populations include:

- *barriers to movements in both upstream and downstream directions for adults, juveniles, eggs and larvae;*
- *blockages of access to floodplains and tributaries;*
- *changes to natural flow regimes and decreases in water quality, particularly temperature, and dissolved oxygen;*
- *trapping of nutrients, sediments and drifting fish eggs and larvae; and*
- *increases in still water habitats which favour exotic species such as carp.*

All of these impacts have been recognised as being major causes for declines in our native freshwater fish populations.

Introduction

Threats to our native freshwater fish species have been well recognised (e.g. Cadwallader 1979, Koehn and O'Connor 1990a, Faragher and Harris 1998, Kearney *et al.* 1999, Koehn and Nicol 2000). High on the list of these threats are the impacts of weirs and their operations. As weirs are an integral part of water supply systems, they also contribute to other issues relating to flow regulation which in themselves are major threats to fish species.

Walker (2001) has outlined many of the wider ecological impacts of weirs on river ecosystems. This paper deals with the more direct impacts of weirs on fish, incorporating evidence of detail from the above mentioned and other references. In particular, this paper refers to impacts on native species and presents examples primarily from freshwater rivers in south-eastern Australia. The principles presented here, however, also apply to estuarine reaches (Leadbitter 2001) and to rivers elsewhere in Australia and overseas. Whilst addressing the impacts of weirs, the importance of a holistic approach to rivers and river problems cannot be over emphasised.

The impacts of weirs on fish is of the highest importance because the public identify and relate to impacts on fish more than any other environmental component. Angling is one of

Australia's most popular sports and fish, particularly large, "flagship" angling species, are viewed as measures of management success and can also be used to promote wider environmental issues relating to rivers.

This paper outlines the variety of both direct and indirect impacts that weirs may have on fish populations. It emphasises the importance of fish movement to the lifecycles of some species and details how this may be affected by physical barriers, changes to flows, water quality and habitats.

Fish Movement

Fish are mobile creatures and have a need to move widely throughout the river system. Whilst it has been known for some time that the adults of species such as golden perch can migrate over 1000km (Reynolds 1983), it has only recently been discovered that large numbers of juvenile fish of species such as silver perch also move upstream (Mallen-Cooper *et al.* 1995). Species such as Murray cod, which were previously thought to be sedentary, have also now been shown to undertake relatively large movements (Koehn 1997). Whilst these species may be able to survive and reproduce even if such movements are restricted, their ultimate survival and distribution over the longer term may be detrimentally affected. Some of the major migrations that we do understand occur in a particular season, often stimulated by flows or an urge to spawn. Whilst we know that some major fish migrations are initiated by individual flow events often occurring during spawning seasons, other movements are not understood. Until they are understood, it is important that fish passage is available to all species throughout the year. The capacity to move throughout the river system is crucial to fish recolonisation, breeding and recruitment. Examples of some movement types are given in Table 1, including basic reasons such as finding mates and spawning sites, and accessing new food and habitat resources. Many freshwater fish need to complete part of their lifecycle in marine environments and so have more complicated movement patterns (McDowall 1988).

Understanding the movement requirements of fish species is important to be able to better manage the impacts of weirs.

Upstream movements: These have traditionally received the most attention and are being addressed through the construction of fish ladders (see Harris 2001). Fish movements from lakes into inflowing rivers to spawn have also been documented (Koehn 1996).

Downstream movements: Whilst most attention to movement barriers has been for fish passage to

Table 1: *Types of movements and examples of why they may occur (from Koehn 2000)*

Movement types	Example
large scale	movements between spawning, feeding and nursery habitats
local	feeding, habitat preference, territoriality, home range
migratory	generally larger scale, for spawning, recolonisation
seasonal	spawning, temperature / condition related
daily	local, diurnal
regular	related to regular cues such as light
opportunistic	feeding related / prey abundance, flooding
obligate	innate spawning mechanisms
preferential	habitat selection
active	upstream movements, unassisted
passive	using currents or streamflows for assistance or drift
diurnal	activity based, predator avoidance related to light levels
upstream	active, often spawning or recolonising
downstream	may be passive or active, post spawning
vertical	may be following prey / avoiding predators, advantages to placement in the water column e.g. temperature, light
lateral	on or off the floodplain or in and out of anabranches

allow upstream movements, downstream movements are also important. Examples of downstream movements of adult fish have now been documented for species such as Australian bass (Harris 1986), common galaxias (Frankenberg 1966), Murray cod (Koehn 1997), golden perch (Koehn and Nicol 1998, McKinnon 1997) and carp (Koehn and Nicol 1998); the latter three species being restricted wholly to freshwater environments.

Lateral movements to and from the floodplain or floodplain channels: Within rivers, fish can also move opportunistically into anabranches (Koehn 1997) or onto the floodplain, although Australian evidence for the latter has been somewhat limited to date (Humphries *et al.* 1999). Lateral movements form the river channel may be extensive in large floodplain areas such as Barmah Forest (McKinnon 1997).

Adult movement: This generally receives the most attention, particularly for large, angling species such as golden perch (Reynolds 1983) and Murray cod (Koehn 1998)

Juvenile movement: Recolonisation is important and has been more widely recognised following the work by Mallen–Cooper *et al.* (1995). Over 20,000 native fish (predominantly golden perch and silver perch) moved through the Torrumbarry fishway in its first 2.5 years of operation (Mallen-Cooper *et al.* 1995), the majority being large numbers of juvenile fish moving upstream.

Egg and larval drift: Drifting eggs and larvae have only recently been discovered and considered (Koehn and Nicol 1998), and are currently being further investigated.

Social behaviour and interactions of the species such as territoriality, aggression and schooling can also influence movement types. Movements can avoid competition, and prevent or enhance predation. Recent research (Koehn and Nicol 1988) has shown that although there are peak times for fish migration, many fish move up and down the river during all seasons and move out into anabranches and floodplains during floods.

Although there are many threatened species (e.g. Australian grayling, silver perch) which need to be able to migrate and are threatened by barriers to their movements caused by weirs, there is a need to consider all species and all life stages

Barriers to Fish Passage

Presenting a physical barrier to fish movement is the most obvious impact that weirs have on fish. Physical barriers and solutions to them have been reviewed by many authors (e.g. Harris 1984a, 1984b, Mallen-Cooper 1989, Harris and Mallen-Cooper 1994, O'Brien in press) and include both large (e.g. dam walls) and small (e.g. culverts) structures. There are over 3,600 barriers to fish movement in the Murray-Darling Basin (Murray-Darling Basin Commission in prep) with more than 3,325 in New South Wales (Lay 2001).

Habitat is of no value if fish cannot access it. Harris (1984a, 1984b) calculated from a study in south-eastern Australia that about half the potential fish habitat in coastal rivers was not available to migratory species due to blockages by barriers. In general, about seventy percent of fish species in these rivers require migrations to complete their life cycles (Koehn and O'Connor 1990b), so barriers can affect the majority of the fish fauna, particularly in coastal rivers (Koehn and O'Connor 1990a).

Barriers have also been recognised as a major threat to totally freshwater species (Koehn and O'Connor 1990a), with at least half the species thought to make major migrations, although the movement requirements for many species remain completely unknown (see Koehn and O'Connor 1990b). Species such as golden perch have been shown to have suffered localised extinctions above some barriers (Brumley *et al.* 1987). The additional effects of genetic isolation caused by barriers are unknown. Continuity of fish passage along the river is also important and reinforces the need for a whole of catchment approach. There is no point getting fish past one barrier to have them congregate at the next barrier a short distance upstream. Aggregations of fish migrating upstream often occur immediately downstream of barriers (weirs and dams) making these fish very susceptible to capture by anglers.

In addition to the capacity for native fish to move throughout the river during the year, they often also need access into anabranches, floodplain channels and onto the floodplain. Such movements can be obstructed by smaller barriers such as regulators, levees, culverts, road crossings as well as dams, weirs or locks. They can also result in fish getting stranded behind them when water levels recede.

Power Stations

Many weirs have power stations associated with them, meaning that fish may have to pass downstream via a turbine with detrimental consequences. Operation of hydro power stations on streams can also result in highly variable flow patterns, which can potentially impact on fish populations, especially during breeding seasons.

Access to Irrigation Channels

Larvae can also be transferred into irrigation channels where they are either unlikely to survive in unsuitable channel habitats or continue with irrigation water to pass through pumps with irrigations needs (Koehn and Nicol 1998).

Changes to Natural Flow Regimes

As weirs are part of a water supply system, they also play a considerable part in changing flow regimes.

Reductions in Available Water

Environmental water allocations is a detailed, vexed and important issue for our native fish species. Reductions of available water, particularly through reduced floodplain flooding, can have major impacts on native fish species (Humphries *et al*. 1999, Gehrke 1997, Thoms *et al*. 2000, Whittington and Hillman 2000). For example, the successful recruitment of many native species is thought to be linked to flooding (Koehn and O'Connor 1990b).

Seasonality

Supply of irrigation water often means that the seasonality of flows is reversed. For example, along the Murray River, high flows now occur during the drier summer months and reduced flows occur when water is being stored during winter and early spring. As our native fish species have evolved to seasonal flows, alterations to these can be detrimental to their various life stages and in particular, recruitment.

Another form of movement, which is often forgotten, is the drift of larval fish. With the purpose of recolonisation and distribution of offspring, this aspect can be affected by altered flow rates and impounded waters. High irrigation flows during early summer may now mean that larvae are carried greater distances than would have occurred naturally. Such effects on the overall structure of fish populations is unquantified but is likely to result in some form of population fragmentation.

Variability

Increases in water levels, both large and small can be cues to stimulate fish movements (Mallen-Cooper *et al.* 1995). Reductions in such cues through changes to flooding and constant flow levels may restrict movements affecting the spawning success and distribution of species. As mentioned earlier, sudden reductions in flow levels can also lead to the stranding of fish.

Changes to Water Quality

Temperature

Low level releases from many dams cause "cold water pollution" which can have a major impact on native fish species. Many native fish species can be described generally as 'warm water' species. Water temperature is important for the functioning of fish species, particularly for reproduction and growth. They have specific temperature requirements which are generally higher than 16°C for optimal spawning (see Koehn and O'Connor 1990b, Koehn *et al.* 1995), but which vary from species to species. The release of cold water from low level storage outlets poses a major problem to such 'warm water' fish assemblages.

Lower temperatures have two types of effects. Metabolic rates and biochemical rates are reduced and this will affect all processes within the river such as photosynthesis, breakdown of organic matter and respiration resulting in a reduction in river productivity. For most species, there are temperature thresholds that must be reached, for processes such as fish spawning. Generalised optimal spawning temperatures for fish species are in the order of 18°C for trout cod, 20°C for Murray cod and 23°C for golden perch, silver perch and catfish. Lowering river temperatures will favour introduced coldwater species such as trout. This has already occurred in the Mitta Mitta River as a result of construction and operation of Dartmouth Dam (Koehn *et al.* 1995) with the loss of three warm water native fish, Murray cod, trout cod and Macquarie perch. All were popular angling species with trout cod now being classified as endangered and Macquarie perch as threatened. A corresponding four-fold increase occurred in the abundance of brown trout (an introduced coldwater species) populations. The loss of these fish has also occurred in the mid reaches of the Murrumbidgee river system below Blowering and Burrinjuck dams (Lugg 2001). It is also likely that temperature reduction has influenced some species of aquatic macroinvertebrates, reducing their ability to complete their life cycle during the summer months.

Whilst such large decreases in water temperatures (often in the order of 10°C) occur below larger dams, smaller decreases of around 1 to 2°C have been recorded for smaller weirs (Keenan 2001).

Dissolved Oxygen and Salinity

Weir pools can often stratify with deeper waters containing low levels of dissolved oxygen, and high levels of salinity and sulphides, making these waters uninhabitable for fish (Anderson and Morison 1989).

Sediment

Weirs trap sediment (see below), which ultimately reduces the capacity of the weir itself and smothers habitats. This often necessitates weir desilting, which has the potential to release high levels of sediment downstream, with serious environmental consequences. Doeg and Koehn (1994) reported on the declines of freshwater blackfish populations and the supporting macroinvertebrate community following the desilting of a small weir.

Habitat Changes

Weir Pools

Weir pools are significant because they change the predominant characteristic of the river behind the structure from flowing water to standing water. The retaining structure and supply of water maintain high water levels within the channel rather than fluctuating as in the natural situation. The result is the river system is now highly modified. Where weir pools are close together or contiguous, or if a weir pool is particularly large, then the whole ecological character of the river can be changed. This is true for the lower reaches of the Murray river, which Walker (2001) described as “a river of lakes”. Such weir pools may however provide more constant and preferred habitats for many exotic species. In particular, these include:

- brown and rainbow trout – which prefer deeper, cooler waters and prey on many native species;
- redfin – which prefer slower waters and prey on many native species;
- gambusia – which prefer slower waters and may harass many native species; and
- carp – which prefer slower waters.

Downstream Scouring

Bed and bank erosion, which often occurs downstream of weirs (see Brizga 2001), can cause destruction of instream habitats.

Sediment, Nutrient, Egg and Larval Traps

Weirs trap particles that flow downstream and settle out into the still waters of the weir pool. This includes sediments, nutrients and drifting macroinvertebrates, which can lead to a deficit of these natural components in the river immediately downstream. Some fish eggs and larvae also drift downstream and may become trapped in the weir pool. This settling effect will interrupt the natural downstream recolonisation of these species. As weir pools are usually full of sediment, the survival of oxygen sensitive eggs (in particular) or larvae may be reduced through smothering, thus reducing potential recruitment.

Summary

Impacts of weirs can decrease: spawning success, egg and larval survival, genetic diversity, recolonisation, access to riverine and floodplain habitats, water quality, natural flows and the variability of habitats. Conversely, impacts of weirs can increase: population fragmentation, localised extinctions, slow water habitats, access to irrigation canals, exotic species and fishing mortality. All of these impacts mean that weirs do have major detrimental impacts on native fish.

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Biography

John Koehn is an aquatic biologist specialising in all aspects of the ecology of freshwater native fish. John has over 18 years experience in research, assessment, conservation and management of freshwater ecosystems and is the author of over 50 publications. He has gained an international reputation for his research and is a key player in providing biological information and management advice. He has been active in assessing the conservation status and threats to many endangered species as well as preparing and implementing action statements and management plans for them. This has been reflected in his inclusion on ministerial committees, national recovery teams and project steering committees.

John has been recognised for his contribution to the conservation of native freshwater fish by being awarded the 1997 Gold Banksia Award, one of the most prestigious environmental awards in Australia. Recently he has been involved in the expert panel for the Murray and Murrumbidgee rivers and authored the Native Fish Management Strategy for the Murray-Darling Basin and a book 'Managing the Impacts of Carp'.

Altering Weir Structures and Weir Operations to be More Environmentally Friendly

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Abstract

Water managers in Australia find themselves in a worsening dilemma. Weirs and related structures are an integral part of our settlement and use of the land, but their impacts are increasingly recognised as environmentally damaging. Given that many of the thousands of existing weirs that help us exploit water resources will continue to be needed, what can practically be done to minimise their damaging effects?

Much has been learned over recent years about the diverse ways in which weirs degrade riverine environments. Their main function has been to facilitate water diversion and their most immediate environmental effects have been to reduce streamflows and to change natural flow regimes. Upstream and down, weirs have changed rivers into strings of separate pools, blocked fish passage, interrupted nutrient flows, degraded water quality, changed habitats, increased bank erosion and encouraged pest species. We have also learnt that impacts are on a scale larger than individual weirs; multiple structures in streams have important large-scale, cumulative effects. Weirs are directly implicated, along with other factors, in the damaged condition of our rivers (Harris and Gehrke 1997).

The process of identifying weirs' ecological effects is leading in turn to ideas of how their structures and operations might be altered to reduce their environmental impacts. In a few instances – such as building fishways to restore free passage – efforts to ameliorate weir impacts are already under way. More than ten thousand weirs and related structures affect stream environments in south-eastern Australia alone and only a small proportion can be removed in the short term. So, if we are to have healthy rivers again, it is imperative that we examine and test options for altering the remaining weirs to make them more 'environmentally friendly'.

I have adopted the term 'weir' in a very broad and inclusive sense to encompass all low-level (i.e. below about seven metres in height), artificial structures in streams. It includes gated and fixed-crest weirs, low dams, gauging weirs, barrages, floodgates, regulators, block banks, road causeways and culverts, navigation locks and probably some other kinds of structures. A number of these do not fit easily into narrower definitions of 'weirs'.

There are options for altering weir structures or weir operations to improve river health and the condition of natural resources. The kinds of options depend on the nature of the weir, its location in the river system, the type of construction, whether it is in a tidal or fluvial reach, and its basic design. These options may be either structural or operational in nature and are outlined below.

Structural Options for Reducing Weirs Effects

Reducing the Size of Weirs to Reduce Their Impacts

Most adverse effects of weirs are size-related. Reduce the size and you reduce the impact. The severity of barrier effects (which relates mainly to the wall height and size of the storage); the length of stream changed from a fluctuating, fluvial habitat to a stabilised, still-water habitat; the extent of weir-pool sedimentation; the evaporative water losses; the intensity of stratification: most weir impacts can be ameliorated in proportion to the reduction in size.

In cases where a weir's continuing benefits outweigh the environmental benefits of removal, reducing the size of the storage may offer a worthwhile compromise. While I am unaware of any specific instances, so far, where weirs have been reduced solely to ease environmental impacts, there are many cases where it would be an appropriate modification to consider.

One particular environmental effect of water-resource development that has so far had little scrutiny outside the irrigation industry is the effect of water storage in exacerbating evaporative losses of water from river systems. Evaporation is a function of several variables, particularly wind, surface-area-to-volume ratio, and temperatures. It is a potent factor controlling surface water over much of the continent. Bowler (1990) plotted an east-west transect of average annual precipitation and water-surface evaporation rates from the Flinders Ranges in South Australia to the coast near Canberra. Evaporation varied from about 2,600mm to about 800mm, and the ratio of evaporation to precipitation ranged from 2 to 6 over about three-quarters of the transect. Storages expose increased surface areas to evaporation. They are generally more open to wind effects than river channels. And temperature regimes are modified by stratification, by lengthy detention and because of heat absorption by storages' broad surface areas. While it is difficult to generalise, I recall a senior dam-construction engineer's rule-of-thumb that each increase of one Centigrade degree in water temperature led to a doubling of the effective evaporation rate. Clearly, the thermal regime and surface heating of storages have important implications, not only for downstream temperature regimes but also for the river system's overall water resources.

The significance of increased evaporative losses emphasises the need to manage our water resources better; to minimise overall storage, to reduce detention times, to control wind effects by riparian tree management, and to investigate more carefully the values of this particular aspect of storage-destratification schemes.

Modifying Fixed-Crest Weirs to Create Fluctuating Pool Levels and Flows

Gated weirs can be operated to vary flows and pool levels, but fixed-crest weirs offer few opportunities for flexible operation. Fixed-crest weirs artificially stabilise water levels in the storage pool and lead to sudden, unnatural changes in the downstream flow pattern as the pool level varies around the crest level. This is because water flows downstream only when the weir pool level is high enough to spill over the crest. The sudden changes lead to a range of adverse ecological effects above and below the weir. A beneficial way to restore a more natural pattern of variation in the pool level, and downstream flows, whilst also reducing the size of a fixed-crest weir would be to create a 'notched weir' (Fig. 1). A similar type of modification has been used to enhance the function of fishways, for example the ones at Cobbitty and Camden weirs on the Nepean River and Delegate Weir in the Snowy River system.

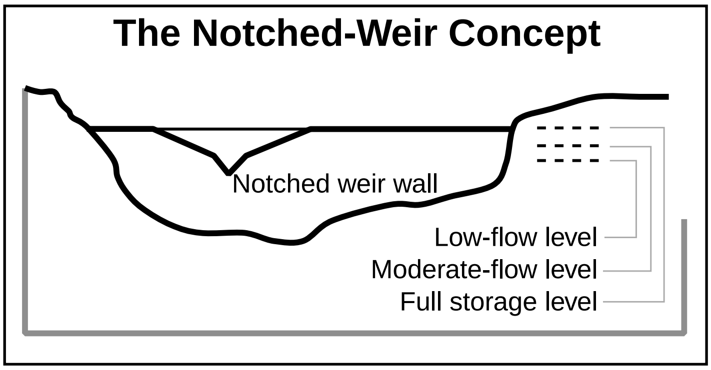

Figure 1. *Schematic cross-section of a fixed-crest weir after modification to produce a notched crest, showing how fluctuating pool levels and downstream flows could be re-established.*

With a notched weir, changes in river inflows to the weir pool would lead to more natural, fluctuating pool levels and downstream flows, rather than the unnatural regime caused by fixed-crest weirs. The depth and profile of notches could be designed to suit site characteristics and varied depending on the desirability of reducing the storage's size.

Changing Weirs' Outlet Arrangements

The environmental impacts of many weirs, especially those with fixed crests, can be ameliorated by changing their outlet arrangements. Providing downstream environmental flow regimes will often require a capacity to enhance releases at low river discharges, and an ability to regulate flow rates when the weir is not spilling. These improvements would require fitting of a suitable outlet controlled by a valve. Supplying the outlet through a trunnion (a hinged-pipe device that can be adjusted to draw water for release from suitable depths in the storage) would enable downstream water quality to be managed appropriately. Trunnions have often been fitted to water-supply dams at regional centres such as Lake Canobolas near Orange.

In inland areas, where river gradients are slight, low-level fixed-crest weirs (or 'regulators') are often simply built with earthen banks. For example, seventeen such structures create a string of weir pools along the 400 kilometre length of the Great Darling Anabranch. These weirs were originally fitted with piped outlets, controlled by gate valves and located close to the stream bed. The outlets provide no options for releasing water from the most suitable pool depth, other than allowing them to spill via a bypass, risking erosion and outflanking. Nor is there any useful fish passage through such outlets. The pipes are being progressively replaced with steel gated outlets that can release from deeper layers in the storage or be lifted clear of the water surface. This flexibility enables operators to develop release strategies to manage problems such as salt build-up through saline stratification in the storages. The change in the kind of outlet also permits the design of lightweight, modular fishways that can be lifted clear as floods approach. A project to develop these fishways, funded by Agriculture, Fisheries and Forestry Australia has recently begun at Narrandera (NSW Fisheries, unpublished).

A recent scoping study by Sherman (2000) has outlined the options available for ameliorating the insidious and widespread problem of cold water pollution caused by hypolimnetic (deep-water) releases from density-stratified storages. The discrete water-body layers formed in density stratification follow differences in water density caused by variations in temperature and/or salt content. The options, mostly developed and tested in the USA, involve various ways of delivering ambient-temperature surface water to outlets deep in the storage. They include underwater curtains (impermeable membranes suspended at various levels in the water column), trunnions, and surface impeller pumps (high-volume, low-velocity pumps that direct water downwards through the water column). These are far less costly than installing multi-level offtake towers (water offtakes with moveable screens that allow water to be drawn from different levels), and are likely to be more effective than de-stratification systems (which generally use bubble streams from submerged, pressurised airlines to disrupt density stratification).

Fish Passage and Fishways

Fish passage is the term describing the directed movement of fish past a point in a stream. It particularly relates to the engineering and biological aspects of restoring free passage at weirs and other in-stream barriers. Fishways are structures that allow fish to pass barriers. They generally do so by reducing an impassable vertical break in the continuity of the river's long profile to a number of smaller rises that can be negotiated one at a time. The seven broad categories of fishways that have been used or considered in Australia are the pool type (including vertical-slot), Denil, lock, trap-and-transport (including lifts and pumps), rock-ramp, bypass, and eel fishways (see the paper in these proceedings by Cameron Lay).

Freshwater fish and some other aquatic fauna, such as turtles and shrimps, need to move freely between the various areas of their habitat to search for food and shelter, to disperse into available habitats, or to reproduce. Only the scales and directions of their movements are different. Of the 55 species of native freshwater fish living in New South Wales, for example, 32 are at present recognised as migratory and known to require free passage to sustain populations (Thorncraft and Harris 2000). The scale of movement ranges from thousands of kilometres for species such as golden perch and silver perch, to hundreds of kilometres for Australian bass and Murray cod, to much shorter distances for rainbowfish or gudgeons. But all species have a requirement for passage at some scale.

Blocking migrations interferes with the two fundamental ecological processes that sustain populations: recruitment and growth. Population recruitment includes spawning, the nursery phase, and juvenile dispersal into adult growth habitats. Growth relates primarily to home-range feeding activity. A third critical ecological process is the dispersal of fish from drought-refuge areas, especially remnant deep pools, into newly regenerated habitats, such as billabongs or previously dried-out river channels, after rainfall and renewed streamflow. Complete obstruction of migrations leads to local extinction of species. This seems mainly attributable to blockage of the recruitment migration of young fish from downstream recruitment zones, so that the upstream population gradually ages and dies out. For example, wild-bred populations of golden perch disappeared from the River Murray above the Hume Weir, and from the Macquarie River above Burrendong Dam.

The fish passage status of streams has been extensively compromised. There are known to be 4,308 barriers to fish passage, excluding floodgates and culverts, in New South Wales streams alone (NSW Fisheries, unpublished data). These barriers can cause local extinctions or greatly reduce fish abundance and diversity. Obstructed fish passage is one of the main causes of declining biodiversity and fisheries production in Australian freshwater systems (Harris and Mallen-Cooper 1994, Mallen-Cooper 1994). It is also implicated in the listing of many Australian fish as threatened species (Wager and Jackson 1993).

Weir walls block upstream and downstream movements of fish at various life-cycle stages. Individual low weirs may produce insidious effects on fish populations but these effects are cumulative. Each successive weir adds impacts in both space and time so that the more weirs there are, the greater the overall impact on the river system's populations.

Depending on the nature of the weir, particularly its size, design and location in the river system, fish movements may be entirely prevented. But, more often, they are diminished, being reduced to intermittent, brief episodes during high flows. The result is that fish populations have generally declined rather than completely disappeared. Upstream-migrating fish accumulate below weirs while waiting for suitable conditions for passage. Meanwhile, their crowded populations suffer radically accelerated mortality rates because of increased predation (hence the flocks of cormorants usually visible), because they are vulnerable targets for fishing, because their food supply is quickly used up, or because of disease in the close-contact conditions.

Although dams, weirs and similar structural barriers physically impede fish movement, acceptable rates of passage for most Australian species can be restored by fitting suitable fishways. But the process of design, testing and refinement of fishways is far from complete. There are also important behavioural barriers to migration, such as cold-water pollution (Astles *et al.* 2000) or acid-soil drainage (Gibbs *et al.* 1999), that either deter fish from attempting to migrate or else inhibit their swimming ability.

NSW Fisheries and the Cooperative Research Centre for Freshwater Ecology have allocated substantial resources to fish passage research over the past 15 years. The results of that work have been summarised in Thorncraft and Harris (2000). Recently there has been a very satisfying surge in fishway building, especially in New South Wales, Queensland and Victoria, with increasing activity in the other states and territories. The Murray-Darling Basin Commission's development of the Native Fish Management Strategy is providing a valuable stimulus and direction for this form of stream rehabilitation work. In New South Wales, we have described the ecology of fish migrations, proved fishway designs for native fish and pursued the construction of effective, low-cost and innovative fishways.

There have been many problems in the history of fishways and fish passage in south-eastern Australia. Lack of knowledge about the region's fish fauna, inappropriate fishway designs, inadequate resources and poor fishway maintenance have each contributed to these problems. While the situation has improved greatly over recent years, there remains a substantial burden of ineffective fishways in our streams that represent both a challenge and an opportunity. These structures need to be modified to achieve their original purpose and to restore the free passage of fish. Many such ineffective fishways provide a basic structure that can be adapted and renovated, and a project funded by Agriculture, Fisheries and Forestry Australia has recently begun at Narrandera to test the Deelder Lock design for such renovations (NSW Fisheries, unpublished).

Staff reductions and declining resources in government agencies have unfortunately reduced their capacity to design and build fishways. One result has been that agencies have little ability to create the broad range of fishway types needed to cope with the diverse fish passage issues that confront them. In New South Wales in recent years only one design, the rock-ramp fishway has been widely used because of its somewhat lower cost and the availability of the particular engineering skills within the relevant government agency. This design remains experimental; its success in passing fish has so far had only limited evaluation (Harris *et al.* 1998). Although there has been considerable progress, problems have been associated with performance, construction standards, stability, maintenance and basic design criteria for rock-ramps (Thorncraft and Harris 2000) and many of these remain unresolved.

Notwithstanding the difficulties with rock ramps, provided there is good collaboration between experienced engineers and fishways biologists, and with adequate funding, reliable fishways can now be built to serve Australian native fish. What is desperately needed in the future is a greatly enhanced commitment to government support for comprehensive fish passage programs. The continuing need for improved fishway designs and reduced fishway costs emphasises the requirement for ongoing research and development. Improving the knowledge base remains an urgent priority, especially in the areas of migratory fish behaviour, fishway hydraulics and design, and innovations such as prefabricated modular fishways and less expensive fishway designs.

Modifying Culverts and Causeways for Fish Passage

Great numbers of road crossings, culverts and causeways create in-stream barriers to fish passage. Pethebridge *et al.* (1998) surveyed New South Wales south coast streams and identified 254 artificial barriers, mostly associated with roads. With varying degrees of difficulty, depending on the individual site, these barriers can be modified to restore partial or full fish passage. Boubee *et al.* (1999) produced comprehensive recommendations for providing fish passage in New Zealand culverts and, as with earlier North American work (Clay 1995), the principles are equally applicable for Australian streams. A new project on the New South Wales north coast is testing the suitability of improved culvert designs for local fish species (NSW Fisheries, unpublished).

Culverts can act either as physical or behavioural barriers. Fish movement can be impeded by excessive head-loss (the vertical discontinuity in water-surface profile), especially at the downstream end of the culvert, by excessive water velocities and turbulence, by inadequate depth along the culvert bed, and – in some species – by long stretches of darkened channel, especially in pipes.

The procedures used in restoring passage through culverts include replacing small diameter piped structures with larger channels, especially box or arch culvert designs. Excessive head-loss at the downstream end can be corrected by raising the pool level with a rock-ramp or artificial riffle to submerge the culvert's base. Various baffle designs have been tested for controlling velocity and turbulence through steep culverts, and roughening with rocks or natural stream bed-load may also be effective (see Boubee *et al.* 1999). There should be sufficient capacity in the culvert to accommodate flood flows while maintaining a free air/water interface. Daylight penetration can be enhanced by minimising the length of culverts, maximising their diameter, and providing grids or openings where possible.

Causeways on minor roads tend to be built as level, fixed-crest structures, with water flow distributed as a broad, shallow sheet over their surface. This arrangement provides poor conditions for fish movement. Passage may be restored relatively simply and inexpensively by creating a channel across the causeway to concentrate low flows. This could have an open, V-shaped profile, or be narrow and deep and covered with a grid. Where there is little head-loss between the upstream and downstream sides of the causeway, the gradient will probably be suitably low. If there is a significant fall it may be necessary to raise the downstream pool level with a rock ramp, or else to install fishway baffles in the new channel.

Operational Options for Ameliorating Weirs Effects

Modifying the Operation of Gated Weirs

Because the gate-control mechanisms of gated weirs can be manipulated to regulate flow downstream, the operation of gated weirs is more flexible than fixed-crest weirs. Thus it is feasible to ameliorate many of their environmental impacts by revising the procedures under which they operate. The principles underlying the NSW Weirs Policy, a component of the State's Water Reforms (Anon. 1997) include: '…. owners of weirs with regulatory works shall prepare and adhere to operational plans to reduce the environmental impact of those weirs.' Specific examples include achieving water-level variations; mimicking natural rates of water-level change in and below the weir; raising gates fully in parts of the year when the weir is not needed, or at times critical to maintenance of river health, wetlands, fish, etc.

It can be practicable to use weir gates to vary discharge and create beneficial short-term fluctuations in pool level, as described by Glenn

Wilson in these proceedings for the studies at Lock 8 near Mildura. Expected benefits from pool fluctuations include restoring food-web functions and habitat diversity as well as aiding the control of animal and plant pests. An improved operating routine could also minimise the sudden fluctuations of downstream flow that can cause stranding of aquatic biota and channel erosion.

Water extractors exert powerful control over flows and weir pool levels. The value of using staged water extraction rules for manipulating flow regimes to achieve environmental benefits has been tested in the Interim North-west Flow Management Plan that was applied in the Barwon-Darling system (Thoms *et al*. 1996). Staged-extraction rules could become an integral feature of 'environmentally friendly' weir management in most areas to regulate the rates of change of river flow, restore short-term variability and protect minimum flows.

Seasonal drawdown of the whole weir pool is practised at some gated weirs, such as Torrumbarry, on the Murray River. The free flow of the river enables fish passage, restores the flow of sediments, enhances the flow of catchment nutrients and the processes of nutrient cycling, removes stratification, aids in pest control and encourages recession of the groundwater mounds responsible for land salination through river regulation. Difficulties in establishing seasonal drawdown include reduced amenity for tourist and recreational boating and the return of saline groundwater to the river channel, at least in the short term.

Nuisance and toxic blooms of blue-green algae (cyanobacteria) are often stimulated by the effects of weirs (Hart *et al*. 1995). Webster *et al*. (1997) showed that river discharge plays an important part in regulating the growth of cyanobacteria. Above a certain minimum discharge rate cyanobacteria were unable to dominate the phytoplankton. They found that blooms could be minimised if base discharge rates from weirs were increased up to critical levels, or if flows were pulsed so that for periods of time the minimum discharge rates were exceeded. Other techniques for disrupting thermal stratification, such as artificial mixing or selective withdrawal, also have the potential to limit cyanobacterial blooms.

At Boggabilla Weir and similar gated weirs fitted with fishways, selective operation of the gates can enhance fish passage. By concentrating river flows towards the fishway entrance, fish can be guided towards the fishway entrance, reducing searching time and the severe predation that usually occurs in these areas (Mallen-Cooper *et al*. 1995). Issues for weir managers implementing such a strategy may include the possibility of localised scouring of the river bed and uneven stresses on gate mechanisms.

Persistent thermal and oxygen stratification is a widespread phenomenon in Australian weir pools. Turner and Erskine (1997) showed that stratification, often accompanied by high salt loads and order-of-magnitude increases in total phosphorus concentrations, remained stable in three Nepean River weir pools unless disrupted by winds of over 50 kilometres per hour. Cold water pollution occurs below gated weirs, such as Marebone Weir on the Macquarie River, which discharge from deep layers in the stratified storage. Although the individual impact of these cold releases from weirs is less than occurs below large dams (Astles *et al*. 2000), the abundance of weirs and the likelihood of cumulative environmental effects constitutes a serious issue that warrants further study.

Like other environmental problems with weirs, the potentially cumulative impact of coldwater pollution raises the need to consider managing whole river reaches as integrated systems, rather than merely concentrating on individual locations and structures. In seeking to manage fish passage and water quality problems, there is a need to integrate the operations of all the weirs in a reach to achieve maximum amelioration. This is especially true in systems like the Barwon-Darling, where 40% of the river is composed of weir pools, or the Condamine-Balonne, Great Darling Anabranch, Loddon, Nepean or lower Murray rivers, that are repeatedly regulated through long sequences of weirs. To achieve integration will require a high standard of monitoring and information management, as well as good planning and strong communications links between the disparate authorities sometimes responsible for weir operations.

Regulators

Many of the options described for gated weirs apply also, in simpler, scaled down ways, to the numerous low-level weirs of inland streams that are described as regulators. Earlier regulators were built with removable drop-boards that were intended to be removed during high flows. This style of weir is progressively being replaced by steel-gated sluices. Surveys have shown that up to 90% of dropboard structures are not adjusted according to licence conditions, and many are inoperable.

The semi-permanent, stable weir pools held back by many regulators have caused wave-fretting action to be concentrated at one level of the stream bank (Thoms *et al.* 1996), causing extensive undercutting and collapse of riparian trees in susceptible soils such as those of the Barwon-Darling or lower Lachlan regions. This undercutting has sometimes been wrongly attributed to carp, but can be halted by re-instating pool levels that mimic natural stream fluctuations.

Floodgates

A complex of environmental problems is associated with floodgates that form the tidal limit in upper estuaries. Loss of tidal ventilation, sudden influxes of anoxic water from runoff, acid drainage from oxidised acid-sulphate soils, subsidence of drained land, physical and behavioural barriers to passage of fish and invertebrates and alteration of vegetation communities; the issues are numerous (Pollard and Hannan 1994, White *et al.* 1997, Gibbs *et al.* 1999, Leadbitter, these proceedings). It may appear simple to minimise these problems by holding floodgates open until they are needed to prevent back-flow inundation during floods, and floodgates at a number of sites such as the Belmore River and Hexham Swamp have now been opened. But White *et al.* (1997) documented a variety of reasons why such decisions must be approached with caution and with a good understanding of the range of factors that need to be considered. Leadbitter and Kuswadi (both in these proceedings) discuss the issues of floodgate management more fully.

Navigation Locks

There are opportunities to enhance fish passage using the navigation locks on many Murray River weirs, without requiring major changes to their operations. An experimental study by Mallen-Cooper *et al.* (1992) at Euston Weir showed that fish passage in the river could be effectively boosted by modifying the operating regime of the navigation lock. The modified regime involved slightly opening the lock gates to provide attraction flows to encourage fish to enter the lock before filling, then to pass upstream when the lock reached its full level. Auxiliary flow valves may also be available in the structure of some locks to implement this fish passage regime. At some sites, these fish passage flows could also contribute to environmental flow regimes.

Options for Pest Control at Weirs

Some trade-off benefits through using weir operations to control pests such as carp or redfin perch are potentially available. One popular suggestion has been to design selective fishways that would pass native species but be a barrier to exclude pests. Regrettably, this attractive notion seems unlikely to succeed in the near future. The swimming ability and behaviour of carp and redfin have not proved sufficiently different from those of the native species to permit the design of selective fishways. Perhaps, with the development of electronic systems for counting and identifying fish in fishways (Owen *et al.* 1997,1998), an automated sorting mechanism, like a sheep-drafting race, might eventually become feasible and allow removal of unwanted fish.

A more immediately practicable carp-control option is emerging in research at the Mildura Lower Basin Laboratory. Wilson (2000) has shown that it is possible to manipulate water levels to initiate spawning by carp. When he raised the level of experimental ponds by 40cm to simulate flooding during the carp breeding season, the test fish immediately moved into freshly inundated shallow areas and spawned on submerged vegetation overnight. Subsequent lowering of the water level stranded the eggs, desiccating and killing them quickly. These results show how it may be feasible to limit carp reproduction. They also indicate a way that carp behaviour in response to water-level manipulation could be exploited with specially designed traps to remove this pest from waterbodies.

Drown-out Flows for Fish Passage

Low-level weirs up to about five metres in height usually allow some fish movement in periods of high flow. Great numbers of fish migrate along the main and subsidiary river channels during high flows, mostly juvenile fish travelling in an upstream direction (Mallen-Cooper *et al.* 1995). Although high flows provide occasional passage past weirs, the fish have evolved to depend on an environment that provided passage far more frequently. Without building fishways or removing weirs, fish passage can only occur infrequently when weirs are inundated or 'drowned-out' by high stream-flows. In the Barwon-Darling River, drown-out flows were designed to provide at least some fish passage under the 'Fish Rule' of NSW Department of Land and Water Conservation's Interim Unregulated Flow Management Plan For The North-West (Thoms *et al.* 1996). The intention, as an interim, partial measure, was to permit some of the river's high flows to pass undiminished down the river to drown out weirs briefly so that some fish can pass over them.

If environmental flows are to be used to reinstate some fish passage at weirs, then the flow that is required to drown out each weir must be known. The important criteria are the depth and velocity of flow over the weir crest, the head-loss and structural features of the weir.

The size of flows needed to drown out weirs had not been estimated until Darling River floods in 1990-1991 provided an opportunity for a study at the four metre high Bourke Weir (Harris *et al.* 1992). The study was based on the premise that fish migrating upstream would accumulate below the weir until river levels rose to the point where passage was possible. At this stage the fish would continue their travel, population densities below the weir would decline, and densities above the weir would increase. Large numbers of golden perch passed over the weir when head-loss had decreased from the initial 2.7 metres to 0.2 metres, when the location of the weir was barely detectable in the flooded river. Passage occurred at a river discharge of approximately 10,000 megalitres per day.

Providing drown-out flows for fish passage requires an understanding of the flow volume required, the period for which it is needed, and the seasonal patterns of fish movements. The Fish Rule of the flow management plan restored occasional five day periods of fish passage. But passage was naturally unrestricted in most of the Barwon-Darling River except during periods of little or no flow. The fish fauna has evolved with relatively uninterrupted passage and their population-dynamics processes reached their natural rates in those conditions. Whether such infrequent and brief drown-out flows are sufficient to help rehabilitate native fish is uncertain.

Unfortunately, the abundance and timing of native fish migrations are not yet well known (but see Mallen-Cooper *et al.* 1995 and Koehn and Nicol 1998). But the study's results, plus experience with other native fish communities and insights from the literature made some broad, preliminary estimates possible. It was estimated that flows at Bourke Weir exceeding 10,000 megalitres per day for five days' duration would be required, with these flows occurring once in each eight weeks from the beginning of September to the end of May.

Summary

The assessment of environmental benefits from weir modification is in its infancy, except in the area of fish passage, where some progress has been made. But a significant amount of science is now being focussed on better weirs and weir operations. Exciting new ways have been documented for avoiding coldwater pollution below storages at reasonable cost. A number of fishways have been assessed and shown to be operating successfully. Fish migrations have been assisted by altering the routine of navigation locks. Large-scale fish movement over weirs drowned out by water-extraction rules has been documented. Improved biodiversity and water quality have been shown after changing pipe culverts to the box design at Kooragang Island in the Hunter River estuary (R. Williams, NSW Fisheries, pers. comm.). It has been shown that carp eggs can be killed by selective pool drawdown. Several projects under way in Queensland and New South Wales are testing the benefits of altering the way floodgates are managed. Another is measuring the ecological effectiveness of providing fluctuating weir pool levels.

The range of options for modifying weir structures and weir operations to make them more environmentally friendly is summarised in Table 1.

Conclusions

Problems associated with weirs that affect water quality, fish passage, downstream habitats, weir pool habitats, commercial and recreational assets and control over nutrients, algae and pest species are all potentially manageable. Altering weirs and weir operations need not unduly impact on the

Table 1. *Summary table of options available for reducing the environmental impacts of weirs and similar structures through structural and operational modifications at various types of weirs.*

	Options for modification:		
Structure	**Structural**	**Operational**	**Objectives**
Fixed-crest weir	Notched-weir crest		Fluctuating pool level & downstream flows, reduced storage size
	Fit outlet & valve		Provide low-flow releases, environmental flows, de-stratify / de-silt pool
	Fishway		Fish passage
Gated weir		Seasonal drawdown	Fish passage, nutrient cycling, de-silting pool, pest control, lowering groundwater
		Short-term drawdown	Fluctuating pool level, nutrient cycling, de-stratify pool, environmental flows
	Fishway		Fish passage
Tidal floodgate		Opening regime	Tidal ventilation, habitat rehabilitation, water quality, fish / invertebrate passage
	Fishway		Fish passage
Drop-board & gated regulators	Removable fishway		Fish passage
		Seasonal & short-term drawdowns	As for gated weir
Pipe & valve regulator	Install gated structure		Water quality, environmental flows
	Fishway		Fish passage
Gauging weir	Rock-ramp fishway	Re-calibrate gauge	Fish passage
Navigation lock	Auxiliary outlet	Operating regime	Environmental flows, fish passage
Culvert	Roughen & deepen, add lighting, raise pool level downstream, increase culvert diameter		Fish passage
Causeway	Cut channel, grid cover		Fluctuating pool level & downstream flows, fish passage

original purpose of the weir. Most alterations would work best in combination with other measures. At fixed-crest weirs, for example, various combinations of staged water extraction rules, fishways, stepped notching to provide pool levels and downstream flows that fluctuate with different river discharges, and flow-release strategies to limit water-quality problems would provide far greater environmental benefits than would occur from any of these alterations alone. To maximise the overall benefits, we also need to evaluate options for the integrated management of a string of weirs in a system, for example in salinity control or fish passage.

Structural habitat rehabilitation (such as re-snagging and downstream bank stabilisation) in and below weirs would be a valuable adjunct to these alterations. The special significance of snags in Australian stream ecology, and the need to manage them appropriately, has recently been summarised by Koehn *et al.* (2000). The valuable references produced by Katsantoni (1990), Newbury and Gaboury (1993) and Cowx and Welcomme (1998) provide detailed techniques for habitat rehabilitation and enhancement in streams and weir pools.

Community support is needed to achieve the potential benefits from weir alterations. That support depends on good education and awareness programs to enhance community understanding of the issues. The knowledge base needs further development and a strong, ongoing commitment to research and development is the key. Greater resources are needed to make weirs more environmentally friendly, since the necessary modifications are usually not cheap. Programs that are inclusive – where the relevant agencies, non-government organisations, individuals and interest groups work together – will succeed. Local community involvement will be needed also for practical trials to apply the research, to test the ideas. The challenge is not small; it is to ensure that new generations of Australians grow up believing that healthy rivers are their natural heritage.

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Biography

Dr John Harris is a consultant for freshwater ecology and fisheries as well as being part-time Senior Ecologist for the Cooperative Research Centre for Freshwater Ecology. He has obtained BVSc at the University of Sydney in 1966 and a PhD at the University of New South Wales in 1984.

Dr Harris worked in a rural veterinary practice before joining the School of Zoology at the University of New South Wales, first as a Tutor while completing his doctorate, and then as a Project Scientist studying the ecology of the La Trobe River. His doctoral thesis investigated the biology of the Australian bass.

In 1984 Dr Harris joined NSW Fisheries and in 1987 he was appointed to lead freshwater research in the NSW Fisheries Research Institute at Cronulla. There he became Principal Research Scientist in the Office of Conservation, and was also Program Leader for the Fish Ecology Program of the Cooperative Research Centre for Freshwater Ecology. He led research studies on environmental flow regimes, cold-water pollution, fish passage, river-health assessment, threatened species conservation and the effects of alien pest species, especially carp. This research led to over 40 scientific papers on the biology of Australian freshwater fish and on the ecology of rivers, plus numerous popular articles and scientific reports.

Weir Pool Drawdown as a Management Option for the Murray

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Abstract

Thirteen low-level weirs on the River Murray have imposed base pool levels and daily variations in river height (stage) and damped seasonal flow variation. These changes have modified riverine and floodplain floral and faunal communities, changed patterns of sediment transport and increased flows of saline groundwater to the river. The Murray-Darling Basin Commission has invited us to plan a trial to determine efficacy of drawdowns as a tool to rehabilitate the instream environment. The first stage of this project is a scoping review of possible locations, likely ecological outcomes and socio-economic implications. The potential ecological benefits are examined here under the broad categories of water and sediment. Investigations allow some predictions, but the benefits at any one site will depend heavily on the existing flow regime, as well as drawdown frequency, seasonal timing, depth and duration. Moreover, seasonal variations in weir pool usage for irrigation, or by groups such as houseboat operators, will impose strong constraints. Ultimately, socio-economic factors may determine the timing and, therefore, the nature of the ecological response.

Introduction

Riverine flows along most lowland sections of the Murray-Darling Basin (MDB) are intensively regulated (e.g. Close, 1990). Weirs are one of the major control devices, and play an important role in irrigation, domestic water supply and recreation. However, weirs exert a considerable impact on the instream physical and biological environment (Thoms & Walker 1993, Walker & Thoms 1993, Walker *et al.* 1994). These effects have been extensively studied in South Australia, where the Murray has been converted into a series of weir pools (e.g. Walker, these proceedings). Acting in concert, weirs and upstream dams have reduced the total flow volume, reduced the incidence of flooding, reduced the seasonal variability in stage height, and altered channel morphology (Thoms & Walker 1993). In turn, changes in flow variability and channel morphology have affected the distribution of littoral plants (Walker *et al.* 1994) and the composition of biofilms (Walker *et al.* 1992). Furthermore, weirs isolate large sections of the river from the floodplain, prevent fish migration and reduce the downstream transport of organic matter and sediment (Thoms & Walker 1993).

River managers are exploring ways of minimising the negative impacts of weirs whilst retaining some, if not all, of the services they provide to the wider community. For example, fish ladders have been installed to facilitate the movement and migration of native fish (Mallen-Cooper & Brand 1991). Other initiatives have been aimed at the restoration of elements of natural flow regimes in weir pools as part of programs to manage environmental flows (Blanch *et al.* 1996). One of the major impacts of weirs has been to reduce the seasonal variation in stage, but to increase the short-term (e.g. daily) variation. To address these impacts, it has been suggested that a sustained drawdown with controlled rates of rise and fall may provide significant ecological benefits to the river.

The present study commenced in response to a call through the Murray-Darling Basin Commission's Basin Sustainability Program for the design and conduct of a trial weir pool drawdown. Its objectives are fourfold:

1. to identify physical constraints to drawdowns in the context of present weir operations;

2. to identify attainable environmental objectives within socio-economic constraints;

3. to specify a trial weir pool drawdown; and

4. to undertake an ecological, economic and social analysis of the benefits and costs.

This paper firstly reviews the likely ecological outcomes arising from the drawdown of a weir pool on the Murray. Secondly, it examines socio-economic factors that need to be considered in planning the timing, duration and depth of a drawdown event. Issues relating to weir operation and potential impacts on individual weir pool users are considered separately. This paper is by no means exhaustive; rather, it highlights the main benefits and issues faced in employing drawdowns as a flow management tool along the River Murray.

Results

Information Sources

Opportunities for flow manipulation in Murray weir pools were reviewed by Ohlmeyer (1991), Jensen *et al.* (1997) and Jensen & Nicholls (1997) for weirs 1-10, and by White & Jacobs (1998) for weirs 10-26. These were the main sources of operational and socio-economic information. Ohlmeyer (1991) monitored a number of trial drawdowns during the course of his study, including weir 3 by 0.5m (May 1989) and weirs 1-6 by 0.3m (July 1990). Predicted ecological outcomes from weir pool drawdown were primarily gauged from Ohlmeyer (1991) and peer-reviewed scientific literature on the aquatic ecology of the Murray. These are examined first, prior to assessments of operational and socio-economic factors.

Likely Ecological Outcomes

A key objective of flow manipulation, particularly in using drawdowns, is to ensure that maximal environmental benefits are realised (Blanch *et al.* 1996, Jensen & Nicholls 1997). At even a moderate drawdown of 1m, ecological changes are likely to be most pronounced within the littoral zone and any wetlands connected to the weir pool. Further, these will depend on the drawdown depth, duration and seasonal timing. For this exercise, drawdowns are considered in terms of a single arbitrary depth (1 metre), over two durations (2 weeks, 2 months), and two times of the year (mid-winter, mid-spring).

Water and Sediment Chemistry

Drawdowns are likely to have broad effects on water and sediment chemistry. First, reductions in height would lead to a short-term reduction in hydraulic pressure from the weir pool on the surrounding groundwater. This would lead to a minor rise in salinity within the weir pool and downstream, complemented by further salt intrusion from backwater inflows (Ohlmeyer 1991). These effects would be most pronounced following a 1–2 month drawdown at sites with raised groundwater mounds underlying and adjacent to the weir pool. A 2 week drawdown would probably be too brief to have any significant impact on groundwater levels unless the local soil was very sandy, irrespective of the season. Salinity increases would be a short-term feature, declining once the groundwater level adjacent to the weir pool had dropped. Some local changes may also occur in the behaviour of riparian saline springs. In both winter and spring, water flow from springs may allow saline patches to develop largely on soil particle size and permeability.

Second, a drawdown may affect the nutrient dynamics of a weir pool, both during the drawdown phase and following re-inundation. In particular, exposure will modify nutrient dynamics in both sediments and biofilms associated with substrata like snags. Recent studies (Mitchell & Baldwin 1998, Baldwin & Mitchell 1999) suggest that partial drying of wet (previously inundated) sediments would result in an increase in the sediments affinity for phosphorus (P) and produce a zone for nutrification / denitrification. Hence, partial drying would result in the reduction of the availability of nitrogen (N) and P. Conversely, complete desiccation may lead to the death of bacteria and subsequent mineralisation of N and P, a decrease in the affinity of P by iron minerals, a decrease in microbial activity and a cessation of all anaerobic bacterial processes (e.g. denitrification). Subsequent colonisation of the exposed sediments by terrestrial plants may then lead to N and P moving from the sediments to plant biomass. Re-wetting of desiccated soils and sediments would result in an initial flush of available N and P (which can be incorporated into bacterial or macrophyte biomass), coupled with an increase in bacterial activity, particularly nitrification. Given the importance of P to blue-green algae (see below), removing some of this from the water column may have benefits. These predictions are partly speculative, and need to be tested.

During spring, these responses would be most dramatic after a 2 month drawdown as a result of likely increases in the extent and depth of sediment drying. This may also have an impact on the subsequent rate of recolonisation by anaerobic bacteria into surface sediments. However, as these processes result either directly or indirectly from temperature dependent rates of microbial activity, a 2 week winter drawdown may have little impact.

Phytoplankton and Biofilms

The potential for blooms of phytoplankton (cyanobacteria or blue-green algae) to occur within weir pool is a dominant community concern. In general terms, these occur when anaerobic conditions are allowed to form low in the water column, leading to release of bioavailable phosphorus from sediments. This in turn promotes the population growth of cyanobacteria (Annodotter *et al.* 1999). A drawdown will be unlikely to have any immediate dilution effects on the density of suspended phytoplankton cells or concentration of their preferred nutrients. However, lowered water levels would temporarily shift the photosynthetic zone downwards, and thus may lead to a short-term increase in phytoplankton growth. This would be most evident during spring, particularly as a result of a 2 month drawdown. Either a 2 week or 2 month drawdown would also assist in dissipating any anoxic lower layer low in the water column, reducing the conditions for a large-scale bloom in the near future. Re-inundation would continue this mixing and also dilute the density of phytoplankton cells. Furthermore, it would also reduce the average light conditions available to algal cells as they are mixed through the water column, and some population collapse could occur. Any enhanced zooplankton abundances following re-inundation may also have a positive impact on phytoplankton levels. These effects would be far lower in winter and may be difficult to detect.

Substrate surfaces (sediment, woody debris, macrophyte leaves) near the air-water interface tend to be colonised by a successful 'biofilm' sequence, dominated by either blue-green algae or other attached (filamentous) algae (Mullen 1998, Sheldon & Walker 1997, 1998, Burns & Walker, in press). These biofilms would become desiccated and killed off soon after their exposure to air during the drawdown, resetting the successional sequence. A 2 month downward shift of the photosynthetic zone would allow a new 'phytobenthic' community to form on any available substrate. As this would not occur significantly during a 2 week drawdown, longer drawdowns would have less impact on overall algal productivity levels. Initial colonisation of new substrate during a drawdown, and re-colonisation of higher areas after re-inundation, would commence with palatable fungi and diatoms, eventually followed by the initial community of blue-green or other attached (filamentous) algae.

Variation in this effect between winter and spring drawdowns is likely to relate primarily to temperature and, to a lesser extent, light levels. Rates of biofilm accumulation and succession would be slower in winter, although a longer exposure time would also be required to kill the original community and fully reset the successional process.

Macrophytes and Riparian Vegetation

The effects of a drawdown on macrophytes are likely to be complex, given the diversity of species and their water-regime tolerances (e.g. Blanch *et al.* 1999, in press). A 2 week drawdown is likely to produce some germination or vegetative growth of macrophytes on exposed sediment, though these are unlikely to survive re-inundation. Differences between winter and spring will mainly occur in the species composition and extent of emergence. A 2 week drawdown is also likely to promote rhizomatous growth in emergent, clonal perennials, with some new shoot development also possible. This response would primarily occur during spring, and may not survive re-inundation during winter. Some shoot survival of stranded floating, free-living and submerged species during a 2 week drawdown is likely during winter, though not during warmer spring weather.

A 2 month drawdown will produce a more extensive response, particularly in spring. During winter, germination on exposed sediment will probably be accompanied by terrestrial weeds, although again these may not grow enough to survive re-inundation. Propagation of rhizomatous species will occur as above, though may have sufficient time for shoot survival. Shoot systems of stranded floating, submerged and free-living species would be killed. A 2 month spring drawdown would result in a complex germination assemblage from recently dispersed/dispersing species. Significant establishment would occur, as well as increased post-inundation survival. Some species may begin to flower. Strong rhizomatous growth and stand expansion would be expected, with subsequent survival of resulting shoots following re-inundation. Shoots of all stranded floating, submerged and free-living would be killed, though countered by vigorous rhizome/stolon growth in many species.

A significant issue with drawdown design is determining the rates of lowering and raising the weir pool height. This is particularly pertinent for riparian tree cover in that too rapid a drawdown can lead to bank slumping or slip-circle failure and a concomitant loss of trees. Results from previous studies recommend a fluctuation rate of 20-30mm/day (Blanch *et al.* 1996, Jensen & Nicholls 1997).

Invertebrates

Following the early demise of any 'bath-tub' ring of algae (see above), its replacement by fungi and diatoms will provide a more palatable food source for insect larvae (e.g. midges, mayflies), gastropods and crustaceans (e.g. copepods, isopods). Local abundances of the latter groups may increase, but the net effect is likely to be diffuse and/or expressed at fine (<1m) spatial scales. A second, less cryptic mechanism through which drawdowns may promote invertebrate populations follows on from any enhancement of macrophyte or riparian communities. Littoral vegetative cover is an important habitat parameter for both immature and adult insect stages, as well as diverse assemblages of Crustacea (e.g. Humphries 1996, Sheldon & Walker 1997). Increased germination and/or growth amongst riparian and macrophyte communities (see above) is likely to result in corresponding changes to invertebrate communities. A response of this nature is most likely to result from a spring drawdown over at least one month, whereas winter and less prolonged (e.g. 2 week) drawdowns may have little impact. Seasonally low invertebrate abundances throughout winter (B. Gawne & I. Ellis, unpublished data) will potentially make any changes from a drawdown difficult or impossible to detect, irrespective of drawdown duration or depth.

Fish

The position of freshwater fishes at the top of aquatic food chains, and their low species diversity in the Murray (Gehrke 1997), suggest that direct benefits from a drawdown will be diffuse and difficult to detect. Benefits will most likely occur as a 'trophic cascade' arising from changes to biofilm, macrophyte or invertebrate assemblages. In particular, recruitment of all species, either from within the weir pool or as a result of longstream larval drift, could be enhanced by increased levels of food (rotifers, microcrustacea) and/or shelter (macrophyte beds). Enhanced food resources might also boost spawning output (increased fecundity, spawning frequency, or larval energy levels) in smaller demersal or mid-water species.

Carp populations in the MDB show a strong affinity with areas of stable gauge-height such as weir pools (Driver *et al.* 1996). Spawning activity tends to be strongly seasonal, peaking in mid-spring (Wilson & Smith in prep.), with egg deposition occurring primarily along littoral margins. Appropriately timed drawdown of weir pools during spring could feasibly act as a carp control measure through drying out any recently-spawned eggs. Use of flow manipulation as a carp control strategy has been trialed (Wilson *et al.* in prep.) with promising results. However, the ascending limb of a spring drawdown may trigger additional minor spawning activity, particularly during a brief drawdown. Furthermore, other fishes such as gudgeons (particularly *Hypseleotris* spp.) and possibly Murray cod (*Maccullochella peelii peelii*) are known to deposit demersal egg masses within shallow sites. Drawdowns may have a similar impact on annual spawning success in these species, although a later spawning season in indigenous fishes may provide some safeguard. A winter drawdown would be unlikely to have any ramifications for egg destruction in either carp or native fishes.

A further effect of drawdowns on fish communities will occur as a by-product of their reliance on fishways for upstream migration (Table 1). Firstly, flows into the head-pool (top of fishway) will decrease during the descending limb of the drawdown, diminishing the attraction of downstream fish to the base of the fishway. In the case of the Yarrawonga fish elevator, similar minimum flow levels are required to maintain exit race velocities and aeration within the chamber (White & Jacobs 1998). Secondly, once gauge height drops below a level specific to each weir, flows into the fishway head-pool cease, removing the fishway from operation until flows are restored.

Fishway effects are important to consider both in terms of drawdown depth, duration and timing. Fish migration along the Murray is highly seasonal and cued by rises in flow and water temperature (Mallen-Cooper *et al*. 1995, Koehn & Nicol 1998). A clear, though broad, peak in fish migration generally occurs between September and February (NSW Fisheries unpubl. data, Mallen-Cooper *et al*. 1995). Thus, upstream fish migration is unlikely to be impacted by a winter drawdown of any depth or duration. However, depth and duration will be important considerations in the design of any spring or summer drawdowns.

Recent Flow History within Murray Weir Pools

Hydrographs from a number of weir pools along the River Murray, and other nearby systems (e.g. Murrumbidgee, Goulburn), indicate varying drawdown frequency over the last decade (Fig. 1). This has implications for both the location of a drawdown trial and the ongoing use of drawdowns as a management tool. Where past hydrographs indicate drawdown activity, any ecological benefits obtainable from such action may already be realised. However, this should not be a deterrent. Indeed, significant drawdown frequency within some weir pools adds weight to assessments of feasibility. Nevertheless, any weir pool with a record of recent drawdowns may be a poor site for the currently proposed trial.

Weir Operational Constraints for Drawdown of River Murray Weir Pools

Weirs currently have a primary function balancing entitlement flow rates for domestic, agricultural and industrial consumption. Weir operational issues will, therefore, be a crucial consideration in designing and planning any drawdown activity. A range of these is summarised in Table 2, and discussed below.

The challenge when planning drawdown of a weir pool is to achieve a significant manipulation at entitlement flows whilst maintaining some capacity for storage and diversions. However, the capacity for individual weir pools to capture flow pulses differs between locations in relation to channel shape and width. For example, Torrumbarry Weir requires 8GL to achieve a 1.05m return in gauge height to the 86.05m AHD design full supply level (White & Jacobs 1998). In contrast, a 0.8m rise to 47.8m AHD (0.2m surcharge) at Euston Weir requires 11GL. To achieve a drawdown of around 1m at some weirs during a dry season or year, volumes needed to return the pool to full supply level may be large. Overcoming this would require either a single large flow into the weir pool, or a protracted return to design full supply level. Neither is likely to be acceptable from environmental, management or social perspectives. This suggests that feasible drawdown depths will vary slightly between weir pools, due to operational factors alone.

Table 1: *Impacts of drawdown depth on fishway operation in the Murray. Source: Yarrawonga, Torrumbarry, Euston and Mildura weirs: White & Jacobs 1998; Murtho weir: B. Porter, pers. comm. Data on the Murtho (Weir 6) fishway were not available.*

Weir	Drawdown depth when effects commence (m)		Additional comments
	Fishway operation adversely affected	Head-pool flows cease	
Yarrawonga (26)	0.15	≥0.25	Fish elevator in use, but still requiring attraction flows for effective operation and chamber aeration
Torrumbarry (21)	0.05	1.05	
Euston (15)	0.20	0.40	Poor use of fishway at downstream flows of <5,500ML / d
Mildura (11)	0.06	Detail not available	Fishway not yet constructed

Some weir pools, particularly Euston, function as a mid-river balancing or re-regulating storage. Water is diverted temporarily for 'topping-up' shortfalls in downstream entitlement-availability during periods of critical need. Lowering of weir pool gauge height during periods of re-regulation can lead to operational difficulties for weir staff and poor water quality (White & Jacobs 1998).

Additional problems may be experienced with transferring irrigator entitlements into supply channels. Direct diversions occur at the Yarrawonga and Turrumbarry weirs, and at weirs on smaller Murray Valley systems (e.g. Goulburn, Loddon, Little Murray rivers). The minimum weir pool gauge heights for diversion into individual channels are well known, and will be a critical parameter in deciding the depth of a drawdown. However, this will also vary seasonally in relation to levels of weed growth within channels (White & Jacobs 1998). For example, diversion into Yarrawonga Main Channel (Fig. 2) requires a minimum gauge height in Lake Mulwala of 124.8m AHD at times of heavy macrophyte growth (summer to autumn). By contrast, diversion at 124.7m AHD will only occur under virtually macrophyte-free conditions.

Flows through weir pools 7 and 9 have direct effects on regulating entitlement flows into South Australia. At Weir 9, flows are diverted into Lake Victoria, a large natural deflation basin now used as a re-regulatory storage. Connectivity with the Murray is achieved through Frenchmans Creek (upstream inflows) and Rufus River (downstream outflows). Flows into Lake Victoria are achieved through gravity feed from the Weir 9 pool. A flow gauging station immediately downstream of Weir 7 is used to monitor Murray flows entering South

Figure 1: *Temporal variability in daily gauge height within three Murray weir pools, January 1990 to June 2000. Weir pool 7 experienced no drawdown activity during this interval. By contrast, hydrographs for weir pools 11 and 15 show significant drawdown frequency, particularly prior to 1997. Raw data from River Murray Water, Canberra.*

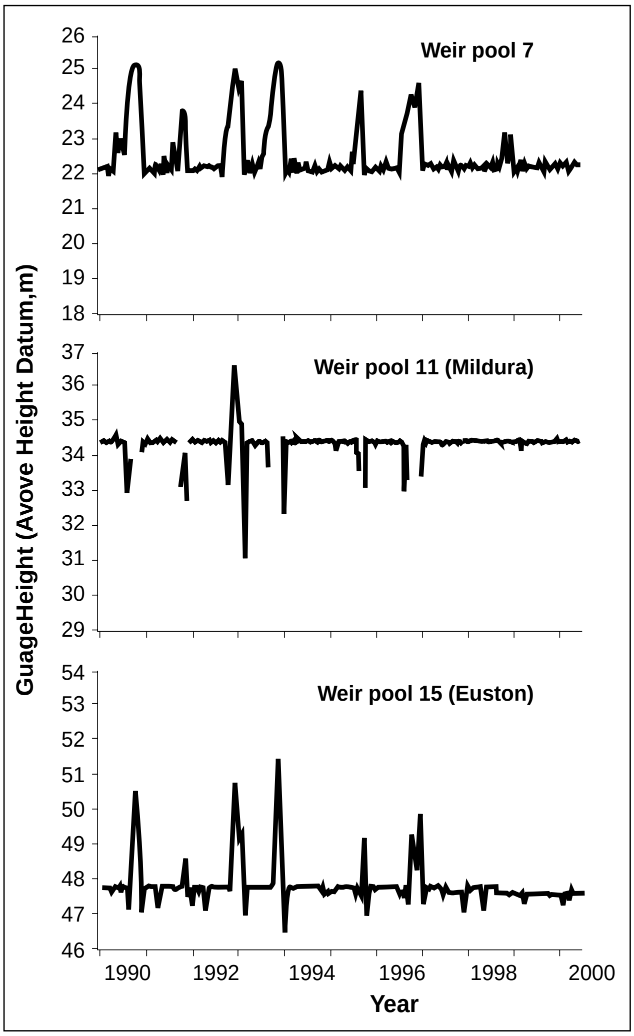

Table 2: *Summary of effects of drawdown timing, duration and depth on weir operational factors along the Murray. 1 = primary (main) effects; 2 = secondary effects.*

Factor	**Affected by**		
	Drawdown timing	**Drawdown duration**	**Drawdown depth**
Flow-capturing capacity of weirs		2	1
Mid-river flow re-regulation	1		2
Channel diversions	2		1
Entitlement-flow gauging	2	1	
Cathodic protection of weir components	2	2	1
SCADA (weir flow-control system)		2	1
Hydro-electricity generation (Yarrawonga)		2	1

Australia and (when necessary) adjust 'balancing flows' from Lake Victoria. A drawdown at either of these weirs (particularly 7) will have potential ramifications for calculating these entitlement diversions.

Many metallic weir components rely on cathodic (reduction-oxidation) protection to avoid chemical corrosion. This functions at an optimal level when weirs are at design full supply level or greater (e.g. 0.2m surcharge at Euston: White & Jacobs 1998). However, this effect is likely to be diminished during large or prolonged drawdowns, and may add significantly to maintenance requirements should frequent drawdowns be required. Several other considerations in relation to large drawdowns include operational difficulties with the flow-control systems (SCADA) of weirs, and hydro-electricity generation capacity at the Yarrawonga Weir Power Station. The latter relies on the head difference between the weir pool above and below the weir, reducing generation potential during a drawdown.

Socio-Economic Considerations for Drawdown of Murray Weir Pools

Socio-economic factors relating to direct users of weir pools may also be affected by the timing, duration and depth of a drawdown (Table 3). A full appraisal requires a formal cost-benefit analysis approach. At the same time, this will need to draw upon a range of non-market economic valuation techniques (e.g. James & Gillespie 1997). The following considers a number of social and economic factors likely to be significant.

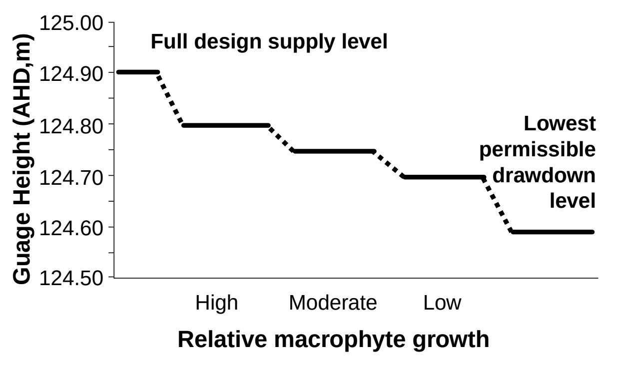

Figure 2: *Differences in minimum weir pool gauge height (Lake Mulwala) required for diversion into the Yarrawonga Main Channel under varying levels of macrophyte growth in the channel.*

Irrigator entitlement flows are probably the major socio-economic parameter to be considered. Diversions from most weir pools over the last decade have reflected a broad seasonal distribution, with a consistent low in June (Fig. 3). Some inter-annual variability is evident, although primarily in the presence / absence of large peaks in late September / early October (e.g. Yarrawonga, Fig. 3A). Given the low desirability of mid-winter drawdowns from an ecological perspective ('Likely ecological outcomes of weir pool drawdowns' above), it will be imperative that strategies allow drawdowns during periods of high irrigation demand. This may include reductions in drawdown depth with increased duration.

Bank-side caravan parks occur within most lower Murray weir pools. Caravan park use is likely to reflect seasonal peaks during school holiday intervals (December to January; late April; July; late August). Caravan park operators and guests

Table 3: *Summary of effects of drawdown timing, duration and depth on socio-economic factors considered in this study. 1 = primary (main) effects; 2 = secondary effects.*

Factor	Affected by		
	Drawdown timing	**Drawdown duration**	**Drawdown depth**
Irrigator diversions	1	2	2
Pump foot-valve (offtake) depth	2	2	1
Bank-side caravan parks	1	2	2
Houseboats (tourist)	2	2	1
Houseboats (permanent accommodation)		2	1
Boat-ramp and car-ferry access	2	2	1
Submerged hazards to boating			1
Cattle watering		2	1

are likely to find the exposed banks from moderate to large drawdowns unsightly and a significant inconvenience should river access for swimming or water-craft use be impeded. Similar views may be expressed by visitors to the information centre overlooking Torrumbarry Weir.

Houseboats are a prominent direct recreational user of Murray weir pools, and are a significant source of income to local communities. Many owners/hirers operate pooton-style craft, which are likely to be heavily impacted by drawdowns. However, in some locations (e.g. Mildura and Wentworth), permanently-moored craft (usually bank-side) provide a cheap housing option. These are often in shallow areas (ca. 0.5m), and would easily be stranded on exposed river-bed (e.g. Tuckers Creek, Wentworth weir pool; Bumbang Cut, Euston weir pool).

Seasonal patterns in houseboat hiring rates were examined for the Sunraysia area through discussion with the Sunraysia Houseboat Association. Seasonal patterns vary among houseboat operators, although overall seasonality in the Sunraysia area is low (W. Kerridge, pers. comm.). August is a universally quiet month, reserved for boat maintenance. November also tends to be a quiet month, in the lead up to the summer holidays. While drawdowns may have little impact on houseboat operation (apart from increased risk from exposed snags, see below), difficulties with mooring craft along banks overnight will need to be considered.

Recreational boating for activities such as fishing and water-skiing is also popular along the River Murray. Often concentrated within weir pools. Stage-height stability within weir pools provides for consistent launching conditions along the main channel, and these are often the main locations for boat ramps. Accordingly, drawdown of weir pools beyond ca. 0.5m may have implications for recreational boating and use of boat-ramps. Similarly, navigation at the marina at the upstream end of the Torrumbarry weir pool is severely restricted or impossible at drawdowns of 0.6m or more. Furthermore, any reliance on boat ramps or marinas by emergency services (principally water police and the State Emergency Service) will need to be considered in relation to the planning of any drawdown. This has been identified as a significant issue for the Euston weir pool (White & Jacobs 1998). Similarly, operation of car ferries crossing the lower Murray (e.g. Waikerie or Walkers Flat) is difficult below certain depths (Ohlmeyer 1991).

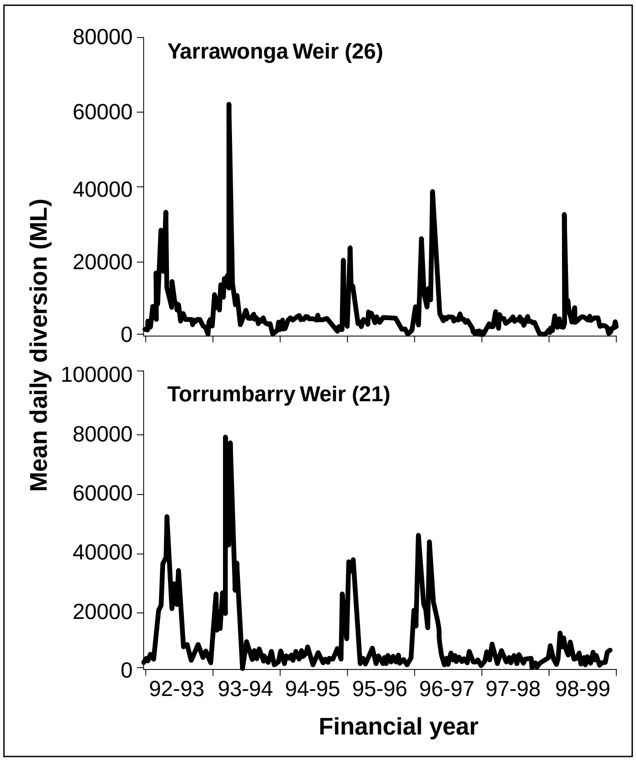

Fig. 3: *Temporal variation in mean flow diversion at two large weirs in the lower River Murray. Data were calculated as a mean of daily inflow and outflow volumes at each weir pool. Raw data from Goulburn-Murray Water, Tatura.*

Submerged snags within or adjacent to areas of heavy boating (e.g. water skiing) may become a danger to boats during drawdown intervals. Water-skiing and fishing activity peaks during school holiday periods along the entire river, and annual water-skiing competitions are held in some weir pools (e.g. Euston). Apart from this, boating in general is unlikely to place seasonal limits on drawdowns. However, boat-ramp access and snag exposure will both need to be considered when determining the duration and depth of any drawdown.

Finally, graziers watering cattle directly from the riverine or backwater sites may experience difficulties with cattle getting stuck or causing excessive trampling along soft banks during a drawdown (Ohlmeyer 1991).

Conclusions

Our somewhat limited understanding of lowland river ecology indicates that significant changes in river condition may be expected as a result of changing the management of weir pools. One obvious change is to alter water levels within the pools through initiatives like a drawdown. While this approach holds considerable promise, there will be a trade-off between the types of manipulations that would maximise the ecological response and those that minimise social, economic and operational impacts. This will require decisions regarding the seasonal timing, depth and duration of any drawdown, using constraints such as the permissible drawdown rate and weir operational issues.

The ecological changes outlined here suggest considerable benefit could be achieved from an appropriately planned manipulation. These include enhanced recruitment (macrophytes, micro-invertebrates, fish), greater species diversity (particularly invertebrates), and reduced conditions for blue-green algal blooms. Nevertheless, weir pools represent an extremely altered environment and several short-term 'negative impacts' could also arise following a major drawdown. For example, key community concern will be the increased salinity load likely to be transferred into the river during and after a drawdown. This aspect of any drawdown will require careful public relations management given the current public and political focus on salinity-related degradation. However, while any salinity spike is likely to be a short-term feature, there is also the potential for it to counter some of the concomitant increases in rotifer or microcrustacean abundance. In turn, this may obviate any potential benefits to fish assemblages and possibly also reduce the browsing pressure on biofilms or phytoplankton.

This last point underscores the fact that it will be simplistic to consider in isolation any ecological outcomes from such a large-scale habitat manipulation. Drawdowns will almost certainly have both large- and small-scale effects on the riverine environment, and produce correspondingly complex ecological changes. Current knowledge of River Murray ecology is scant, although it does allow for some predictions of how individual ecosystem components (e.g. macrophytes) may respond to a drawdown. However, assessing the validity of drawdowns as a management tool will require a stronger appreciation of synergistic (complementary or antagonistic) changes. An appropriate understanding of these will require a trial drawdown to be performed. This should be based on robust statistical methods (e.g. MBACI: Underwood 1991, Reid & Brooks 1998) that allow concomitant changes to be detected both within and below a weir pool, and in any adjacent wetlands connected to the weir pool.

Clearly, no alteration to weir pool operation can be undertaken without the involvement of the community who depend on the weir pool for their livelihood and recreation. It is equally apparent that it will be these same communities that will benefit from improvements in the condition of the river and associated gains in water quality. The primary objective of the present project is to demonstrate the ecological benefits of altered weir pool management, while simultaneously demonstrating that the change in management need not produce adverse economic and social consequences that many people fear. Ensuring widespread acceptance of a drawdown trial will require direct involvement by the community in its design and evaluation. A first step in this process will be to develop a consultation plan that includes a program of advertising, public consultation and opportunities for feedback.

Acknowledgements

This study (Riverine Project R13) was funded through the Strategic Investigation & Education Program of the Murray-Darling Basin Commission. Additional support was received from the Cooperative Research Centre for Freshwater Ecology, the New South Wales Department of Land and Water Conservation, and the Murray Wetlands Working Group. Flow and diversion data was provided by River Murray Water and Goulburn-Murray Water. This paper benefited from discussions with Darren Baldwin, Rob Gillespie, Anne Jensen, Lance Lloyd, Rod Oliver, Jane Roberts, and Michael Williams.

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Weir pool Drawdown as a Management Option for the River Murray was presented by Glenn Wilson[1] and co-written with Ben Gawne[2], Keith F. Walker[3], Paul G. Lloyd[4] and David Harriss[5].

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Biography

Glenn Wilson has a research background in the population dynamics of marine and freshwater fishes. Following doctoral studies through James Cook University, Glenn completed a 2 year study on the efficacy of drawdowns within carp spawning sites as a control technique. In March 2000, he began managing a consultancy for the Murray-Darling Basin Commission on weir pool drawdowns. Currently, Glenn is a scientist-in-charge of the Murray-Darling Freshwater Research Centre's new Northern Laboratory in Goondiwindi, southern Queensland.

Weirs of the Murrumbidgee River: Operational Protocols for the Enhancement of Water Quality

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Abstract

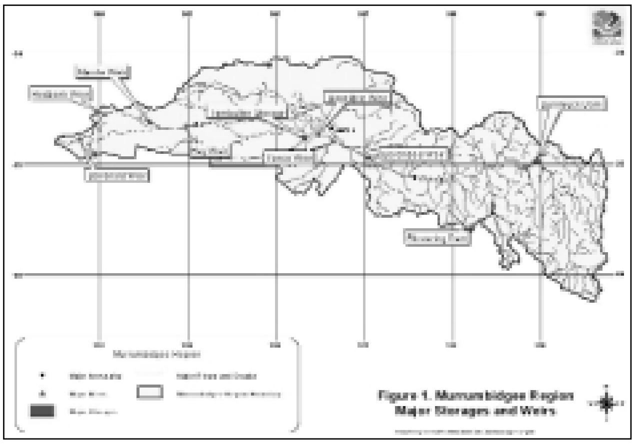
State Water, the commercial water supply arm of the Department of Land and Water Conservation, administers one minor and two major storages and seven weirs along the Murrumbidgee River. The weirs and storages are primarily for water supply to the major irrigation areas and to towns and individuals along the Murrumbidgee River. Assessment of water quality is becoming increasingly important as users expect high quality water to be constantly available. In the past, short-term operational management of storages and weirs has only considered volumetric supply and demand, rather than quality of the water supplied. With increased concerns about sustainability and ecosystem health (e.g. NSW Water Reforms), quality has become increasingly important. Consequently, water quality and biological information need to be used to improve the management of storages and weirs from an environmental perspective.

Operational protocols for the storages and weirs along the Murrumbidgee River have been prepared to enhance water quality. Monitoring equipment has been installed in the western weirs in the Murrumbidgee River. Weir operation will depend on State Water manipulating gate settings according to real time water quality information and the operational protocols in addition to water demand. For each weir an operating protocol has been tailored to ensure that maximum environmental benefit is achieved with a minimum cost to irrigators or other water users. This will result in more environmentally sensitive and cost efficient weir management. Future improvements to the system will include installation of equipment on Burrinjuck Dam to manipulate release water temperatures and installation of algal monitoring equipment on Tombullen Storage to reduce the impacts of blue-green algal blooms.

Thermal stratification is a major cause of algal blooms in western weirs, and is caused principally by low flows through the weirs. Manipulating flows will reduce or destroy thermal stratification. Options for flow manipulation include increasing base flows, pulsing flows, high level releases and drawing down the weir pool. There are four components for successful weir manipulation. Operational protocols are decision support trees based on real time information. Monitoring equipment in situ *provides information necessary to make management decisions. Operational structures are a major constraint on the actions taken; decisions are limited by the structure. The communication / control network is a vital link. Without the ability to receive information and act on it quickly and efficiently, the protocols will not work.*

Introduction

The Murrumbidgee River in south western New South Wales is a major tributary of the Murray Darling River system. It rises in the Snowy Mountains and flows west, draining a catchment of around 84,000 square kilometres. Two major dams, seven weirs and one minor on-route storage supply 92% of summer irrigation needs (SOR 1994). Twenty-three percent of New South Wales rural water use occurs in the Murrumbidgee Region. Provision of good quality water to consumptive users along the Murrumbidgee River is becoming increasingly important. With the implementation of the NSW Water Reforms and a greater emphasis on 'ecosystem health', the operation of storages and weirs is under scrutiny from resource managers, aquatic scientists and



environmentalists. Consequently, water quality and biological information are being used to improve the management of storages and weirs from an environmental perspective.

Operational protocols for storages and weirs along the Murrumbidgee River have been prepared to enhance water quality and to maintain ecosystem health within the system, at minimum cost to irrigators or the water supply authority (State Water). These protocols cover a whole range of environmental issues such as fish passage, algal blooms, environmental flows, wetland filling and thermal pollution. This paper's focus is the proposed manipulation of weirs to reduce algal blooms along the Murrumbidgee River, as well as a brief discussion of proposed methods to reduce cold water pollution downstream of storages.

Weirs along the Murrumbidgee River

The seven weirs along the Murrumbidgee River act as diversion or reregulation structures (Fig. 1). They supply water for irrigation, towns and stock and domestic use. The majority of water is used in the Murrumbidgee Irrigation areas around Griffith. The weirs can be grouped depending on the release structures present (see Fig. 2).

- Overshot weirs, where water flows over the top of the weir and the height of the weir can be altered (Balranald).
- Undershot or bottom release weirs, where the weir gates can be controlled electronically to vary the volume of water being released through the bottom of the weir (Gogeldrie, Maude and Redbank).
- As a combination of overshot and undershot, with both bottom release gates and fixed crest structures present (Yanco, Berembed).
- Hay Weir is an undershot weir that also has a small independently controllable surface release gate.

Weirs and Algae: Background

A study of the relationship between flow and algae in Maude Weir, west of Hay showed that thermal stratification within weirs is a major cause of blue green algal blooms (Webster, et al., 1997). Thermal stratification can occur between October and April when there is high solar radiation, low flow and little wind. Solar radiation heats up surface water that forms a still layer over the cooler, flowing water within the weir. Low flow and low wind conditions mean little turbulence within the weir pool to reduce the effects of solar radiation. Once formed, the warm surface layer provides ideal conditions for the growth of blue-green algae. The temperature of the inflow water may also influence the severity of stratification. When inflow water is warm, there will be less of a difference between surface and

Figure 2a: *Weir types in the Murrumbidgee. Bottom release gates. Gogeldrie Weir.*

Figure 2b: Weir types in the Murrumbidgee. Overshot weir. Yanco Weir.

During summer, river flows are principally driven by user requirements along the system, with allocations dependant on the available water. Seasons can be classed as 'wet' or 'dry', depending on the amount of rain during the previous winter. Periods where flow is less than the estimated critical flow will be longer and more frequent during dry years (Tables 2 and 3).

When flows are moderate to high, diatoms (especially the filamentous *Aualcoseira* sp.) are the dominant algal group and they are brought to the surface by turbulence where they can compete for nutrients and light. Under low flow conditions diatoms will sink, and other more buoyant taxa (such as the blue-green alga *Anabaena* sp.) will have a competitive advantage (Webster *et al.* 1997). Blue-green algae are part of the natural algal population and may not increase in numbers unless environmental conditions change. A combination of low flow and thermal stratification will provide the ideal conditions for a blue-green algal bloom. Once environmental conditions are good for blue-green algae, the population will go into a rapid growth phase (Mitrovic and Bowling 1996). A bloom usually takes two to three weeks to develop fully in a stratified weir pool (Webster and Pengelly 1998).

bottom waters than if the inflow water is cooler. Diurnal variation in thermal stratification also occurs, as at night water will lose most heat absorbed during the day. The greatest difference between surface and bottom water temperature occurs in the afternoon.

Thermal stratification within weirs is directly linked to low flow conditions (Webster *et al.* 1997). Flow requirements in each weir to prevent thermal stratification have been extrapolated from Webster *et al.*'s (1997) work (Table 1, Webster and Pengelly 1998). The amount of flow required to destroy thermal stratification is dependent on the cross-sectional shape of the weir pool (discussed below).

Table 1: *Average daily flow (summer 2000) and estimated critical flow (algal bloom suppression) in weirs along the Murrumbidgee River (after Webster and Pengelly, 1998).*

Weir	Average Daily Flow (ML d-1)	Estimated Critical Flow (ML d-1.)	Structure width (m)	Maximum weir depth (m)
Berembed	8323	1050	80	4.94
Yanco	9038	200	26	3.2
Gogeldrie	3743	1500	86	6.1
Hay	2121	1250	45	8.6
Maude	1785	1000	59	6.0
Redbank	1850	900	59	5.64
Balranald	1302	300	44	3.0

Of the seven weirs in the Murrumbidgee River, Hay, Maude and Redbank Weirs have seasonally recurring thermal stratification that can be attributed to low flow conditions. The most easterly weirs that are used to supply water to the major irrigation areas have flows that are much higher than the estimated critical flow and do not suffer from thermal stratification (Fig. 3). Within these weir pools, diatoms dominate algal populations. In contrast, the western weirs of Hay, Maude and Redbank are downstream of the major irrigation areas. This results in summer flows that are often below the estimated critical flow (Tables 2 and 3, Fig. 4). These three weirs have recurring blue-green algal blooms over summer. Balranald Weir very rarely has blue-green algal

***Table 2:** Number of days per month that average daily flows do not exceed the estimated critical flow at each weir during 1997-1998 summer (dry year). Numbers in brackets are number of consecutive days that average daily flows are below estimated critical flow.*

1997-1998	Berembed	Gogeldrie	Hay	Maude	Redbank
September	0	8	6	9	20 (10)
October	0	7	14 (11)	24 (10)	21 (14)
November	0	7	5	22 (14)	25 (17)
December	0	1	18 (15)	(31)	(31)
January	0	0	11 (8)	17 (14)	19 (15)
February	0	8	16 (8)	25 (17)	23 (17)
March	0	2	3	20 (5)	20 (15)
April	0	14	16 (11)	24 (14)	17 (9)
May	11	(30)	(25)	(23)	23 (22)

***Table 3:** Number of days per month that average daily flows do not exceed the estimated critical flow at each weir during 1999-2000 summer (wet year). Numbers in brackets are number of consecutive days that average daily flows are below estimated critical flow.*

1999-2000	Berembed	Gogeldrie	Hay	Maude	Redbank
September	0	5	4	12	20
October	0	1	4	10	7
November	0	9	(16)	(18)	(18)
December	0	8	(16)	17 (16)	(25)
January	0	(7)	15 (13)	14 (12)	12 (10)
February	0	3	(6)	(7)	(8)
March	0	6 (5)	(6)	(6)	2
April	0	26	21 (14)	21 (14)	19 (14)
May	0	29 (24)	14 (11)	14 (11)	(10)

blooms despite having low flows for most of summer. This is because it is overshot and relatively shallow which means that water in the weir pool has a short residence time.

Blue-Green Algae Suppression in Weirs

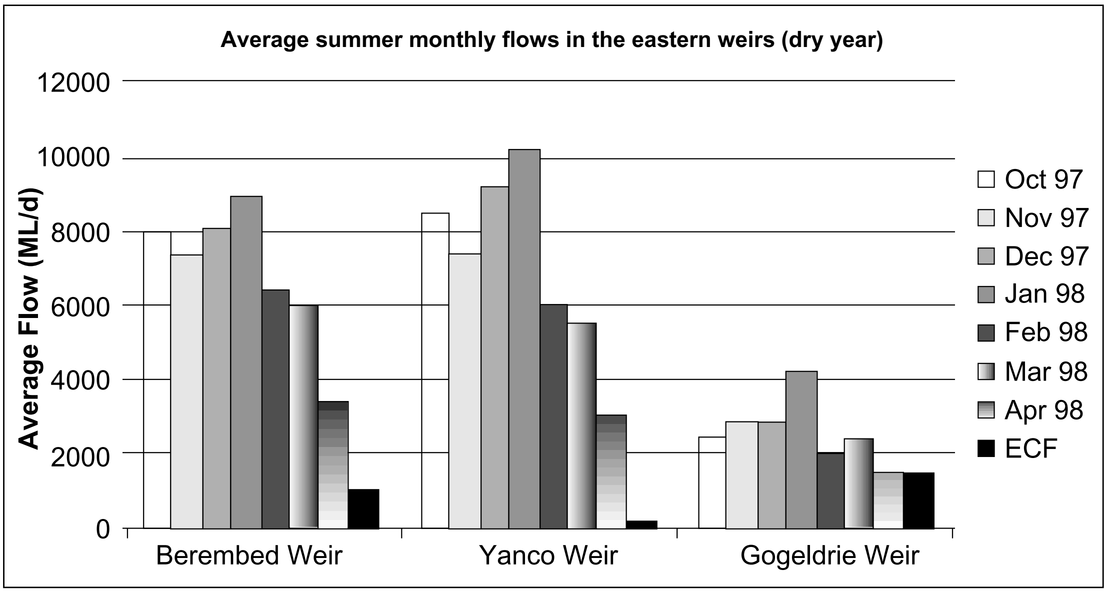
There are four main options to prevent thermal stratification within the weir pools that are based on manipulation of gate settings and flow. These are:

- increasing base flows;
- pulsing flows;
- selected level releases; and
- drawing down the weir pool.

Increasing Base Flows

Increasing base flows through the system would alleviate the problem of thermal stratification if the lowest flows through the western weirs were always greater than the estimated critical flow (Fig. 4). However, for Hay, Maude and Redbank Weirs the option of increasing base flows beyond current is not practical. During summer, the majority of water is diverted above or at Gogeldrie Weir (Fig. 5).

***Figure 3:** Average flows in eastern weirs (dry year) compared to the Estimated Critical Flow (ECF).*



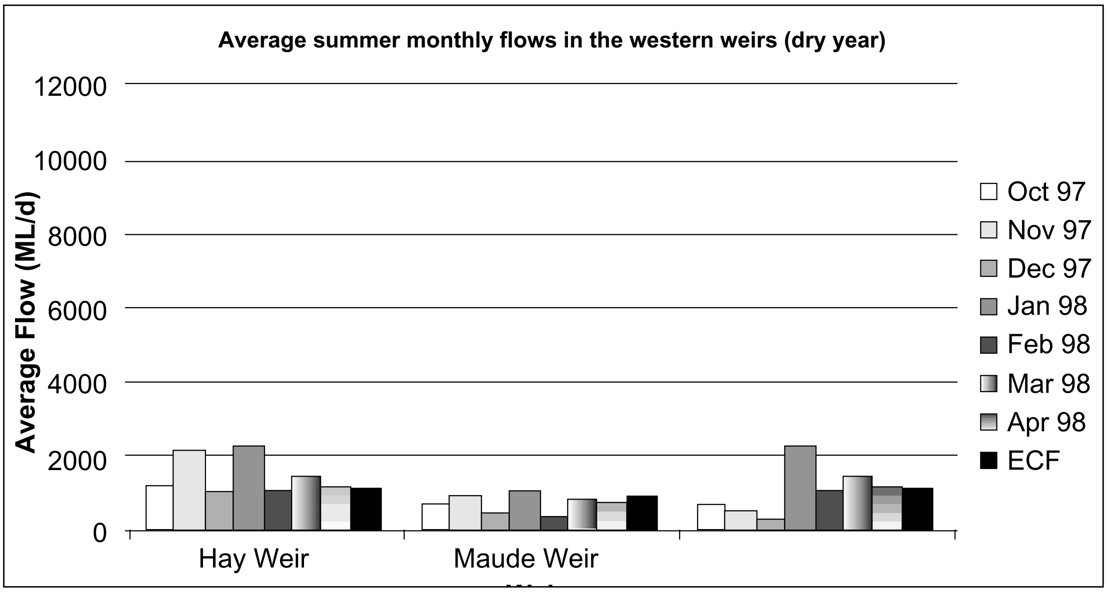


Figure 4: *Average flows in western weirs (dry year) compared to the Estimated Critical Flow (ECF). Average flows in eastern weirs (dry year) compared to the Estimated Critical Flow (ECF).*

Consequently, there is little flow through the western weirs beyond what is needed to supply consumptive demand. At Balranald there is an 'end of system' requirement that means 200 to 300ML/d must flow past Balranald Weir into the Murray River, depending on water allocations.

Under rules established by the Murrumbidgee River Management Committee, an Environmental Contingency Allowance (ECA) is set aside every year. It is used principally as emergency supply (such as for wetland refilling if bird breeding is threatened). There are a series of 'triggers' that allow water to be released: without the triggers the water remains in the storage to be reallocated the following year. Current rules will not allow the provision of ECA water to increase base flows through the western weirs.

Pulsing Flows

When it is not possible or desirable to increase base flows above the critical level, it may still be possible to pulse flows through a weir pool to destroy or prevent thermal stratification. A pulsed flow can be generated by withholding 'extra' water at the next upstream weir. This water can then be released to create a flow that is higher than the critical requirement for one to two days. For example, in Hay Weir, a flow of 1,250ML/day for two days is thought to be sufficient to destroy thermal stratification. This can be achieved for short durations during peak periods of irrigation demand, when flows are most restricted. Stratification may take weeks to develop in a weir pool, and a single pulsed flow of up to two days duration, timed to move through the weir pool just as thermal stratification begins to establish, may be the most water efficient method of preventing it.

A second advantage of allowing a pulse of a higher volume of water to move through one weir is that it can have a follow-on effect in weirs downstream of it. As the conditions required to induce thermal stratification are likely to occur in all weir pools concurrently, the benefit of a single pulsed flow can be maximised to destroy thermal stratification in all weirs.

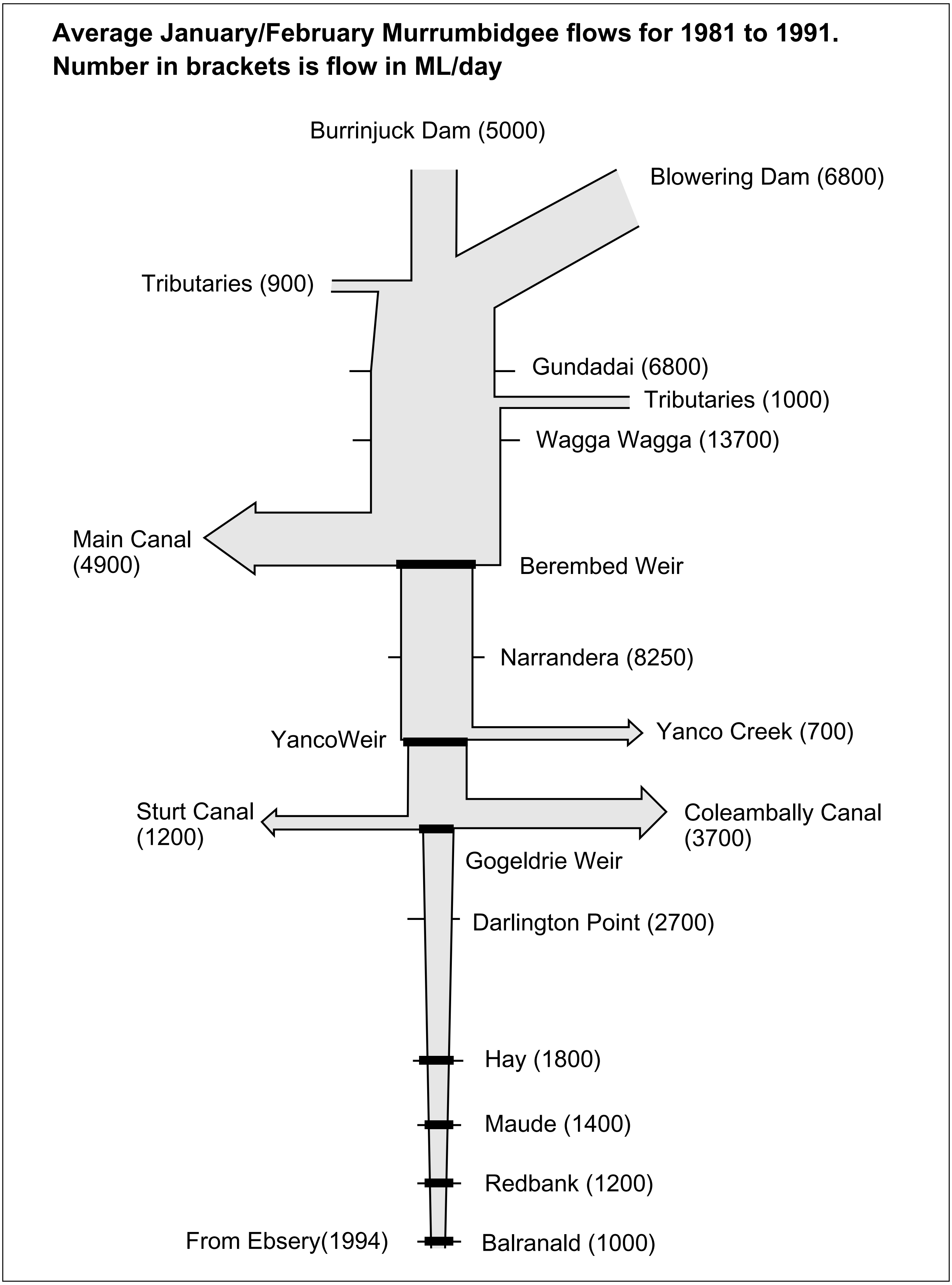
Surface Layer Releases

Selective withdrawal of warm surface waters can potentially reduce algal blooms by decreasing the residence time of surface water. Once stratified, the long residence time of surface water allows for more heating and intensifies stratification. Early removal of warm surface waters may prevent further heating and facilitate mixing of surface and bottom waters. For Hay Weir, effective discharge volume appears to be a minimum of 500ML/d from the surface. Below this, surface layer releases are not effective in reducing stratification (Pengelly, pers. comm. August 2000).

Blue-green algal blooms take several weeks to develop in a fully stratified weir pool. If surface water can be moved through the weir pool during this early stage, then a bloom will not have enough time to form before passing back into the well mixed river system below the weir pool.

Another advantage of high level releases is the

Figure 5: *Average flows and diversions along the Murrumbidgee River during summer. From State of the Rivers vol.1 (1995).*



flow on effect to weir pools further down river. Releasing warm surface water as well as cooler bottom water will increase the temperature of river water downstream. The severity of thermal stratification is dependent on the difference between surface and inflow waters. Warmer inflow water will lessen the effects of thermal stratification in the next weir pool.

Currently Hay is the only weir in the western Murrumbidgee with the ability to release water via a surface gate.

Drawing Down the Weir Pool

The cross sectional shape of a weir pool has been found to directly correspond to the critical flow required to destroy thermal stratification (Webster *et al.* 1997, Webster and Pengelly 1998, Fig. 5). Deep or wide weir pools have a greater estimated critical flow than shallow or narrow weir pools (Table 1, Webster and Pengelly 1998). Hay Weir has an estimated critical flow of 1,250ML/d, compared to 300ML/d for Balranald, which is almost the same width. However, Hay is 8.6m deep, compared to Balranald at 3.7m depth (Table 1). If the depth of a weir is reduced but the flow is kept the same, this will reduce the critical flow required to destroy stratification. For example, reducing the depth of Hay Weir from 8.6m to 6.0m would bring the required estimated critical flow to less than 1,000ML/d. For a great proportion of time, the flow through the weir would be above this and thermal stratification would be prevented.

Theory and Principles

Operating protocols exist for many environmental management problems. These include increasing flows to facilitate wetland filling at critical times and to promote river health. For simplicity, this paper only deals with the operating protocol that addresses blue-green algae and weir pool stratification.

There are four components to the successful implementation of the operational protocols. These are:

- the research based operational protocols;
- physical water release structures;
- the monitoring equipment; and
- the communications/control network.

Operational Protocols

Operational protocols have been drafted as simple decision support documents, with each level a yes/no decision in the process (see Chart 1 – Hay Weir Operational Protocol). They have been designed this way for easy programming and automation and to ensure accountability at each step. They are based on the 4 options discussed above. The protocols are dependent on the availability of real time data and the speed of analysis and action. The adaptive management process that the operational protocols depend on means that there is no one right chain of actions that will be consistently used to destroy incipient thermal stratification. Rather, the actions taken will be dependant on a series of factors such as the availability of water, the presence and abundance of blue-green algae, the available release structures (surface/bottom release).

Current protocols are based on a risk analysis approach. Temperature and flow are surrogates for a direct measure of algal condition. We know that the risk of blue-green algal blooms increases with an increase in stratification in a weir. This enables us to determine when an algal bloom is likely to occur, and what steps can be taken to prevent this. At present, protocols are dependent on two data sets – 'real time' temperature profiles and algal concentration which is collected and analysed up to a week earlier. Flourimeters are hand held probes that measure the amount of chlorophyll a in a water body. Chlorophyll a is a pigment found in all algae. Some are available that can give an immediate estimate of algal biomass and types, and are currently being trialed in the Murrumbidgee (McLean, in prep).

Improved ability to predict algal blooms using real time algal data may not be economically viable (cost of probe, maintenance) or may not improve the risk analysis enough to warrant the increased costs. The field trials include consideration of questions such as: are current temperature protocols efficient; are temperature profiles effective indicators of algal risk; and whether we need real time algal data (McLean, in prep).

Operational Structures

The configuration of gates on a weir is the major constraint on the operational protocol, whether it is designed to reduce thermal stratification or to address another environmental issue. If the weir has a fixed crest, no manipulation of the structure can be done without major engineering works. However if the weir has a series of movable gates or offtakes at several levels, such as Hay, the options available to resource managers are greater. Depending on what environmental outcomes are required, (such as warm surface layer releases to improve fish habitat downstream; selective withdrawal to avoid algae-rich water; destratification) and the funds available, there are a number of engineering solutions that could be implemented. These include submerged curtains, trunnions, surface pumps and multilevel offtakes (Sherman 2000).

Monitoring Equipment

Within each of Hay, Maude and Redbank Weir pools a buoy moored approximately 200m upstream of the weir wall has a series of temperature probes (thermistors) which measure the water temperature at various depths throughout the water column. These are linked to a logger that automatically records the temperature every 30 minutes, giving a detailed, high resolution picture of changes over time.

Communications/Control

State Water South have installed a series of radio communications towers that allow River Operations staff (who control weir gates and thus flow) in Leeton to remotely observe and adjust gate settings. This SCADA (Supervisory Control and Data Acquisition) system links all weirs with the operations centre. Changes in flow can be achieved almost instantly, without the need to have an operator on site. The monitoring equipment is linked by radio to the SCADA network. This allows River Operations staff to access temperature data in real time, and make decisions using the operational protocols.

The method chosen each time to destroy thermal stratification in Hay, Maude and Redbank Weirs will depend on several factors: the available water supply; the amount of potentially toxic algae present (in particular *Anabaena* sp.); the structures at each weir; and, the estimated cost of each potential solution. This adaptive management strategy allows the most to be made of a given situation and ensures that environmental and user requirements are balanced to optimise water use. It also provides users with good quality water.

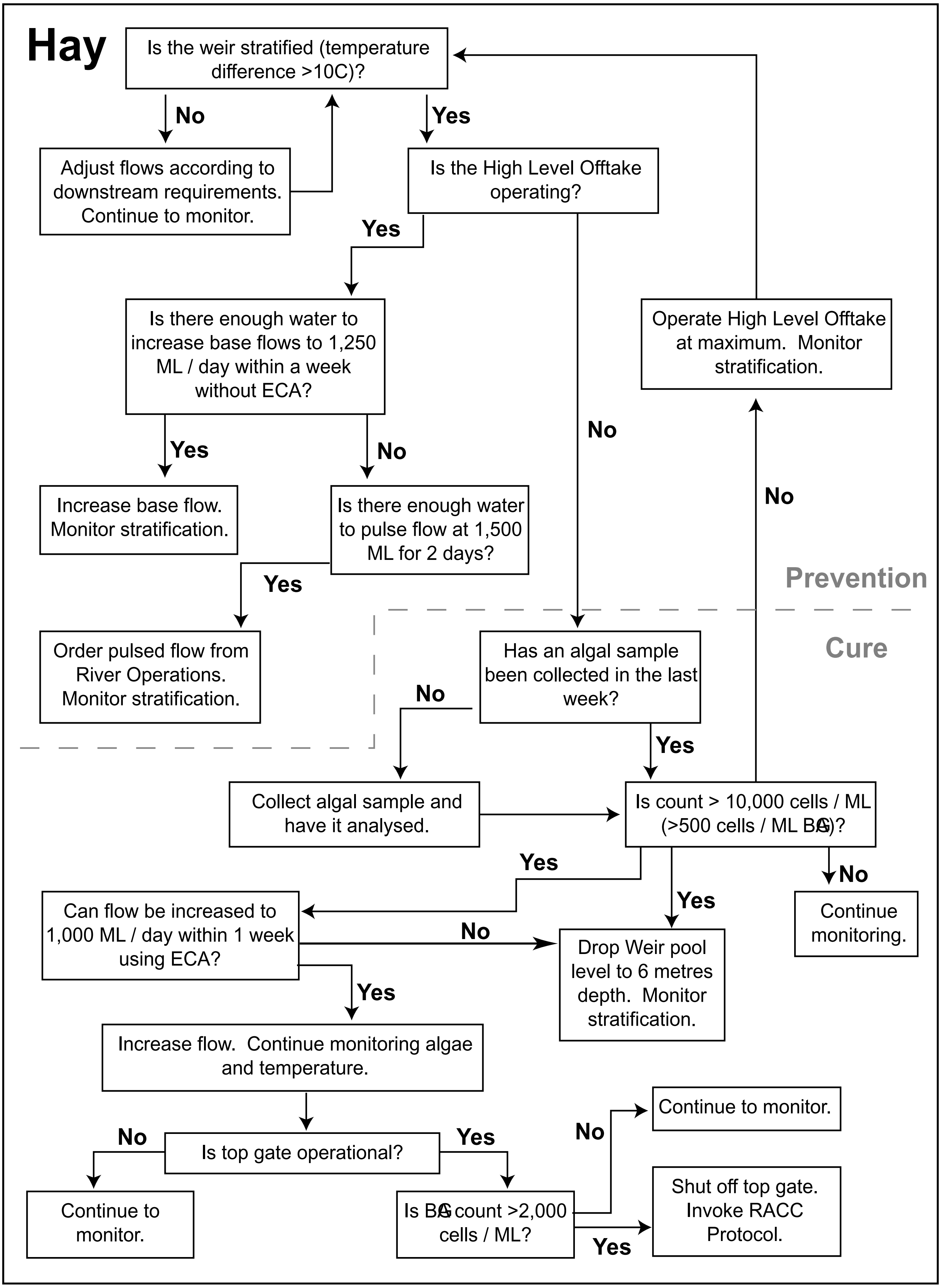
Implementation

The implementation of the operational protocols within each weir will depend on the relative impact of the methods available. Each time it is necessary to manipulate weirs according to the operating protocols, the least ‘costly’ method can be chosen. The relative impact of each of the options can be investigated and compared so that the method that will cause minimal disruption, is the easiest to implement or the most cost effective can be chosen. For example, the relative cost of increased flow will be measured in terms of the water ‘lost’ down the system. This can be compared to the cost of dropping the level in the weir pool, which can be measured in terms of the increased costs of pumping water (electricity/ diesel). In the operating protocols, the ‘costs’ of each method determine which is near the top of the decision tree, so that the most cost-effective method is first choice and the least cost-effective the last. A complicating factor here is who pays? Should it be the State, bearing the cost of ‘lost’ water, or the individual, who has increased pumping costs?

The various methods can be used in tandem to increase water use efficiency. For example, there may not be enough water to provide a large pulse for two days, but there may be enough water to send a smaller pulse down river. This smaller volume would not be enough to destroy stratification under normal ‘high’ weir levels. However, if the weir level is dropped and the smaller pulse sent down, the two actions together may be enough to destroy the stratification.

Example — Hay Weir

There is a moored buoy in Hay Weir. This has eight thermistors at 1m intervals below it that are linked into a logger. The logger obtains temperature data from each of the thermistors every 30 minutes. This information is transmitted via radio direct to the SCADA equipment on site, which in turn transmits this data to River Operations. Operations staff receive this information almost immediately and feed it into the operational protocol. Actions at this point are based on the protocol and will depend on temperature variation with depth and algal


Hay
Is the weir stratified (temperature difference >10C)?
No
Yes
Adjust flows according to downstream requirements. Continue to monitor.
Is the High Level Offtake operating?
Yes
Is there enough water to increase base flows to 1,250 ML / day within a week without ECA?
Operate High Level Offtake at maximum. Monitor stratification.
No
Yes
No
No
Increase base flow. Monitor stratification.
Is there enough water to pulse flow at 1,500 ML for 2 days?
Yes
Prevention
Cure
Order pulsed flow from River Operations. Monitor stratification.
Has an algal sample been collected in the last week?
No
Yes
Collect algal sample and have it analysed.
Is count > 10,000 cells / ML (>500 cells / ML BGA)?
Yes
No
Yes
Can flow be increased to 1,000 ML / day within 1 week using ECA?
No
Drop Weir pool level to 6 metres depth. Monitor stratification.
Continue monitoring.
Yes
Increase flow. Continue monitoring algae and temperature.
No
Is top gate operational?
Yes
No
Continue to monitor.
Continue to monitor.
Is BGA count >2,000 cells / ML?
Shut off top gate. Invoke RACC Protocol.
Yes

numbers. The protocol on page 97 is the current draft that will be implemented in summer 2000 at Hay Weir.

Scenario

- Operations staff observe a temperature difference of 1.5°C between surface and bottom waters in a full weir pool. An algal sample was collected and analysed in the last week. Analysis of the sample showed Blue-green algal numbers were below 500cells/mL.
- The High Level Offtake (HLO) is not in use.
- Current and expected flows are below the estimated critical flow (1,250ML/d).

Initial Responses

- Start to operate the HLO at maximum capacity (500ML/d), while closing bottom release gates to compensate.
- Begin to slowly decrease volume in Hay Weir.
- Increase volume released from Gogeldrie Weir to provide a flow that is greater than 1,250ML/d through Hay Weir for 24 hours.
- Release equivalent amount from upstream (storage or weir) to compensate for extra water used.
- Continue to monitor stratification.

Final Response

- Return Gogeldrie Weir release to pre-pulse level.
- Monitor stratification within Hay as the pulsed flow moves through the weir pool.
- Continue to monitor after stratification is destroyed.
- Monitor effects of the pulsed flow on other weir pools downstream of Hay.

Application to other areas

The risk assessment system that is in place in the western weirs along the Murrumbidgee River can be viewed as a generic water quality monitoring system that provides data in real time to water managers. Flexibility of the data loggers and availability of probes that measure various water quality parameters means that the system can be modified to suit whatever the current needs may be. The application of this concept of operational protocols coupled with *in situ* monitoring equipment is limited in scope only by equipment available and the requirements of a particular system. Further, it could be modified for use as an early warning tool or for on-line access by water users. This could provide information on the suitability of the water for various uses, including salt sensitive crops (installation of an electrical conductivity probe) and algal levels to determine required treatment and suitability for domestic use.

Operations

State Water's maintenance and refurbishment program provides opportunities for change or modification of existing structures. These changes could be planned in tandem with modifications to operational protocols to maximise water quality and environmental benefits of the changes.

Assessment

In many weirs and storages, water quality monitoring equipment may already be in place, having been installed in the past for other projects. It may be possible to use existing equipment with little modification to direct daily operations and save on capital and installation costs.

Communications

SCADA networks have been or are being installed across New South Wales by State Water to increase the efficiency of their operations. Once the communication equipment is installed for a weir or storage, it is a reasonably simple and inexpensive task to piggyback other electronic equipment onto this to provide real time information to water managers. Similar communications networks are also being installed in other states.

The Future in the Murrumbidgee

Future regional applications of this approach will include installation of thermistor chains in Burrinjuck and Blowering Dams and a thermistor chain and a flourimeter on Tombullen Storage.

Mitigating Cold Water Pollution

Cold water pollution from Burrinjuck Dam currently affects approximately 100km of the Murrumbidgee River. The dam has offtakes at the bottom, midlevel and surface. Real time temperature information would enable the operator to 'shandy' water to provide flows below the dam that are warm enough to promote native fish breeding and generate other environmental benefits. These protocols will ensure that all factors are taken into consideration such as algal conditions within the dam, power generation requirements and environmental needs.

Algal Reduction in Tombullen Storage

Tombullen Storage is a shallow, off-river storage used to hold 'extra' water in the system. Its westerly location and current management practices (fill the storage and hold the water until required) means that the storage is prone to algal blooms. *In situ* water quality monitoring equipment will provide an early warning system for algal bloom development, and coupled with operating protocols, more rapid and effective management decisions will be made.

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Biography

Helen Keenan has been a Resource Officer (Water Quality) with the NSW Department of Land and Water Conservation for almost four years, based in Leeton. Before then she was employed by AWT EnSight in their Algal Identification Laboratory in West Ryde (Sydney). Her PhD thesis was an assessment of the modern and fossil freshwater and terrestrial environments on subantarctic Macquarie Island, using diatoms (Bacillariophyceae) as indicators of environmental condition. Her current work includes assessment status and trend of water quality and the manipulation of weirs and storages to improve environmental health in the Murrumbidgee River.

The Importance of Healthy Ecosystems to Indigenous People

Liz McNiven, NSW Aboriginal Land Council, Parramatta, NSW

The following is a transcript of the presentation given by Liz McNiven who, at the time of the conference, was working for the New South Wales Aboriginal Land Council. Liz belongs to the Budjiti Nation in the Paroo region of far western Queensland.

I've decided today to begin with a poem which I wrote quite a long time ago. It expresses the belief that Aboriginal law is based on the laws of nature and that nature never fails to punish. It's called Spiritual Land.

A distant rock, a far off land,
Deeply planted stands loyal and grand;
Remembrance of timeless years gone by,
Alone at night that rock will cry.
Hunger for money stripped the land,
Mined the earth in which she's bound;
Bulldozed the surface to graze their beef,
Distorting the earth in disbelief.
Soon the winds will change course,
Swept in fortune a powerful force;
Nature reclaims a desolate mess,
Reclaims the people who related best.
Peace, strength makes a home,
A land once more free to roam.

Introduction

Aboriginal people from the inland river systems used flora and fauna and minerals within their local aquatic ecosystems for cultural, spiritual, social and economic purposes. The survival of some species of local flora and fauna depends on the natural rise and fall of the rivers. The introduction of weirs disrupted the natural balance of the inland river systems. Fortunately for the Budjiti people, the Paroo remains a free flowing river, and unlike other rivers within the Murray Darling Basin, the Paroo regularly flows in its ancient rhythmic patterns. The changes to inland river ecosystems created by weirs threaten the maintenance of Aboriginal cultural practices, particularly the collection of certain aboriginal bush foods and medicines, the level of fish stocks in the rivers, the use of fish traps in the rivers, access to cultural sites, and the ability to adequately care for country in a spiritual manner. Some sites on the inland rivers hold high spiritual value to Aboriginal people. Traditionally, entry to these water holes required strict ritual procedures; Aboriginals from other nations required permission from the relevant custodians before being permitted entry. This whole process existed within, and was protected by, Aboriginal law.

Today many sites are used for recreation, farming or grazing purposes with little or no recognition of the Aboriginal law and custom pertaining to these sites. A kinship system defined ownership of, and responsibility for, all aspects of the natural world. Customary law is the source of our understanding and our spirituality. This knowledge has been passed down from generation to generation through songs, dances, ceremonies, rituals and sites in the land and water scapes. Our law requires recognition and implementation within the legislative frameworks of the dominant legal system. A bi-cultural approach to legal matters would strengthen our environmental rights and interests, and allow for the co-existence of Aboriginal law. Aboriginal cultures place great importance on the conservation and maintenance of biodiversity and associated traditional knowledge. Land and resource managers need to involve the rightful Aboriginal custodians and knowledge holders in decision making processes that affect Aboriginal cultural traditions. Some individuals possess more knowledge than others and access may be restricted to a given status; such as women, a kinship group, clan, or elders.

Our knowledge of local ecosystems relates to the distribution and population of species, seasonal cycles, bush food and medicinal plants. The survival of these knowledge systems depends on the continued transmission of our customs and practices to future generations. Recognition and respect for Aboriginal ecological knowledge provides an opportunity for future planners to consider all interests. Self-determination, self-development and land-rights remain the guiding principles for the accommodation of Aboriginal peoples' rights in the environment. Aboriginal custodians managed our clan estates for countless millennia. The connection between the protection of Indigenous biological diversity and Indigenous cultural diversity is fundamental to both entities. The cultural boundaries of our inland river nations mirror the biological boundaries within the landscape. The local environments influence the development of Aboriginal cultures, and our cultures influence the development of biodiversity. Our ancestors nurtured the existence of culturally useful or spiritually significant species of flora and fauna, creating an Indigenous cultural landscape based on our laws, culture, kinship system, and customs and beliefs. The UN Convention on Biodiversity recognises the relationship between Indigenous cultures and biological diversity, and advocates an ecosystems approach to the protection of traditional knowledge, innovations and practices relevant to the conservation and use of biodiversity.

Aboriginal Law and Rights to Aquatic Environments

The 1986 Australian Law Reform Commission's report on the recognition of Aboriginal law, provides, to this date, the most comprehensive analysis. The report drew on anthropologist Dianne Bell's work to argue the strength of Aboriginal peoples' customary relationship with the land and with resources. Access to the country of one's forebears provides sustenance for the Dreamtime experience and an identity based on the continuity of life and values, which were constantly reaffirmed in ritual and in the use of the land. Economic exploitation of the land to support material needs and its spiritual maintenance were not separate in the peoples' relationship to country but rather each validated and underwrote the other. The land was a living resource from which people drew sustenance, both physical and spiritual.

The Law Reform report examines Indigenous peoples' customary hunting, gathering and fishing activities. Although that report did not recommend any special legislative action to recognise Indigenous traditional hunting, fishing, and gathering activities, it did suggest a range of measures to facilitate these activities, including an agreed statement of principles.

Community consultation by the New South Wales Aboriginal Land Council (NSW ALC) identified clear dissatisfaction with the current regime of water management. The current system does not recognise the unique and continuing connection that Aboriginal people have to water and lands managed under it, and does not recognise the traditional rights and interests which Aboriginal people have in relation to water.

These rights include:

The maintenance and restoration of traditional supplies of water for human consumption, such as rock wells, springs and soaks.

Our experience of the current water management system is that the traditional supplies of water are very vulnerable and easily lost through changes to the water environment. This cultural loss is frequently ignored.

The maintenance of traditional supplies of water for sustaining animals, fish and plants including rivers, lagoons, creeks, springs and soaks that provide habitat and sustenance for animals, fish and plants.

The destruction or pollution of traditional supplies of water often destroy their habitat and lead to their extinction in a locality if not in entirety. Aboriginal people hunted and gathered animals, fish and plants living in and around traditional supplies of water under our traditional laws and customs. Those plants, animals and fish are also used for medicinal purposes, ceremonial purposes, for food and for ensuring ritual and religious wellbeing for Aboriginal people.

Ceremonial clays and ochres are also found in aquatic environments. The protection of those resources is contingent on the proper protection of the environment in which they are located. The loss of habitat as a result of the destruction or pollution to traditional supplies of water has had a direct impact on the observance of traditional laws and customs by Aboriginal people.

The maintenance and restoration of Aboriginal cultural heritage in areas significant to Aboriginal people under our laws, customs and beliefs.

The importance of the area will relate to the general locality or surrounds. In other instances it may be the water itself which is significant. The protection of that heritage is a fundamental human right of Aboriginal people.

The insight that we can provide, quite apart form the important role which we play in everyday Aboriginal society, can also actively assist the State. Aboriginal people in particular, wish to ensure the maintenance and restoration of water for traditional uses and the maintenance and protection of Aboriginal cultural heritage in areas significant to Aboriginal people under our laws and customs.

Legislated Paternalism and Aboriginal Involvement in Natural Resource Management

In New South Wales, Aboriginal cultural heritage is managed under the National Parks and Wildlife Act (NPW Act) 1975. The NPW Act provides a paternalistic response to the protection of Aboriginal cultural heritage. The fundamental flaw in this legislation is that it fails to recognise Aboriginal people as the legal owners of our cultural heritage. Decision-making processes occur within a non-Aboriginal framework, and our involvement often amounts to no more than token representation. Decisions that affect Aboriginal cultures and heritage need to be made by the owners of the culture or the heritage concerned, and need to occur within an Aboriginal framework based on our laws and customs.

In the NPW Act, the word “relic refers” to all physical items of our heritage including human remains. This sterile language effectively leaches the spiritual value from our cultural material and replaces it with scientific, historic or archaeological values. These European values effectively disinherit Aboriginal people from our culture and heritage. It is the Director-General of the National Parks and Wildlife Service, and not the rightful Aboriginal owners of the culture, who decides whether or not to grant a consent to destroy, deface or damage an Aboriginal relic or place. Under our own customs and laws, ownership of cultural heritage belongs to the Aboriginal descendants or to the community of origin.

In conclusion, the NSW ALC supports the rights of farmers and other leaseholders to earn a living from the land. We support the rights of scientists to gain knowledge and understanding from the land, we support the concerns of environmentalists who endeavour to protect the land, and we support the rights of other people who enjoy the land. However, we oppose any further destruction or damage to our cultural heritage as a result of these, or any other, activities on the land.

Our people also maintain the right to use the land and the waterscape to pursue our economic, social, cultural and spiritual aspirations. Managed effectively, and considering all interests, the inland river systems can support all sorts of uses and purposes. The NSW ALC wants to work with the government and other stakeholders to secure a future beneficial to all sectors of the community. The NSW ALC calls on the NSW Government, though, to recognise and respect the existence of Aboriginal custom and law. Several models for specific legislation have been developed as a guide for governments who intend to pass laws to protect cultural heritage. The “Our Culture, Our Future” report on Australian Indigenous cultural and intellectual property rights, produced by Terry Janke in 1998, explores options for the creation of specific legislation to protect our cultural heritage.

We maintain our right to practise and revitalise our cultural traditions and customs, including our right to maintain, protect and develop the past, present and future manifestations of our cultures. Reciprocal respect, equality and understanding provide solutions for bi-cultural problems and allow for the co-existence of two systems of law in Australia, both of which need to be given proper weight and recognition.

Fish Passage in New South Wales: Past Problems and Future Directions

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Abstract

Fish passage restoration forms a major component of NSW Fisheries' commitment towards maintaining aquatic biodiversity and rehabilitating riverine environments. Fishway construction in south eastern Australia has a long history of inappropriate design and ineffective management, however recent advances in research and technology have provided realistic alternatives for the restoration of free passage. Through a statewide review, NSW Fisheries has developed a strategic framework to help address the growing need for the restoration of fish passage in NSW. The review provides guidelines for the application of suitable fishway designs in relation to the biological requirements, hydrological characteristics and conservation value of each site.

Introduction

The impediment of free passage to native fish is a major consequence of weirs on Australian riverine environments. Unobstructed movement of native fish within rivers for the purpose of breeding, dispersal into available habitat or away from spawning grounds is crucial in maintaining long-term sustainability of native fish populations (Harris 1985, Mallen-Cooper 1988). Whilst factors contributing to declines in native fish numbers are numerous, the proliferation of dams, weirs and regulatory structures throughout south-eastern Australia has undoubtedly had a major influence on both the abundance and diversity of native fish populations. The exact number of barriers in New South Wales is unclear, as many structures are unlicensed. Estimates have ranged from 3,325 (Thorncraft, 1993; Mallen-Cooper and Copeland 1997) to 4,308 (Thorncraft and Harris 2000). A recent review of structures by NSW Fisheries places the number closer to 3,300 although this excludes tidal barriers and unlicensed structures.

To mitigate this impact, the development of fishways has been pursued for over 300 years in an attempt to restore fish passage past impoundments (Clay 1996). Fishways attempt to provide connectivity between the upstream and downstream pools created by artificial instream barriers. Clay (1996) described fishways as "…essentially a water passage around or through an obstruction, designed to dissipate the energy in the water in such a manner as to enable fish to ascend without undue stress."

Unfortunately, for much of these 300 years, a poor understanding of the biology and life history requirements of target species has hampered fishway development. Prior to 1985, Australian fishways had a history of inappropriate design, inadequate assessment and a poor understanding of native fish biology and the unique hydrology of Australian rivers (Eicher 1982, Harris 1984, 1986, Mallen-Cooper 1988, Mallen-Cooper and Harris 1991).

The Pre- 85 Problem

From Australia's first completed fishway at Audley weir in 1913 to the mid-1980's, Australian fishway technology has borrowed heavily from

Northern Hemisphere experiences. During this period, 66 fishways were built in eastern Australia based on designs commonly used in Europe and North America (Mallen-Cooper 1993). Designed for anadromous salmonids, these fishways typically consisted of pools connected through a series of shallow weirs or baffles with submerged openings. Whilst these designs proved effective for certain Northern Hemisphere species, differing life history characteristics of Australian native fish significantly reduced their effectiveness within local rivers.

Pre-1985 fishway inadequacies have been well documented in recent times (Kowarsky and Ross 1981, Eicher 1982, Harris 1984, 1986, Mallen-Cooper 1988, 1992b, 1993, 1994, Mallen-Cooper and Harris 1991). These designs were biased towards benthic fishes, in particular, adults of larger species with relatively strong swimming abilities. Data collected from submerged orifice fishways at Euston and Murtho (Mallen-Cooper and Brand 1992) indicated that numbers of golden perch and bony herring attempting to enter the fishway were up to 100 times greater than those successfully reaching the exit.

Post-1985 Developments

Growing concerns over a continuing decline in native fish numbers led to NSW Fisheries commissioning George Eicher, an American fish biologist, to inspect structures and provide advice on a fish passage program. The resulting report (Eicher 1982) provided details on research directions and suggested fishway designs that may have useful application in Australia. Subsequent research by Mallen-Cooper (1992a, 1992b, 1994) provided hydraulic and biological data that helped refine design criteria for fishways in south-eastern Australia.

Four different fishway designs have been used throughout NSW since the mid-1980's. All four designs have proved successful at allowing native fish passage under certain conditions, however, their efficacy at passing a full range of species, over a full complement of flows, is the focus of ongoing research. The fishway designs currently in use in New South Wales are as follows:

Vertical slot fishways

Vertical slot fishways comprise a series of interconnected pools each divided by evenly spaced baffles. The presence of a vertical slot allows the fishway to operate over a greater head and tailwater range than conventional submerged orifice fishways and also provides fish passage throughout the full range of the water column. Depth is maximised over low flow conditions producing consistent, predictable hydraulics that can be matched to the swimming ability of target species.

Vertical slot fishways have been subject to the most comprehensive sampling program of all the fishway designs in New South Wales. Laboratory work (Mallen-Cooper 1988) on experimental vertical slots provided empirical data on the swimming ability of some native fish over various life stages. This information established the initial specifications for vertical slot fishways in south eastern Australia. Intensive assessment of the Torrumbarry fishway on the Murray River followed, with large numbers of native fish recorded moving through the fishway while accumulations below the weir diminished (Mallen-Cooper *et al.* 1995).

Rock-Ramp Fishways

Exploring more cost effective solutions to fish passage problems has become a critical aspect of fishway development partly due to the relatively high capital cost of vertical slot fishways. Rock-ramp fishways have been used in recent times to provide a relatively low cost adjunct to more formally engineered fishway designs (Thorncraft and Harris 1996, 2000).

The term "rock-ramp fishway" has been used to describe a wide variety of fishways that involve the use of rocks or boulders to create an artificial riffle that facilitates passage of fish over a barrier (Fig. 2). Rock-ramps vary from full to partial-width designs; incorporating straight or return-leg channels, which utilise high, low or random ridge-rock designs. The 'ridge-rocks' separate the ramp into a series of pools and riffles, creating a sequence of small hydraulic steps which can be negotiated by migratory fish.

Australian research on the effectiveness of rock-ramp fishways has been limited to an assessment of four full-width rock-ramps in New South Wales (Thorncraft & Harris 1996). Results indicated that certain species and size classes of fish could obtain passage over a limited range of flows, however further monitoring and assessment is needed to determine the utility of rock-ramp fishways in south eastern Australia (Thorncraft and Harris 2000).

Rock-ramp fishways have significant potential for wider use in Australia primarily due to potential cost savings and relatively low maintenance requirements, however, future use should be approached with caution. The informal nature of rock-ramps creates difficulty in meeting precise design criteria, and as a result, they are susceptible to operational problems. Where the fishway design approaches critical limits for headloss, width or depth, these limits are often exceeded due to the inherent variability of rock and construction techniques. Adopting conservative design parameters for future fishways is an important aspect of their more widespread use.

Denil Fishways

Denil fishway development is another exploration into more cost-effective solutions to fish passage. Denils incorporate a channel containing many closely spaced U-shaped baffles to reduce water velocity. Denils, for application in Australian conditions, can be built on steeper slopes (1:12) than vertical slots (1:18 to 1:30), but perhaps their greatest potential lies in the remediation of ineffective fishways.

Denil fishways have been widely used and proven to be effective throughout the world, however assessment in Australia has been limited. Small-scale trials within the existing Euston fishway channel have provided encouraging results (Mallen-Cooper & White 1995), however, a more comprehensive assessment of their suitability for Australian native fish is required.

Lock Fishways

Lock fishways are an alternative means of fish passage restoration that have had limited application in Australia. These fishways are conceptually similar to navigation locks, with attraction, filling and exit phases combining to assist fish in negotiating the barrier. The only lock fishway in New South Wales, at Yarrawonga on the Murray River, has experienced a number of difficulties with its operation since construction. A co-operative project between NSW Fisheries, River Murray Water and Goulburn Murray Water is currently exploring remedial options to improve the operating efficiency of the fishway. Preliminary investigations carried out by Thorncraft and Harris (1997) provided some encouraging results, however, a more comprehensive appraisal should follow the proposed remedial actions.

NSW Fisheries is also investigating the potential of lock fishways as a remedial measure on smaller barriers with existing ineffective fishways. A research project is currently underway on the Murrumbidgee River at Balranald, funded through the National Heritage Trust MB2001 fishrehab program, to assess the effectiveness of a Deelder fish lock that utilises a simple two-gate operation to improve fish passage past the barrier.

Which Fishway Where?

In recent years, legislative changes and an increasing awareness of fish passage issues have led to a statewide increase in fishway construction. The first 72 years of fishway development in New South Wales saw 44 separate structures completed. In contrast, the last 15 years have seen 32 fishways of varying designs constructed throughout the state (Thorncraft and Harris 2000). As a result, the application of a number of fishway designs in recent times has outstripped our knowledge of their effectiveness. Fishway managers are now presented with the challenge of determining which fishway design is suitable for a particular location without having a complete understanding of behavioural responses of native fish to various fishway designs.

In 1999, NSW Fisheries commissioned the “Review of Fish Passage in NSW” (Mallen-Cooper 2000). One of its key goals involved developing a statewide implementation strategy to assist in the fishway decision making process for New South Wales. The resultant framework is based on the biological data currently available and the known advantages and limitations of each fishway design.

A challenge of any such implementation strategy is to ensure the most suitable fishway design is used at each site, given the realities of limited capital resources and the need to continue exploring more cost effective fish passage options. To achieve this, Mallen-Cooper (2000) developed the concept of conservation priority zones to introduce a more quantitative approach to the implementation of fishway design The strategy is based on the premise that areas of high conservation value require fishway designs in which there is the greatest degree of confidence. Typically, sites deemed to be of 'high conservation value' support diverse and abundant fish populations or populations of known threatened species. Sites with compromised habitats and/or fish communities will receive a lower conservation priority and can subsequently be considered for a greater number of fishway designs.

Factors determining suitability for fishway designs are then based on size of the watercourse and relative locations of barriers within each priority zone. Tidal barriers or sites in lowland reaches typically restrict access to the largest proportion of the catchment and assume the greatest level of importance. Sites in lower reaches of streams generally exhibit greater species diversity due to carbon accumulation along the course of the stream (Junk *et al.* 1989). As a result, biologically diverse sites require a more conservative approach in relation to fishway design.

An implementation strategy must be responsive to changes in our knowledge base. This includes research advancements, improved management strategies and changes in our knowledge of native fish biology. To highlight an example, the limited biological data available regarding the performance of Denil and rock-ramp fishways under Australian conditions requires careful assessment before their use at sites of high conservation value. Results from ongoing monitoring programs will afford a greater degree of confidence in the future application of experimental fishway designs, which in turn will result in modifications to the implementation strategy.

Future Directions

Perhaps the major challenge facing the development of fishways in New South Wales is to access sufficient public resources to make a significant and sustained impression on what is an enormous problem. Sufficient and sustained funding is necessary to complement recent advances in fish passage technology and research. Combining adequate resources with the lessons learnt from past experience is the most significant challenge for fishway development in the future.

Problems that have been encountered on some projects utilising "post-'85" fishway designs should serve as a reminder of the importance of dealing with fish passage issues as part of a holistic management process. The vertical slot fishway constructed on the Macintyre River at Boggabilla utilised the best available fishway technology and was built in conjunction with the barrier. In a cost saving measure, an agreement was reached to maintain weir pool levels at 50% or less over the spring/summer period to reduce the capital cost of the fishway. Despite these operating conditions being outlined in the Environmental Impact Statement (EIS), the weir pool has been continually maintained at levels close to capacity, severely compromising fishway effectiveness.

A fishway can only be successful if, at first, the site specific biology and hydrology have been matched to the chosen design. The flow regime and life history of potential migrants are crucial factors in ensuring free passage is achieved for the maximum number of fish over the widest possible range of flows (Mallen-Cooper 2000). Success is also dependent upon the fishway being incorporated into management plans for the barrier and integrated with flow regimes of the waterway. An effective maintenance program must be implemented to ensure the operation of the fishway is maximised. An appropriate assessment program must be implemented to ensure the fishway passes fish and an appropriate monitoring program must be included to determine changes in fish communities in response to the fishway. Innovative or experimental designs can only be considered for wider application once initial assessment and monitoring have provided adequate results.

By working within the bounds of our current knowledge, the success of future fishway developments can be looked upon with increasing levels of confidence. A decade and a half of excellent science now needs to be matched with a strategic management focus to ensure that these advancements are translated into improved on-ground decisions.

This paper was presented by Cameron Lay and co-written with Lee Baumgartner, NSW Fisheries, Narrandera Fisheries Centre, Narrandera, NSW.

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Biography

Cameron Lay has been employed by NSW Fisheries as the Fishway Development Officer since June 1999. He has overall responsibility for the management of fish passage issue in the state.

Floodgates and Flows: The Upper Belmore, New South Wales

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Abstract

The lower Macleay flood mitigation scheme consists of a network of drains, levees, floodgates and floodways. One area where the scheme has resulted in impacts on the environment is the Belmore River, where large drains have been constructed through freshwater coastal wetlands. Observed effects include an altered hydrologic regime, poor water quality with regular discharges of deoxygenated water, and acidic products from exposed acid sulfate soils. Impacts include fish kills and changes to wetland ecology. This paper considers the effects of the flood mitigation scheme on the environment and describes the efforts being made to modify its operations so that the scheme becomes more environmentally sensitive.

Setting

The Macleay Valley on the mid north coast of New South Wales is a large coastal catchment with almost 400 square kilometres of low lying floodplain. The floodplain includes well-defined natural levees up to seven metres AHD adjacent to the river banks and creeks below Kempsey. The natural levees grade into large low-lying semi-permanent backswamps often below one metre AHD (DPW, 1978 cited in Tulau and Naylor 1999).

Belmore Swamp is a large semi-permanent backswamp situated approximately ten kilometres east of Kempsey. It has a total area of approximately 5,000 hectares. Richardson (1983, cited in Tulau and Naylor 1999) records that the Belmore Swamp, prior to flood mitigation works, included approximately 1,300 hectares of seasonal freshwater wetlands for about six months of the year. However, following construction of extensive drainage works completed as part of the flood mitigation scheme, significant areas of wetland are now ephemeral, remaining for several weeks after flooding.

The Upper Belmore area is characterised by deep soils formed in a depositional environment with some small areas of residual soils (Atkinson 1999). Soils typically consist of a peaty surface layer overlying thin river clays of low permeability with underlying estuarine deposits close to the surface. Grey estuarine clays are close enough to the surface to be exposed to air during dry seasons when the water table falls to a low level. This is now recognised to cause oxidation of sulfidic sediments present within soils, which results in highly acidic runoff after rain. These types of soils are now known as acid sulfate soils (ASS) and had been previously recognised in the area and named 'catclays' by Walker (1970).

Sammut *et al.* (1993, 1995 cited in White et al., 1998) has found pH in the range of 3 to 4, in the area, and this is directly lethal to most fish species as it causes impairment of water and ion regulation and oxygen transport mechanisms within cells. Thirteen fish kills have been recorded in the Belmore River or Killick Creek between 1977 and 1999. NSW Fisheries have attributed most of those fish kills to either deoxygenated water discharged into the river or low pH river water with high levels of dissolved aluminium (NSW Fisheries Fish Kills database). Deoxygenated water, sometimes referred to locally as 'black water', is thought to occur when non water-tolerant vegetation is inundated and subsequently rots discharging dark coloured water with very low dissolved oxygen levels into receiving waterbodies.

Historical Influences on the Environment

Since the time of European settlement, the Macleay has experienced the climatic extremes of drought and flood. The town of Kempsey was settled in 1835 with the satellite towns of Smithtown, Gladstone and Frederickton established by 1890. Original settlers of the Macleay Valley gathered cedar, with floodplains appearing attractive for agriculture due to better rainfall, warmer temperature regimes and young, fertile alluvial soils.

Along the coastal floodplains of the north coast, European settlers found conditions harsh compared to England. Extensive flooding during the 1870s resulted in serious losses for agricultural enterprises developed on floodplains. Severe losses of cattle occurred. Whilst landholders realised the benefits of swamps in dry times as drought grazing refuges, they also knew of losses which could result from flooding.

The frustration of living with flooding prompted farmers to take their own action to drain land. Drains were constructed and properties were altered from spongy land covered with water to firm ground where cattle could graze.

During the early 1900s, landholders in coastal New South Wales commonly formed drainage unions that operated in accordance with the *Water Act* 1912 and subsequently the *Drainage Act* 1939. Drainage unions would work cooperatively to construct drains on private property. Thirteen drainage unions were in operation in the lower Macleay during the early part of the twentieth century. By the 1930s, there were three drainage unions in the Belmore area.

In 1949 and 1950, two large flood events occurred, each approaching the 1% event. Large tracts of land were flooded leading to significant stock and pasture losses. In response, the Macleay Valley Flood Mitigation Committee was established to enquire into the problems of flood control and flood mitigation for the Macleay River. A smaller committee known as the Jacka Committee was also established to report on options. In 1953, this Committee produced the Jacka Report outlining options for flood mitigation works for the lower Macleay Valley.

In relation to the Upper Belmore area, the Jacka Committee found that the detrimental effects of nuisance flooding were more pronounced in the Frogmore and Belmore areas than elsewhere in the valley. In the higher stages of nuisance floods, the upper reaches of the Belmore River would freely discharge into the swamp by overflowing the low banks. Local rainfall provided additional runoff, but due to the amount of water in the Belmore River, it was unable to escape. It was noted that the river level rose and fell much more quickly than the water level in the swamps.

After completing their investigations, the Jacka Committee made a number of recommendations to alleviate the impacts of flooding in the Upper Belmore. These included:

- the installation of large culverts fitted with tide and flood flaps to prevent the majority of small floods penetrating the upper reaches of the Belmore and flowing into the backswamps;

- the enlargement of nearly all drainage union drains in the valley with the aim of maintaining a lower water level in the swamps;

- redesigning existing drains to increase capacity so swamp levels could rise and fall more quickly to reflect the height of the river; and

- dredging the Belmore River to improve hydraulic characteristics.

By 1980, $9 million had been spent on flood mitigation works in the lower Macleay (LM&P 1980). These works and further secondary works have resulted in an environment, which is characterised by drains that extend from the river into the backswamps. The majority of the drains are fitted with non-return floodgates which prevent the inflow of floodwaters and saline tidal waters through the drains. It is now accepted that drains constructed in floodplains have lowered the water table, exposed sulfidic sediments and exacerbated the impacts of acid sulfate soils.

Lower Macleay Floodplain Management

The operation and maintenance of the flood mitigation scheme is the responsibility of Kempsey Shire Council (KSC). Over the last five years, as part of the NSW Government's Floodplain

Management Program, the Department of Land and Water Conservation (DLWC) and Kempsey Shire Council (KSC) have been funding investigations which focus on better management of the floodplain during both flood and non-flood periods. This developed from the Lower Macleay Floodplain Management Study (Webb McKeown 1997) which assessed the operations of the flood mitigation scheme to achieve better management in both flood and non-flood periods.

During the Study, interest was high within the farming community. Farmers were concerned about the dramatic variability of water levels on their land caused by the mitigation scheme and the poor water quality in drains caused by 'black water' and the exposure of acid sulfate soils. The Study recommended focussing on drainage basins to develop site specific management plans. The first of these to be completed is the Upper Belmore Floodplain Management Strategy (Webb McKeown 2000).

Concurrently, DLWC and KSC have funded seven continuous submersible water quality data loggers which have been in place since May 1997. These loggers measure water level, water temperature, pH, dissolved oxygen and electrical conductivity. Four of the loggers are located at the end of significant drains which have floodgates separating the drains from the Belmore River. This data has allowed long term trends to be established as well as establishing a continuous data record which allows observation of the effects of prolonged rainfall and dry periods on water quality in the river.

Upper Belmore Floodplain Management Strategy

The Upper Belmore Floodplain Management Strategy aims to identify actions and works needed to enhance the environment and improve water quality and, at the same time to sustain the land productivity of the Upper Belmore area. The strategy was directed by a Steering Committee made up of representatives from KSC, DLWC, NSW Fisheries and the farming community.

The study area for the Strategy consists mainly of dairy farming. Seven major floodgated drains and two non-floodgated drains are included within the study area. In some cases the farmers have constructed secondary branch drains extending into the backswamps. The floodgate structures fall on Crown land, freehold land and Council owned land, with the majority of drains passing through freehold land (Webb McKeown 2000).

The process established for the Strategy's development was to identify the issues that needed to be addressed in the Upper Belmore and to identify solutions that were able to be implemented on a local scale. The Strategy aimed to not only address flooding issues as would normally be considered in a floodplain management context, but aimed to provide a holistic consideration of the issues of land and water management.

The Strategy was developed primarily through a program of consultation including workshops, farm visits and discussions with farmers. The particular issues and concerns for the Upper Belmore were identified through farm visits, and an initial workshop. Through this consultation process solutions were identified, many of which were already being implemented by farmers.

The Strategy identifies issues particularly concerning poor water quality and land management, associated with the flood mitigation and drainage system. The water quality in the Upper Belmore is seasonally affected by high salinity, low dissolved oxygen levels and acid runoff products. As previously discussed, this results in fish kills and fish diseases and reduces the value of water for stock and irrigation. This causes concern for all involved with land and water management in the Belmore and provided a basis for discussion aimed at solving these problems.

Outcomes

The final outcome was a Strategy document which was unanimously adopted by landholders, KSC, DLWC and NSW Fisheries based on five central strategy statements.

Strategy 1: Establish Floodgate and Drain Management Groups.

Strategy 2: Management Groups are to establish water table levels within their respective areas.

Strategy 3: Enable Floodgate and Drain Management Groups to operate floodgates.

Strategy 4: Ensure unobstructed flow paths for the removal of excess floodwaters.

Strategy 5: Minimise exposure of acid sulfate soils.

These five statements enable environmental management decisions to be put into the hands of all those involved in management of the floodplain. Strategy 1 is to establish Floodgate and Drain Management Groups. This enables landholders to be central to the decision making process. The Management Group's responsibility, alongside KSC, is to implement Strategies 2-5 in their own management areas. How each group decides to implement the Strategies is to a large extent up to the group, with technical advice and assistance provided by Council and state agencies (DLWC, NSW Fisheries and NSW Agriculture).

Strategy 1: Establish floodgate and drain management groups

This strategy is fundamental to future floodplain management in the Upper Belmore. The Strategy's outcome will be the formation of six management groups focused on the six drainage basins in the study area.

Each Floodgate and Drain Management Group will centre around the management of one or two major drains and comprise landholders adjoining the drain. The effects of overdrainage and opening floodgates on drains are not limited by farm boundaries, therefore decisions regarding management in the Belmore require input from a number of interested parties. The groups are intended to be the instrument through which all decisions are made on the management of the particular drains.

Strategy 2: Management groups are to establish water table levels within their respective areas

The primary objective of the floodgate and drain management groups will be to agree upon a range of water table levels for their area. Water table levels affect many of the issues of water quality and are therefore fundamental to good management of the area.

Strategy 3: Enable floodgate and drain management groups to operate floodgates

Strategy 4: Ensure unobstructed flow paths for the removal of excess floodwaters

Strategy 5: Minimise exposure of acid sulfate soils

In general, Strategies 3, 4 and 5 provide guidelines and a method for achieving Strategy 2. Their aim is to enable the groups to manage their environment and express the particular desires of those involved in the consultation process.

Strategy 3 is the formalisation of the practice of opening floodgates to allow the interchange of water between the river and the backswamps. This can raise safety issues as floodgates are not designed to be opened for backflows. Enabling the opening of floodgates will allow management groups greater control over the water table levels.

Strategy 4 is to ensure that water levels can be maintained. Excess floodwaters that remain over the land can cause rotting of vegetation unless quickly removed before causing deoxygenated water. The removal of floodwaters needs to be carefully balanced with maintaining water table levels so as to prevent overdrainage.

Strategy 5 addresses the exposure of acid sulfate soils; to minimise their exposure lessens the acidity of the water in the Belmore River and the backswamps.

The Upper Belmore Floodplain Management Strategy provides an official framework for farmers to manage water and land that is recognised formally by the Council and Government. It is a process and method by which farmers can work together, receiving expert advice and assistance when needed. The Strategy also allows access to various funding sources.

The Importance of Consultation

The Upper Belmore Floodplain Management Strategy provides relatively simple solutions to the problems of acid sulfate soils, overdrainage and the management of water in the Upper Belmore. The major achievement of this Strategy is not in the technical solutions, but rather in how the Strategy was developed. The knowledge, desire and involvement of landholders and farmers, is fundamental to the success of this project.

Farmers know and understand the problems that result from poorly managed land and water. In the Macleay, farmers have enthusiastically involved themselves in the Floodplain Management process. Many are pro-active, already developing water retention structures and opening floodgates to improve water quality, involving commitment of money and time. The commitment of farmers to working with Government and Council was important to the development of the Upper Belmore Floodplain Management Strategy.

The involvement of farmers in implementing the Strategy will also be essential. They are on site, able to undertake regular maintenance and monitoring, and can respond to the environment as it changes, opening and closing floodgates with changes in the river's water quality.

Lessons Learnt

The way the Upper Belmore Floodplain Management Strategy developed was not always smooth. The many different interests involved in the area made the consultation process an exercise in negotiation. To produce a document that was acceptable to all parties, required careful listening to the different parties and on-site farm discussions with landholders in order to reach agreement.

Farmers were concerned that they were being assigned sole responsibility for the water quality in the drains and were afraid of legal implications. This meant that they were hesitant to agree to principles set out in the Strategy. The history of the area shaped the views of the farmers, whose families have lived in the Upper Belmore for generations. They have seen State Governments change, and with them changes to policies and structures. They feared that if particular individuals from State government departments made commitments to support them, it would not be remembered in the future by others to follow. This was overcome through allowing the farmers to shape the document and themselves participate in the wording of the Strategies.

Farmers also expressed suspicion of the intentions of Council and Government departments. They were concerned that in agreeing to be involved in the Strategy they would be allowing others to take advantage of them, allowing government to have more influence over how they used their land. This attitude of suspicion was alleviated only through honest and direct communication between farmers, Council and state agencies, and again the opportunity for all parties to influence the wording of the final Strategy. The suspicion may still remain, but the Strategy can and will be implemented as all those involved have made a commitment to implement the document they have created together. The Strategy could be incorporated into a broader initiative such as the Macleay River Floodplain Project.

Expected Environmental Benefits

One of the main priorities for the Upper Belmore Strategy is to avoid further disturbance of sulfidic sediments and to minimise exposure of potential ASS to air. By maintaining water levels at higher levels than they have been since the time drains were constructed, the likelihood of exposing sulfidic sediments in the soil profile is minimised. Also, the controlled opening and closing of floodgates will allow tidal flushing of drains on a more regular basis and the likelihood of neutralisation of acidic discharges with the bicarbonate in seawater will increase.

Further, by maintaining more water in the swamps, it is hoped that natural freshwater wetland vegetation species will re-establish and allow restoration of wetland ecosystems. In his survey of coastal wetlands in New South Wales, Goodrick (1970) identified areas of waterfowl habitat requiring preservation or rehabilitation. Areas of the Upper Belmore consisting of fresh meadows, seasonal fresh swamp and reed swamp were identified. The area previously supported thousands of ducks during wetter months. LM&P (1980) also reported an extensive littoral zone which provided a large extent of feeding habitat for aquatic bird species. It is hoped that returning water to the wetlands will provide valuable aquatic bird and fish nursery habitat, restore hydrologic patterns and associated water tolerant vegetation species, and with floodgates generally open during non-flood periods, fish passage will also be improved.

Conclusion

The history of flooding and the management of floods in the Macleay Valley has shaped the environment of the Upper Belmore. Flood mitigation structures have brought significant protection from flooding but have also adversely impacted on water quality and the environment.

The basis of the Upper Belmore Floodplain Management Strategy is to involve the community in management of the floodplain. The Strategy was developed primarily through a process of consultation with the farming community. Solutions to environmental problems came about through respecting the knowledge and expertise of the people on the land. This has resulted in a Strategy that will bring environmental benefits and involve the whole community.

To properly develop future management strategies it is important that the existing farming community be involved, and they must remain a fundamental part of the decision making process. The Upper Belmore Floodplain Management Strategy provides an example of how Council, State Government and farmers can work together to achieve an outcome that works towards a sustainable future for both the environment and the farming community.

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Biography

Joanna Kuswadi is an Environmental Engineer at Webb McKeown and Associates. She holds an Environmental Engineering Degree with Honours from the University of New South Wales. Joanna has recently been involved with the development of the Upper Belmore Floodplain Management Strategy undertaken for Kempsey Shire Council. She has a particular interest in community consultation and environmental issues, within the areas of floodplain management and estuary management.

Jane Gibbs is an Environmental Scientist currently employed by the New South Wales Department of Land and Water Conservation's Specialist Coastal and Flood Services branch in Newcastle. She provides advice on environmental and planning issues relevant to floodplain management in coastal areas throughout New South Wales. Jane has a Bachelor of Environmental Science (Honours) degree from the University of Newcastle specialising in fluvial geomorphology and is currently studying natural resources law at the University of Wollongong. Jane was previously employed at ERM Mitchell McCotter, environmental and planning consultants, where she specialised in environmental impact assessment.

Identifying and Mitigating Impacts from Weir Construction: Recent Queensland Experience

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Abstract

During the late 1990s, a large number of weirs were proposed for Queensland waterways, subject to suitable environmental and social assessment. GHD Pty Ltd was commissioned for a number of these studies, five of which have been reviewed for this paper. The review has identified significant inconsistencies in the overall approach to weir impact assessment in Queensland but also improving trends in the scope and level of investigation of these studies. Based on the case studies selected, a number of elements have been identified which, if appropriately addressed during the planning, design, construction and operational phases, will contribute to identifying sustainable utilisation of water resources and minimise environmental impacts.

Introduction

The 1990s saw a high level of activity in the planning and design of weirs in Queensland. This resulted in part from State Government initiatives to develop water resource utilisation, primarily for agricultural applications, and to a lesser extent for potable water supply. The extent of this development was highlighted by the formation of the Water Infrastructure Task Force in the mid-1990s, which called for public submissions and expressions of interest regarding potential water resource development projects (Department of Natural Resources 1998).

As a result of this activity, a number of projects were identified and detailed engineering, economic, social and environmental studies undertaken. In some instances, these studies were integrated with catchment or basin-wide hydrological studies such as the Water Allocation and Management Plans (WAMP) undertaken by the Queensland Department of Natural Resources (DNR). In these cases, the opportunities existed to examine the "whole of catchment" impacts of weir operation.

GHD Pty Ltd (GHD) were involved in a number of these projects in the preparation of environmental assessment reports ranging from major Environmental Impact Studies (EIS) to Review of Environmental Factors (REF). In each case, a number of potential impacts were identified, many of which are typical of weir impacts around the country. Comprehensive mitigation strategies (i.e. Environmental Management Plans) were also developed to manage the potential impacts of weir construction and operation.

These projects highlighted some inconsistencies and weaknesses in the Queensland approach to impact assessment, but also identified improving trends in the assessment process and a greater willingness to mitigate potential impacts on the natural environment.

Water Allocation and Management Plans (WAMP)

The Queensland Government has introduced a water resource planning process designed to plan for the allocation and sustainable management of water to meet Queensland's future water requirements, including the protection of natural ecosystems and security of supply to water users (Department of Natural Resources 2000).

Outcomes of this planning process included the preparation of:

- Water Allocation and Management Plans (WAMPs); and

- Water Management Plans (WMPs).

Both these plans involve consulting with the community and other key stakeholders to identify water allocation and management issues within river catchments.

Figure 1 summarises the current status of water resource planning in Queensland.

Case Studies

Five case studies were selected for this review, each of which has unique characteristics regarding the proposed site, potential impacts or the environmental solutions required to satisfy the approvals process. A brief description of each is given below, with further details of strengths and weaknesses of the assessment process following. It is not intended that this paper provide detailed descriptions of the proposals or the impacts, rather, these examples have been specifically identified to highlight the assessment process and mitigation strategies developed.

Figure 1: *Status of Water Resource Planning in Queensland, July 2000*
Source: *Department of Natural Resources 2000 (www.dnr.qld.gov.au)*

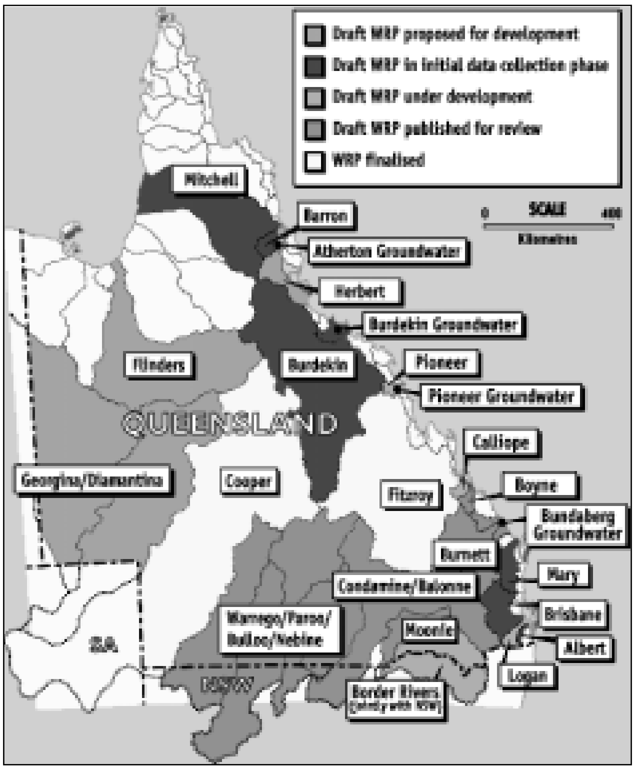


Figure 2: *Location of Case Studies*

The five studies have all been undertaken in the last two years. The sites (Fig. 2) include:

- Bucca Weir on the Kolan River at Bucca located just to the north west of Bundaberg;

- Bilwon Weir approximately 20km downstream of Mareeba west of Cairns on the Barron River;

- Cedar Grove Weir on the Logan River near Beaudesert, just west of Brisbane;

- O'Connell Weir on the O'Connell River approximately 100km north-west of Mackay; and

- Condamine Weir at Condamine on the Condamine River, some 350km west of Brisbane.

Raising Bucca Weir

In 1998, DNR commissioned GHD to prepare a (REF) for the proposed raising of the existing Bucca Weir, located on the Kolan River in the Bundaberg Irrigation Area (BIA) (Fig. 3). The proposed weir raising is part of DNR's Groundwater Rescue Project, which falls within the Queensland

Government's Water Infrastructure Planning and Development 1997-1998 to 2001-2002.

An Initial Advice Statement (IAS) for the Stage II project was prepared by DNR in November 1997. The IAS outlined the need for the proposal, possible project alternatives and presented a preliminary environmental assessment of the potential impacts on the natural, cultural and socio-economic environment (Department of Natural Resources 1997).

The BIA supports sugarcane and horticulture industries that had a production value of around $348M in 1994-95 and $295M in 1995-96 (Department of Natural Resources 1997). Irrigation waters are supplied from both ground and surface sources and groundwater is also extracted for domestic supplies by the Burnett Shire Council and Bundaberg City Council.

The groundwater system in the region is currently faced with the problem of intrusion of salt water. Intrusion of salt water into aquifers was first noted in the late 1960s, and the BIA was then established with the intention of integrating the use of both ground and surface waters and replacing groundwater with surface water supplies (Department of Natural Resources 1997). The main surface water storages in the area are the Ben Anderson Barrage on the Burnett River and Lake Monduran (Fred Haigh Dam, Adopted Middle Thread Distance (AMTD) 76.0km), Bucca Weir Stage I (38.0km AMTD) and the Kolan River Barrage (14.5km AMTD) on the Kolan River (Department of Natural Resources 1997).

The intrusion of salt water into aquifers indicates that the use of groundwater at present exceeds the sustainable yield of the system. As the water becomes increasingly saline, it will become unsuitable for use as either irrigation or drinking water. This is seen as a threat to the production value and viability of the sugarcane and horticultural industries in the area. In the coastal areas where saline intrusion is most pronounced, the resultant substantial decrease in cane production is also a threat to the viability of at least one of the Bundaberg Sugar Mills (Department of Natural Resources 1997).

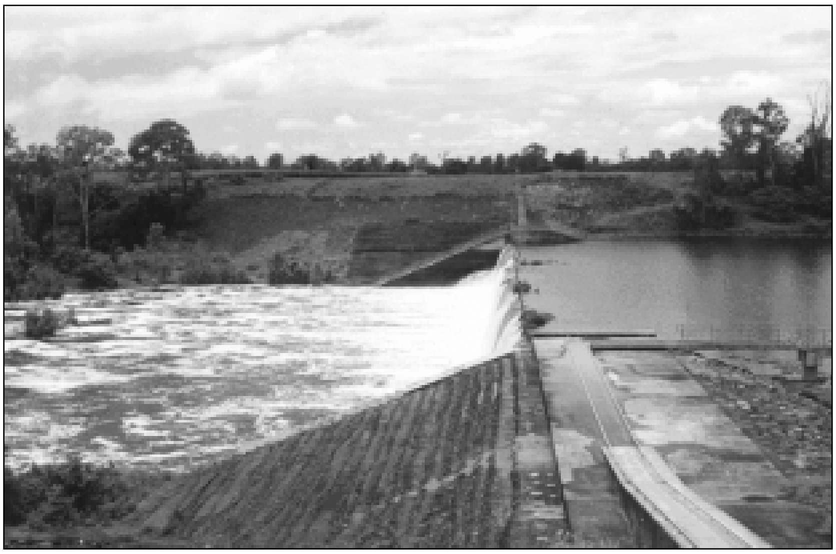
The present high extent of salt water intrusion has resulted from a combination of high demand and poor recharge events (Department of Natural Resources 1997). The intrusion and consequent reduction in water quality necessitates a reduction in the use of groundwater; an action which will result in the same loss of productive land as would the use of saline groundwater. In response to salt water intrusion, groundwater allocations have already been substantially reduced (Department of Natural Resources 1997).

The BIA was therefore looking to further replace current groundwater allocations with surface water sources. The proposal to raise the Bucca Weir stems from the substantial and immediate need to supply additional surface water resources to reduce the current demand on groundwater sources. Given the multimillion dollar production value of the sugarcane and horticultural industries supported by the BIA, this is of major economic and therefore social concern for the region.

The proposal was to raise the existing Bucca Weir by 2m using a concrete addition to the fixed crest. This would raise the Weir from its current elevation of 16.2m AHD to 18.2m AHD.

Raising the Bucca Weir by 2m will increase its storage capacity by 5,615ML (from 11,605ML to 17,220ML) and an additional yield of 10,500ML will be provided. This is expected to increase the area inundated from 250 hectares to 305 hectares, with the upper limit of the storage extending a further 0.4km up the Kolan River and 1km up Gin

Figure 3: *The Existing Bucca Weir on the Kolan River*



Gin Creek, the only major tributary affected by the proposal. This would extend the limits of the storage to 21km up the Kolan River and 5km along Gin Gin Creek (Department of Natural Resources 1999a). The REF was conducted at the same time as the Burnett WAMP.

Bilwon Weir

The proposed Bilwon Weir site is located about 20km downstream of Mareeba on the Barron River at AMTD 52.6km. At this site, a significant portion of the tailwater that flows into the Barron River from the upstream irrigation area was proposed for capture and regulated for further use. The natural catchment commanded by the weir would also provide a useful stand alone yield. The weir would have had a multi-purpose function in providing additional water for irrigation north of Mareeba and possibly regulate supplies downstream for Cairns City and the Kuranda Power Station (Department of Natural Resources 1999b).

The land use surrounding the Bilwon Weir site is a mixture of low level grazing and intensive perennial horticulture of which mangoes are dominant (Fig. 4). On the left bank of the Barron, there are significant areas cleared for rain fed pastures that border onto the northern end of the MDIA irrigated sugar lands. Some of this area is now being developed to grow sugar cane.

During the development of the IAS, the proposal of a 6m high fixed crest weir with a 4m high inflatable rubber dam (FSL 371m) was determined to have the least impact on flooding upstream. As such, this option was assessed.

The EIS also assessed the impacts from the proposed new irrigation areas, but was undertaken prior to the preparation of the Barron River WAMP which includes the Barron River Catchment.

Figure 4: *Vegetation in area of inundation for the proposed expansion of the balancing storage*

Cedar Grove Weir

The South East Queensland Water Board (SEQWB) commissioned GHD in 1998 to conduct an Environmental Impact Study (EIS) for the construction and operation of a weir on the Logan River at Cedar Grove in order to increase the supply of water for urban use throughout Beaudesert Shire.

As a result of projected increases in population and rural residential growth throughout Beaudesert Shire and neighbouring localities, there was a predicted increase in demand for water supply. In order to address the pressures that are likely to occur on existing water resource supplies, it was considered necessary that current water supply capacities be increased (SEQWB 1997).

The proposal to construct Cedar Grove Weir is part of a Queensland Cabinet approved strategy to increase water supplies to meet demands for the next 50 years throughout South East Queensland. Essentially, the proposed Cedar Grove Weir would act as a pumping pool for water releases from the proposed Wyaralong Dam. The weir is located at approximately 81.3km AMTD on the Logan River.

The weir structure is likely to have a height of 6.2m and would comprise four stepped sheet piles, each having an approximate length of 6m. The weir would provide a storage capacity of approximately 1,040ML at Full Supply Level (FSL). At FSL the impoundment area would extend some 9.9km up the Logan River and 2.8km up Teviot Brook. A fish ladder will be incorporated in the weir design which would allow fish movement between the up and downstream waters at the weir (GHD 1998).

The surrounding landscape has a predominantly rural/rural-residential nature, with flat to gently undulating topography (Fig. 5). Isolated copses of native vegetation exist within the riparian zone with little evidence of regeneration. Serious infestations of weeds generally exist along the entire length of the proposed impoundment area. One native plant species (*Cymbidium suave*) was noted as being endangered and having special conservation value.

Vegetation providing fauna habitat is limited to isolated individual trees. Further, the lack of quality, complexity and diversity of such vegetation renders it non-critical habitat to native vertebrate species. Of the species of mammals recorded for the study area, five are introduced and two are native. None are listed as having special conservation value.

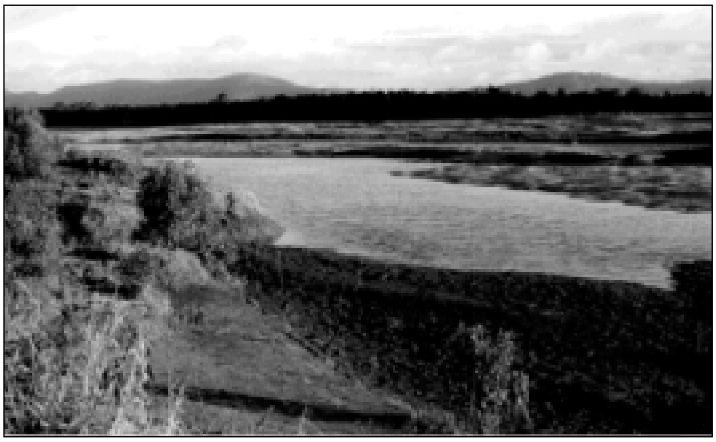
O'Connell Weir

The O'Connell River Weir Irrigation Scheme Steering Committee (ORWISSC) has identified that an increase in the available water supply, as well as the presence of a more reliable supply, would be the best way to improve primary production in the O'Connell River district. As sugar cane production is the principal farming activity in the district, the benefits of the scheme focused on the effect of a larger and more reliable water supply on sugar production (ORWISSC 1999). The river is currently unregulated.

Figure 5: *Typical river section of the Logan River upstream of the proposed weir site*

The proposal was for a concrete weir to be constructed on the O'Connell River at a site close to the present Bruce Highway, approximately 100km north west of Mackay. This site is within the zone of tidal influence with saltwater intrusion occurring during high tides (Fig.6). The capacity of the weir has been determined so that the irrigation needs of the surrounding farms would be met in most years.

Figure 6: *The O'Connell River at the upper limit of tidal influence*



The weir's structural features include a crest level of 5.55m AHD, a spillway crest length of 122m, with a total weir length of 207.3m. Facilities will be operated and administered by the O'Connell River Water Board constituted under the *Water Resources Act* 1989. The safe yield of the storage is estimated to be approximately 3,000ML/year for a storage of 1,988ML. Water distribution from the weir storage will be via private pump and pipeline arrangements to individual ratepayers (ORWISSC 1999).

A vertical slot type fish ladder was designed to be located on the southern bank. The fishway would be divided into four segments with the ladder invert entering the weir below FSL (5.55m AHD). A control gate would be used to close off the ladder when the weir is not overflowing. Environmental releases, fish ladder operation and weir pond management issues are to be addressed separately in a flow management plan.

The Terms of Reference for the EIS included assessment of the weir footprint but did not include the proposed new irrigation area in the study.

Condamine Weir

The Condamine River is one of the upper tributaries of the Darling River. The headwaters of the Condamine are to the south-east of Warwick in southern Queensland, from which water flows through a number of different waterways, north-west, west and ultimately south, forming the Darling south-west of Bourke in New South Wales. The catchment is primarily semi-arid and whilst the system flows most of the time, the majority of tributaries would be considered ephemeral.

The Condamine-Balonne system is heavily regulated through most of its length including the management of overland flows from a number of weirs and dams. The Condamine-Balonne catchment alone (upstream of St George) contains 4 dams and 24 weirs as shown in Table 1. A WAMP study is currently being undertaken by DNR for the Condamine-Balonne, a draft of which was released in June 2000.

A weir at Condamine, some 350km west of Brisbane, has been proposed since the early 1940s. Several sites had been examined in the 1980s and early 1990s, however the Water Infrastructure Task Force recommended in 1998 that the Condamine Weir be approved as a category one recommendation, the highest priority. GHD were commissioned by DNR in 1999 to undertake an EIS of the proposal, which included economic, social and environmental components. The EIS was undertaken in conjunction with the Condamine-Balonne WAMP being undertaken by DNR at the time, in order to provide a "whole of catchment" assessment.

Figure 7: *Condamine River at the proposed weir site*

Construction of the proposed Condamine Weir would consist of a mass concrete overflow structure with a fixed crest level elevation (EL) 274.0m, which would support a 2m high by 55m long inflatable rubber dam in the river channel (fabridam). At full supply level EL 276.0, the weir would have a maximum height of 8.8m and a storage capacity of 12,600ML. The storage volume of the fixed weir structure is estimated to be 7,400ML, increasing to 12,600ML when the rubber dam is inflated (Department of Natural Resources,

Table 1: *Storages on Condamine-Bolonne System upstream of St George. Source: DNR (2000)*

Storage Name	**Capacity (ML) at Full Supply Level (FSL)**
Killarney Weir	10
Connelly Dam	2,600
Leslie Dam	106,250
Talgai Weir	640
Yarramalong Weir	390
Lemon Tree Weir	149
Cecil Plains Weir	160
Tipton Weir	122
Cooby Creek Dam	28,650
Loudoun Weir	588
Bell Town Water Storage	60
Jandowae Town Water Storage	980
Warra Weir	120
Chinchilla Weir	9,780
Charleys Creek Weir	250
Rileys Weir	300
Tara Town Water Supply	200
Brigalow Weir	40
Freers Weir	1,000
Dogwood Creek Weir	1,000
Drillham Creek Weir	260
Dulacca Creek Weir	6
Surat Weir	610
Neil Turner Weir	1,470
Beardmore Dam	81,700
Jack Taylor Weir	10,100
Moolabah Weir	3,950
Buckinbah Weir	5,120
28 Structures	**256,505ML**

1999c). The impoundment area would extend approximately 45km upstream. The weir would also contain a fish lock which would comprise a floating open top fish follower to guide fish either up or down stream within the lock chamber as the water level fluctuates.

The study also incorporated the cumulative impacts of a second weir proposal directly upstream of the proposed Condamine Weir impoundment. At FSL, impounded water within the Condamine Weir would reach the Nangram Weir wall, which would in turn reach the existing Chinchilla Weir, forming a potential continuous impoundment spanning the three weirs. Whilst the cumulative impacts were to be considered, the EIS was not to consider the suitability or otherwise of Nangram Weir, as this would be undertaken by a separate study and through the WAMP process.

The proposed site and impoundment is located within a semi-arid region characterised by dryland grazing land uses. The riparian corridor forms one of the only contiguous vegetation corridors within the region, although land use and grazing pressures have reduced this to a narrow band of native species, restricted in parts to the upper banks and terraces. The middle reaches of this system, within which the weir is proposed, have been largely unregulated. Chinchilla Weir, a 9,780ML weir used for agricultural and domestic water supply, is located some 100km upstream (Department of Natural Resources 1999c).

The EIS included assessment of the proposed irrigation area and impacts as well as the cumulative impacts of Condamine and Nangram Weirs. The study outcomes were also dependent on the conclusions of the Condamine - Balonne WAMP.

Impact Assessment in Queensland

Impact assessment of major water infrastructure proposals in Queensland is generally triggered under the *State Development and Public Works Organisation Act* 1971-1981. Although all these case studies were undertaken under the same legislation there are significant differences in the requirements of each study. This is in part due to the number of different proponents involved.

Some examples of these inconsistencies include:

- the lack of appropriate guidelines for preparation of Terms of Reference (ToR) ensures that the structure and content of both the ToR and EIS varies considerably;
- only the Condamine and Bilwon Weir EISs required assessment of the impacts of the water use (i.e. an irrigation scheme). Other projects where water was used for irrigation were not required to assess these impacts;
- a “whole of catchment” approach to impact assessment is seldom considered although this is improving. In some instances hydrological assessment (using such models as IQQM) take into consideration changes in flows, however this is rarely transformed to ecological process. The DNR has spent considerable resources undertaking WAMP studies for many catchments, but the integration of WAMP and EIS studies is again inconsistent. Bilwon Weir EIS was undertaken prior to the preparation of the Baron WAMP whilst Condamine Weir EIS was prepared during the final stages of preparation of the draft Condamine-Balonne WAMP;
- the integration of environmental flows into the hydrological assessment is not consistently applied. Again, Condamine Weir could readily incorporate the environmental flows developed in the WAMP study;
- the way in which cumulative impacts are assessed. This includes impacts from a series of instream structures (i.e. Condamine and Nangram Weirs were assessed separately) and the holistic view of regulation of Queensland waters. This has become particularly relevant for the O’Connell River which is the last unregulated coastal river in Queensland;
- the level of assessment. A lesser level of assessment (a Review of Environmental Factors) was considered appropriate for a weir raising (Bucca Weir) and a new weir (Nangram Weir) which was associated with an existing weir; and
- the management responsibilities for impoundment areas and surrounding lands is a key weakness in the sustainable management of these infrastructures. As such, the implementation of detailed Environmental

Management Plans is often difficult. Responsibilities for cooperative land management crosses property boundaries and requires a consultative approach.

Another difficulty is the often conflicting objectives of different sections of the same departments. The Department of Natural Resources for example, is responsible for regional infrastructure development (and are therefore the weir proponents in many cases), hydrological monitoring and modelling, aquatic studies, riparian protection and management of irrigation entitlements. This has been addressed in part with the devolution of environmental management responsibilities from DNR to the recently formed Environmental Protection Agency (EPA).

Weir Impacts

For the most part, the impacts identified in all the studies are those common to most impoundment infrastructure. Some are highlighted because of the environment of the weir site, but are of similar nature, if not magnitude, to weirs in general. Impacts typically include:

- modification of flow regimes effecting frequency, duration and intensity of flows;
- inundation within the impoundment area;
- increased flood risks;
- aquatic habitat modification;
- mortality of riparian vegetation within the impoundment area and fragmentation of riparian corridors;
- bank instability, particularly in systems with frequently fluctuating water levels;
- sediment retention within the impoundment area;
- downstream scouring and modifications to sediment movement;
- barrier to movement of aquatic organisms;
- stratification (with associated impacts such as algal growth, fish mortality etc.);
- groundwater impacts (particularly associated with irrigation schemes);
- aquatic weed invasion and spread;
- loss of sites of cultural significance; and
- inundation of livestock and vehicle crossings.

Specifics of the individual case studies, as well as details of the study outcomes are provided below.

Bucca Weir

The raising of Bucca Weir could result in both positive and negative impacts. A detailed consultation program with landowners adjacent to the impoundment area was a key component of the REF. Other major components of the REF included detailed hydrological modelling, assessment of vegetation loss and studies into the implications for fish movement along the river corridor.

The REF determined that potentially significant impacts may result from:

- impoundment of water further upstream into riparian and aquatic habitats which are currently unaffected by the weir;
- loss of river cattle crossings; and
- increased frequency in flooding of upstream bridges and property access points.

Potential irreversible impacts will be those which occur in the impoundment area, notably loss of vegetation and habitat within the riparian zone, particularly in upstream areas.

Impacts which may be managed to an acceptable degree include:

- increased frequency of flooding of upstream bridges, through upgrade works; and
- loss of river cattle crossings, through property management consultation between affected landowners and DNR.

The REF also concluded that there would be some positive environmental benefits from the proposal relating to the installation of a fishlock in the existing weir. The REF recommended that the project could proceed providing the full implementation and adherence to the Environmental Mangement Plan (EMP).

Bilwon Weir

The construction of Bilwon Weir in the proposed form was considered to result in irreversible impacts on the environment and socio-economic structure of the area.

The construction of the weir would inundate an area of significant biotic resources in the form of a remnant section of closed canopy riparian rainforest. As a result, loss of habitat and an important wildlife corridor and refuge will occur.

As a result of the inundation, a number of landowners will require compensation for loss of land. Flooding associated with the weir (even the option of a crest height of 367m with an inflatable rubber dam of 4m) will result in increased flooding effects upstream of the dam. Associated with economic loss, the social impact in terms of amenity is perceived as being unacceptable by local residents as it is of little benefit to existing irrigators in the Bilwon area.

On reviewing the analysis of impacts, it was considered by the DNR that the impacts most likely outweighed the benefits (Department of Natural Resources 1999b).

Cedar Grove Weir

The highly modified terrestrial and aquatic environments of the upper Logan River limited the potential impacts on the natural environment in many areas. Impacts on adjacent landowners in regards to property acquisition and land use were perceived as key issues by the community. In addition, the use of the weir for potable water storage placed constraints on the surrounding land, which conflicted with the rural land uses.

Potentially significant impacts identified in the Cedar Grove EIS may result from:

- creating a weir barrier, which may restrict fish movements between up and downstream waters;
- changes in aquatic habitat characteristics upstream (i.e. creation of a lentic environment), which may favour introduced species;
- impoundment of water upstream, potentially increasing the risk of algae occurrence and siltation;
- altered patterns of downstream water flows, changing aquatic ecology; and
- loss of river cattle crossings (with economic implications).

Irreversible impacts will be those which occur in the impoundment area, notably:

- loss of terrestrial vegetation and habitat within the riparian zone;
- loss of habitat for fauna which are not mobile or for which there is no alternative habitat; and
- loss of grazing ability within the riparian zone.

Impacts which may be managed to an acceptable degree include:

- restriction of fish movement upstream and downstream of the weir, through construction of a fishway;
- alterations in the downstream flow regime, through environmental water releases;
- algal growth in the lake, through improved catchment management and contingency measures; and
- economic losses associated with primary production (through compensation).

The recommendation of the draft EIS was that the construction and operation of the proposed Cedar Grove Weir will provide a net community benefit, subject to the implementation of and adherence to the EMP. Subsequent to the release of the EIS, the proponent, the South East Queensland Water Board (SEQWB) was corporatised by the State Government and responsibility for the weir has been passed to DNR. The project is currently on hold.

Management of the Impoundment Area

The draft EIS identified a number of issues associated with the construction and operation of the proposed weir that would be of concern to landowners adjacent to the proposed impoundment area. These issues included:

- loss of cross river movement of livestock;
- loss of cattle feeding areas in the bed and banks of the river;
- worsening of bank instability problems through re-profiling and relocation of cattle to the top banks for watering and fodder;
- a decrease in water quality arising from further bank instability and subsequent sedimentation and other types of water pollution;
- guaranteeing the security of stock, crops and farming rights;
- management of the impoundment area and sensitive riparian zone;
- potential for property inundation, erosion and weed infestation and the nature of controls needed to protect against such;
- potential siltation of submerged pump sites; and
- a decrease in property security were the impoundment area and banks permitted to be used for recreational purposes or public access.

All of the above issues were addressed to varying degrees in the EMP contained within the EIS. In relation to the matter of the long term management of the riparian zone surrounding the weir and impoundment area, and addressing the perceived loss of stock access to the river, the EMP concluded that these matters needed further detailed assessment by the SEQWB in terms of setting policy directions for construction and operation of the weir. A number of land management options were scoped. These are briefly discussed below.

The 'Do Nothing' option retains the land owners' current use rights to the bed and banks of Crown land. In broad terms this option should minimise disruption/impacts to landowners associated with siltation of pump sites, loss of cross river access for stock and a reduction in grazing access. Without good management of stock and ground cover, this option would not address the erosion and re-profiling impacts of activities beside the proposed impoundment. This option also includes the lack of a physical buffer, which would better allow the control of access and security and the issue of responsibility for stock losses along the full supply line.

The 'Restricted Grazing with a Fenced Buffer' option would involve the additional costs of fencing, restricted, or nil, access of stock to water and therefore possible provision of a stock water scheme. The benefits of bank stabilisation would depend on the extent of cattle grazing restrictions, which would be subject to management decisions and occupancy arrangements.

The 'Fenced Buffer with no Grazing' option would incur the highest cost and the greatest disruption to existing landowners. However, it would provide the highest level of bank stabilisation and buffer effectiveness. On-going management of the buffer for weed control and for bush fire fuel loads would be a major operational and long term commitment.

The 'Fenced Buffer with Grazing Excluded for Interim Period and then Restricted' option would involve the same level of costs and opportunities as the previous option in the initial period whilst works associated with the weir are being established and the river banks are being stabilised. Once a stabilised condition is obtained (approximately 3 to 5 years) land owners could be granted limited stock access rights to assist in the management and control of excess grass growth and weed control. This strategy would require a re-assessment of the stability of the system after 3 to 5 years of operation at the new FSL. This option would require the installation of temporary fencing from time to time for land/water management (SEQWB 1998).

These options are currently being reviewed by the new proponent, DNR.

O Connell Weir

The O'Connell River is currently unregulated and as such, regulation could potentially have significant impacts. The location of the weir at the tidal interface was also a key area of investigation during the EIS.

The major impacts identified in the EIS were:

- potential increase in groundwater levels and potential higher fertiliser and salinity loads;

- partial inundation of endangered gallery forest including flow-on effects to fauna associated with these forests;
- changes in water quality characteristics in the impoundment and in water released/extracted from the impoundment;
- increased yields and economic benefits (assuming sugar prices are favourable);
- barriers to migrating aquatic species which may be mitigated by an effectively designed fishway;
- alterations to sediment transport downstream;
- changes to flood regimes and environmental flows;
- possible hydraulic impacts in the vicinity of the weir during 'drownouts', including stream bank and Bruce Highway infrastructure threats;
- increase in potential for expansion and/or introduction of exotic plants and animals; and
- medium to coarse sediment supply to the southern section of Repulse Bay will be substantially reduced.

The EIS did not conclude that there were any irreversible, unmitigatable impacts from the proposal. Further studies in addition to those detailed in the study Terms of Reference were subsequently requested by EPA. During this period, a letter was sent to the Steering Committee by the Minister for Environment requesting that, as the O'Connell River was the last unregulated coastal river in Queensland, further work on the EIS should cease (ORWISSC 1999).

Condamine Weir

As stated previously, the proposed weir would be located in a waterway already under considerable stress through existing water extractions directly from the waterway and from interception of overland flows. In addition, the narrow riparian corridor was potentially threatened by inundation.

A detailed EIS was undertaken, the final draft of which is currently on public display.

Key potential impacts identified as part of the study included:

- the restriction of downstream sediment transport;
- an increased rate of upstream bank slumping or slippage within the impoundment area;
- alterations in the downstream flow regime;
- the loss of important riparian vegetation upstream of the impoundment for a length of 40-45km;
- the spread of terrestrial weeds on neighbouring properties;
- the loss of access to critical arboreal mammal habitat (large trees with hollows);
- a change in species composition and habitat diversity within the impoundment area;
- a reduction in fish and macro-invertebrate abundance due to impounded water upstream of weir;
- a potential broad scale reduction in aquatic biota as a result of stratification and mixing of the impoundment;
- the restriction of fish movement up and downstream of the weir; and
- drowning of riparian vegetation creating 'dead vegetation' and subsequent alteration to weir environment.

A comprehensive Environmental Management Plan was developed to address these potential impacts during the design, construction and operational phases. The EIS concluded that the construction and operation of the proposed Condamine Weir would provide a positive benefit providing the full implementation and adherence to the EMP (Department of Natural Resources, 1999). Importantly, the proposal is ultimately subject to the Condamine-Balonne WAMP outcomes. The EIS also concluded that the construction of both Condamine and Nangram

Weirs would have significant cumulative ecological impacts.

Draft Condamine-Balonne WAMP

The outcomes of the draft WAMP study released in June 2000 in relation to the Condamine Weir are detailed below:

"The draft WAMP provides for limited additional water allocations in some parts of the basin. The additional allocation provided for in the draft Plan is small in recognition of the poor existing ecological condition and assessments of environmental flow at the end of the basin. It is generally being provided for high priority town water supply and industrial needs, including:

- *447ML of high priority water allocation in the Upper Condamine Irrigation Project from the proposed North Toolburra Weir;*
- *92ML of medium priority water allocation from the existing Upper Condamine Irrigation Project which was retrieved from a beneficial use review some years ago;*
- *300ML of additional high priority water allocation from the raised Loudoun Weir for Dalby's town water supply;*
- *300ML of mean annual diversion from Kings Creek for Clifton Shire's town water supply, in recognition that the water quality of the town's current groundwater resource has deteriorated to the extent that hardness and nitrate levels now exceed national guidelines for potable water;*
- *permits for riparian stock and domestic purposes; and*
- *short-term permits for a range of temporary or emergency purposes.*

It is clear that these small additional allocations will provide for only a very small proportion of the total future water demands that will arise within the Condamine-Balonne Basin. The policy positions proposed in the draft Plan <u>do not provide for any further major allocation of water supplies within the basin, such as for Nangram Weir or Condamine Weir</u>, unless it can be shown that such allocations would be consistent with the objectives contained within the draft Plan.

The draft Plan's provisions would mean that, in the future, people who wish to obtain an additional allocation of water, including those with outstanding water licence applications, must look to new ways of securing a water supply rather than seek approval for the issue of a new water licence. The primary option available to people seeking additional supplies of water would be through the temporary and permanent transfer of water allocations within the basin." (DNR 2000 pp 30 - 31)

(underlining is the authors emphasis)

Based on the above, unless the conclusions of the WAMP change with the finalisation of the report, the Condamine Weir would appear unlikely to proceed.

Mitigation Strategies: How Can Weir Operations be Altered to Reduce Environmental Impacts

This paper has taken a broad view of "weir operations" in examining how to reduce environmental impacts. We consider that aspects of the planning, design, construction and operation phases of the weir can all be improved to reduce potential impacts. Critical to the planning phase is the impact assessment process and how this is managed. This includes the production of Terms of Reference and the scope and level of detail required. The preparation of a detailed Environmental Management Plan is the most appropriate mechanism to ensure the design, construction and operation of the weir is undertaken in a manner which minimises environmental harm.

Environmental Management Plans are the recognised mechanism for identifying mitigation strategies and responsibilities. In the past, EMPs in Queensland have often dealt with this responsibility in a token manner, being characteristically vague, simplistic and lacking an auditable element with which to gauge performance.

In more recent times, assessment agencies have required a more accountable document, one that sets sustainable objectives and measurable actions. This has seen the development of comprehensive EMPs with more rigorous requirements, for the planning, design, operation, maintenance and often decommissioning of projects. The EIS (with incorporated EMP) therefore has a greater role than simply assessing the potential impacts of a proposal, but can more readily determine if the potential impacts can be managed in a sustainable manner.

Planning Phase

The preparation of adequate Terms of Reference (ToR) for environmental assessment have been shown in the previous case studies to be inconsistent in the scope and level of detail required. Given the potential impacts identified in these and other studies, the following should be considered as minimum requirements for inclusion in the ToR:

- a whole of catchment approach should be undertaken for all relevant elements, such as: environmental flows, hydrology / hydraulics, aquatic vertebrates and water quality;
- detailed hydrological modelling which incorporates environmental flows;
- assessment of impacts from proposed water use (i.e. irrigation schemes) particularly on soils, groundwater, salinity, water quality etc. This should include the types of crops proposed or likely to be grown, management practices and associated potential pollutants such as pesticides and fertilisers;
- cumulative impacts of other proposals and with existing infrastructure and water extraction;
- the preparation of a detailed benefit - cost analysis which includes costs for environmental monitoring and rehabilitation; and
- the preparation of a detailed EMP for the design, construction and operation of the weir.

Choosing weir locations should also incorporate environmental elements and not be totally determined by hydrological, geological or other engineering constraints.

Design Phase

A number of elements are now considered essential in the design of weir structures to minimise environmental impacts. These include:

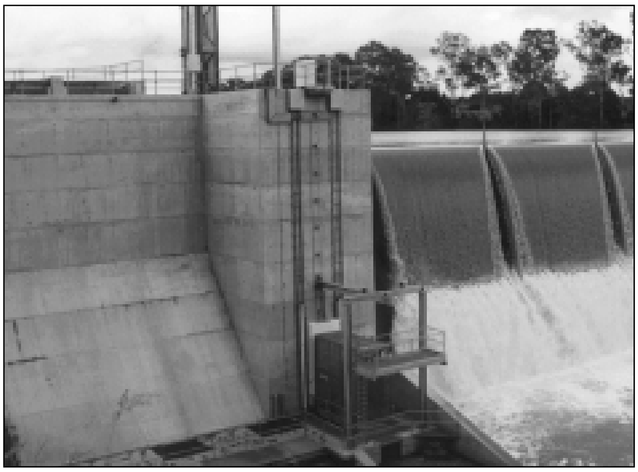
- self-cleaning weirs to maintain sediment movement and reduce operation costs; and
- the inclusion of fish transfer devices. Fish locks are now a standard consideration for weir projects in Queensland where other devices (such as fish ladders) are not considered appropriate. Bucca Weir raising also included a retrofit of a fishlock in the weir and a ladder on a downstream barrage. The device design should incorporate features to allow monitoring of fish movement.

Construction Phase

Strategies would include:

- minimising disturbance area. Locating access tracks etc. to minimise vegetation loss which may further impact on fauna movement;
- re-establishment of sustainable landscape once construction is complete;
- weed control and vehicle washdown; and
- appropriate storage of fuels and other potential pollutants.

Figure 8: *Fish Lock at Walla Weir near Bundaberg*



Operational Phase

The operational phase has potentially the greatest impacts associated with the natural environment. Accordingly, there are a number of strategies available to mitigate environmental harm. These include:

- revegetation and rehabilitation programs to establish, maintain or enhance vegetation surrounding the impoundment area and immediately downstream. This will usually require a cooperative approach with adjacent landowners and could include widening the riparian corridor, fencing erosion or bank slump sites, restricting livestock access and possible compensation issues;

- limiting recreational use to minimise wave action and therefore bank slumping;
- the operation and monitoring of the fish transfer device during all flow conditions;
- no unauthorised introduction of any fish species without appropriate approval;
- minimising frequent water level fluctuations which may impact on bank stability;
- maintaining appropriate environmental flow regime in accordance with catchment studies; and
- a detailed monitoring program to target water quality, bank stability, rehabilitation, water and terrestrial weeds, stratification (if appropriate) and any site specific requirements (i.e. platypus, other flora and fauna species).

Conclusion

The assessment of potential impacts, and mitigation of those impacts for weir projects, needs to be managed through a 'whole of catchment' approach rather than one of treating each site as having a defined footprint. More recently, impact assessment in Queensland has moved in this direction, however inconsistencies in the approach to these studies, and the management of weir projects have been identified. In some instances, these have caused problems with the studies or outcomes.

A number of critical elements have been identified which should be addressed in all weir or dam studies for the planning, design, construction and operational phases as well as study requirements outlined in the Terms of Reference. The consistent implementation of these requirements will significantly improve the decision making process and impact mitigation.

In the most recent study in which GHD has been involved, the Condamine Weir EIS, these key elements have been incorporated into the study program. As a result, the assessment process has been one of the most thorough to date and has critically examined the whole of catchment impacts. Whilst not a perfect model, the technical approach to the project, Terms of Reference and level of assessment is a significant step towards a more sustainable utilisation of our water resources.

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Biography

Bryce Skarratt is a senior environmental scientist in GHD's Brisbane office. He has recently managed or been involved in several environmental assessment studies for a variety of infrastructure projects including dams, weirs, roads, railways, sewage treatment plants, industrial and residential developments. A large number of these and other studies have principally involved waterway components, including impact assessment, flow management, catchment management plans, environmental inventories and State of the Environment reporting.

Prior to working with GHD, Bryce was employed by the CRC for Tropical Pest Management and the University of Queensland, primarily modelling the distribution of weed species and biological control agents.

Bryce has recently worked on four environmental assessment studies of weir proposals in southern Queensland and a number of dam proposals.

Restoring Rivers through the Selective Removal of Small Dams: An American Overview and the Wisconsin Experience

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Abstract

There are tens of thousands of small dams across the United States that are no longer used for their original purpose, serve no economic function and are badly deteriorated. Selective dam removal is an important river restoration tool that often makes the most sense economically and environmentally. Nonetheless, the vast majority of dam repair/removal decisions end in repair, at great cost to communities and to our rivers.

Meanwhile, public dialogue about dams and dam removal has dramatically increased nationwide. In an effort to meet this growing need for information the Small Dams Program has developed the Citizen's Guide to Restoring Rivers Through Selective Removal of Small Dams. *Based on extensive firsthand experience this guide provides citizens, local officials and others with the information they need to increase consideration of dam removal at the local level. Contents include: how to research a dam of concern; issues that need to be considered during the dam repair/removal decision; tools to use when pursuing a dam removal; developing a strategy and identifying tactics for increasing consideration of dam removal locally; planning and carrying out river restoration work; worksheets to use throughout the process and more.*

Dam removal is not appropriate in all situations, but for many rivers dam removal is the single most important thing we can do to restore the health of the waterway. In Wisconsin more than 80 dams have been removed ranging from 1 to 18m high, over the past 50 years. The cost of repairing an old dam is around three to five times that of removal. At least 465 dams have been removed throughout the US in recent decades. Today we know that a healthy river is not just the heart of a healthy ecosystem, it is also the heart of a healthy community.

This paper is based on the first chapter of the handbook, *The Citizen's Guide to Restoring Rivers through Selective Removal of Small Dams*. This guide is available from the River Alliance of Wisconsin and Trout Unlimited National (www.riveralliance.org).

Dams[1] played a critical role in the settling of the United States. Today, there are an estimated 2.5 million dams and weirs of various sizes in our rivers and streams (National Research Council 1992). While many still make valuable contributions to society, many others have outlived their usefulness and are relics of earlier generations. Such structures pose public safety hazards and are economic burdens to dam owners. Dams can also be extremely damaging to fisheries and river ecosystems, through fragmenting and blocking rivers, and preventing rivers from carrying out their natural functions, such as sediment and nutrient transport.

Removing old, unsafe and uneconomical dams can be a win for public safety, a win for financially burdened dam owners, and a win for the rivers that enabled the dams to serve a purpose that has now passed.

The fate of American rivers will largely be determined by how each state and the nation as a whole views aging dams. The economic fate of

[1] Note that the term 'dam' is here used to describe all barriers across a waterway including low structures referred to as 'weirs' in Australia.

many dam owners, which are often communities, will be impacted by whether they decide to remain burdened by these relics of an earlier time. The fate of the public's ability to enjoy healthy rivers and everything they can offer will also be determined by how we choose to deal with dams that no longer make sense.

Thousands of communities, dam owners and government agencies are facing or will need to face the issue of what to do about a dam. Some of these dams should be kept and some should be removed. The decision of whether to repair or remove a dam is a complicated issue. This paper serves as a primer on: dam regulation in the United States; why dam removal is increasingly discussed; why not all dams should be removed; why focus on small dams; and the role of citizen involvement in the dam repair / removal decision in the State of Wisconsin.

Dam Regulation

The decision of whether to repair or remove a dam in the United States often arises because the government agency in charge of regulating the dam orders it to be made safe or removed. Sometimes the dam owner is faced with this decision when they simply can no longer afford the dam, see it as a financial burden and want to get rid of it. In other situations, the decision is brought about because the dam is having a devastating effect on an economically valuable sport fishery or on a protected species.

How a dam is regulated and by whom is an important factor in the decisions that determine the dam's future. A dam may be regulated by a federal, state or local government agency, or by a combination of these agencies. It may also be under no regulation at all if it doesn't meet a state's minimum size requirement for regulation (this varies between states). Dams that produce hydropower are regularly licensed by an agency. But most other dams are not licensed; thereby limiting the scrutiny allowed for public interest concerns mostly to safety issues.

The main purpose of regulating dams is to keep them safe and reduce their risk to the public. Depending on the state, dams of a certain size are regularly inspected for safety. Sometimes this inspection results in an order to either make the dam safe or have it removed in the interest of public safety.

Most dams in the United States are either privately owned or owned by local governments (i.e. taxpayers). Owning a dam involves a substantial amount of financial and legal responsibility. Dam owners are required by law to keep these structures safe, but this can be an expensive process, and many dam owners have a difficult time paying for required repairs. Dams that generate no income yet continue to demand upkeep are viewed as particularly burdensome. It is commonly at this point when the decision to repair or remove a dam needs to be made.

Why Dam Removal is Increasingly Discussed

The question of whether to repair or remove some dams is becoming an increasingly visible issue in the United States. Some believe that dam removal is a "radical" new idea. On the contrary, people have been removing dams as long as we've been building them. Dam owners have chosen to disassemble dams throughout history, primarily because it made financial sense. A recent report documents 465 dams that have been removed across the country in the last several decades (American Rivers *et al.* 1999).

Even though the decision of whether to repair or remove dams is not new, the issue is increasingly in the news. Five primary factors have caused increased discussion of the option of dam removal.

1. Dams harm rivers. Dams change the natural river environment by flooding areas, turning rivers into impoundments that are deeper, wider and slower moving than they are naturally. Because they are artificial they also tend to require costly maintenance to keep them in useable condition, such as dredging sediment, stocking fish, removing undesirable fish, weeds and algae.

Scientific research on rivers in recent decades has shown that rivers play a critical role in ecosystem health. Rivers and the lands near them contain some of the highest numbers of species of any ecosystem on earth. The United States has been called a global center of aquatic biodiversity, ranking first worldwide in species diversity of freshwater mussels, crayfish, snails, and aquatic insects (Master *et al.* 1998). Studies have shown that dams harm rivers in a variety of ways.

- Fragmenting rivers and blocking the movement of fish, mussels and other species.

Ecosystem fragmentation causes serious problems with the ability of species to survive and thrive. Dams have caused many species to become threatened and endangered (Master *et al.* 1998, Stein and Flack 1997, Wilcove *et al.* 1992).

- Harming water quality, both above and below the dam structure. For example, dams can negatively change water temperatures, dissolved oxygen content, turbidity and salinity (Kanehl *et al.* 1997, Doppelt *et al.* 1993).

- Impeding the river's natural "flushing" functions. Dams change a river's ability to move sediment and other nutrients downstream. Sediments build up behind the dam, causing a variety of problems, from the need to dredge sediments to excessive amounts of nutrients that lead to blooms of algae, robbing the water of vital oxygen supplies (Petts 1980, Poff *et al.*, Collier *et al.* 1996).

- Altering prime spawning habitat. Prime fish spawning habitats tend to be places where there is a high gradient to the river, resulting in well-oxygenated waters and gravelly streambeds. Unfortunately these places are also preferred sites for dam building, because of the "fall" of the water. Since the majority of these prime dam sites have been developed in the United States, many prime spawning sites have also been lost. Likewise, many rapids and waterfalls have disappeared under impoundments and dams that were built on top of them (Kanehl *et al.* 1997).

2. Thousands of dams are at or beyond their safe life expectancy. According to the Association of State Dam Safety Officials (1999) dams are typically designed to have a safe life expectancy of about 50 years. The U.S. Army Corps of Engineers' National Inventory of Dams (1999) says there are about 76,000 large or high hazard dams in the country. Thirty percent of these dams are already more than 50 years old. By 2020, eighty percent will be older than their safe life expectancy. The American Society of Civil Engineers gave dams a grade of "D" in a recent report (1998) – citing age, downstream development, dam abandonment and lack of funding for dam safety programs.

These statistics are daunting, but a greater problem is that the United States lacks a complete dams inventory. The Army Corps' inventory includes some dams, but the National Research Council (1992) estimates there are actually about 2.5 million dams nationwide. This discrepancy is due to the fact that the vast majority of smaller dams, many of which are regulated by states or are unregulated, are not included in the National Inventory of Dams. These smaller, often unrecognised dams cause significant public safety, economic and environmental concerns.

3. Old dams can pose public safety hazards. Dams are inherent safety hazards (Association of State Dam Safety Officials 1999). This hazard is created by the potential for a dam failure and simply due to the dam's existence. A dam failure can be devastating to people, animals and property. Property damages from dam failures have ranged from thousands to billions of dollars. No price can be put on losses of life caused by dam failures. Deceiving water currents created by dams kill swimmers, anglers, paddlers and hikers every year. Even people that understand the dangers of dams can become disoriented and trapped in waters around dams. Poorly operated dams can cause serious property damage above and below the dam structure. All dams present public safety hazards, but abandoned or ownerless dams are especially concerning.

4. Old dams are expensive to keep. Dam maintenance and repair is costly, especially when a dam is no longer generating power or otherwise helping to pay for itself. Since many dams are publicly owned (i.e. by municipalities and states) this financial burden falls upon the taxpayers.

For example, the cost of repairing a dam once in the State of Wisconsin tends to be three to five times more expensive than removing the dam entirely (Born *et al.* 1996). The average cost of bringing an old, small dam to Wisconsin dam safety standards is US$300,000 (Galloway 1999). It is important to note that these figures do not include the on-going cost of maintaining, operating and insuring the dam for the lifetime of the structure. In Wisconsin these costs range from US$5,000 - $75,000 per year (Galloway 1999).

5. Our relationship to rivers is changing. Public appreciation for rivers continues to grow as millions of people who fish, swim, paddle or simply enjoy walking along rivers are becoming interested in and concerned about protecting and restoring rivers, especially rivers flowing through their communities. Water quality issues consistently top the list when people across the country are asked about their environmental concerns. Downtown revitalisation along healthy rivers is increasing. Rivers are seen as assets to communities and many people feel that their quality of life is enhanced by living near healthy, natural areas. This is evidenced in part by the rapidly growing number of citizen groups with river protection and restoration goals. There are currently 30 statewide river groups in the United States, as opposed to 5 in 1990 (River Network 2000).

Watershed-level restoration is also gaining ground. Over the past 10 years agencies responsible for the well being of natural resources are changing their management districts to follow watershed boundaries. This enables agencies to work within the natural layout of the area, rather than within political boundaries, which rarely correspond to the natural boundaries. As dam removal is increasingly seen as a tool to restore watersheds and improve water quality, decisions can be made about several dams in a river at once, rather than in a piecemeal process. This enables watershed-wide improvements that benefit larger areas with a smaller price tag.

Why Not All Dams Should Be Removed

Some situations highlight the critical need to be selective in removing dams, and to look at the cumulative impact of dams on a specific river system.

Economically viable dams. Some dams still provide important societal and economic values. For example, Trout Unlimited National, the River Alliance of Wisconsin and other river conservation groups work to improve the operation of many economically viable hydropower dams licensed through the Federal Energy Regulatory Commission. The groups do not call for the removal of these dams, but seek ways to lessen their impact on the rivers upon which they depend.

Dams with true historical significance. While tens of thousands of old dams have played important roles in the history of local communities, some dams have true local, regional or national historical significance, and should be restored when economically possible and socially desirable.

Protecting existing river health. River health might be worsened by some dam removals. Some dams serve as barriers that prevent contaminated sediments from moving downstream and polluting those waters. Other specialised dams can help control problematic species from moving upstream and affecting healthier waters.

Why Focus on Small Dams?

The majority of dams that have been removed in recent years have been "small dams." While the technical definition of a small dam varies by state the term is used in this paper regarding dams 7m high or less. Small dams in particular are increasingly being removed for several reasons.

Sheer numbers. Only two percent of America's rivers remain free-flowing (Benke 1990). There are many more small dams than large dams. In many parts of the United States, especially the Upper Midwest and New England regions, virtually every stream is or has been dammed. Few, if any, states have a complete inventory of all the dams – large and small – blocking their rivers and streams. This is due in part to the fact that many dams fall under the States' size requirements for safety inspections.

Age. Many small dams were built over 100 years ago and have not been used for their original purpose for decades. Even if they have been periodically repaired many turn-of-the-century dams are well beyond their safe life expectancy of 50 years. Some are beyond repair and would need to be replaced if they were to continue to exist.

Economic benefits often easier to quantify. The economic cost and benefit estimates for the options of small dam repair and removal are easier to determine. And, since hundreds of small dams have been repaired or removed it is relatively easy to look to other sites for examples of what each option might cost.

Cumulative impact. Because there are so many small dams the cumulative economic and environmental impact of repairing or removing these dams promises to be huge. Federal officials have estimated that dam safety costs over the next 20 years could range from US$750 million to US$1.5 billion annually (Federal Emergency Management Agency 1999). Simultaneously, the cumulative beneficial impact of restoring rivers through the removal of small dams located in sensitive headwaters areas could be ecologically monumental (Doppelt *et al.* 1993).

Smaller scale is relatively easy to manage. Small dam issues tend to be less controversial than large dam issues. While most dam repair or removal decisions involve some controversy, the issues involved with smaller dams tend to be more easily addressed during the decision-making process simply because fewer people are affected by the outcome. Most small dam removals are fairly localised issues (e.g. within the region or the state) and have relatively fewer stakeholders involved than dam removals of national significance.

Easier to plan and implement river restoration campaigns through small dam removal. The technical issues involved with a small dam's removal are at a manageable scale. Interested stakeholders can become deeply involved with river restorations through small dam removal. Community members can be the people who decide what happens to the area through the river's restoration, such as designing a park or a trail system along the restored river flowing through their community.

Citizen Involvement in the Repair or Removal Decision: The Wisconsin Experience

In many cases in the United States today, the people deciding the fate of a dam grew up in the dam building era, where control of nature was perceived a good and necessary thing. Therefore it is not surprising that mere mention of the words "dam removal" can elicit a negative, knee-jerk response. In most cases there is no one alive in the community who remembers the free-flowing river before the dam. But times, and needs, have changed. The cost and benefit of many dams across the country, especially the smaller ones, needs to be seriously reconsidered.

Decisions regarding the repair or removal of dams typically are highly charged emotionally, and often based on inaccurate and incomplete information. Simply getting dam removal considered as an option on its factual merits can be a major step. But selective dam removal can be the best option, not only for the river, but also for the local community and the dam owner.

A study done in 1996 by the University of Wisconsin Extension (Born *et al.* 1996) looked at 14 dam repair/removal decision processes in the state. The predominant Wisconsin experience has been that the requirement to make a dam safe is the trigger for the repair/removal decision. Another common experience has been that the decisions to remove dams have primarily been based on economics. The study also found that:

- efforts to involve citizens in the decision-making process have been met with varying levels of success;
- the basis for making decisions regarding dam removal has been rather narrowly focused to dam safety issues;
- communities tended not to fully understand the hazards presented by existing dams that have been found unsafe, and therefore see the need to repair or remove the dam as unnecessary;
- the suggestion to remove a small dam tends to generate strong emotional reactions and a divisive atmosphere;
- many people that were involved in dam repair/removal decisions demonstrated only partial understanding of the legal, financial and environmental issues involved with the decision;
- local support for removal tended to be lacking during the decision-making process; and
- the estimated costs of repairing a dam once is typically three to five times more expensive than the estimated cost of removing the dam.

The Small Dams Program

In January 1999, the River Alliance of Wisconsin and Trout Unlimited National embarked on a joint effort, the Small Dams Program, to improve the dam removal/repair decision-making process in communities across Wisconsin by providing information that enables selective dam removal to be considered on its merits. By working with resource agency personnel, dam owners, media, local officials, and citizens, the Small Dams Program helps communities make the most informed choices possible about their dams and local rivers.

The State of Wisconsin has removed more dams than any other state in the nation. Over 3,800 dams block Wisconsin's rivers and streams – some having stood for more than 150 years. Once a leader in developing waterways for mechanical and hydropower energy, Wisconsin now leads the country in restoring rivers through selective dam removal. In the past 50 years, Wisconsin has removed more than 80 dams ranging from 1 to 18m high. These dam removals have taken place across the state, from large cities to tiny rural communities.

Public dialogue about dams and dam removal has dramatically increased since the Small Dams Program began. The program receives numerous requests for guidance and information from citizens across Wisconsin, the United States and elsewhere. In an effort to meet this increasing need for information, the program has developed the *Citizen's Guide to Restoring Rivers through Selective Dam Removal.* Based on the River Alliance's extensive firsthand experience this guide provides citizens, local officials and others with the information they need to increase consideration of dam removal at the local level. Contents of the Guide include: how to research a dam of concern; issues that need to be considered during the dam repair/removal decision; tools to use when pursuing a dam removal; developing a strategy and identifying tactics for increasing consideration of dam removal locally; planning and carrying out river restoration work; worksheets to use throughout the process and more.

Several of the nation's leading river conservation organisations, including the River Alliance, have collaborated to produce a video on the option of dam removal. The National Park Service's 'Rivers, Trails and Conservation Assistance Program' is a partner in the project. Featuring case studies of communities that have chosen to remove dams in Wisconsin, Maine and California, the video addresses many of the issues and concerns that are involved in the dam repair/removal decision-making process. Before and after video, photographic footage and testimonials from local officials, citizens and others tell the story of dam removal in three communities. The 15 minute video is an excellent resource to show at local meetings for the purpose of enabling an increased awareness and understanding of the option of dam removal. It is scheduled to be available for distribution in November 2000.

It is an exciting time for rivers, the fish and wildlife that depend upon them, and the people who care about them. During the past quarter-century, important advances have been made in policy and science, presenting new opportunities to restore rivers and watersheds. People are increasingly recognising the value and importance of healthy rivers and watersheds, evidenced by the rapidly growing numbers of citizen groups that have river protection and restoration goals.

Dam removal is quite possibly the most significant river restoration opportunity of our time. It is true that these structures once served a purpose. But many smaller dams have fallen into serious disrepair and are now safety hazards, while continuing to devastate river ecosystems. Todd Ambs, executive director of the River Alliance of Wisconsin acknowledges that, "Dam removal is not appropriate in all situations but for many rivers dam removal is the single most important thing we can do to restore the health of the waterway. Today we know that a healthy river is not just the heart of a healthy ecosystem; it is also the heart of a healthy community."

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Biography

Stephanie Lindloff is the Small Dams Program Manager for the River Alliance of Wisconsin in the United States of America, a statewide citizen advocacy organisation for river protection and restoration. Portions of the Small Dams Program are a collaborative effort of the River Alliance and Trout Unlimited National.

As the first manager of this unique program Stephanie works to improve the dam repair/removal decision-making process by providing communities with information that enables dam removal to be considered on its merits. She works with resource agency personnel, dam owners, media, local officials and citizens to help communities make the most informed decision possible. The essence of the program is to educate communities and promote dialogue about restoring rivers through selective dam removal. Stephanie has provided information and expertise to countless people concerned about this issue and has been involved with a dozen dam removals.

Stephanie has a Master of Science degree in Water Resources Management from the University of Wisconsin. She has also written technical documents for the national groups, American Rivers and Trout Unlimited. When not working to help rivers she enjoys flyfishing, cycling and photography.

New South Wales Weirs Policy: The Results of the Initial Assessment of Weirs in New South Wales

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Abstract

As part of the Water Reform process the New South Wales Government released the State Weirs Policy in 1997. One component of the Policy was the establishment of the Weir Review Program to review all existing weirs in NSW. This program is overseen by the State Weir Review Committee which first met in November 1998. The acceleration of this process involving an initial assessment of all weirs has been undertaken by NSW Fisheries throughout the State. The results of this assessment have been reported to the respective River and Water Management Committees and recommendations made to the State Weir Review Committee.

All recommended actions require more detailed discussion with weir owners prior to any work but at this stage the bulk of the recommendations are for no further action. This is generally because most of the weirs and dams are at the top of catchments and the result of any ameliorative action would be minimal environmental improvement. The next most common recommendation is for the construction of (around 200) fishways. To a large extent these are recommended in the main channels of rivers on weirs owned and managed by the New South Wales Government. A significant number of weirs are also mentioned for decommissioning (around 100). This recommendation often relates to structures that have been enhanced or duplicated or changes in land use in an area, reducing the need for the weir pool as a water storage. Finally, about 50 structures are mentioned for complex review where changes in the weir pool and upgrading the structure or fishway will entail significant assessment or public discussion.

These recommendations are discussed in detail and the implications for future action by Government, industry and weir owners are discussed. Although costly, implementation of management changes to weir pools, decommissioning of weirs and the building of fishways will result in large and measurable improvements to the functioning of New South Wales's riverine ecosystems.

Introduction

There are a total of 3,328 licensed weirs or barriers on the rivers of New South Wales. Weirs provide a water supply to towns and properties but it has become increasingly apparent that this has been at a significant environmental cost. They reduce water quality, obstruct the passage of native fish and create an environment that favours introduced species, such as carp. The State Weirs Policy was developed in 1997 by the NSW Government to provide a framework for the review and ongoing management of weirs to reduce their impact on the environment.

The State Weirs Policy has three components. The first sets out the criteria used to assess applications to build a new weir or expand an existing one. The second component looks at the factors taken into account when considering installing a fishway in a weir and the third component is a review of all existing weirs (Weir Review Program).

The State Weir Review Committee overseas the implementation of the State Weirs Policy. The committee comprises of representatives from State agencies, industry and the community. The terms of reference for the committee are to:

- review and refine criteria for weir review;
- review and refine criteria for approval to construct new weirs or modify existing weirs;
- provide advice on State priorities for weir management;
- make recommendations on funding priorities;
- promote the goals and principles of the State Weirs Policy;
- conduct an annual audit over the implementation and performance of the State Weirs Policy according to its goals and principles; and
- recommend guidelines for the operation of weirs.

The Department of Land and Water Conservation (DLWC) coordinates the Weir Review Program for the Weir Review Committee, the aim of which is to examine the impacts of existing works and to develop a strategy which would lead to benefits for the environment. It will be achieved by undertaking an environmental audit of all weirs throughout the State and assessing the appropriateness of the existence and/or operation of each weir, against a set of established criteria. The state wide audit of weirs is a project managed by NSW Fisheries and jointly funded by the NSW Recreational Fishing (Freshwater) Trust Fund and DLWC.

The review is being carried out in regions corresponding to those set up for the Water Reform Process of which the State Weirs Policy is one component.

Assessment Process

NSW Fisheries completed a detailed prioritisation of weirs within each catchment between September 1999 and August 2000. Weirs were ranked using the following criteria:

1. River Size – A score was provided as follows: Named River = 10, Named Creek = 6 and Unnamed Watercourse = 2;

2. Location in System – Core habitat including tidal waterways and waterways below 700m elevation (namely floodplain areas) were given a score of 10. Non-core habitat areas above 700m elevation on coastal waterways and 'Montane areas on inland flowing waters' scores were used for weirs that were located in first and second order streams;

3. Threatened Species – The national listings of threatened species were examined to determine whether any threatened species were listed within catchments. From the recent High Conservation Value assessment, subcatchments that were likely habitat for threatened species were given a scoring of 6. All other catchment areas scored 2;

4. Upstream Habitat – An assessment of the amount of stream habitat that would become accessible if fish passage was improved at the site was determined by examining 1:100,000 maps. No structures upstream = 10, 2 or less structures upstream = 6 and greater than 2 structures = 2;

5. Downstream Obstructions – An assessment of the number of artificial obstructions downstream of the site was examined from the DLWC Weirs Inventory Database maps of each catchment. No structures downstream = 10, 2 or less structures downstream = 6 and greater than 2 structures = 2;

6. Fishway – The presence or absence of a fishway on the barrier was recorded using the DLWC Weirs Inventory Database information per barrier. Weirs with a fishway were given a score of 5. This included non-functional fishways, as retrofitting of new fishway designs to old fishway channels is most often easier than construction of new fishways. All others scored 3; and

7. Thermal Pollution – Weirs located downstream of large dams are prone to thermal pollution problems. The distance of this impact was based on the Lugg (1999) report. Weirs influenced in this way were given a lower score (i.e. 2) compared to those weirs on waterways unaffected by thermal pollution sources (i.e. given a score of 10). No consideration was given to the dilution of impact with distance from the dam.

This review was based on Pethebridge, Lugg and Harris (1998). These results were then presented and reviewed by the relevant River Management Committees (at the time of publication some reviews were still in progress).

In November 1999, NSW Fisheries employed project officers, or in remote locations used Field Service staff, to conduct weir reviews throughout each catchment. The first part of the process involved accessing the Licensing Administration database System (LAS) created by DLWC to identify the location and contact details for licensed weirs. Landholders were contacted by phone and where necessary by mail and informed of the Weir Review Program. Permission was gained to inspect sites and arrange meetings with landholders to discuss the social, ecological and hydrological issues associated with the weir / dam.

Following the initial desk study to prioritise the weirs, field assessments were undertaken using additional criteria to consider other environmental and socio-economic factors. These included:

- weir purpose and consideration for number of users and benefactors;
- heritage and cultural values;
- whether the weir owner had noted evidence of specific water quality problems such as salinisation of surrounding land, deoxygenation, and blue green algal blooms; and
- evidence of riparian degradation such as localised erosion, sedimentation, reduced health of riparian vegetation.

These factors supplemented the prioritisation criteria to determine what course of action would be the most appropriate for a given weir.

Once landholders were contacted the weir assessment was carried out using a field survey proforma developed by the State Weir Review Committee based on the review criteria listed above. Photographs were also taken of the weir from the upstream and downstream sides. Additional photos were taken to show any other important details, such as fishways, spillways, sites of erosion or where repairs may be required. All information was then entered into the database and a summary report outlining sociological, ecological and hydrological issues associated with each structure was produced. Recommendations were made on the basis of these initial reviews.

Once data has been entered into the database and the summary reports prepared each weir owner will be sent a copy of their database information and the summary report. A 1800 Freecall number will be established to allow weir owners to respond with any corrections they believe are necessary.

Weirs situated on named watercourses were targeted as priority sites for inspections and weirs on unnamed watercourses as well as unlicensed weirs were not reviewed. These actions will be undertaken on completion of this project.

The acceptance of the Weir Review Program by the farming community is in part a reflection on their recognition that weirs do have an environmental impact and on the manner in which the State Weir Review Committee has handled the process.

Results

At the time of writing, 822 weirs had been inspected throughout New South Wales. A list of the suggested actions in each catchment is presented in Table 1. These recommendations are only preliminary and must be first considered by the Weir Review Committee and endorsed by the relevant River or Water Management Committee. Following endorsement, detailed reviews must be carried out in the priority order agreed to by the River or Water Management Committee before any course of action is taken. These detailed reviews will assess the comments from the views of the owners and the views of adjacent landholders. In addition, detailed information will be collected so that the proposed activity can be costed and its potential environmental impact reviewed.

Fishways

One hundred and ninety-eight fishways have been suggested as a viable option in New South Wales. The bulk of these fishways are suggested for weirs that are owned by the State Government. This result was expected given that most of the weirs owned by the State occur in lowland reaches of main river channels. They are required in this position to service irrigated agriculture, which means that in most cases their removal is not an option, however this location provides a significant impediment to the free passage of fish.

Removal

Currently 103 weirs are candidates for removal. Before removal is undertaken, a further detailed review to confirm the current use of the weir pool and the weir will take place. The majority of these sites are privately owned structures that have been

Table 1: *Preliminary Results for NSW Weir Reviews*

Catchment/ Area	Status*	Fishway	Removal	Weir Management	Not There	No Action
Far North Coast	Assessments completed	6	16	1	5	35
Mid-North Coast	Assessments completed	8	2	8	1	9
Lower North Coast	Assessments completed	2	0	1	7	11
Hunter	1 week to completion	9	5	16	17	25
Hawkesbury-Nepean	2 weeks to completion	12	12	0	5	75
Illawarra / Shoalhaven	1 week to completion		0	0	0	
South Coast	1 week to completion	7	0	0	0	16
Murray	Report submitted	13	11	8	9	40
Murrumbidgee	6 weeks to completion	10	0	0	0	35
Lachlan	Assessments commenced	3	4	4	20	46
Macquarie	Assessments commenced	17	5	7	37	63
Gwydir	Report completed	9	11	6	0	23
Namoi	Report submitted	21	3	0	37	14
Border	Report completed	7	4	3	3	25
Darling	Assessments commenced	6	8	5	8	11
Total		**130**	**81**	**59**	**149**	**403**

**As at August 18, 2000*

Note that this data has changed following subsequent reviews of weirs in New South Wales

Complex reviews are required at 8 locations one of which is currently being undertaken by NSW Fisheries.

allowed to deteriorate because the value of the weir has been replaced by another nearby structure, or the land use for which the weir pool was required no longer exists.

Weir Management

Fifty-nine weirs have been suggested as requiring some form of management. This includes maintenance of existing fishways, improved use of gates to manage the weir pool and associated effects, construction of gates for the same reason and de-silting the weir pool, particularly where it effects the operation of gates or fishways.

Not There

One hundred and forty nine weirs were not in place at the time of the review. In most instances this is because the weir had washed away and never been replaced. In some cases a licence had been issued and the weir had not been constructed.

Conclusion

With additional funding from the NSW Recreational Fishing (Freshwater) Trust Fund and DLWC, detailed reviews of priority structures will be pursued. This will allow assessment of costs for the remediation of the environmental impact of weirs. Once this information is known, the State Weir Review Committee will be able to endorse a joint cabinet submission by NSW Fisheries and DLWC for a Capital Works Program. This submission will seek funds for the construction of fishways, the removal of weirs and the upgrade of management structures to allow improved management of weir pools.

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Acknowledgements

This paper would not have been possible without the support of the recreational fishers of New South Wales who through their licence are contributing to the improved management of the State's freshwater fish resources. The Department of Land and Water Conservation matched their contribution. NSW Fisheries have also contributed significant staff time to the review.

The information was gathered by the following NSW Fisheries staff: Phoebe Boydell (Border, Gwydir), Richard Braga (Far North Coast), Suzannah Erwin (Hawkesbury-Nepean), Milly Hobson (Namoi, Macquarie), Scott Norris (Mid North Coast, Lower North Coast and Hunter), Rob Peever (Shoalhaven, South Coast), Hamish Rutherford (Macquarie), Suzanne Unthank (Lachlan) and Steve Ward (Darling). In addition Richard Nevill from the Department of Land and Water Conservation carried out audits in the Hawkesbury-Nepean and Charles Sturt University carried audits under contract to NSW Fisheries in the Murray and Murrumbidgee. This work was managed by Dr Adrienne Burns and Martin Asmus.

Staff in all DLWC offices have been very helpful with access to weir licence files as well as the provision of office space and vehicles at Tamworth, Dubbo, Penrith and Forbes. The database has been managed by Richard Braga and Chrisy Collins of NSW Fisheries.

Comments on an earlier draft of this paper and advice on the direction of the audit were provided by Richard Denham and Sarah McGirr of DLWC and Greg Hillis of State Water. An anonymous reviewer provided thoughtful recommendations for improvements to the paper.

Biography

Craig Copeland has been with NSW Fisheries for 11 years as a Conservation Manager. He is responsible for restoring fish passage through weirs and floodgates, as well as wetland rehabilitation. Craig chairs the Clarence Floodgate Project and Kooragang Rehabilitation Project and manages the Weir Review Project for the State Weir Review Committee.

Weirs: Where s What?

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Abstract

State Water is a commercial business within the NSW Department of Land & Water Conservation. It is responsible for resource operations of water delivery and asset management. State Water's asset portfolio has over 260 weirs and regulators statewide. In addition to these there are 140 related structures. Most of these weirs perform an essential function by providing access to water by licensed water users and riparian water users. To manage these effectively, State Water has an Asset Management Strategy and an ongoing Total Asset Management Program. This program provides the means of examining various issues related to each structure, reach and system, to develop options and alternatives.

The first Total Asset Management Plan (TAMP) has been completed, and includes a 30 year works program. The TAMP takes into account many factors, such as the condition of each structure, the present and future levels of service, and compliance with legislation. Lifecycle management plans for each structure will be developed.

A 2 year program of safety audits has been completed. State Water has completed its Asset Register identifying structures, locations and other relevant details to enable informed decisions to be made about each structure. This paper outlines the TAMP process and the implications for management of weirs.

Introduction

In response to the 1994 Council of Australian Governments Agreement and the National Competition Policy, the NSW Government separated the roles of the resource regulator and the operator. Initially, a Major Water Infrastructure group was set up within the Department of Land & Water Conservation (DLWC) in 1996.

Under New South Wales legislation, the Independent Pricing & Regulatory Tribunal (IPART) recommends the maximum prices for water, based on submissions by the DLWC. Following the first such submission in 1996, IPART engaged consultants to review the 30 year works program and the forward estimates. Consequently, a decision was made to commence a Total Asset Management Plan (TAMP).

A Bulk Water Delivery Business was formed in September 1997, and the entity State Water became functional in July 1998 as a commercial business of the NSW Department of Land & Water Conservation.

State Water's vision statement is "improving life with water". It is responsible for resource operations of water delivery, asset management and customer service.

State Water is organised into four Customer Service Areas: North Area covering Border, Gwydir, Namoi-Peel Valleys; Central Area covering Macquarie and Lachlan Valleys; South Area covering Murray and Murrumbidgee Valleys; and Coastal Area covering all the coastal valleys, including the Toonumbar and Brogo regulated systems.

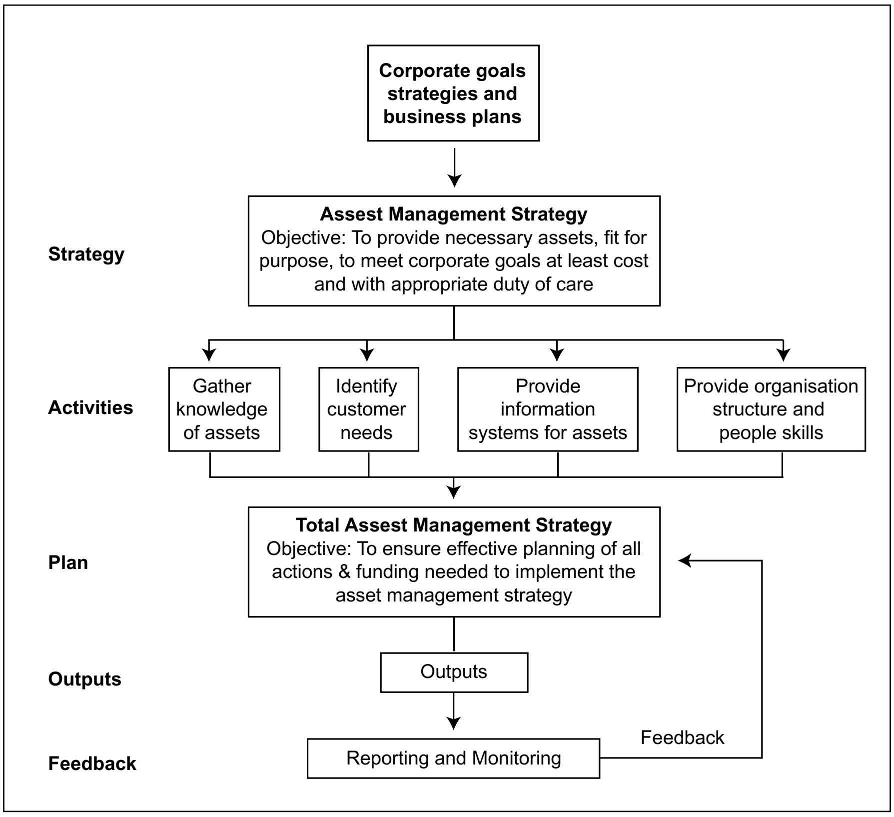
State Water has over 21,000 customers, including irrigators, towns and cities, mines, hydro-electricity generators and industry. State Water has eight Customer Service Committees.

State Water's asset portfolio consists of 18 large dams, 14 minor dams, and over 400 river structures. These include 264 weirs and regulators and 140 related structures. The related structures consist of banks, channels, bridges, cuttings, culverts, levees, off-takes, log-sills, access roads and pipe inlets. The asset portfolio is estimated at $2.2 billion. State Water structures are the now largest source of 'new green' energy in Australia.

Asset Management

State Water's Asset Management Strategy is to provide necessary assets fit for purpose, to meet its corporate goals at least cost and with appropriate duty of care. A Total Asset Management Plan (TAMP) is essential to implement the strategy. A TAMP ensures effective planning of all actions and funding needed to implement the Asset Management Strategy.

Figure 1: *Framework for a Total Asset Management Plan*



State Water has completed the first TAMP for all its major and minor dams and river structures (weirs, regulators and related structures). Because it is a dynamic process, the document will be subject to reviews and updated with new information. Future revisions will incorporate management of land, buildings, plant and machinery, heritage and energy.

Figures 1 and 2 show the framework for asset management and the TAMP process. There are four preliminary steps leading to the TAMP – knowledge of assets, asset levels of service, management information system and organisation. The first two steps are dealt with in more detail as follows.

Knowledge of the assets

- Location, description and ownership: most of the structures on the river systems have been located, inspected and registered.

- Condition and risk assessments and safety audits: most of the river structures have been assessed and safety audits conducted to appropriate level of detail. The more detailed audits involved de-watering and underwater diving inspections to assess the structures' condition.

- Portfolio risk assessment: probabilities of various failure events, consequences of failure and populations at risk and loss of life have been estimated.

Analysis and review of functions and levels of service

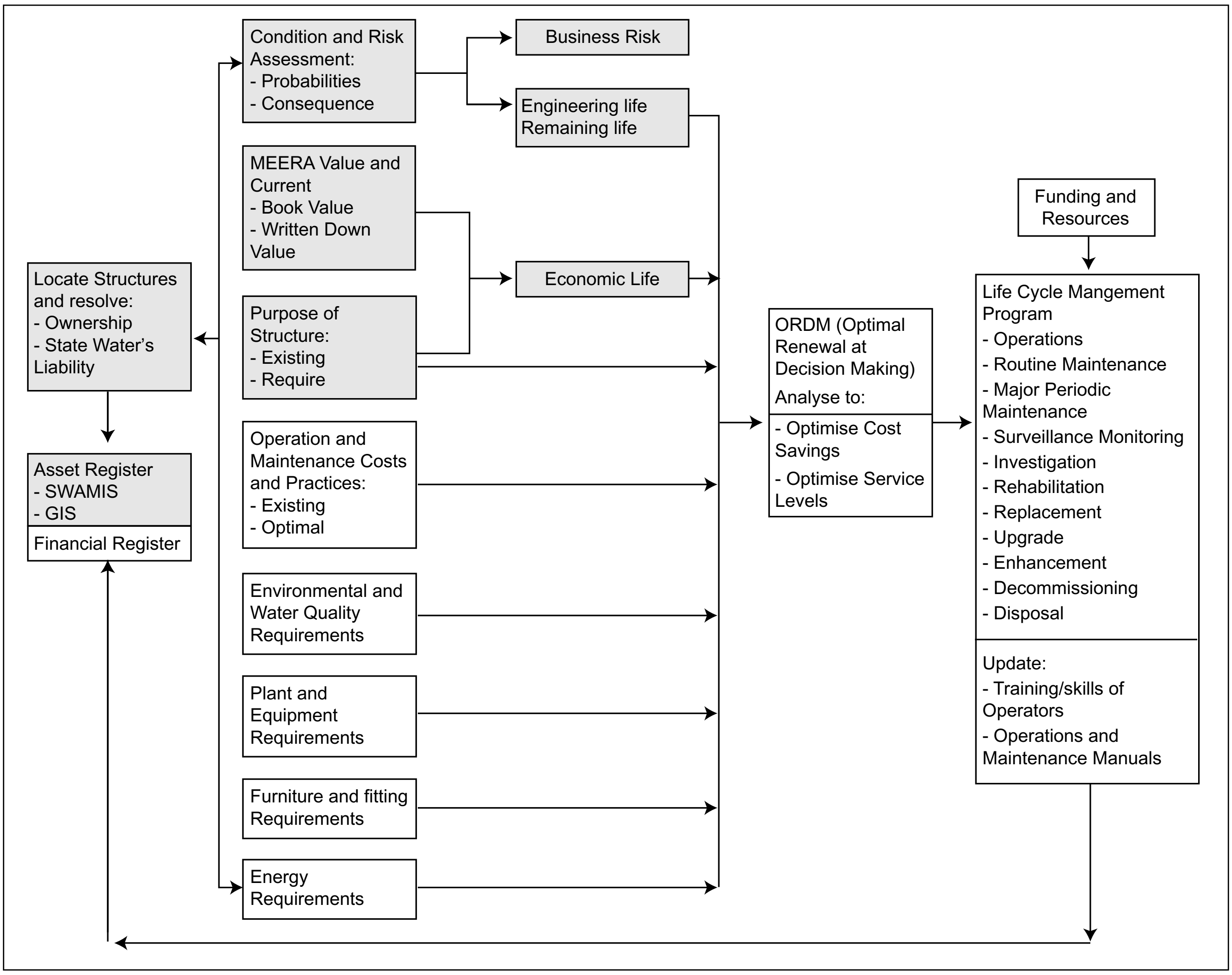
- Reliability.

- Operations and maintenance.

- Customer needs – current and future.

- Environmental needs – current and future.

Figure 2: *Development of life cycle management plans.*



- Integration of water delivery operations and asset management.

The main outputs from these steps have been the Safety Audit Reports. The information in these reports in turn has been used to develop the following:

- a Risk Analysis and ranking for structures of comparative assessment;
- an Asset Register for all State Water river assets;
- an Asset Management Information System; and
- a 30 Year Works Program for State Water structures.

The Safety Audit Reports for all structures included the following:

- inspection conditions: the weather, date of most recent rain, pool and tail water levels, discharge rates;
- components and their condition: the structure, foundations, crest wall, aprons, wing walls, fishways, spillways, gates, mechanical and electrical systems;
- safety, reliability and serviceability: any issues related to safety of operations personnel, users and the public;
- corrective works: identified corrective works including further investigations where required to bring the structures' safety and serviceability to the required standard. All works recommended are scheduled, costed and ranked in priority;

- routine and periodic maintenance activities including periodic monitoring, the frequency and costs for each structure;
- an estimate of the remaining life of each of the components and an overall assessment of the remaining life of the structure; and
- a risk assessment with consequence ranking. Consequences of failure are ranked for 5 categories, namely: injury or loss of life; community loss; environmental damage; replacement cost; and annual loss of irrigation revenue.

State Water also has historic data, reports, plans and drawings of the structures as well as soil samples from critical sites.

Risk Analysis

A simple risk assessment was conducted on most river structures as part of the Safety Audits.

The condition of all major components on a structure was checked, examining each one for probable events that could lead to failure, injuries or fatalities. All issues raised were then rated from 1 to 5 for:

- the combined probability that the event would occur causing malfunction, loss, damage and/or failure; and
- the consequences of any malfunction, loss, damage and/or failure.

Table 1 shows the rating system used for the likelihood of an event to cause malfunction, loss, damage and/or failure, and Table 2 shows the failure consequence ratings.

An overall risk rating for all issues raised for all structures was determined as the product of the rating for the event likelihood and the average rating for its resulting consequences.

This risk rating was used for priority ranking of issues for each structure, and a priority ranking was assigned to each structure. The TAMP includes within the risk assessment: the list of issues raised, the average consequence rating, its overall risk rating, and the priority rankings for each issue raised and priority ranking for each structure.

A condition rating from 1 to 5 was awarded to the whole structure, and not to its individual components, where 1 indicated satisfactory condition, and 5 unsatisfactory. Table 3 shows the structure condition ratings and their descriptions.

All structures were then given two risk ratings:

- a product of their condition rating and the average failure consequence rating; and
- a product of their condition rating and the maximum failure consequence rating.

A total of 84 weirs and regulators have now been assessed in detail with another 53 now in progress. In addition, another 226 weirs and regulators and 133 related structures have been assessed to a lesser level of detail.

Table 1: *Failure Probability Rating*

Rating	Judged Likelihood of Occurrence (30 Years)
5	Event/failure is virtually certain
4	Event/failure is likely
3	Uncertain about the event/failure or event/failure has a fairly even chance of occurring
2	Event/failure possible but unlikely
1	Event/failure virtually impossible

Table 2: *Failure Consequence Ratings*

Rating	Loss of Life or Injury	Community Loss	Replacement Structure Cost ($)	Environmental Damage	Annual Loss of Irrigation Revenue
5	Fatalities: >10 people	Major loss of town water supply / public access	>$10M	Very high damages and prosecution by Regulatory Authority	>$100M
4	Fatalities:	Some loss of town 1-10 people Major loss of recreation / public access >100 domestic intakes	$5M-$10M water supply.	High damages and prosecution by Regulatory Authority	$50M-$100M
3	Disability	Medium loss of recreation / public access <100 stock and domestic intakes	$0.5-$5M	Moderate damages and remedial action required by Regulatory Authority	$10M-$50M
2	Loss of time with injury	Minor loss of recreation public access	$0.1-$0.5M	Low damages and reported to Regulatory Authority	$1M-$10M
1	Minor medical aid only or no injury	Very minor or no effect	<$0.1M	Very low damages and / or minimal impact	<$1M

Using the risk analysis results from the Safety Audit Reports, a risk ranking for all structures in terms of loss of life and costs has been developed.

Asset Register

Based on the Safety Audits, State Water determined its river structure portfolio with December 1999 as the baseline. The portfolio will be further refined as ownership of some structures is yet to be resolved. It is also anticipated that ownership of some State Water structures may be transferred to other agencies or users. Other structures may be decommissioned and / or removed altogether.

An Asset Register has been created containing details of all State Water assets:

- asset name and general description of the structure: the weir, its components and dimensions, photographs of the structure;
- the location of the structure: river valley / system and name of waterway; GPS coordinates, nearest village / town / city; names of roads to access the structure;

Table 3: *Structure Condition Rating*

Rating	Subjective Condition Assessment	Description
5	Unsatisfactory	A deficiency exists under normal conditions. Immediate remedial works are required.
4	Poor	A potential safety deficiency is recognised for normal loading conditions. Immediate action to repair the deficiency is recommended. Restrictions may be necessary until the problem is fixed.
3	Conditionally Poor	A potential safety deficiency is recognised for unusual loading conditions, which may realistically occur during the expected life.
2	Fair	No existing deficiencies are recognised for normal loading conditions.
1	Satisfactory	Safe performance is expected under all anticipated loading and operating conditions.

- structure history: date when constructed, design life at construction and all major refurbishments;
- financial details: Financial Asset Number, Written Down Value and Modern Engineering Replacement Asset (MEERA) Value;
- function of the asset: for irrigation, stock and domestic, town water supply etc;
- age when built and dates of any major refurbishments;
- plan and / or drawing number;
- structure operational systems: electrical, mechanical, hydraulic, manual, automatic, monitoring and communications;
- significance of structure rated 0 to 4, where 0 means 'no function identified' and 4 means 'absolutely essential', for environmental, industrial, irrigation, recreation, stock and domestic, and town water purposes; and
- number and type of licences served.

The Asset Register is essentially a database containing the details of State Water's assets. Maps of the locations of each of the structures have been prepared using the spatial attributes. It supports the functionality and implementation of the TAMP. As it becomes available, detailed information on flow regimes, environmental issues, options will be added to the database. Changes and updates to its content will be carried out within the various functions of the TAMP.

The portfolio was established following the Safety Audit Inspections on State Water structures in 1988 and 1999. State Water has taken responsibility for these structures although ownership of some is yet to be determined.

Maps 1 to 4 show the location of these structures in each Area. See Table 4 for a summary of structures.

These structures are operated according to annual operations plans covering each valley. The structures are maintained according to a schedule or as required. Some of these structures have been automated and can be remotely operated to optimise system performance.

State Water Asset Management Information System (SWAMIS)

State Water is in the process of developing an asset management information system to implement the TAMP.

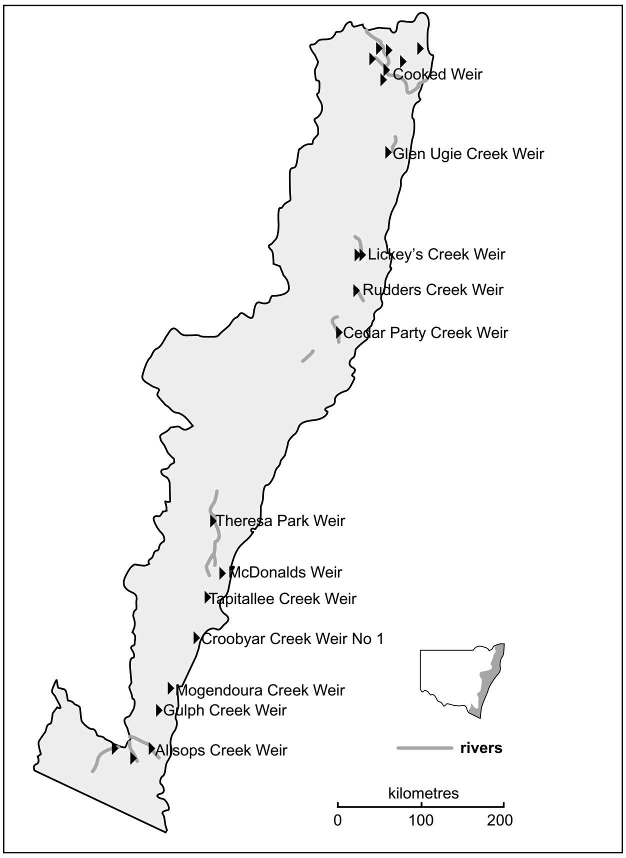
State Water Asset Management Information System (SWAMIS) is the basic Asset Register, Maintenance Management System and the repository for the detailed asset maintenance management. It is also the hub for the following information systems. Different databases from the following systems will be able to interact with each other delivering real time information. Data entry, reporting and updates in all relevant databases are in real time.

- River Operations: local operational data related to the day to day operation of the river system, such as Computer Aided Integrated River Operations (CAIRO). While it is a specific operational tool, it also provides strategic data for asset management and flow audits.
- Geographic Information System (GIS): spatial information and mapping capability relating to the physical location of State Water structures and their logical situation

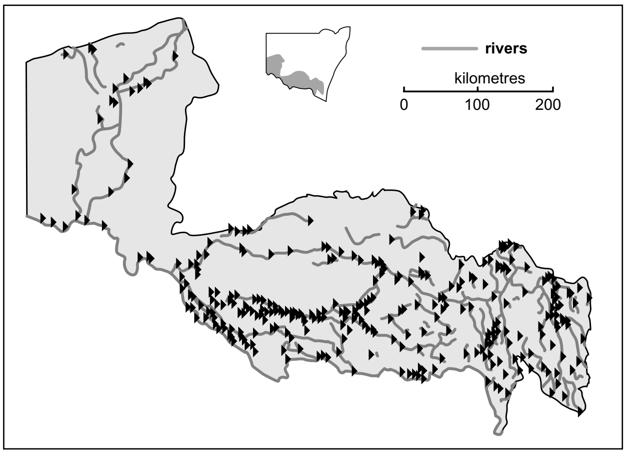
Table 4: *Summary of State Water River Structures*

Area	Weirs	Regulators	Related Structures	Total
North Area	30	0	2	32
Central Area	44	35	71	150
South Area	28	95	65	188
Coastal Area	32	0	2	34
Total	**134**	**130**	**140**	**404**

Coastal River Stuctures

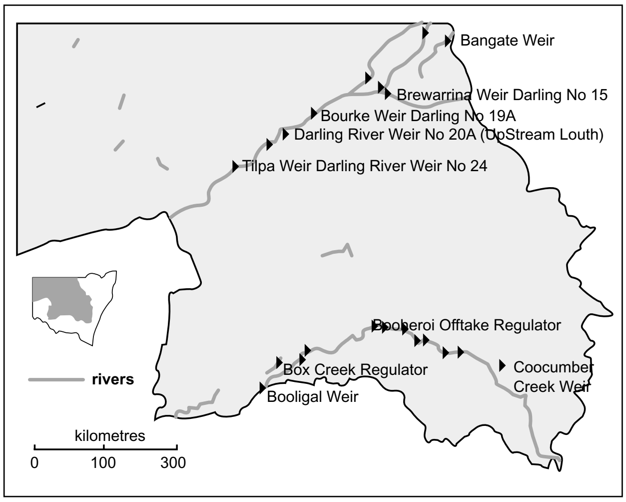


South River Stuctures

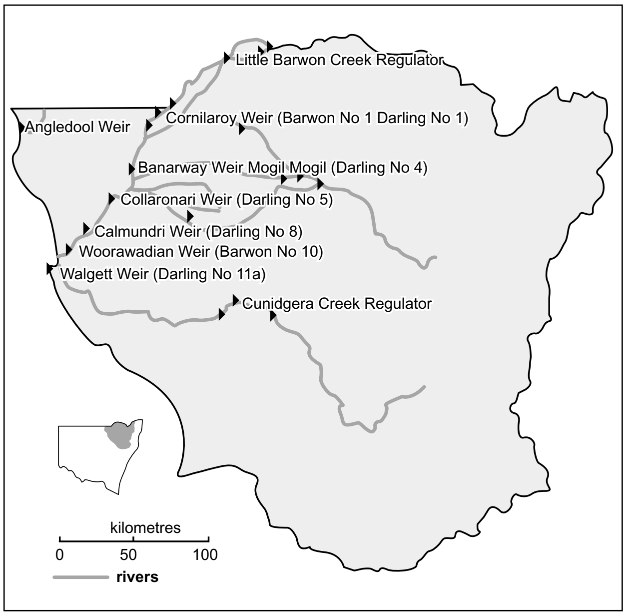


within their respective river systems. It allows mapping of River Systems for SWAMIS support. All available plans, drawings and maps are being scanned into digital images and maintained on a centralised database. This database will be linked to enable the asset management system to access and display these data in conjunction with the basic asset data.

Central River Stuctures



North River Stuctures



- Internet and Intranet: for dissemination of information of interest to the wider community. By connecting to the GIS and SWAMIS, it is possible to display graphics and relevant data about individual structures.

30 Year Works Program

The 30 Year Works Program has been developed and costed. The works program consists of a series of lifecycle management plans for individual structures. The next revision of the TAMP will incorporate:

- Optimal Renewal Decision Making; and
- Lifecycle Management Plans for river reaches and systems.

The 30 Year Works Program and all the other components of the TAMP will be the basis of State Water's activities in the maintenance and management of assets.

Lifecycle Management Plans

A Lifecycle Management Plan for each asset has been developed consisting of all or some of the following:

- an Investigation Program: to develop options to address structural deficiencies;
- a Monitoring Program: for inspection and monitoring of the structure and its components;
- a Routine Maintenance Program: covering activities done throughout each year and such as gate operations, mechanical/electrical maintenance, ground maintenance;
- a Renewal Works Program: major periodic maintenance such as discharge gate painting, maintenance or replacement of mechanical/electrical/civil components. It also includes rehabilitation works and investigations related to rehabilitation;
- an Enhancement Program: these are works planned for structures that result in an upgrade or enhancement in its operation and/or service delivery, such as automation of gates, increases in crest height, provision of fish passages, multi level off-takes, and works related to compliance issues including emergency warning systems; and
- a Decommissioning and Disposal Program. At the end of a structure's life it may be decommissioned or dismantled or disposed of.

This program is structure specific, showing all activities planned for each structure over the 30 years commencing in 1999/2000, and the relevant cost estimates. The activities and costs are derived from the Safety Audit Reports and/or determined through asset planning workshops. The next update of each Lifecycle Management Plan will integrate reaches and systems.

The TAMP is a dynamic document, reviewed and updated from time to time to reflect changes in the assets condition, changes in technology, and/or availability of more accurate data on the structure. Activities will also be re-scheduled with changes in priorities and resources.

The history of actual costs and maintenance records are also recorded in this document periodically and can be compared with the estimates and plans. In addition, estimates themselves will be tracked to enable improved planning.

Some Recent Works Undertaken

Most State Water assets are regularly operated, maintained and monitored. Maintenance can be of routine nature (servicing gate actuators) or a major activity such as painting or regalvanising the gates.

State Water is automating many of its structures to increase the efficiency of its operation. A total of 30 structures have already been automated and another ten are expected to be automated over the next few years. This has led to improved operation of systems.

Other activities have been aimed towards environmental and water quality improvements. These include:

- construction of Booligal Swamp Regulator (1992) to regulate water pools for the Ibis rookery at Booligal Swamp in the Lachlan River Valley;
- construction of Buckiinguy Return Weir (1997), Milmiland Weir (1998), and the three Monkeygar Breakaway Weirs (1994) for erosion control and to retain water in the Macquarie Marshes;
- installation of six gates for road crossings (North Macquarie By-pass Channel) to prevent escape of water from the channel. Another four gates will be installed this year (2000) as water level permits;

- repairs to fishways in the Gwydir and Namoi river valleys (Combadello Weir, Tareelaroi Weir, Mollee Weir and Gunidgera Weirs in 1996);
- installation of water quality instrumentation at the existing gauge stations;
- scour protection works on the banks and river beds of many structures, most recent of which are Gunidgera, Mollee, Weeta and Tareelaroi Weirs, and Mehi and Gundare Regulators, all in the North Area (August 2000);
- operation protocols to minimise silt build-up and maintain fishway operation, releasing environmental flows, minimising the rate of pool drawdown to prevent bank slump;
- commissioning of a water quality regulator at Hay Weir (1998) to mitigate blue-green algae occurrence;
- installation of a fishway on Edward River Offtake (1999) using a prefabricated structure;
- development of a prototype retrofit fishway at Balranald Weir. This is being carried out with NSW Fisheries and Department of Public Works & Services. A successful outcome may lead to retrofitting similar works at existing weirs to enable improved fish passage; and
- extensive bank protection works along the Murrumbidgee including Yanco, Gogeldrie, Hay and Balranald Weirs.

Current and Future Works

The 30 Year Program lists all activities planned for each river structure. Following the Safety Audits in 1998/99, many issues were raised and remedial works recommended over the immediate following years.

A more detailed 5 Year Program is being developed which is largely a rehabilitation program to bring assets into compliance with governing statutory and engineering codes.

Some of the proposed capital works for the 5 years 2001 to 2005 include:

- replacement structures at Berembed Canal Bridge No.1, St. Helena's Regulator, Gulpa Creek Weir, Gunningbar Creek Weir, Warren Weir, Crooked Creek Weir, and Duck Creek Weir;
- fishways to be included on replacement structures for Gunningbar Creek Weir, Warren Weir, Crooked Creek Weir, and Duck Creek Weir;
- decommissioning of six structures in the Coastal Area including Rudder's Creek Weir, Hickey's Creek Weir, Cedar Party Creek Weir, Gulph Creek Weir, Mogendura Creek Weir, and Yackungarrah Creek Weir. In addition, some of the minor dams have also been identified for decommissioning and disposal;
- automation of ten structures for remote operation and the development of a state wide Supervisory Control & Data Acquisition (SCADA) network;
- compliance work including provision of appropriate warning signs, installation of gantry cranes, and provision of guardrails on structures;
- stabilisation of stream beds and banks, and repair works; and
- civil and mechanical repairs to structures, aprons, fishway baffles, gates and machinery.

The 5 Year Program is subject to change depending on investigations and studies for structures, and financial and resource constraints. The program also includes routine and major periodic activities for each structure.

Consultation

In order to achieve the goals of the Asset Management Strategy and the resultant benefits, a program of consultation has commenced. This will lead to a better understanding of the needs of customers and the wider community, development of options and trade-offs, and an appropriate works program.

A protocol has been drafted for works programs to enable compliance with statutory requirements as well as customer and community consultation. This protocol is being tested on the proposed works for year 2000.

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Removal of Edwards Dam, Kennebec River, Maine USA: A Landmark Example of Watershed Restoration

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Abstract

The Kennebec River once contained commercially important stocks of Atlantic salmon and other valuable species of fish, which were almost entirely eliminated by construction of dams. Edwards Dam, the lowermost barrier on the river, was built in 1837 without effective fish passage, a condition that existed until it was breached in 1999. Its removal was precipitated by a precedent setting decision by the U.S. Federal Energy Regulatory Commission (FERC) in 1997, which denied a new long-term license and called for project decommissioning. Following numerous appeals of the FERC order, a comprehensive settlement agreement was reached that included a US$7.25 million fund for removal of the dam and additional fish restoration measures in the Kennebec River watershed. Fifteen parties participated in the agreement, representing state and federal agencies, upstream dam owners, private conservation organisations, municipalities, and industry.

The removal of Edwards Dam firmly established the precedent of decommissioning as a viable alternative to hydroelectric project relicensing in the United Staes of America. The collaborative settlement process that ultimately resulted in its removal provides an example of how interested parties can work together toward watershed restoration goals, rather than fighting one another in court. Both lessons will undoubtedly be useful in working toward similar restoration goals in other watersheds.

Introduction

The *Federal Power Act* allows a private dam owner in the United States to operate a hydroelectric project for up to 50 years before they must apply to the Federal Energy Regulatory Commission (FERC) for a new license. Over the course of such a long license term, environmental statutes and regulations change, along with public attitudes and priorities for using the waterways that hydroelectric developments occupy. Procedural burdens make it difficult to modify operations at an existing project before the license term expires. Thus the public process that accompanies the renewal of an operating license is viewed by many as a singular opportunity to gain environmental improvements and to address watershed restoration needs (Echeverria *et al.* 1989, American Rivers *et al.* 1996).

The Kennebec River once contained vast numbers of migratory fish, which were largely eliminated by the construction of dams, widespread water pollution and over-fishing (MESPO 1993). Restrictions in harvest and improved water quality in recent decades leave dams as the greatest impediment to restoring historic fish stocks in the river. The inability of certain species to utilise fish passage facilities at dams has led to an increased interest in removing barriers such as Edwards Dam as the best means for achieving watershed restoration goals.

On 25 November 1997 the FERC denied a new license for the Edwards project, and ordered decommissioning of the existing generating facilities together with the removal of the 160 year old dam (FERC 1997b). Until that time, the FERC had never denied a new license for an active hydroelectric project with an accompanying order for dam removal. The FERC's decision immediately sparked a series of appeals by the dam's owners and other hydropower interests throughout the country. It was clear to all who were involved that the issue of dam removal would not be resolved in the near future, with the outcome likely to be settled ultimately in the courts. Faced with the prospect of years of litigation over the FERC's precedent setting decision on Edwards Dam, a number of stakeholders engaged in intense negotiations over the next several months, and on 26 May 1998 signed a comprehensive settlement agreement, which resulted in removal of the dam in 1999.

In this paper I describe the fishery resources of the Kennebec River, and discuss how initial attempts to gain fish passage at Edwards Dam failed. I also explain the rationale for taking out Edwards Dam, and describe the major provisions of the stakeholder settlement agreement reached in 1998, which ultimately resulted in the removal of the project in 1999. I also recount the construction techniques used to demolish and remove the dam. Finally, I discuss some of the important lessons learned in the Edwards Dam case, including the merits of using a collaborative approach to achieve watershed restoration goals.

Fishery Resources in the Kennebec River — Past and Present

The Kennebec River is the second largest river system in the state of Maine, north-east USA, with a total drainage area of about 15,200 sq. km. From its source at Moosehead Lake, it flows approximately 212km to the Atlantic Ocean (Fig. 1). The drainage contains 26 federally authorised hydroelectric projects, 9 of these on the main stem of the river (MESPO 1993). Until it was removed in 1999, Edwards Dam was the most downstream barrier on the main stem, located in the capital city of Augusta, Maine; the river was tidally influenced below the dam. In its lowermost reaches, the Kennebec River flows into Merrymeeting Bay, one of the largest freshwater tidal bays in the eastern United States (FERC 1997a).

The Kennebec River and its associated estuary (Merrymeeting Bay) contain a diverse fish community, including at least 43 species (USFWS 1996). Prior to construction of Edwards Dam and other barriers in the 18th and 19th centuries, the river supported large numbers of migratory fish, including Atlantic salmon (*Salmo salar*), American shad (*Alosa sapidissima*), alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), striped bass (*Morone saxatilis*), Atlantic sturgeon (*Acipenser oxyrhynchus*), shortnose sturgeon (*Acipenser brevirostrum*), rainbow smelt (*Osmerus mordax*), and American eel (*Anguilla rostrata*). Together, these runs of fish, which numbered in the millions in any given year, provided sustenance to native Americans and the colonial settlers occupying the area, and supported important commercial fisheries (MESPO 1993). Absence of adequate fish passage facilities at dams, together with pollution and over-fishing led to the virtual extinction of most of the historic runs of fish. State and federal natural resource agencies have achieved some success over the past 20 years in re-establishing spawning populations in the Kennebec River drainage, although the numbers of fish returning to the river each year continue to be critically low compared to historic levels. One species, shortnose sturgeon is listed as endangered under the federal *Endangered Species Act*.

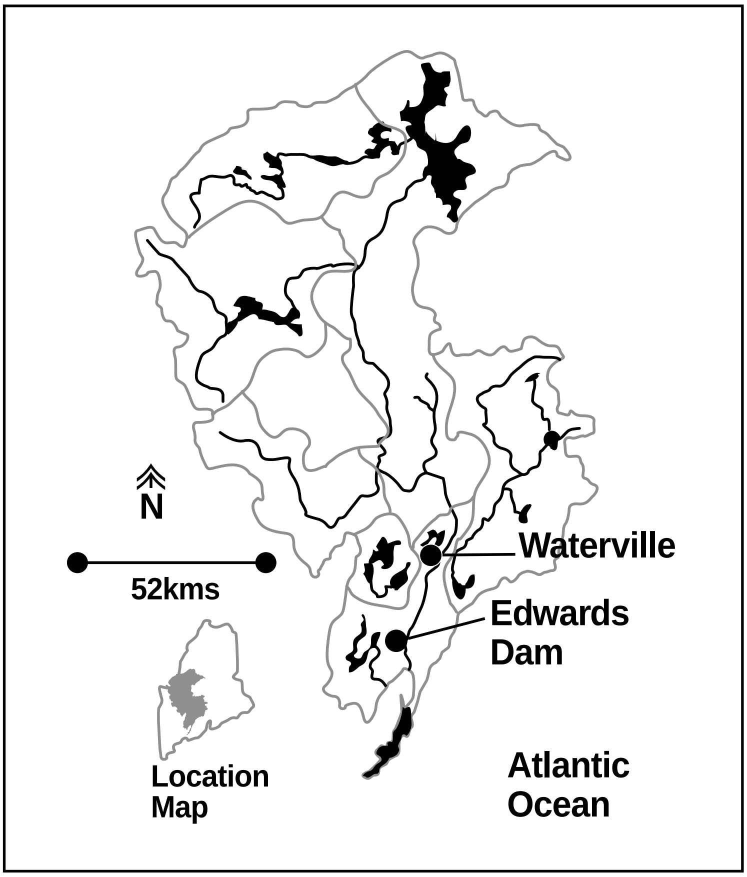

Figure 1: *Location of former Edwards Dam in Kennebec River Drainage*

Current fishery management goals call for restoring anadromous fish[1] to their historic habitat in the Kennebec River, and for enhancing existing populations of American eel, a catadromous species[2] (MESPO 1993, ME DMR *et al.* 1996, ASMFC 2000). Several species (striped bass, Atlantic and shortnose sturgeon, and rainbow smelt) historically migrated upstream only to Ticonic Falls in Waterville, Maine (Fig. 1), located approximately 27km above the former site of Edwards Dam, and now occupied by a hydroelectric development (Lockwood Dam). Habitat for other anadromous species (Atlantic salmon, American shad, alewife and blueback herring) existed historically for many miles beyond Waterville on the main stem, and in several tributaries. Numerous dams throughout the drainage have altered the suitability of historic habitat, thereby reducing the size of the potential runs of anadromous fish to a fraction of their former magnitude. However, restoration of migratory fish to much of the watershed can be achieved through dam removal, installation of fish passage, and protection of habitat through instream flow releases and other means (MESPO 1993).

Permanent fish passage facilities do not exist at any of the lower Kennebec River dams. This has been a major impediment to restoring runs of migratory fish in the river for the species that will use fishways at dams (salmon, shad, alewives, blueback herring, and eels). Other species that historically spawned in the Kennebec River (striped bass, sturgeon and rainbow smelt) are not known to take advantage of conventional fish passage devices, leading to the breaching or removal of barriers as the best means for achieving watershed restoration goals (USFWS 1996). In 1989 the owners of Edwards Dam installed a vacuum-pump fish lift to allow for the collection of upstream migrating river herring (alewives and blueback herring), which the Maine fishery agencies used as an interim means of capture and transport to upstream spawning locations (FERC 1997b).

Fish Passage at Edwards Dam — 162 Years in the Making

Edwards Dam was built on the Kennebec River in 1837, and initially provided mechanical power for the lumber and textile industries. Hydroelectric generating facilities were added in 1913, and the project received its first federal license in 1964 (FERC 1997b).[3] The Edwards Dam project included a 280m long, 7.6m high dam, which created a 462ha impoundment that extended approximately 24km upstream. The dam itself consisted of a timber crib filled with rock and other ballast, and is similar in design to other low-head spillways that were built in Maine in the 19th century. The spillway had a concrete surface that had been repaired periodically throughout the dam's history. The Edwards Dam project included three separate powerhouses, containing a total of nine generating units, which provided a combined hydroelectric capacity of 3.5 megawatts (MW). Total annual electrical generation was roughly 20 gigawatt-hours, most of which was sold to the local utility, Central Maine Power Company.[4] Prior to its being breached in 1999, the Edwards Dam project contained about 0.13% of the total electrical generating capacity that was available in the state of Maine (MESPO 1993).

The need for effective fish passage at Edwards Dam had been an issue since its construction in the 19th century, when it was recognised that measures would have to be incorporated to accommodate the prolific runs of fish that had inhabited the river at the time. Unfortunately, such fishways were not provided at the dam, or if built, were ineffective and did not last.[5] During initial licensing of Edwards Dam in the early 1960s, water quality conditions in the Kennebec River had not improved to the point where fish restoration could proceed. Consequently, the FERC (then Federal Power Commission) did not order fishways at the dam. It was not until the late 1970s and 1980s that there was a renewed interest in achieving fish passage at Edwards Dam, which

1 Anadromous fish mature in the sea before returning to freshwater to spawn.

2 Catadromous fish mature in freshwater before returning to the sea to spawn.

3 Passage of the Federal Power Act in 1920 did not result in the automatic requirement for licensing of Edwards Dam and other existing hydroelectric projects. Jurisdiction over those projects by the FERC was decided later, often as a result of litigation.

4 Public utilities are required to buy power from independent producers such as the owners of Edwards Dam.

5 The Kennebec Coalition's June 5, 1995 filing with the FERC contains a summary of the legal history of Edwards Dam, including failed efforts to get effective fish passage at the site.

at the time of re-licensing (in 1993) became a call for dam removal.

Central to the dam removal debate surrounding Edwards Dam was the State of Maine's comprehensive management plan for the Kennebec River basin, in which it sought to balance hydropower production with fishery and recreational needs in the watershed (MESPO 1993). The state's plan, which was supported by federal resource agencies and non-governmental conservation groups made it clear that Edwards Dam needed to be removed in order to accomplish fish restoration goals and maintain balance among competing resource interests within the watershed. Such restoration goals were in direct conflict with the re-licensing plans by the owners of Edwards Dam.

The Decision to Remove Edwards Dam

In July 1997 the FERC published its Final Environmental Impact Statement (FEIS) on the Kennebec River Basin, covering the proposed re-licensing of Edwards Dam and 10 other hydroelectric projects (FERC 1997a). The FEIS included a summary of studies and other analyses by the FERC which supported the conclusion that Edwards Dam should not be re-licensed. The environmental report found that conventional fish passage facilities, if installed at Edwards would likely accommodate some, but not all of the fish stocks that had been identified for restoration in the Kennebec River. Atlantic salmon, American shad, river herring, and American eel are known to use fishways, and would be expected to pass Edwards Dam, given the installation of properly designed facilities. The FEIS stated that fishways were not likely to work for the other species historically occupying the river (striped bass, sturgeon and smelt). The FERC found that removal of the dam also would restore 24km of riverine habitat and benefit a number of species that spawn under free-flowing conditions. While the FERC did not conclude that any of the other dams on the Kennebec should be removed, it did acknowledge that without Edwards there would be less adverse cumulative impact of the hydropower developments that remained in the drainage. The FEIS and associated environmental studies (SWETS 1995) did not find any significant impact to resident fish or wetlands that were present in the Edwards impoundment. The FERC also did not find substantial deposits of sediment accumulated behind the dam, which if released, could degrade water quality and downstream habitats. The FEIS also found that angling and other river related recreational opportunities would increase in the lower Kennebec River with the removal of the dam, resulting in substantial economic benefits.

The cost of dam removal, estimated to be approximately US$2.7 million, was also far less than the US$10 million that likely would be needed to install fishways, which as previously noted would not accommodate all of the species targeted for restoration (FERC 1997b). The FERC also found that alternative sources of energy, currently available in the region were far cheaper than the power that was produced at Edwards Dam, particularly when the costs of fish passage and other mitigative measures were taken into account. Considering the availability of a cost-effective alternative for energy, together with the biological objectives that could not be met entirely with the project remaining in place, the FERC concluded that re-licensing Edwards Dam was not in the public interest (FERC 1997b).

Lower Kennebec River Comprehensive Hydropower Settlement Accord

The FERC's order to remove Edwards Dam was immediately appealed by dam's owners, who until that time desired a new operating license. Other hydropower interests throughout the country also filed legal challenges to FERC's dam removal order, claiming that the agency had over-stepped its authority under the *Federal Power Act* (it had never issued such an order to decommission and remove an existing operating project). Based on the nature of the legal appeals and lack of clear-cut precedent, it was evident to all who were involved that the issue of dam removal would not be resolved quickly, with the outcome likely to be settled ultimately in the courts. Faced with the prospect of years of litigation, the resource agencies, dam owners, and Kennebec Coalition, and City of Augusta engaged in intense negotiations over the next several months. On 26 May 1998 the parties signed an extensive settlement agreement, known as the Lower Kennebec River Comprehensive Hydropower Settlement Accord (Settlement Accord) to end the legal disputes and begin steps toward removing the dam in 1999.

Under the terms of the Accord, a US$7.25 million Kennebec River Restoration Fund was established to pay for dam removal and fisheries restoration activities above Edwards. Projects designed to enhance migratory fish stocks in the Kennebec River included expansion of an existing hatchery for American shad, continuation of an interim trap-and-transport program for river herring, and studies for helping to site and evaluate the effectiveness of permanent fish passage facilities at barriers upstream from Edwards Dam. All of the funds for carrying out dam removal and fish restoration were collected from upstream dam owners (KHDG) and from Bath Iron Works (BIW), a major shipbuilding industry, located downstream from Edwards Dam. The BIW's contribution (US$2.5 million) was related to its requirement to provide mitigation for habitat impacts associated with expansion of its shipyard, located in the Kennebec River estuary. The KHDG provided its share of the funds (US$4.75 million) in exchange for an extension in the established schedule for installing fish passage facilities at its dams, pending growth of fish populations and accomplishment of other restoration objectives in the watershed.

The owners of Edwards Dam agreed to the settlement in light of the fact that their power sales contract with Central Maine Power Company was about to change, and would result in a substantial drop in generating revenues. The settlement also allowed the owners to transfer the project to the state for no cost and avoid any responsibility for dam removal or site restoration. On September 16, 1998 the FERC approved the Accord, which is to remain in effect until at least 2014 depending upon the progress in achieving fish restoration goals.

Removal of the Dam

In reaching its decision to remove Edwards Dam, the FERC relied heavily on studies that were done as part of the re-licensing process to identify impacts to existing environmental resources and to evaluate potential benefits to fish populations and associated aquatic communities (SWETS 1995, ORNL 1997). Those investigations concluded that removal of the dam would not result in any significant adverse environmental impacts, due in part to the minor amount of sediment accumulation behind the low-head dam, and given that the impoundment shoreline was mostly forest land and undeveloped (FERC 1997b). Nevertheless, the studies and subsequent dam removal plans identified a number of criteria that needed to be established in order to achieve safe and efficient removal of the dam. These included:

- controlled drawdown of the impoundment to minimise potential slumping of impoundment embankments and discharge of sediment to the river, and to reduce potential stranding of freshwater mussels and other aquatic organisms;
- modification of existing intake and outfall structures of industrial and municipal waste treatment facilities located in the proximity of the dam;
- implementation of erosion and sedimentation controls to minimise impacts associated with demolition and removal of debris;
- modification of boat launching facilities in the impoundment to ensure continued recreational access; and
- seasonal restrictions on construction work to avoid impacts to threatened and endangered species (shortnose sturgeon and bald eagle).

Under the terms of the Settlement Accord, the license for the Edwards Dam was transferred to the state of Maine in January 1999. The state secured the necessary environmental permits, and hired the contractor to demolish the dam, remove debris and restore conditions at the site. Mobilisation for actual dam removal activities commenced in the Spring of 1999, with plans to begin demolition in early July 1999 after river flows receded to normal mid-summer levels (approximately $125m^3/s$), and following the end of the spawning season for the majority of anadromous fish inhabiting the river (MESPO 1998).

The initial stage of removal involved placement of a short earthen coffer dam on the upstream face of the west end of the spillway. Flashboards on the crest of the spillway were used to deflect river flow over the opposite end of the dam. With the coffer dam in place, workers accessed the top of the spillway, and used tracked excavators fitted with hydraulic jack hammers to break up the timber crib, rock and concrete. This eventually resulted in approximately an 18m breach in the dam.[6] On July

6 An earlier dam removal plan called for blasting a 45 m hole in the center of the dam to drain the impoundment. The strategy was abandoned based on safety concerns, and questions about the efficacy of blasting the rock-filled timber crib.

1, 1999 workers created a small hole in the top of the coffer dam, and allowed the river flow to remove the remaining earthen fill. The initial flush of water through the 18m breach was witnessed by over 1,000 people, including numerous dignitaries, in a memorable ceremony that was widely reported in the media.

Immediately following the July 1, 1999 breaching event, water levels behind the dam began to recede, but not to the level that existed before the dam was built. With the river flow passing through the newly created 18m hole, workers began to open up a second breach on the opposite end (east side) of the spillway. This second opening (approximately 45m wide) was achieved by mid-August, and became the principal sluiceway for the river flow. With the river flowing through the east side of dam, workers re-established access from the west end, and continued to demolish the rest of the spillway. Dry conditions during the summer and early fall of 1999 permitted continuous demolition work, and the removal was completed ahead of schedule in mid-October.

The remains of the old dam and other demolition debris were largely used on-site to fill in the power canal, which helped contain overall cost of the project. The former location of the powerhouses and other hydroelectric facilities has largely been restored, and will be used to provide public access to the river or other recreational opportunities. Other identified mitigation measures (i.e. extension of outfall structures and boat ramp) have also been completed. The shallow areas of the impoundment that became exposed following dam breaching were relatively stable, as had been expected, and were allowed to vegetate naturally without the need for rip-rap or other measures.

The 24km segment of the Kennebec River that was formally stilled by the dam now flows freely for the first time since 1837. Use of the restored river by migratory fish and other aquatic life is already evident[7]. More importantly, the public use of the river for fishing and boating has dramatically increased since the dam was removed. Such activity bodes well for continued support for additional restoration efforts in the Kennebec River and in other watersheds.

The Collaborative Approach to Watershed Restoration

Approval of the Settlement Accord effectively resolved a long running dispute over the future of the Edwards Dam project (FERC 1998). Although the FERC claims it has the authority to deny applications for new licenses and to order decommissioning and dam removal, as was done in the case of Edwards Dam, such decisions are likely to be contentious. Aggrieved parties can seek administrative and judicial relief, if they disagree with the FERC's conclusions. Years may pass before an issue is resolved in the courts, with the outcome never certain until the end.

Parties who were involved in the Edwards Dam project sought to avoid protracted litigation and delays in achieving watershed restoration goals. The settlement that was reached not only provided for the removal of Edwards Dam, but will ensure that fish passage and other mitigative measures are implemented at the barriers that are upstream from the project. Most importantly, the settlement process guarantees that federal and state resource agencies, municipalities, non-government conservation organisations, and other stakeholders will continue to support the watershed restoration efforts in the Kennebec River basin. The diversity of participants also will bring a wealth of experience and expertise to help generate solutions to problems that are encountered, as was necessary in the case of securing funds for dam removal and fish restoration activities.

The FERC's action on Edwards Dam is an important precedent because it established the legitimacy of examining the alternative of project decommissioning and dam removal during the re-licensing process. Receipt of a new operating license can no longer be taken for granted when the existing term has run out. As was true for Edwards Dam, there may be lengthy legal battles when the dam removal option is put forth. The Settlement Accord represented a much more efficient means of removing Edwards Dam, than would have otherwise occurred, as evidenced by the long unsuccessful attempts to secure fish passage at the dam during the 1970s and 1980s. Lessons learned in the Edwards case (legitimacy of a dam removal alternative and utility of settlements for ending disputes) will undoubtedly

7 The Maine Department of Environmental Protection is studying the re-colonization of the river by aquatic invertebrates. The Maine Department of Marine Resources estimated that as many as two million alewives may have been present at the next dam upstream from Edwards during the spring of 2000. Anglers have caught striped bass and shad, and have observed sturgeon and salmon leaping in the river above the old dam site.

be useful in working toward similar restoration goals in other watersheds.

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Biography

Gordon Russell has been with the U.S. Fish and Wildlife Service since 1978, and has spent most of his career specialising in hydroelectric project licensing in the northeast U.S. He has helped others inside and outside of his agency navigate through the sometimes confusing morass of regulations and procedures accompanying the licensing and re-licensing of dams. He also has provided guidance on environmental impact assessments at dams on issues such as instream flows, fish passage, and effects of reservoir fluctuations on wetlands and wildlife. More recently he has been focusing on decommissioning of dams in lieu of re-licensing, and has been involved in several comprehensive settlement agreements, including one on the lower Kennebec River in Maine, which resulted in the removal of Edwards Dam. Gordon received his undergraduate degree in zoology from the University of Connecticut, and a master's degree in fisheries biology from the University of North Dakota. He currently is the Field Supervisor of the USFWS Maine Field Office in Old Town, Maine.

The Removal Option: A Case Study of the Bomaderry Creek Weir

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Abstract

Bomaderry Creek weir was a 3m high disused water supply weir on a tributary of the Shoalhaven River. A local recreational fishing groups asked that it be removed to allow bass to return to the upper creek. Whilst seemingly straightforward, removal entailed overcoming a host of issues and opposition including recreational use of the weir pool, threatened species (bat) management, heritage considerations, restoration and sediment and weed control. Indeed opposition came from those organisations whom you would expect to be supportive. As a final compromise a 3 metre section of the wall was removed thereby satisfying both heritage and fish passage objectives.

Background

Bomaderry Creek weir was constructed in 1938 to supply water to the township of Bomaderry on the south coast of New South Wales near Nowra. Its use was discontinued around 1961 when water quality became problematic and a new supply system drawing water directly from the Shoalhaven River was installed.

The weir consisted of a simple, fixed crest, concrete structure – 31m in length, 3.0m high and 1.07m thick at the crest. The central 10m section of the crest was approximately 30cm lower than the wings and concentrated the flow. The weir impounded a pool approximately 300m long, 25m wide on average and up to 5.7m deep.

The weir site is located on public land reserved for recreation on Bomaderry Creek, which is part of the Shoalhaven River catchment. It is in a shallow sandstone gorge about 2.5km upstream of the tidal limit. The weir alienated about 80% of the fish habitat in the Bomaderry Creek catchment (6 to 8km of permanently flowing stream) although another smaller weir (with a submerged orifice fishway) about 5km upstream also affects fish access.

Up to 18 species of native fish are expected to inhabit the freshwater reaches of Bomaderry Creek. The weir was obviously a complete barrier to some species such as bass as sampling indicated a strong population downstream of the weir but none upstream. Other species such as eels, smelt, Cox's gudgeon and climbing galaxid were present upstream of the weir. It appears that these species could either climb the weir during suitable flow conditions or had maintained populations since the weir was constructed.

The surrounding area is natural bushland and is used for recreational bushwalking. The weir itself is only 50m from a car park and picnic area from which several walking tracks commence. It is a reasonably high profile site.

The Removal Saga

The story commences in August 1994 when members of a local fishing club (Southern Bass), approached NSW Fisheries and requested that we take steps to remove the weir to allow fish migration to the upper reaches of the creek. Their idea was simply to demolish the weir with explosives and leave the rubble in place. They suggested that the Australian Army would be keen to undertake the task as military exercise.

NSW Fisheries contacted Shoalhaven City Council who was generally recognised to be the owner of the weir. In a written response Council accepted ownership (by its Water Division), indicated that it was indeed redundant, and indicated support for its removal since they considered it to be a public liability risk (a pipeline traverses the weir pool and children used this as a diving platform despite barriers and barbed wire aimed at preventing them from doing so).

The Australian Army was contacted and was keen to undertake the demolition.

Recognising that leaving the concrete rubble in the creek may not be an acceptable solution in such a high profile site, two local crane hire companies were taken to the site and asked about the practicalities of removing the rubble from the creek. They agreed that it could be done but they would need to clear some vegetation to create a safe working platform and there generally would be “a bit of a mess”. They also pointed out that the whole exercise would be expensive because of the difficult location and the need to hand load the concrete rubble into skips. None were keen to commit to a firm price but indicated $20,000-30,000 as a ballpark figure.

Southern Bass indicated that their members would be willing to assist with hand loading the rubble to help defray costs and so a decision was made to pursue approvals and subsequent removal. Approvals would be required from the then Department of Conservation and Land Management (CaLM) as part owners of the land and Shoalhaven City Council as owners of the weir and part owners of the land.

Relevant Government agencies were formally contacted by letter for their views and to help determine if there were any contentious issues that needed to be resolved. This process highlighted the following issues as worthy of further consideration by way of a Review of Environmental Factors (REF):

- precise statement of work methods;
- volume of sediment stored in weir pool and the fate of this material after removal;
- nature, extent and value of aquatic vegetation communities dependent upon the existence of the weir pool;
- nature, extent and value of animal populations dependent upon the existence of the weir pool;
- potential for stream bed erosion and “head cutting” following removal;
- location of Aboriginal archaeological heritage sites and potential impacts;
- heritage values and approvals;
- proposals for rehabilitation / revegetation of creekline;
- need for a pollution control licence;
- impacts upon threatened species;
- impacts upon aesthetics and landscape; and
- impacts upon recreational uses.

At this stage, all agencies except CaLM indicated cautious support for removal of the weir. CaLM stated that they did not support removal because the weir was a “feature of the creek” and “attention is drawn to it in the Department’s literature relating to the walking track”. They were concerned about a number of issues (including some of those outlined above).

Nevertheless, NSW Fisheries decided to pursue the removal of the weir and a REF was completed in September 1995. A one-off fish sampling and simple bathymetric survey of the weir pool was completed to provide information to assist the completion of the REF. The bathymetric survey indicated that the pool was well scoured with only a small quantity of sediment resting against the weir wall on either side of the central spillway.

The REF considered 9 main issues and three options: leave the weir in place; remove the weir; or construct a fishway. It documented a strong case for removal on fish passage grounds and concluded that there would be no other significant environmental impacts

In the REF the option of leaving the weir in place (i.e. the do nothing option) was rejected because of continuing impacts upon fish communities. Construction of a fishway was also rejected because it was too expensive at an estimated cost of $400,000 for construction and more for annual maintenance.

Various inquiries were made regarding the weir's heritage significance. The Australian Heritage Commission confirmed that the weir was not listed on any of its registers. Similarly the NSW Heritage Office indicated that it wasn't listed, but also indicated that under the NSW legislation, any item may have heritage value if it is over 50 years old and possesses some feature of significance. The REF argued that the weir was therefore not a heritage item since it only fulfilled one of the two criteria – i.e. it was over 50 years old but was not of special significance (it was of simple utilitarian design, did not employ any significant construction materials or methods and was not designed or constructed by any notable person).

On completion the REF was distributed to relevant agencies and community interest groups for comment with the following results:

- the Environment Protection Authority (EPA) indicated support, but suggested that partial removal was a better option than full removal because of reduced environmental impact;

- the National Parks and Wildlife Service (NPWS) wavered from their previously supportive position and identified an additional threatened species which could be potentially affected and requested a formal survey and report. The species in question was *Myotis adversus* (large-footed mouse-eared bat) which feeds on aquatic insects and small fish which it captures by raking the surface of pools with its feet;

- the Department of Water Resources (DWR) indicated support;

- the Department of Conservation and Land Management (CaLM) reiterated their opposition to the removal because of: loss of recreational and aesthetic amenity; the affected fish species were not considered to be rare or threatened; a belief that the weir served a useful role in trapping sediment and nutrients; impacts upon other fauna (species not specified); impact of rubble removal; and doubts about the Army's capacity to work in an environmentally friendly manner;

- the local branch of the Australian Conservation Foundation (ACF) did not specifically state opposition to the proposal but was strongly critical of the REF; and

- the Bomaderry Creek Landcare Group did not specifically state opposition to the proposal but was also strongly critical of the REF.

The letters from the ACF and the Bomaderry Creek Landcare Group were almost identical. They were in fact written and signed by the same person. They expressed concern about the fate of sediment, impact upon heritage values, collateral damage to terrestrial vegetation communities as a result of operations to remove concrete rubble, loss of aesthetics, loss of recreational opportunities (specifically swimming opportunities for local kids) and weed invasion. They suggested that a helicopter be used to remove the concrete rubble from the gorge to eliminate ground disturbance and a major long-term regeneration plan be implemented.

To progress the issue, NSW Fisheries did three things:

1. Sought expressions of interest from qualified bat experts to conduct a survey and assess the likely impacts of weir removal upon *M. adversus* if in fact they were present.

2. Contacted the local Naval Aviation base to seek assistance with the use of a helicopter for rubble removal.

3. Initiated an *ad hoc* recreational use survey to determine the number of people actively using the pool.

A bat survey was commissioned and completed about 4 months later. *M. adversus* were detected in the area and were observed foraging over the surface of the weir pool. However, impacts upon the species were considered to be minimal given that extensive pools of water would remain after weir removal. When advised of this result, NPWS again indicated their support.

The Navy declined the opportunity to be involved. They estimated the task as requiring 63 loads and 8 to 10 hours flying time – a resource commitment that was too large.

Recreational use of the weir pool was surveyed on 9 occasions (weekends and after school hours) during January to March 1996 to determine the level of use by swimmers. Only 2 children were present on one occasion. Concerns about loss of swimming opportunities were therefore discounted.

About this time the Department of Water Resources (DWR) and the Department of Conservation and Land Management (CaLM) were amalgamated into the Department of Land and Water Conservation (DLWC). NSW Fisheries was therefore faced with something of a dilemma – two letters from the one organisation, one supporting removal and the other opposing. We wrote seeking clarification of DLWC's position. Numerous phone calls later we received a letter advising that DLWC were undertaking a heritage study of the whole area. The letter requested that no action be taken until this was completed.

An Officer of the Heritage Office subsequently inspected the site. He concluded that the weir was only of local significance but expressed a preference for leaving part of the structure in place so that visitors to the site would be aware of its former existence. NSW Fisheries agreed that removal of a 3m wide section from the centre of the structure would enable fish passage under the majority of flow conditions and still retain sufficient of the structure to allow "interpretation" by visitors.

This agreement was clearly a turning point since it defused the heritage issue and substantially reduced the volume of concrete rubble to be dealt with from $75m^3$ to $9m^3$.

The Navy were again contacted but still indicated that the resource commitment was too large.

DLWC were also contacted and asked if they would agree to partial removal. They advised they would, but were still concerned about the fate of sediment and sought a clear statement of work methods.

The proposal had by this stage acquired a certain level of notoriety amongst members of the ACF with several articles in local newspapers which were critical of the ACF position (which was somewhat misrepresented). Several ACF members were supportive of the weir removal and convinced the executive that it should be debated at a general meeting. An Officer of Shoalhaven City Council (also a member of the ACF), a member of Southern Bass and myself attended the meeting where the proposal was detailed (removal of a 3m section from the middle) and the issues explained. The members present generally agreed that the project was worthwhile, would have minimal adverse impacts and should be supported.

The REF was then redrafted with the following major changes:

1. The proposal was changed from complete removal to partial removal. A 3m section was to be removed from the centre of the spillway by cutting and jackhammering. The remaining sections of the wall were to remain in place. No explosives were to be used.

2. The concrete rubble was to be manually removed from the streambed and gorge by members of Southern Bass using a brick / roof tile elevator.

Shoalhaven Water Division then formally submitted a development application. Council granted development approval in December 1997.

Quotes were sought from local concrete cutting contractors. Only one was keen to do the job. A quote of $13,200 was accepted.

The weir pool was firstly drained by boring a hole through the base. The 3m section was then cut with diamond saws and broken out with jackhammers. Reinforcing steel was cut and removed from the site. All concrete was broken down into relatively small pieces – typically only 5 to 10cm and mostly less than 30cm. The task was conducted in several stages and completed around June 1998.

The full cost of $13,200 was subsequently provided by the State Fishway Program administered by DLWC.

Results

Soon after the cutting and jackhammering was complete, a moderate flood scoured the concrete rubble and distributed it downstream meaning that its removal was impractical. However it has an appearance which is reasonably similar to the natural sandstone of the area, and it is not evident to casual observation. To my knowledge, nobody has expressed any concern about it.

Deliberate regeneration of the stream banks upstream of the weir has not been undertaken since most of the area is bare rock. Where sand and silt substrates are present, regeneration has progressed naturally with a wide range of species (most notably wattles) becoming established. One unforeseen consequence of the draining of the weir pool was the immediate death of two large Casuarina trees adjacent to the pool. It seems that they were dependent upon the weir pool for water and when it was drained they succumbed to drought. Again, to my knowledge, no one has expressed any concern about these aspects.

NSW Fisheries is continuing to monitor fish populations in the creek both upstream and downstream of the weir and in neighbouring creeks to determine the success of the project. However staff changes have meant that progress has been slow and meaningful results are not yet available. Nevertheless, members of Southern Bass have reported catching bass (up to 42cm) from the creek upstream of the weir. Personal observations certainly suggest that the partial removal has been an adequate solution in this case since flow velocities are reasonably low over a range of flows and certainly comparable to the flow velocities in riffle zones upstream and downstream of the weir.

Conclusions

Weir removal is certainly an option, but proponents should not underestimate the magnitude of the task of obtaining agreement and approval. Anticipate that there will be significant concerns and issues to be resolved even when the weir in question is clearly redundant. Expect significant delays. Do not dismiss any issues as unimportant. Be prepared to consult widely and consider alternatives.

Key issues are likely to be:

- fate of sediment stored behind weir during and after removal;
- impact upon dependent aquatic and riparian plant communities;
- impact upon dependent aquatic animal communities;
- heritage considerations;
- recreational values and uses of the weir pool; and
- aesthetic values of the weir pool.

Biography

Allan Lugg works as a Conservation Manager for NSW Fisheries from Nowra on the south coast of New South Wales. He originally trained and worked as a forester in Victoria but a greater interest in freshwater ecology caused him to gravitate toward wetland, river and stream management. He has a particular interest in the aquatic communities of the Murray Darling Basin and the impact of water resource development and management upon these systems. Most recently he has been pursuing the issue of cold-water pollution downstream of large dams.

Balancing the Need for Weirs for Water Supply and Drainage with the Environment — a Case Study

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Abstract

The Broken Creek in northern Victoria is an example of how a Rural Water Authority has managed to balance the need of weirs for water supply and drainage with the environment. The creek, a minor tributary of the River Murray, provides important habitat for thirteen species of native fish, including conditions suitable for breeding Murray cod.

The lower reaches of the creek contain eight weirs, strategic for the supply of irrigation water, that restrict the movement of fish and other aquatic fauna. The weirs have been in existence for 100 years and are in poor condition. Investigations into their on-going management have determined that they are required in their current configuration.

A combination of the poor condition of the weirs and the need to improve the hydraulic characteristics of the creek to allow the extension of the drainage systems in the irrigated part of the catchment provided the opportunity for Goulburn-Murray Water to replace the weirs. The fact that the drainage system extension was being implemented under the approved Shepparton Irrigation Region Land and Water Salinity Management Plan (SIRLWSMP), which includes an environmental program, provided the impetus to include fish passage in the replacement structures.

A combination of limited available flow and the need to ensure the maximum possible operating period for the fish passage, resulted in the choice of vertical slot fishways. The adopted structure dimensions allow the passage of most fish in the creek, whilst minimising the flow lost to the system and the cost of construction. Six fishways have been installed with drops in the normal flow levels ranging from 1.5 metres to 0.6 metres.

Independent preliminary monitoring of fish in the creek prior to fishway construction, using the first of the fishways and in the creek following the construction of the first four fishways, have concluded that the fishways are working.

The success of the project has led to the Goulburn Broken Catchment Management Authority, a partner in the project, constructing fish passage at barriers on streams in the upper reaches of the catchment. This will open up about 400 kilometres of waterway in the Broken Creek system for the migration of fish from the River Murray.

Introduction

The Broken Creek provides important habitat for 13 species of native freshwater fish, nine of which are listed as threatened in Victoria, and is recognised as one of the most important streams in Victoria for the breeding of Murray cod. The lower reaches of the creek also supports a population of the threatened spiny freshwater crayfish or Murray cray.

While the creek is expected to be a natural waterway, it has for over one hundred years been required to function as a conduit for water supply and for seventy years as a receiving water for channel outfall and drainage. Initially, the water supply was for domestic and stock purposes, however for the last forty years it has been used for irrigation water. Significantly, it is obstructed by numerous weirs that are in an advanced state of deterioration, which are used to form pumping pools for irrigators and urban water supply. These weirs are significant barriers to native fish migration and other in-stream aquatic fauna. They also act as silt traps and prevent or inhibit biological downstream drift and energy flow.

The creek suffers from fluctuating water levels, particularly during the irrigation season, that undermine the creek banks resulting in significant silt deposition within the waterway, and the collapse of many of the native trees. The creek waterway has been further reduced by the infestation of willows, introduced for 'old world' aesthetic values and in an attempt to control the erosion of the banks. Aquatic weeds, endemic to the irrigation environment, also proliferate in the lower reaches of the creek system. On top of all this, the Broken Creek outfalls into the River Murray through the Barmah Forest, a wetland of international importance and listed on the Ramsar Register.

Many of these conflicting requirements on the Broken Creek needed to be addressed by the authorities and the communities with an interest in the management of the creek. The on-going need for management of the irrigation water supply and the extension of the drainage network in the catchment required that the problems associated with the weirs be addressed in an integrated management program.

This paper has been prepared to document the history, process and outcomes of balancing the needs of the weirs for water supply and drainage, with the environment.

Background

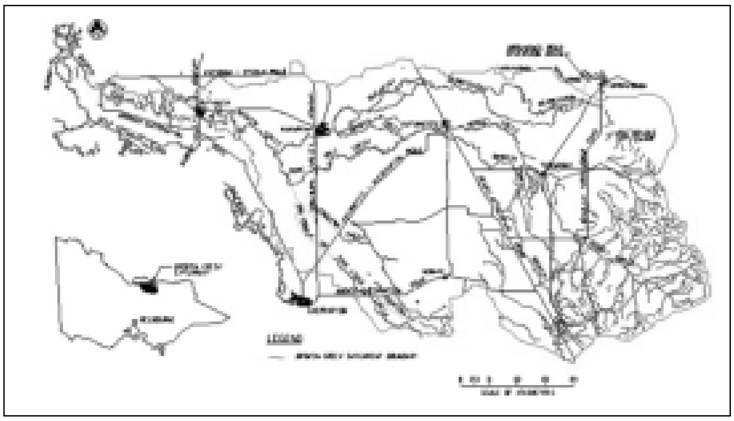
The Broken Creek catchment lies between the River Murray and Goulburn/Broken River systems in northern Victoria, covering a catchment area of approximately 3,500km^2, as shown in Figure 1. The catchment is drained by an extensive system of minor creeks and depressions, the principal waterway being the Broken Creek, which outfalls to the River Murray just upstream of Barmah township.

The catchment rises in the east in the Warby Ranges and the Dookie Hills, and transitions to the typically flat Murray Valley Plains topography further west. The area experiences mean annual rainfalls of approximately 500mm with a semi-arid environment typical of inland southern Australia.

Prior to European settlement and the advent of irrigation, the catchment was largely open woodland, treeless in parts, with extensive areas of Box Eucalypts and White Cyprus Pine. Heavy stands of River Red Gum existed along watercourses (Bossence 1979). Creeks and depressions would naturally have been highly ephemeral, becoming little more than unconnected pools and billabongs during the summer months.

With European settlement and the development of

Figure 1: *The Broken Creek Catchment*



the catchment for agriculture over the last 100 years, the nature of the catchment and its waterways has been significantly altered. Current land and water use in the catchment includes:

- extensive areas of irrigation, predominantly flood irrigation of pasture for dairying in the lower and middle parts of the catchment. These areas are supplied through open channel systems from both the River Murray and Goulburn River systems. There is a substantial amount of pumping from the creek systems for irrigation, particularly along the Major, Broken and Nine Mile Creeks. Pumped diversion entitlements in the catchment total approximately 35,000ML, and water is diverted into the creeks from the open channel system for supply;

- dryland cropping on the plains area outside the irrigation areas, predominantly south and east of Katamatite township. This development is supported by a domestic and stock water supply system, constructed in the late 1800's, that utilises the natural waterway system of the catchment and an extensive network of channels to fill farm dams. The system diverts water by gravity from the Broken River to the upper reaches of the Broken Creek. It also provides a *de facto* drainage service by removing excess surface water; and

- grazing of sheep and a limited amount of cattle grazing in cropping and uplands areas of the catchment.

Works undertaken within the catchment to support the agricultural development include:

- numerous low level weirs within the creek system to facilitate both urban and rural water. Downstream of Nathalia, eight low level weirs were constructed in the early 1900's by the community and local government to provide a more secure water supply for settlers in the area. These weirs are the cornerstones of irrigation development along the lower reaches of the Broken Creek and critical as barriers to the migration of fish;

- extensive rural drainage, both in the irrigation and dryland areas, in the form of open cut earthen drains. These systems drain to the creek systems in the catchment, and include government drains and private and municipal schemes;

- weirs and channels for the transfer of water to the creek system for water supply. There is no water storage within the catchment and transfer occurs from the Broken River to the upper reaches of the Broken / Boosey / Major Creeks, and from the Goulburn River to the Broken / Nine Mile Creeks at Katandra Weir;

- discharge from groundwater control pumps that may be either directly to the drainage system or to on farm systems for reuse in conjunction with channel water. Pumps vary in capacity from 0.5 to 2.5ML / d, with salinities from 500 to 2,500EC units. Operation of these pumps is managed to limit water quality impacts on downstream systems;

- extensive clearing of native vegetation for agriculture. Riparian zone vegetation has been severely depleted along many sections of the creek system due to clearing, stock damage, construction practices in waterway enhancement and weed infestation;

- numerous levy systems along the lower Broken Creek to protect against flooding; and

- use of the creek for recreation, and its enhancement as an aesthetic feature of townships such as Nathalia and Numurkah.

These changes in the catchment have resulted in a significant decline in the aquatic environment of the creek systems, including deteriorated water quality, siltation of the waterway, restricted migration capability of aquatic species, loss of aquatic and riparian vegetation and changed flow regimes.

Waterway Management

The management of the Broken Creek was not clearly defined until 1961 when Rices Weir, the furthermost downstream weir on the creek failed and the local community sought its replacement. The recommendations of a (Victorian Government) Parliamentary Public Works Committee inquiry into the management of the Broken Creek (PPWC 1961) concluded that:

1. The Goulburn Murray Irrigation District be extended to include lands adjoining the Broken Creek between Katamatite and the Murray River, and lands adjoining the Nine Mile Creek, and the landholders be granted water rights to the limits available upon application as provided in the *Water Act*.

2. Goulburn-Murray Water's predecessor, the State Rivers and Water Supply Commission, completely plan the improvement of these creeks to ensure satisfactory performance of the following functions:

(a) the conveyance of surplus irrigation water and drainage water from the Shepparton Irrigation and Murray Valley Irrigation Areas, with appropriate provision for the future development of those areas; and

(b) the irrigation by pumping by the adjoining landholders on the basis of a secure supply.

3. Where necessary, the Commission remove, replace, repair, or modify existing weirs, and construct new fixed, movable or regulating weirs, with special consideration being given to the need for a weir at the extreme lower section of the Broken Creek.

Although Rices Weir was replaced with a concrete structure and numerous investigations have been undertaken into rationalising and replacing the weirs, the lack of the significant funds required to replace the remaining structures has led to a "band-aid" approach to maintain their functionality. This included the replacement of some of the weirs with freestanding steel sheet piling structures. Hence, they remain generally in their original form as barriers in the creek.

The need for a catchment wide approach to manage salinity within the irrigated and dryland sections of the Goulburn and Broken Rivers catchment led to the development of regional land and water salinity management plans. These were developed under the overall direction of a community based steering committee, which in the catchment of the Goulburn and Broken Rivers became the Goulburn Broken Catchment Management Authority. The Authority, amongst other functions, assumed overall control of salinity and waterway management.

The Goulburn Broken Catchment Management Authority, through its implementation arm Goulburn Broken Waterways, has undertaken an annual waterway management works program within the Broken Creek catchment since 1997.

Plate 1: *Replacement Rices Weir*

Works projects have included bed and bank stabilisation, the continuation of the environmental (woody) weed control commenced by Goulburn-Murray Water, fencing and revegetation of the riparian zone and the extension of the lower Broken Creek fish passage program to provide fish passage at artificial barriers in the upper reaches of the creek system.

Two of the components of the SIRLWSMP that impacted on the Broken Creek were the Surface Drainage Program and the Environmental Program. The surface drainage program proposed the expansion of surface drainage in the Broken Creek catchment while the environmental program ensured that works would be implemented in such a way that environmental values would be protected and where possible enhanced.

The major Broken Creek catchment project that was proposed in the drainage program was the provision of drainage in the Muckatah Depression sub–catchment that enters the creek in the mid part of the catchment. As a result of protracted consultation, including a mediation process, where agreement was reached between the various community groups along the creek and Government authorities, all replacement weirs on the lower Broken Creek were to include gate openings, as proposed by Goulburn-Murray Water, and provide for fish passage.

Broken Creek

Typically the Broken Creek has a main channel flow width of about 60 metres and a depth of two metres. The bank full capacity of the creek is about 3,500ML/d and it has experienced major flood flows of up to about 10,000ML/d. The weirs become submerged with creek flows in the range of 1,200 to 1,500ML/d, which occurs on average about once every year.

The maximum regulated flow in the creek for water supply is 250ML/d, with the major input being a flow of 200ML/d from the East Goulburn Main Channel. The creek is operated for water supply during the irrigation season from the middle of August to the middle of May each year when the weir pools generally remain full. Hence, although there is plenty of water in the lower reaches of the creek, the weirs are barriers, particularly during the spawning period for native fish migration from September to December.

As well as being used for water supply, the creek provides outfall for rural drainage. An area of about 140km^2 of the Broken Creek catchment is within the Murray Valley and Shepparton Areas of Goulburn-Murray Water. Of this area, about 50km^2 is intensely developed to irrigation. To provide for the changed runoff characteristics in this area, it is served by surface drainage systems that outfall to the Broken Creek. Consequently the creek can be subjected to high flows during the irrigation season following rainfall, when there will be a reduction in the demand for irrigation water. There are proposals under the SIRLWSMP Surface Drainage Program to extend the surface drainage in the irrigated areas of the Broken Creek catchment.

Waterway and Environs

The agricultural development of the Broken Creek catchment has brought about a dramatic reduction in the distribution of native vegetation. The Plains Grassy Woodlands that once dominated the area surrounding the Broken Creek have been reduced to 2% of their pre-European distribution. Most of this remnant vegetation is located on public land such as the Crown Water Frontages that form a narrow corridor both sides of the Broken Creek.

The remnant vegetation located within the riparian zone of the Broken Creek and its tributaries form one of the largest remaining stands of Plains Grassy Woodland in Victoria and it contains examples of approximately one tenth of Victoria's native vascular flora. The riparian zones of the Broken Creek and its tributary streams contains 27 species of plants threatened in Victoria and more than 100 further species that are considered to be regionally significant. The Broken Creek corridor is also the only known area in Victoria where three plant species occur: Spiny Saltbush, Fat Spectacles and Pepper Grass.

The remnant vegetation along the Broken Creek also provides habitat for nine species of threatened birds, one threatened mammal species and one species of threatened frog.

The nature conservation value of the Broken Creek corridor has recently been recognised by the Victorian Environment Conservation Council (ECC). The ECC has recently completed their "Box-Ironbark Forests and Woodlands Investigation". This report contains a series of draft recommendations for the use and management of Victoria's Box-Ironbark Forests and Woodlands. The review included a recommendation that the remnant vegetation adjacent to the Broken Creek and its tributary streams be formed into a new State Park. This is the highest conservation status available to such a linear reserve.

The presence of artificial barriers and the inputs of irrigation and drainage water have modified the aquatic environment of the Broken Creek system. Despite this, the Broken Creek system still provides significant habitat for thirteen species of native fish, of which nine are listed as threatened. It is also important habitat for the threatened spiny freshwater crayfish.

Plate 2: *Broken Creek*

The Goulburn Broken Catchment Management Authority, in partnership with local individuals, groups and organisations, has undertaken significant work to protect the important natural values of the Broken Creek. Environmental (woody) weed control has been extensive, particularly around the urban centres of Numurkah and Nathalia. Willow has been controlled in the entire lower Broken Creek, including the Nine-Mile Creek anabranch. Other exotic species targeted have included Desert Ash, Peppercorn, Poplar, Canary Island Date-palm and Olive.

A co-operative fencing and revegetation program has also been undertaken to protect the Broken Creek and its riparian zone from the effects of excess grazing by stock. Approximately 40 kilometres of fencing has been completed protecting approximately 50 kilometres of stream and 120 hectares of riparian land.

Barriers to fish passage have also been removed at several smaller structures throughout the Broken Creek system. Vertical slot fishways, similar to those on the lower Broken Creek, have been installed at two existing structures, while small rock chutes / ramps have been retrofitted to three further artificial barriers.

Plate 3: *Typical Original Weir*

Existing Weirs

The weirs on the lower Broken Creek that have the most impact on the environment are located over a distance of 65 kilometres from the River Murray. The longitudinal slope of this section of the creek is very flat, rising less than five metres over that distance. The weirs are integral to the management of flows for irrigation, providing a more stable water level for regulated flows and in stream storage for irrigation diverters.

Rices Weir, the furthermost downstream weir, is about 140 kilometres downstream of where the major source of water, the East Goulburn Main Channel, discharges to the creek. The outlet from the channel to the creek is about 100 kilometres from its off-take from the Goulburn River at Goulburn Weir. Hence, the water supply for diverters on the lower reaches of the Broken Creek has to be managed over a considerable distance and would be impossible without the weirs.

The original weirs were constructed of timber, with earthen abutments. They are typically 20 to 30 metres wide, and about 1.8 metres high. The drops in the pool water levels range from one metre to 0.3 metres. Provision for flow regulation was included in only one structure, making it difficult to manage irrigation flows. The height of the weirs is such that they become submerged by flows that occur on average once every year.

Some weirs had outlets for the draining of the weir pools, which were inoperable when the creek management was taken over for irrigation water supply. Leakage through and around the weirs made it difficult to maintain the storage, and a continual flow down the system was necessary to maintain supply. This, combined with the limited water resource, particularly for the downstream reaches of the creek, and the limited available funds resulted in the replacement of some of the weirs with freestanding sheet piling structures. This could then be used as the cut-off wall for a more permanent structure.

With the significant cost of permanent concrete structures and the relatively small drop in water level across some of the weirs, investigations into their replacement have included a reduction in the number of structures. This has met with opposition due to both the raising of pool levels on some sections of the creek and the reduction in the number of pools. The raising of the pools would have resulted in the destruction of more native vegetation in an area that has already experienced substantial clearing of native vegetation for agriculture. The reduction in the number of weirs and the associated lowering of the pools was opposed by the diverters on account of the loss of storage and the change in the distribution of the number of diverters in each pool. Hence the system of weirs was maintained in its original format until the funds could be made available for their replacement.

Replacement Weirs

The replacement of the weirs was brought about through a proposal to extend surface drainage serving irrigated development in the catchment under the SIRLWSMP. A feasibility study undertaken for the community identified the need to increase the capacity of the Broken Creek at the weirs for medium size flows. Following a project development process that included:

- detailed design of the Muckatah drainage scheme;
- the preparation of a strategy for the replacement of the weirs;
- extensive community consultation both within the drain catchment and along the Broken Creek downstream of the drain scheme entry;
- objections to the planning scheme amendments, primarily from landowners downstream of the drain scheme entry; and
- a formal mediation process facilitated by the (Victorian Government) Department of Infrastructure.

An agreement was struck between all the representative parties in March 1996. The mediation agreement, in relation to the weirs, included that:

9(iv) *"in relation to weirs on Broken Creek the design investigation to date were agreed to be sound. Alternatives to crest levels, gate dimensions and number of weirs should be thoroughly investigated to achieve the optimum system,…*

An advisory group, including appropriate community representatives, will be established prior to the weir investigation proceeding." and

9(v) *"we agree to the provisions for fish passage. These involve rock ramp placement on all weirs and a fish ladder on Rices Weir;".*

The weir investigation Advisory Group comprised representatives of Goulburn-Murray Water Rural Water Authority, Sinclair Knight Merz, the Authority's design consultants, the irrigation diverters, landowners adjacent to the creek, local government, the Department of Natural Resources and Environment, and the urban water authority supplying water from the creek to adjacent towns. The Group considered:

- the number and location of the existing weirs and options for their reorganisation;
- results of computer hydraulic modelling of the creek to evaluate the reorganisation of the weirs and gate opening widths to provide additional medium flow capacity;
- results from the monitoring of flows and water levels at the weirs to determine weir crest elevations;
- a survey of the riparian vegetation along the creek to determine the impact of changing water levels;
- trials of changed operating water levels in the creek to assess the impact of weir removal;
- alternatives to the replacement of the weirs;
- optional arrangements for the replacement weir structure;
- alternatives for the provision of fish passage; and
- the cost sharing of their replacement between Goulburn-Murray Water, the weir owners and the SIRLWSMP Surface Drainage Program, which required the increased capacity and accelerated replacement.

Issues considered for the provision of fish passage were that it operates over the maximum possible flow range, the regulated flow is diminishing and further reductions in creek flow were expected through the implementation of measures to reduce irrigation tailwater flow from drains to improve water quality. The Group recommended:

- the retention of seven of the eight weirs;
- the provision of a gate opening width of 6 metres in all weirs, including the existing Rices Weir structure;
- the raising of three of the weir pools, based on normal regulated flow levels, to provide some in stream water harvesting and storage capability;
- the removal of the eighth weir and the lowering the pump suction pipes for the lower water level;
- the provision of vertical slot fishways at each weir due to their low flow requirements; and
- construction to commence at the downstream weir and continue upstream.

The replacement of the eighth weir, which affected the amenity of the creek through the township of Nathalia, is to proceed following representations from the community to the Government that were successful in obtaining the allocation of a Government grant for a weir and fishway.

The choice of fishway arrangement was made with the knowledge that the weirs were likely to include earth and rock fill secondary spillways, in addition to the gated openings for flow regulation. Consideration was given to the use of rock ramp type fishways for the more upstream weirs where regulated flows were higher. This was discarded due to the regular nature of flows, the drop in water level, the width of the weirs, the need to accurately maintain water levels and uncertainty over their performance.

In designing the replacement weirs, the objective was to locate the gate opening in the main flow stream of the creek. In some cases this allowed the creek to be returned to its original alignment, as the original weirs were constructed off stream and the creek realigned. Overshot gates were used to maintain the required water level, with the gate lifting gear located above the maximum recorded flood level.

Fish Passage Design

The design of the weirs and fishways has been undertaken by Sinclair Knight Merz, Goulburn-Murray Water's engineering design consultant, in consultation with Dr Martin Mallen-Cooper of Fishway Consulting Services. Advice on fish species and size was obtained from the Marine and Freshwater Resources Institute of the Department of Natural Resources and Environment.

The fishway program on the Broken Creek was the first of its type for Goulburn-Murray Water and to ensure both its acceptance and success there was a requirement to minimise the regulated flow from the Broken Creek to the River Murray and implementation cost. Both were dependent on the width of the vertical slot and a slot width of 0.3 metre was adopted, which was considered sufficient to pass most fish in the creek. The other factors that influence flow and cost are the length and depth of the fishway. The maximum slope of 1 in 18 and minimum depth of one metre were adopted. The combination of all three resulted in a flow capacity of about 30ML/d, which was acceptable to Goulburn-Murray Water.

The fishway design has been based on that for the vertical slot fish ladder at Torrumbarry Weir. The

Plate 4: *Typical New Weir and Fishway*

key factors in the fishway design are the location of the entrance and the operating flow range. The initial designs had the entrance located close to the gate structures, while the latter designs had the fishway entrance in the gate emplacement wall. The design allows the operation of the fishway for all flows up to when the gates are fully open. The key dimensions for the fishways are:

- Slot Width 300mm
- Slot Depth 1.0m
- Slot Headloss 0.165m
- Slot Velocity 1.55m/s
- Fishway Slope 1 in 18 (maximum)
- Cell Length 3.0m
- Cell Width 1.8m
- Flow Depth 1.0m
- Cell Energy Dissipation 100 W/m^3
- Cell Length 90º Bend standard cell length min. 2 times
- Capacity 30ML/d

The fishways included a door on the upstream end to allow it to be closed during periods of low flow, a slot in the doorway to allow the fitting of a screen for research, grid mesh decking for security and safety with a hinged opening for access and an upstream trash screen with an opening of 3.5 times the cell waterway area. A typical arrangement for the fishways on the lower Broken Creek is shown in Figure 2.

Where additional storage was provided in the weir pool, the fishways were designed to operate for both the lower and upper pool levels. This was achieved by basing the fishway length, and number of slots, on the difference between the upper pool operating level and the tailwater level, and the fishway slope on the lower pool operating level and the tailwater level.

Construction

A Goulburn-Murray Water day labour force gang comprising a foreman, two labourers and a plant operator, undertook the construction of the fishway. The major plant used was a 25 tonne excavator that was also used as a crane.

Construction was simplified by precasting sections of the fishway with the vertical slot baffle, the entry and the offtake at the Authority's precast concrete factory at Tatura and transporting them to the site. On site work involved excavation, the preparation of the foundation, the positioning of the precast units, the forming and pouring of the reinforced

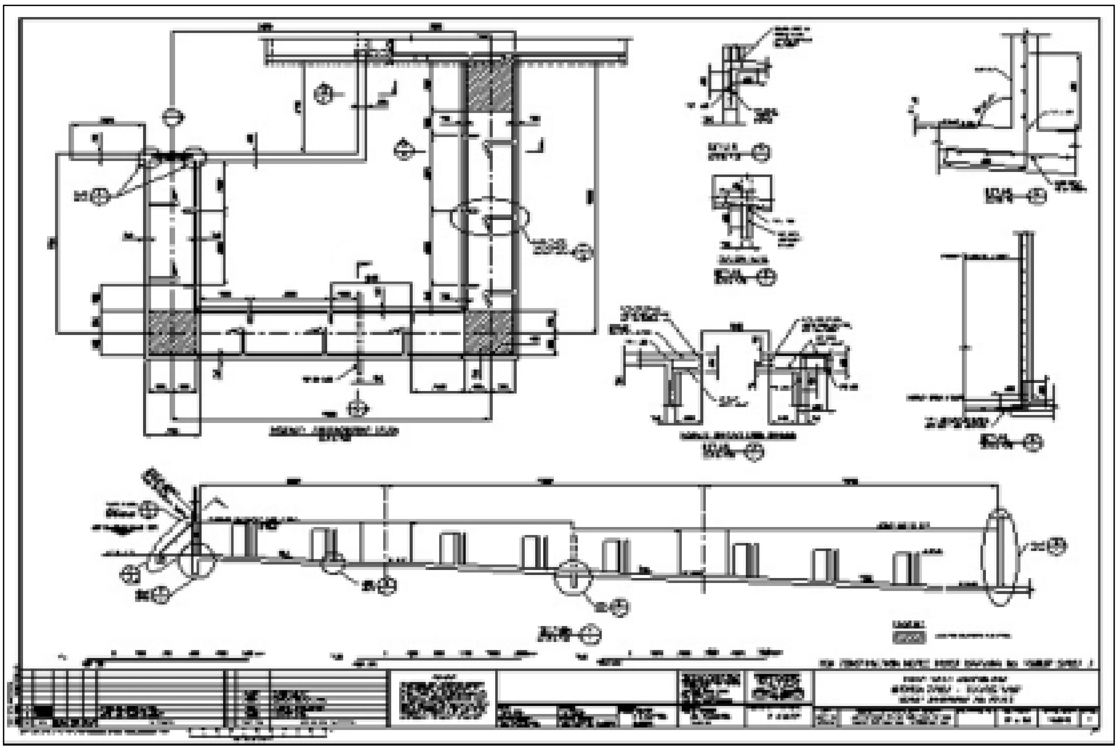


Figure 2: *Fishway Arrangement*

Plate 5: *Fishway Construction*

concrete in-fills and cut-offs and the installation of the decking and offtake door and lifting gear.

The construction of six of the fishways has been completed. It expected that the remaining two will be completed in the next twelve months.

Operation

Goulburn-Murray Water and the Department of Natural Resources and Environment developed the operating procedure for the fishway. The plan is for the fishways to remain in operation while the flow in the creek exceeds the capacity of the fishways of about 30ML/d. During a normal winter it is expected that there will be sufficient flows available in the creek to operate the fishways. It is unlikely that winter flows would be available from the channel system in a dry winter due to maintenance works in the channel system.

Summer flows will most likely be available from the irrigation source although at times it is expected that a 30ML/d flow at Rices Weir may not be sustainable. Summer irrigation flows ordered through the East Goulburn Main Channel usually commence about the end of September and last until mid April. This period covers the main fish migration period.

The weirs are automatically controlled to maintain the normal pool operating level and water levels are remotely monitored from the Authority's office at Cobram. Any unexpected behaviour of the weirs can be identified and corrected remotely or attended by field staff should it be necessary to close the fishway. The operating procedures are to be reviewed at the completion of the last weir, scheduled for construction in the middle of 2001.

Monitoring

The Department of Natural Resources and Environment's Marine and Freshwater Resources Institute has undertaken monitoring studies of the fish in the Broken Creek prior to the installation of the first fishway in March-April 1997 (Brown *et al.* October 1997) and post implementation in December 1999 and March 2000 (MAFRI, 2000) and a preliminary assessment of fish passage at Rices Weir fishway in December 1997 (Brown *et al.* December 1997). The studies investigated the efficiency of the fishways by comparing fish communities from an area contiguous with fishways to sites in the creek with no fish access from fishways. Significant to the monitoring periods is that no significant flows had occurred in the creek since November 1998.

The initial creek study found that the abundance of fish decreased with increased distance from the River Murray, there was an accumulation of golden perch below Rices and Kennedys Weirs and Murray cod were more abundant downstream of Kennedys Weir despite abundant available habitat upstream. This indicated that the weirs were barriers to the movement of fish.

Plate 6: *Murray Cod Taken From Creek*

The latter creek study found that there are similarities in the fish communities of the Broken Creek where the fishways have been installed and that these communities are dissimilar to fish assemblages at sites with no fishways. The results indicated that the fishways were working effectively with particular regard to Murray cod, which were only found in the weir pools with fishway access.

The study of Rices Weir fishway found that juvenile golden perch (yellow belly) were the dominant species using the fishway. Other species of interest, which have also been recorded utilising the fishways, include non fish species such as the spiny freshwater crayfish, yabbies, shrimp and the eastern long-neck or snake-neck tortoise. The study also found that the accumulation of fish was higher at the top of the fishway than at the bottom of the fishway, and that the accumulation of fish in the creek below the weir was lower than in the previous survey. The study recorded small numbers of fish. This was possibly due to constant flows in the creek in the survey period. It is known from observations at the Torrumbarry Weir fishway that during the spring and early summer native fish generally moved in response to flow variations (Mallen-Cooper *et al.* 1995).

Conclusion

The Broken Creek experience has demonstrated that it is possible for the community and the Government agencies to work together to manage a waterway to meet the needs of the community and the environment.

The provision of fishways on weirs in the Broken Creek has gone a long way to removing barriers to fish migration and other in-stream aquatic fauna whilst maintaining the functionality of the structures.

The success of the project has led to the Goulburn Broken Catchment Management Authority constructing fishways at a number of other flow control structures on the Broken Creek system. These are near the entry point of flow from the East Goulburn Main Channel and at an erosion control structure on the Nine Mile Creek, an anabranch of the Broken Creek, near Wunghnu. It also has plans for fishways on two urban weirs at Numurkah. When completed this will open up approximately 200 kilometres of natural waterway for fish migration. The Catchment Management Authority has also recently completed fishways on Seven Creeks at Euroa (significant habitat for the threatened trout cod), and on the Broken River at Lake Benalla. The Authority also has plans for a fishway at Caseys Weir on the Broken River downstream of Benalla and is investigating the provision of fishways in the upper Broken Creek catchment and its tributaries.

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Biography

Ron Palmer has 30 years experience in the water industry as a civil engineer with the Rural Water Corporation and Sinclair Knight Merz. Ron is currently employed by Goulburn-Murray Rural Water Authority providing technical support for the management of irrigation infrastructure. He has specialised in rural water supply, design of water supply and drainage channels/pipelines and associated hydraulic structures. As a Senior Design Engineer he has been responsible for the management and technical supervision of a team of engineers and technical staff involved in irrigation channel and drain design, including the design of a number of fish passage structures in northern Victoria.

The Clarence Floodplain Project

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Abstract

The Clarence Floodplain Project has introduced new floodplain management techniques for operation of floodgate structures, which has achieved significant environmental improvements for one of Australia's major estuaries and over 600 square kilometres of associated floodplain.

The Clarence River County Council established the project in 1997 and has coordinated input from State Government agencies such as Fisheries, Land and Water Conservation, Agriculture, etc as well as canegrowers, fishing industry representatives, catchment management committees and community volunteers.

The result has been improvements in water quality (especially acid, dissolved oxygen and nutrient levels), fish passage and other wildlife habitat, wetland and catchment health whilst maintaining both effective flood control and productive farms.

The Clarence Floodplain Project is an innovative way of managing floodgated watercourses to improve fish breeding areas, improve farm productivity, reduce acid run off and rehabilitate natural wetlands.

By allowing saltwater intrusion into flood mitigation drains, weed growth is retarded, fish passage is improved and buffering of acid discharge results. When this is combined with environmentally sensitive land management techniques and drainage maintenance procedures, the whole ecosystem of the floodplain is enhanced.

The Clarence Floodplain Project has achieved unprecedented cooperation between State Government agencies, canegrowers and fishing industry representatives, catchment management committees, community groups and Local Government practitioners to reverse environmental damage and pave the way for further scientific research which will have long term benefits for one of Australia's greatest rivers and its interdependent ecology.

Introduction

Can engineers be environmentalists or is this a contradiction in terms?

Changing long standing practices for the operation of engineering infrastructure such as weirs and floodgates might seem unlikely to the purists within environmental circles but as history shows, engineers can be all things to all people. So is there life after flood mitigation works in the Clarence Valley?

The Clarence Floodplain Project might be the answer.

Geomorphology

The Clarence River is the largest coastal river catchment in New South Wales, at 22,700km^2 (DLWC 1998).

A rise in sea level from a low of approximately 100m stabilised at or near its present level approximately 6,500 years ago, initiating a period of coastal estuary infilling with estuarine muds, sands and silts. A broad floodplain of approximately 2,620km^2 now exists downstream from Grafton.

Underlying the floodplain from approximately Grafton downstream are extensive estuarine deposits, including potential and actual Acid Sulphate Soils (ASS). Approximately 53,000ha of floodplain below Grafton is considered to be underlain by high risk ASS (Dept. Conservation and Land Management 1995).

History

The Clarence River County Council has been the flood management authority for the lower Clarence River since 1959 and was constituted after many disastrous flood events in that area during the decade of the 1950s. In its early years, there was feverish construction activity involving up to 100 field staff and up to 7 large draglines working 12 hour shifts around the clock seven days a week. In some cases, draglines travelled across log rafts in order to drain wetlands, which were planted with sugar cane only two weeks after drainage works were completed. Natural watercourses were redirected, other watercourses were created by joining existing water bodies, and flood levees, drains and floodgate structures sprung up everywhere. Developments over the years have resulted in the provision of assets with a current replacement value of $200 million.

Amongst these assets are 300 large floodgates which perform a similar function to weirs in that water cannot flow upstream as the gates only open one way (i.e. to allow water out of the drains and prevent water flowing in).

What s the Problem?

From an engineering point of view, the structures installed by Council performed well during flood events and generally speaking, despite significant underfunding, have been maintained in a functional state. However, these assets were (generally) put in place when little or no consideration was given to their effects on the surrounding environment. Nor was any effort put in to evaluate whether there were any more far-reaching environmental effects, and if so, to what degree. Hence Council, as with many other flood mitigation authorities, had a reputation as being environmentally insensitive.

Figure 1: *Wants Drain near Ulmarra Before Installation of Lifting Winches*

Hence from an environmental perspective, Council has received increasing pressure in recent years, from different groups regarding the impact of its assets and its apparent reluctance to address such issues.

What Can We Do About It?

It’s easy to say that water quality and wildlife habitat should be improved by better management of drainage networks and rehabilitation of wetlands BUT:

- most of the land is privately owned – not Council controlled;
- primary producers want dry land for farming – not wetland;
- graziers want fresh water for stock watering – not saltwater in their drains;
- floodgates are designed to keep water out – not let water in;
- neighbouring property owners have different needs and differing opinions; and
- management techniques for acid sulfate soils are still evolving and preventing acid runoff requires further research as part of the project.

Caption2: *Wants Drain After Installation of Lifting Winches*

Where do we start? The Clarence Valley is huge and incorporates over 600km^2 of associated floodplain with 160 different drains and 300 major floodgates spread throughout the area.

With seemingly conflicting objectives, the task of winning the cooperation of the sugarcane industry, the fishing industry, state government agencies, catchment management committees, community groups and local government practitioners is a major hurdle in itself.

The other major difficulty is lack of funding which is often the killer of many good ideas.

Enter the Clarence Floodplain Project!

A concept of active management of Council's assets was born out of pressure from NSW Fisheries in particular, whose goal it was to improve fish passage and water quality. Other environmental concerns and benefits were inherent in this proposal but the obstacles still had to be overcome.

To the great credit of the elected Councillors of the day, they embraced the opportunity that this proposal presented, and in 1997/98 the Clarence Floodplain Project (CFP) was born.

Resources

At that stage, the CFP existed in name only. It had no resources, nor was Council able to give it any. It was agreed that this initiative fitted well with the objectives of the Natural Heritage Trust Program and so five separate applications were submitted for funding. All five were successful.

The resources were then available to appoint a full time Project Manager and this person provided the impetus for focused attention on the needs identified at that stage. Once the Manager became fully versed in Council's activities, a Steering Committee was established to oversee the project. Great care was taken to include all major stakeholders, without creating a large and cumbersome committee.

So, What Have We Actually Done?

- Funding: as stated above, Council was successful in obtaining funds under the Natural Heritage Trust for a three-year timeframe to manage the project. Subsequent grant applications for specific projects to assess the existing situation and investigate the potential for floodgate opening have also been successful.

- Steering Committee: a committee consisting of all stakeholders including cane industry representatives, fishing industry representatives, NSW Fisheries, Environment Protection Authority (EPA), Department of Land and Water Conservation (DLWC), Total Catchment Management (TCM) representatives and Council representatives was established. After feeling its way to begin with, the Committee is now functioning extremely well.

- Auditing of water quality: it's no use opening floodgates if environmental damage is likely. Each site needs to be assessed on its merits for the effect of flooding on neighbouring land, potential benefits and willingness of affected landowners.

- Management plans: there are now 14 separate management plans in place with respective landowners and negotiations are underway for a further 20 such plans.

- Hardware: installation of lifting mechanisms, winches and handrails etc has been carried out at each of the agreed sites.

- Operator training: education of landowners who are nominated to operate the floodgates is important and has been carried out.

How did we Open the Floodgates?

- Limited site specific funding has been obtained from the DLWC which, combined with some equally small amounts of Council funds, has paid for the installation of lifting devices at 14 locations so far with a further 23 sites underway.

- The physical technique involves simple winches and cables similar to those used for boat trailers. These are used to wind the gates open and lower when necessary.

- Landowners actually do the work of operating the gates (Council does not have the necessary staff numbers so voluntary labour is essential).

- Landowners' work time during installation and operation has been valued in dollar terms to provide part of the matching funds for the grants involved.

Is That All?

Council is also responsible for a weir at Alumy Creek, which incorporates mechanically operated gates. The gates can be raised to allow water in when the river water is fresh and closed to keep it out when salty.

Council has obtained a grant to investigate the possibility of improving water quality and fish passage at this site and with the involvement of landowners, it may be possible to manage this structure differently in future.

There are also other small weirs across flood mitigation drains within the Clarence Valley which hold water for stock and irrigation purposes and preliminary investigations are underway to modifying some of these to allow tidal flow upstream (e.g. installation of pipes with liftable flood gates underneath).

What other Environmentally Friendly Things has Council Done?

The Clarence River County Council was constituted 41 years ago and possesses a wealth of experience in flood mitigation infrastructure, construction and maintenance. But, apart from construction drawings, safety procedures and administrative records there was a lack of procedural documentation. The Council has now developed documented drain maintenance procedures drawing on those 41 years of experience in the business and incorporating the benefits of recent research.

The result is "state of the art" drain maintenance procedures, particularly for mechanical drain cleaning where acid sulfate soils are likely to be present. Council also developed a "reed bucket" in the early 1980s to minimise the disturbance of acid drain spoil during mechanical cleaning. This is now being advocated throughout the industry to promote usage by contractors and other local government authorities. Council is now developing "on the spot" pH testing techniques to give an instant answer for lime dosage to neutralise acid during drain cleaning in acid sulfate soil areas.

What s the Key to Success?

In the beginning, the concept of active floodgate management was put to Council in an open and comprehensive way that allowed Councillors to develop ownership of the process and determine the speed at which it progressed. The CFP provided Council with an opportunity to enter the age of environmental responsibility in a practical way. That is, without diminishing in any way Council's role as a flood manager, the impacts of its assets could be examined and perhaps improved in the process. The CFP offered Council an opportunity to actively manage its assets in between flood events in a way that had never been done before.

Great care was taken to include all stakeholders and facilitate discussion between organisations that traditionally were far apart. External funding arrived exactly when it was needed. In relation to landowners, the project has been "hastened slowly" in order to maximise landowner support.

The Project has been presented as:

- a “Win” for Council since it addresses contemporary environmental concerns; it draws additional Government funding into the County District; develops partnerships with many organisations, some of which have been traditionally opposed to Council;

- a “Win” for Stakeholders since it provides the opportunity for Council to evaluate the impact of its assets, and seeks to address issues of managing those impacts on behalf of respective stakeholders; and

- a “Win” for the Environment since all the environmental impacts associated with Council’s assets are now being identified and managed.

Personal attributes required along the way included:

- people skills – “selling” the idea to landholders and industry was the most important step before the journey began; and

- perseverance – resistance to change can be overwhelming if you allow it to be and Council continues to take a long-term view where particular stakeholders are yet to be convinced.

Also, Council staff take every opportunity to inform landholders, industry and the community of the benefits to be gained from improved management of drains and floodgates.

This has been done by:

- presentations to industry boards and landholder associations;

- informal meetings with landholders on land adjoining individual drains;

- floodgate operator workshops;

- newsletters;

- personal letters to landholders;

- landholder survey;

- field days; and

- involvement with conferences, workshops etc.

Council continues to promote the concept on all fronts and at all levels in an endeavour to achieve cooperative floodgate management as standard practice throughout the world in time to come.

What s in it for Us?

Apart from the “warm” feeling of knowing that we are making the world a better place, there are some practical advantages.

The Clarence River County Council has only four outdoor staff members and could not possibly instigate best practice in floodgate management on its own.

The development of a cooperative approach means that the system can be operated by stakeholders without large staff numbers on Council’s part.

With more stakeholder involvement, faults and maintenance requirements are reported more quickly and Council’s maintenance program can be kept up to date.

Maybe this project can follow on to other agencies who might then be seen to be proactive in rehabilitating the environment and you too can become a sensitive new age organisation.

The project is “politician friendly” as environmental gains are vote winners these days – especially when politicians are invited to officially open floodgate management sites. The benefit of a “flow on” of more grant funding to our Councils and agencies may result.

Summary

At the end of the day, such projects achieve environmental benefits with limited resources and the Clarence River County Council is pleased to be part of this evolving science.

The environmental effects of constructing broadscale flood mitigation infrastructure was not fully understood 30 or 40 years ago. The implementation of better floodgate management on the Clarence River floodplain and elsewhere in

NSW will become the "norm" in time to come.

The Clarence Floodplain Project is demonstrable proof that the theory of environmental science can be combined with the application of engineering principles to produce real results and show that engineers can be environmentalists too.

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Biography

Ian Dinham is the County Engineer with the Clarence River County Council in north eastern New South Wales and hence is responsible for one of the largest managed floodplains in Australia.

He completed his degree in Civil Engineering at the University of NSW in 1977 and was awarded the Harbin Polytechnic Alumni Association prize for Academic excellence. He has extensive experience in civil engineering and management, which he balances with a passion for Ferraris, music and sport.

He began his career with the Water Resources Commission as design engineer for large dams and prior to accepting his present position in 1998, Ian was the Director of Engineering Services / Deputy General Manager at Maclean Shire Council for 5 years.

Ian seeks to make the Engineering profession more "user friendly" and his research of Engineering Service Delivery in the United States has become a reference document for both Australian and American agencies.

Pathways to Waterways: A Commercial Fishing Perspective

Joe McLeod, Commercial Fisher, Tin Can Bay, Queensland

Abstract

The old mullet fisherman sat in his punt, pondering his thoughts and casting his eyes over what was once wallum wetland, treed hills and fresh brackish waters. His mind slipping into the past and searching for the smells. The smells of sweet and sour, fresh and salt, the smells of river gum, wallum and mangrove.

His thoughts bring back pictures of gum leaves, blossoms and bark forever falling, floating then sinking and mixing with the inflows of wallum stains, of brown swamp water, pushing over the inward surges of the salted green waters of the flooding tide but forever mixing. He remembers the freshes of small storms and local rain. He remembers how in the old days, when looking for mullet, he would test the water temperature and taste with fingers for sweet or salt, forever listening the plonk! plonk! of the mullet. Could these be pathways?

But he is forever longing for the smells of the creeks and the rivers that smell of life, death and decaying matter. To some the smells are offensive, but to the rivermen the differing smells of the river mean the difference between good seasons and bad, catches to pay bills, feed the kids and keep a roof over their heads.

The old netter felt that there were pathways and that the smell within an estuary was the lifeblood that would, in itself, link far greater coastal and offshore environments. He ponders on how catchments, flooding rivers and the ocean currents really work and whether they themselves are linked to coastal pathways that stretch from catchment to catchment. He is not a limnologist but possesses an empirical understanding of how things in his river had worked in days gone by.

The tributaries of rivers and streams in a catchment are more than just pathways to send pollution, top soil and debris downstream. They are pathways linking the waterways with genetic diversity, developed over millions of years. Not only within the catchment but also providing pathways for the coastal fish migration from south to north, upstream and down.

These pathways may link waterways over many thousands of kilometres and provide the essence for salinity niches to permit successful recruitment for larval to post-larval stages of many of our marine species. Just how much of the equilibrium, instincts and niches has already been eroded is anyone's guess.

Australian literature referring to the complex links between catchments, brackish and ocean ecosystems and marine species interdependence appears to be poorly understood. For instance, just how much work has been done on the once vast energy plumes that purged out of the Murray catchment into the Great Australian Bight?

What role do the carbon input and fresh water play on recruitment of fish larvae, algae, lower order invertebrates, pilchards and tuna? Just how much fresh water and carbon (energy) did feed this region and how frequent were the flood plumes prior to the construction of dams, weirs and other irrigation projects?

While over fishing of tuna has been accepted as one cause for the decline in their numbers, one could also argue that loss of fresh water flows severely impacted on the ecological linking to the ocean. Gaps in the food webs would have occurred which would then have reduced the tuna's carrying capacity. Remember this is the largest catchment we have and it would have been the most obvious place for vast aggregations of bait fish, fed by energy pools of lower salinity areas off the South Australian and Victorian coasts. It's well know that the Coorong and lower lakes suffer from hypersaline conditions since the barrages were constructed at the most sensitive part of the Murray for sustainable fisheries.

Just how far this complex web could have been pushed and pulled would be any fisherman's guess. What important role did this play with the colder currents emerging from the southern Antarctic regions? Were the discharges from the Murray a much needed catalyst to make this marine ecosystem work?

Many catchments world-wide have reported collapses of fish and invertebrate populations, after catchment modification by the construction of weirs and dams, with recorded losses in catches of shrimp (prawn) of 75% and catch reductions in sardines (pilchards) of 90%.

Yet in Australia there appears to be no will to cross this frontier or to use pilchards or prawns as bio-indicators for changes in catchments, and so we have to second guess our fisheries management.

How can weirs be removed or modified, given what appear to be large gaps in knowledge of the relationship between oceans and catchments in Australia?

If we are to manage our fisheries well, then it is imperative that we know the difference between fishing pressure, reduced carrying capacity, species alienation and seasonal influences.

Any of these, either alone or in combinations, means fewer fish and prawn numbers. We need to know the effects of impoundments and their impacts on the populations of our native fish species. Especially the marine species. What are the real down stream affects?

Much research into the inter-relationships between land plants and salinity niches or fresh water inflows is yet to be done. It could be said that this is a new frontier for limnologists in Australia, if we hope to manage our ocean resources and ensure sustainability for our commercial fishing industries.

In the past, questioning the impact of dams and tidal barrages always created problems for the commercial fishing sector. Highlighting reduced productivity in fisheries resulted in fishing closures, with other sectors blatantly orchestrating public opinion by allocating blame to the commercial fishers, the "netters have fished it out" mentality and the promotion of any water running to the ocean as a waste, as well as the perception that marine species are salt dependent and have little or no interaction with fresh water inflows. Fishers were themselves a bio-indicator of fish stocks and well-being of a river.

Without the fishers the record keeping would stop. The eyes and ears would be gone. Much of the opposition to further water infrastructure would be solved with commercial closures. The "whingers" would go. The bureaucrats could do whatever they liked and many knew this, especially in Queensland.

Many of the great blunders of building barriers in inappropriate areas have occurred in Queensland, and along south eastern Australia. Such things as Queensland's ponded pastures, (giant walls that extend for tens of kilometres, crossing creeks, salt marsh and mangrove to fill with freshwater) and the massive flood mitigation projects (levees, walls and gates) are just a couple of examples of these blunders.

The tidal barrages that remove tens of kilometres of tidal prism may not be as obviously intrusive in the marine regions, but can have far reaching and masked impacts prism (and that's not to take away from the impacts of weirs and larger dams collectively or individually within catchments).

There is hope that the new generation of environmental engineering minds coming into the work force can develop skills to rectify many of our old problems, such as water for land use and its effects on the sustainablility of our oceans. Let's hope they like recreation, seafood and ecotourism. Our hope is in their hands.

Weirs can be removed or modified any time, any place, in a number of ways, but will not be without social and political will. Rivers such as the Clarence, in northern New South Wales are too important for both Queensland and New South Wales fisheries, for genetic and biodiversity reasons to have dams placed on them. We need to know more!

For instance the inshore set currents push detritus and fresh water north along the beaches as well as sand, as fishers know. Prawns and fish relish fresh inputs. Many of the fish migration paths moving north, close to the beach, probably follow such trails and yet the offshore current, which predominantly sets to the south, would spread its plume over vast areas of ocean, depending on the volume of flow.

Is this nature's way of mixing and are these areas as important as rookeries are to bird migration? Could they be links from river to river as food factories for such migrations for prawns, pilchards and tuna in the bays and oceans? Fishermen would say yes.

A fisherman would also assume that, even in dry times, the Clarence would have stored water in its flood plain and wallum forests to allow inputs for salinity niching over ebb tides. This, in turn, would be a pathway for larval recruitment and algae stimulation in dry times and would help prevent hypersaline conditions which would impair larval progression. The Clarence has a reputation for large prawn and mullet catches and can have a very high biomass when conditions are right.

This river has few impediments and should be left untouched while exploring and developing a better understanding of the environmental engineering practices for storing water for the future.

I believe that an inventory of all the rivers that open to the sea without obstructions should be given priority along with protection from the construction of any new weirs. Small catchments such as the Baffle River in the Burnett region of Queensland need such protection if we have any hope of saving what's left of our fish species and resource carrying capacity.

Bureaucrats and researchers with a kinship to the aquatic resource in Queensland are quite often forced to wear blindfolds to allow water infrastructure to progress. I believe that the aquatic resource industries have been deliberately sacrificed by Queensland's Department of Primary Industries, and have suffered at the hands of other government departments, furthering the spread of monoculture and non-native animals. The Queensland Fisheries Service appears to have in many ways failed in its duty of care to fish and fishers in this regard.

Remember that many of these species of plants and animals are alien to the linkages required to sustain native fish stocks. The aquatic resources need an identity of their own and a Minister who will put the aquatic resources' needs first. If this doesn't happen many species will have to be artificially restocked in marine areas in the next 20 years. Don't blame overfishing!!

I don't think I will ever see weirs modified or removed in Queensland. Governments come and go but the will of the bureaucrats remains in place. If any new minister was considering the removal or modification of weirs, the bureaucratic structures would make short work of that.

Let me use the Burnett catchment in Queensland as an example.

Fishers and conservationists claim that the Burnett is the most impounded river in Australia. I believe it's like many catchments in Queensland. But the claims can be justified. It's unfortunate that this is the driest sugar growing area in Queensland. The soil is good but the area, from time to time, suffers from rain shadows. Sugar has a thirst for water and lots of it. At the federal, state and local level sugar is political strength, and political strength means more water infrastructure. This, in turn, is bad for the river and the fishing industries. This was the area of the once infamous Burnett River salmon and a most productive east coast banana prawn fishery. Today there are few salmon and poor to nil catches of banana prawns, depending on what water is available and when and if it comes.

The boats were forced into other trawl areas and species.

THE BURNETT TODAY. The first 109km hardly resembles the type of ecosystem that marine species would require to evolve and has similar symptoms as other impounded rivers world wide.

The first 25.9km from the mouth suffer from hypersaline conditions, point source pollution, urban runoff, thermal pollution, siltation, port and urban development and the removal of over half of its tidal prism.

The Ben Anderson Barrage is 25.9km above the mouth. The Brigera Barrage is at 42.5km. When the Brigera barrage is full it floods the Ben Anderson; however, the Ben Anderson is kept pumped down when a lower catchment rainfall is imminent. It is then used as a tank so as not to waste any water in the so-called estuary. Fishermen call this tanking. This then covers the full tidal extent of the river, which once ended at around 67.4km from the river mouth.

Then there is a small gap until the Walla Weir at 74.5km. This holds water over the next 34.5km, and there is also an interbasin transfer from the Kolan River to this weir. The first 109km of the Burnett is probably the most important to fisheries and they have been impounded, possibly irreparably.

Above that there are possibly as many as 31 major storages and many 100s of minor stream dams plus old gauging weirs. That's without counting off stream farm dams. There are diversion channels, which link large areas and bring water from other catchments, which have their own problems. So now you can start to see the problems for the marine resource.

With this setting fishers and conservationists went through all the processes and pointed out the problems that could occur if a further weir was built in the Burnett catchment. However this went ahead anyway in 1998! To rub salt into the wound, the precautionary principal, and Ecological Sustainable Development (ESD), were used to justify the approval. That's right, the precautionary principal.

And if that isn't enough. THEY WANT MORE DAMS! That's right. THEY WANT MORE! This time a SUPER DAM about 18km up from the furthest impacts of the Walla Weir. They want to build the Paradise Dam, which would flood a further 60km of river. Yes and both the government and opposition parties think it's a vote winner in Queensland. How do we stop this?

Both the Ben Anderson (Burnett) and Bingera barrages should be removed to at least replace the tidal prism before any further dams are built on the Burnett and a full impact assessment should be carried out on the hypersalinity induced droughts in our rivers, bays and coastline.

Research should also be done to investigate the lack of energy plumes that once fed scallop and prawning grounds as well as whatever role carbon and freshes play in sustaining fish migration in the Great Barrier Reef lagoonal fisheries.

This work should be carried out with the assistance of NOAA, and their National Ocean Service from the USA, especially with their knowledge of salinity niches in the range from 0.05 parts per thousand to 25 parts per thousand on the top 60 commercially and recreationally important species in larval recruitment and the first 8 weeks of life. This may well put some faith back in the fisheries management process in Queensland.

Trawl fisherman in Moreton Bay say they have been suffering drought in the bay for years, with large dams holding back flows that once kept the Brisbane River running, and aquifers in the Lockyer Valley being pumped dry. When the flows do come they're too fast and don't have time to bio-accumulate the diversity needed to make Moreton Bay work. Many of the clawed shrimp, clicker prawn species are poor in number. These require lower salinities to survive and they are probably the decomposers and shredders of native plant litter from within the catchment. Fishermen say it's only the few creeks and small rivers that keep the bay going.

They can remember when the Brisbane River flooded and the good years that followed, times of plenty and how fresh the Bay and it's banks really were. Now all they get is trawl fishing reforms and devalued licences. There's no compensation for fishers in Queensland for such bureaucracy induced disasters.

Many pathways lead to the waterways. No doubt the aquatic resources, looked at collectively are the most productive, renewable, natural, native asset that many coastal economies have and should continue to have. Wake up Queensland, what have you done?

Things appear to be a little better in New South Wales and I want to congratulate them and the sponsors for having the foresight to pull this important Conference together. You have done well.

Yes. Weirs must be removed or modified so that at least some of the pathways within waterways can function as nature intended? How that might happen begins here, with the bringing together of minds.

Enjoy your wild harvested seafood while you can because I am convinced our estuaries, bays and coastal ocean currents are becoming too salty. Are they? Understand that I am only a commercial fisherman, and what is empirical knowledge worth in such a learned forum anyway?

Biography

Joe McLeod was born and bred on the Tweed River, and first started working on the Tweed Estuary after leaving school. He is a third generation fisherman who has only ever worked in the fishing industry. His father and grandfather worked on the Tweed and Northern NSW rivers.

Joe has worked the east coast from mid New South Wales to the Gulf of Carpentaria, Arnhem Land and the east coast of Queensland, operating in various fisheries.

He has been a resident of Tin Can Bay, situated in the Great Sandy Straits, west of Fraser Island, for 23 years.

He currently has a small 42 feet trawler, which operates from Tin Can Bay for prawns, scallops, crabs and bugs etc. The boat predominantly works south of Gladstone but depending on the seasonal variables could work as far north as Townsville.

Joe has always had a keen interest in environmental issues and has represented the Queensland fishing industry on committees such as the Downstream Effects of Agricultural Practices committee, Queensland industry environment committee and is a former vice president of the Queensland Commercial Fishermen's Organisation.

Politics and Economic Drivers for Dam Decommissioning: The Battle Creek, California Case

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Abstract

The deconstruction of five dams in the Battle Creek, California watershed, which will begin in earnest in 2001, may not provide a perfect template for use in other settings, but it does provide some useful lessons about doing such work. We will explain here what the Battle Creek restoration project is, why it is so highly regarded, how the importance of the opportunity it represents was in danger of being overlooked, and the economic and political factors that shaped the actual dam removal project.

Why tear down perfectly good dams in the Sacramento River watershed?

The Sacramento River, the second greatest salmon-producing river south of Canada, historically hosted four vigorous spawning runs of chinook salmon, *Oncorhynchus tshawytscha*. These seasonally different spawning runs are considered under federal *Endangered Species Act* (ESA) rules to be four distinct species. The adult and juvenile forms of these salmon species historically moved in and out of the Golden Gate at all times of the year. This temporal and spatial dispersal helped assure that at least some Sacramento River salmon would survive even the greatest floods and longest droughts.

The California Department of Fish and Game estimated that by the late 1950s the Central Valley's original 6,000 miles of salmon and steelhead stream habitat had shrivelled to less than 300 miles, a 95% loss. Most of this habitat loss was due to blockage by impassible dams.[1] Particularly hard-hit by this habitat loss were those salmon species – winter-run and spring-run chinook salmon and steelhead – that historically ascended to mid- and high-elevation stream reaches in order to hold in cool water until their time to spawn. And most hard-hit of all by the habitat lost to dam development was the winter-run chinook salmon.

Sacramento River winter-run salmon numbers plummeted from 120,000 in the 1960s to fewer than 200 adult fish in 1989, the year the federal government finally moved to list the species for protection under the federal ESA. Immediately upon the 1990 listing, government's winter-run protection rule-making began to tear great chunks of time and area out of California's commercial salmon fishing season.[2] Prior to the listing, California's commercial salmon harvest supported an industry conservatively valued at US$150 million a year. That value has decreased by roughly two-thirds in the past decade, due largely to government's ESA-driven constraints on the fishery.

The impact of the winter-run listing on water diverters, in the way of periodic curtailments of pumping from the Sacramento-San Joaquin Delta, has been moderate since it began in 1992. Water

1 CA Dept. of Fish and Game. 1971. Report of the Citizens Committee on Salmon and Steelhead Trout prepared pursuant to Assembly Concurrent Resolution 64, 1970 Session of the CA Legislature, Sacramento.

2 California's commercial salmon fishery is conducted with hook-and-line by "trollers" working entirely on the ocean. California's recreational salmon fisheries occur in the ocean, bays and rivers.

diverters have, however, contributed significantly to dam and diversion "fixes" for winter-run, including a US$100 million device to cool down the water released from Shasta Dam to the Sacramento River. This temperature control device was needed especially to protect winter-run chinook salmon during their summertime holding, spawning, and egg incubation periods in the flat, open, low-elevation river reaches below the dam. This was not the winter-run's historic habitat, but rather all that was left to them after Shasta Dam's development.

These two stakeholders, then, the commercial fishermen and the urban and farm water users were the groups most directly impacted by the ESA listing of the winter-run. Within a very few years they would unite to take down dams on Battle Creek.

Why Battle Creek?

Two of the most impressive geologic features of California's great Central Valley, the kind that airline pilots regularly point out to their passengers, are Mt. Shasta and Mt. Lassen. Both mountains are volcanoes, resting quietly for the moment. The Pit and McCloud rivers, tributaries to the upper Sacramento River, are fed through the labyrinth of volcanic rock spewed from Mt. Shasta. The resulting deeply incised streams, delivering large volumes of constantly cool water, provided the opportunity for coldwater-loving ancestral salmon to summer within miles of the blistering heat of the Sacramento Valley, and, over time, to evolve into winter-run chinooks. Unfortunately, these streams were blocked by the construction of the 600-foot-high Shasta Dam by the federal government just before World War II.

With the loss of the Pit and McCloud, where else could a winter-run chinook salmon summer safely near the sizzling Sacramento Valley? Perhaps in a stream watered through Mt. Lassen's ancient lava flows? That would be Battle Creek, but, sorry, the damming of Battle Creek began even earlier than that of the upper Sacramento. Battle Creek's abundant year-round flows attracted hydroelectric energy developers even before the turn of the last century. Over the years the Pacific Gas and Electric Company (PG&E) has increased its Battle Creek facilities to include 18 diversion dams, a network of flumes and ditches, and five power houses.

Since Battle Creek has the only remaining potential winter-run chinook salmon habitat anything like that lost behind Shasta Dam, and since the size of Battle Creek's dams are trivial compared to mighty Shasta, Battle Creek is the best – and only – opportunity to recreate a place that winter-run chinook salmon can call their own. This fact was apparently not as obvious to those responsible for the winter-run's recovery as it might have been.

The Central Valley Restoration Gravy Train Arrives

Construction of the federal Central Valley Project (CVP), of which Shasta Dam is the crown jewel, was high on California's Great Depression (1930-1940) priority list. Fifty years later finding some way to prevent the extinction of winter-run chinook salmon had made it to the "A" list. The winter-run chinook salmon issue began to drive a debate in Congress over the need to "reform" the CVP to somehow undo its great damage to the Sacramento and San Joaquin rivers, the grasslands of the San Joaquin Valley, and the San Francisco Bay-Delta estuary. By fall, 1992 the debate was over, the reformers had won, and CVP water and power users were saddled with the cost of a US$50 million-a-year Central Valley Project Improvement Act (CVPIA) Restoration Fund, at least until the damage could be undone.

Opening up Battle Creek for the star of the debate, the winter-run chinook salmon, should have been a “no brainer”. As the U.S. Department of the Interior set about to implement the CVPIA, however, not a word was spoken about removing Battle Creek dams.

In the fall of 1994 California’s governor and the Clinton Administration reached a tentative agreement over the protection of water quality in the San Francisco Bay-Delta estuary and committed their governments to a program of ecosystem restoration in the Bay’s watershed. Urban water users immediately pledged US$60 million, to seal the deal, for priority restoration opportunities. Congress soon thereafter earmarked nearly a half-billion dollars for this new “CALFED” program. This, in turn, inspired California voters to approve a 1996 water bond that produced two-thirds of a billion more to match the congressional earmark. At this point the restoration pot was over US$1.5 billion and rising steeply.

And how were the winter-run salmon doing? Not very well. In 1995 fishery managers could account for only 189 adults on the Sacramento River spawning grounds, a number frighteningly near the extinction level. You might expect that a scramble would have been underway by now to open up Battle Creek for these last few winter-run, that they might have the very best opportunity for a comeback – but you would have been disappointed.

One bright note was the cooperation between PG&E and the California Department of Fish and Game (Fish & Game) to abandon one antiquated hydro diversion, Wildcat Canyon dam, to increase flows in the North Fork of Battle Creek. One half the estimated power revenues lost to those streamflow increases was paid out of the new restoration funds; the second half was absorbed by PG&E. This appeared to bring in some more fish, probably a few winter-run. Meanwhile the Department of the Interior had entered into a contract with the California Department of Water Resources to begin engineering the replacement of damaged or missing fish screens and ladders on PG&E’s Battle Creek dams.

PG&E s Situation

PG&E had renewed the Federal Energy Regulatory Commission (FERC) license for its Battle Creek Hydroelectric Project in the 1970s. As in the case of many other FERC license renewals in the state, Fish & Game contended that more water needed to be released from PG&E’s dams to protect downstream fish life. Just how much more water was needed was unclear. FERC agreed that the parties should conduct a flow / habitat relationship study and report back when they had some news the Commission could use.

In the mid-1980s Fish & Game launched a full-blown instream flow / incremental methodology (IFIM) study on Battle Creek, in close cooperation with PG&E and the other responsible State and federal resource agencies. The IFIM study stretched into the early 1990s. That work might be languishing to this day if hotter heads had not prevailed.

With the arrival of the Central Valley gravy train there was clearly enough money to resolve all the fish-related problems on Battle Creek – some day. By 1997 PG&E had developed a five-year plan for tying up the loose ends of its FERC license process.

Hotter Heads and the Vision Thing

Sometime in late 1996 California commercial salmon fisheries leader Nat Bingham got together with representatives of the state’s chief water-use organisations to review what, if anything, the gravy train crew was doing to restore Battle Creek’s salmon habitat. They concluded not nearly enough was being done. Bingham, together with senior staff of the Central Valley Project Water Association and the Metropolitan Water District of Southern California, set about organising what became the “Battle Creek Working Group”. The leaders of this new Working Group welcomed any and all interested in restoring Battle Creek's salmon habitat, including the responsible agencies and the watershed landowners. It soon became clear, however, that not all members of the Working Group were marching to the same beat.

Because they were traditionally at war, this new union of fishermen and water users represented significant political clout. In addition to their clout, the Working Group had capital in the way of a Battle Creek restoration planning grant awarded to Fish & Game only weeks before. Fish & Game’s local fishery scientist, Harry Rectenwald, thought that the Working Group would be a good vehicle to oversee the development of the plan he had contemplated when he wrote the grant proposal. The Working Group quickly settled on commissioning Kier Associates, specialists in watershed and fisheries restoration, to do the day-to-day work on the plan's development.

At this point, in mid-1997, the only hint that anyone was contemplating removing a dam was that, unlike the other dams in Battle Creek's potential salmon country, no screen and ladder replacement was being contemplated at Wildcat Canyon. Other than that it appeared as though the configuration of PG&E's Battle Creek Hydroelectric Project, for purposes of a new 50-year license period, would sail through the FERC review process unscathed.

During the first week of December, 1997 the Working Group's organisers met to consider their progress. They were not altogether pleased. PG&E had briefed the group on its five-year plan for satisfying its environmental liabilities and completing its FERC relicensing process. Since the government's restoration gravy train engineers were working within PG&E's five-year plan to fit out the Battle Creek facilities with a new suit of publicly-funded fish screens and ladders, the company must have been comfortable with the way things were going. The Working Group organisers decided it was time to turn up the tempo.

Why build new fish screens and ladders, at public cost, on dams that may have limited usefulness – particularly when virtually every metal structure ever placed in the bottom of these rock-rimmed canyons had been crushed flat during one torrent or another? The Working Group organisers rolled out a map of the watershed and began to discuss ways of rearranging PG&E's project to truly open up Battle Creek for winter-run salmon. Within hours the notes and sketches of that meeting were reduced to two poster-sized schematics – Battle Creek in its current condition, and Battle Creek with its salmon habitat restored.

The Working Group leaders set up a meeting with the regional U.S. Fish and Wildlife director to introduce him to the idea of stronger medicine for Battle Creek. Considering how much institutional commitment there was at this point to working with PG&E to achieve its five-year plan, it would take top-down direction to put Battle Creek restoration on a faster track. The regional director looked at the schematics, mulled the estimated costs and the benefits, and wondered aloud why this vision of Battle Creek had not occurred earlier to those responsible for conserving these fish.

The Stealth Plan

When PG&E's northern California hydro management, they who had cooperated so closely with the resource agencies on the original habitat study, on the Wildcat Canyon flow improvement initiative, and on the screen and ladder design efforts, saw the Working Group's new plan they came unglued. This was not the approach the company and the agencies had shaped through a decade of close cooperation. They spent the early weeks of 1998 arguing that dam decommissioning would actually harm, not improve, salmon habitat in the Battle Creek watershed. The referred to the Working Group's plan as the "Stealth Plan", an act of betrayal.

The Working Group was firm that dam removals should be on the table and they were confident that CALFED's leaders would support dam removals if the value could be demonstrated. PG&E managers gradually turned to the job of educating the Working Group about how the proposed dam removals would impact the Battle Creek Hydroelectric Project. By March, a year after the Working Group first organised, PG&E's local managers were beginning to act like they might at least talk about dam removals. There was even talk of meeting with PG&E's San Francisco-based top management.

The View from the Top

The Working Group met PG&E's top management at company headquarters in San Francisco in May, 1998. The company's chief hydroelectric manager was very clear.

PG&E knew there was a national dam-bashing movement building, and they weren't going to contribute to that. The company did, however, need to provide the California Public Utilities Commission (CPUC) with a plan, by fall, 1998, of whatever it intended to do with its generation facilities in the State.

Management said that if there were sober interest in removing one or more of PG&E's dams from the Battle Creek watershed, then the company would consider including such actions in its submission to the CPUC, but only if there was agreement all around that there would be significant benefits to the resources – none of this "tearing down dams just to be tearing down dams". Management stressed that it needed an agreed-upon plan for Battle Creek by Labor Day [the first Monday in September]. The Working Group had 100 days, then, to convince the PG&E technical folks most familiar with Battle Creek that what they wanted to accomplish for salmon there was prudent.

PG&E demonstrated its sincerity for exploring the possibilities by hosting what sometimes seemed endless meetings at their district office in Chicago. The process began with an unhurried discussion of the various habitat requirements of the several salmon species involved during their several freshwater life history stages. The resource agency representatives made clear that their interests in stream restoration were not confined to fish. The restoration of habitat for plants and animals of concern that lived along the creeks, and even upslope of the streams, was on the table.

The Technical Deliberations

The Working Group's "biological committee", which included PG&E's seasoned Battle Creek expert biologists, dove into the data that had been gathered, but never really evaluated during the earlier flow / habitat relationship study and the monitoring of the flow increases which began in 1995. The biologists argued, as biologists will, over the implications of the data for the success of restoring one or another salmon species to the PG&E reaches of the watershed – reach by reach, species by species, life history stage by life history stage.

The resource agency biologists were adamant that the two forks of Battle Creek, joined hydrologically by the power diversions and overland canals for nearly a century, would be separated. Because temperature in the lowermost reaches of the South Fork would, by all calculations, be marginal for winter-run chinook the agency biologists did not want winter-run straying into the South Fork and being lost to the high temperatures. The mixing of North Fork water into the South Fork would, in the agency biologists' view, create a "false attraction" to the South Fork for salmon reared in the North Fork.

PG&E's experts argued that removing the cold North Fork diversions from the South Fork would make South Fork fish conditions unacceptably warm. The agencies said they would take the responsibility for the outcomes. The summer was over and it was time to take a plan back to PG&E's management.

The Rubber Meets the Road

In September, 1998 the agencies and PG&E got down to the important business of deciding who would do what in the Battle Creek watershed – and who would pay for it.

The negotiations would last for eight months, twice as long as the biological "negotiations". The agencies had a significant, if informal, commitment of funds from CALFED. The plan they passionately desired included doing away with the Eagle Canyon diversion upstream of Wildcat Canyon, thereby clearing the track throughout all the North Fork's potential winter-run habitat. PG&E insisted that removal of Eagle Canyon was a deal breaker.

With Eagle Canyon remaining and outfitted with a new fish screen and ladder, the impact of taking down five of PG&E's dams, Wildcat Canyon, Coleman Dam which blocked the South Fork, South Dam above Coleman, and dams on two tributary streams – plus increasing flows below the remaining dams – would eliminate less than a quarter of the Battle Creek Project's hydropower production. The agreed-upon plan would restore salmon conditions on 48 miles of the north and South Forks, as well as Battle Creek's mainstem. Cost estimates stood at US$27 million for the dam removal and the new works to prevent mixing of the water of the two forks. PG&E would absorb the cost of the power losses, which the company estimated at US$20 million. PG&E was still not convinced of the wisdom of severing the two forks of the Battle Creek watershed, from a fish habitat perspective, and asked that there be a comprehensive adaptive management program to track the restoration project's performance. The David and Lucille Packard Foundation pledged US$3 million to underwrite the adaptive management program.

It would be the single largest salmon habitat restoration project CALFED would be able to accomplish. It would become CALFED's finest ecosystem restoration accomplishment. It was certainly is costliest.

Implementing the Project

The U.S. Bureau of Reclamation (Reclamation) is the lead CALFED agency for the Battle Creek salmon and steelhead restoration project. As of this writing, Reclamation has organised technical advisory committees to help complete the design of the fish screens, ladders, and the other new works; to develop the formidable environmental documents and ESA permits necessary not only to facilitate the deconstruction but to satisfy FERC's need for information concerning the substantive alterations to the licensed project, and to guide the overall progress of the project.

The estimated costs of the project are inching upward. PG&E is pointing out needs that were not recognised during the technical and cost-sharing negotiations. The devil, as they say, is in the details. And who among us has had the experience of taking a dam down?

The Lessons Learned

Here are at least a few of the lessons learned as the "five-year plan" cooperation gave way to the more aggressive proposal to take down PG&E's Battle Creek dams:

- watch your tongue. People who own and maintain dams do not take lightly proposals to destroy them. Even engineers have feelings, and the emotional investment in the structures they build and maintain should be treated with as much respect as heady notions of restoring streams;

- you will need data. Dam owners, and eventually politicians, need hard evidence that the removal of their dams will contribute significantly to a public good, and that calls for dam removal aren't just some passing social fancy;

- bring cash. If the Battle Creek is any example, things go better if dam removal advocates can identify their funding source early in the discussions. It will cost a darned sight more to take these old Battle Creek dams down than it cost to put them up;

- be tolerant. The owners of dams will overstate their property's worth. That is any seller's privilege. Since PG&E agreed to absorb the cost of the lost power at Battle Creek, it didn't matter much if they overstated its value. (If on the other hand the public were being asked to compensate the owner for the loss of the power, the valuation issue would have been a great deal more critical.);

- be gentle. Some publicly-regulated utilities have a siege mentality these days. Be quick to give them public 'attaboys' as soon as you have struck your dam removal deal; and

- be patient. None of us has a lot of experience taking down dams. What we are learning on Battle Creek, as Yogi Berra said of baseball games, is that "it ain't over 'til it's over".

Biography

Bill Kier has been involved in river management and fisheries conservation programs in northern California and the U.S. Pacific Northwest, as a scientist and government administrator for more than 40 years. Positions that he has held include those of government scientist, fisheries agency administrator, Assistant Resources Secretary of California, staff director of the California State Senate committees on natural resources and water, director of the Senate's office for research and policy development, and, since 1986, founder and principal fisheries ecologist at Kier Associates, California-based consultants in fisheries and watershed management and restoration.

Benefit Cost Analysis and Weir Management

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Abstract

The elements of benefit cost analysis are presented along with discussion of the potential role of the technique in the development of weir policy. Some related issues are also considered. Benefit cost analysis can contribute significantly to the development of weir policy by providing information for decision makers and offering a framework for planning. The role of the technique in situations characterised by a high incidence of un-priced impacts is considered.

Introduction

The over 3,000 weirs in New South Wales have a range of private and public owners. They serve a variety of purposes including diversions for irrigation, stock and domestic consumption, and town supply. Others include flood control, navigation, recreation and amenity. Some have multi-purpose uses. Individually, many of them represent relatively small investments; however, in total, they represent an important and valuable state resource. Only 264 are owned and operated by State Water. The remainder are owned by a variety of interests. Some have no known owner, whilst others, such as Wellington Dam, have known owners but are not used. Presumably, the situation in other states is similar.

The downstream impact of weirs on the flow and health of rivers and their ecosystems can be substantial and, in many cases, deleterious. Further, the undesirable environmental impacts of weir pools can extend more widely into the riverine environment through such things as groundwater mounds. Some rivers have a large number of weirs with a cumulative impact on river behavior and health, which can be difficult to apportion between them. There is evidence that weirs contribute to reduced water quality and incidence of algal blooms. Loss of vegetation cover, and resultant stream bank erosion, can also contribute to soil loss.

Further, weirs typically have multi-dimensional and inter-related impacts. For example, the Mildura Weir, provides amenity and recreational benefits for the local community, is the basis of a substantial tourist industry, backs up water for extraction by up-stream irrigators, and has generated a growing water mound, which is causing significant environmental degradation to its north and north-east. Such inter-relationships mean that attempts to vary any one of these impacts invariably affect the others and require complex and sometimes stressful decisions. Often there is no one entity that can make decisions taking all impacts into account. How such decisions are made can therefore be a matter for concern.

The undesirable impacts of weirs are prompting questions about the desirability of the continuation of traditional management practices or, even, in some cases, suggestions of their demolition. In addition, the removal or modification of weirs can have positive effects on productive activities, such as downstream grazing of wetlands and fishing. All told, this mix of potential economic and environmental benefits underlies an *a priori* case for investment in the modification or removal of weirs, particularly as the uses, such as mining and pastoralism, for which some weirs were constructed, can be of declining significance and value. The question is: which weirs and who should pay?

In principle, consideration of this question in New South Wales calls for an evaluation of all weirs and a ranking of them for action. In view of the number of weirs and of the complexities involved, this would be a major exercise. The form such an exercise might take is beyond the scope of this paper, though one would hope that there would be some consideration of it during this conference. An important aid in the determination of a plan of action, however, is the economic technique of benefit cost analysis (BCA). This paper is an overview of this technique with a concluding suggestion as to how it might fit into the weir management decision process.

Assessment of investments in weir modifications requires their costs, including foregone economic, social and other benefits, to be set against the environmental, productive and other benefits obtained. Further, identification of the winners and losers, and the extent and nature of their gains and losses, would help greatly in the allocation of the costs involved between stakeholders.[1] Information of this nature would facilitate the formation of weirs policy, such as is being developed in New South Wales, and also contribute to resolution of conflicts over who should pay. BCA provides such information.

Were weir policy to be decided purely on the grounds of (measurable) costs and returns and impacts on the distribution of income, BCA could provide a ranking of weirs (or groups of weirs and/or associated infrastructure) for action. In practice, not all costs and returns are measurable in a satisfactory way, while the determination of priorities involves consideration of more than profitability and income distribution. Consequently, BCA cannot be the sole determinant of weir policy. Hopefully, this paper will contribute to understanding how the technique can help in the decision process.

The Objectives of Weir Management

Weirs are owned and operated by a variety of public and private owners within a regulatory framework imposed by government. The owners seek to use their weirs to maximise the attainment of their objectives. Local government is concerned with the cost-effective provision of an acceptable water supply to its community, along, perhaps, with amenity and recreational benefits consistent with the interests of their community. Irrigators are concerned to maximise the net productive benefits from their weirs. And so on. None is expected to pay attention to the 'off-site' impacts of their weirs, unless required to do so. These impacts are genuinely 'external' to their concerns as weir managers. Their rational target is to maximise the value of the weir in terms of their various objectives.

Given its overall mission to consider the well-being of society as a whole, government is an important weir owner that would seem to be an exception to this generalisation. Its state-wide remit requires it to be prepared to take into account any impact of the weirs under its control, be it cost or benefit, regardless of where it might fall within the state. Once, government handled this obligation by placing weir management in the hands of a single authority, such as the old Department of Water Resources, with a state-wide remit to both deliver weir services and to manage externalities as appeared appropriate.

Current thinking is for the responsibilities of government, as weir operator and promoter of the wider interests of the state as a whole, to be divided between at least two entities. One entity is the weir operator, which is expected to be an efficient provider of commercial services, such as the supply of bulk water. The other is the resource steward with responsibility for the setting of resource standards, for ensuring that those standards are met, and for regulating access to the resource. New South Wales has gone down this path partially, with the commercial service provider, State Water, 'ring-fenced' within an agency, which also has important stewardship responsibilities. Not everyone is convinced that

1 The politically favoured basis for cost sharing appears to be the principle of beneficiary pays, which can result in pollutees rewarding polluters for the correction of external dis-benefits. The principle requires costs to be contributed according to contributors' shares of benefits. If un-priced benefits are significant, these shares cannot be determined and so the distribution must ultimately be determined by negotiation.

this is a satisfactory arrangement.

The supreme objective of government should be to ensure that weir investment and management is in the best interests of society as a whole. In theory, this requires maximisation of the difference between all public and private benefits and costs of their utilisation, regardless of where they fall. The operator should have responsibility for commercial services and costs, while the resource stewards, such as the Department of Land and Water Conservation and the Environment Protection Authority in NSW, should be responsible for the costs and benefits of external impacts. In doing this, the stewards set, and police, standards to be met by all weir owners and operators. Standards are imposed through market or regulatory mechanisms which are intended to internalise the targeted external costs of operators' decisions.

In practice, a combination of the 'baggage of history', and perceptions of community preferences, means that only a sub-set of external effects is taken into account by the standard setters and the operators. Improvements in knowledge about, and concern for, environmental impacts have led to suggestions that, in the case of weirs, the set needs enlarging. This is coupled with the further suggestion that the declining value of the uses of some weirs, along with the high cost of their maintenance, calls their continued use and sometimes their existence into question. Hence this Conference.

The Weir as a Commercial Asset

The wealth-maximising owner of a weir will seek to maximise the value, or net worth, of the asset, taking into account the costs and benefits incurred by them. As already suggested, costs and benefits incurred by other parties are irrelevant to the decisions of such 'economic rationalists'. While unlike most of us, who typically have additional economic (e.g. risk reduction), environmental, social or cultural objectives, this caricature of resource managers is useful. Consideration of the 'simple' objective of net worth maximisation enables the introduction of a number of fundamental concepts, before moving to more complex considerations.

BCA is the appropriate tool to use in determining the management practice, which will maximise net worth. In general, BCA enables managers to rank alternative investments in individual weirs, or across a number of weirs, according to the ratio of benefits to costs or a measure known as the internal rate of return calculated for each alternative. In practice, in situations, such as weir management, where objectives are more than merely commercial, while benefit cost ratios and internal rates of return are typically calculated, they are not used to rank options for the management of individual weirs or a number of weirs.

Even where the maximisation of net worth is not the predominant overall objective, BCA is still a useful technique for the guidance of management of the resource. In the final analysis, the complexities of the issues are typically such that BCA is only one of several aids relevant to the determination of weirs policy. It has the strength, however, in comparison with most other techniques, of resting on an explicit theory of evaluation, and of addressing directly questions of value and choice. Consequently, it provides a useful framework for policy choice in weir management.

To some, this strength of BCA is also a weakness in that it gives an unwarranted weight to monetary outcomes and tilts the decision 'playing field' against impacts, which cannot be similarly valued. While not to be ignored, such concerns should not be allowed to stand in the way of the use of BCA, if only because of the information and structure it brings to the policy process. Further, such concerns can be alleviated by employment of appropriately structured, transparent and consultative decision processes.

Net Present Value

Maximum net worth is achieved by maximising the difference between the present value of the flows of benefits and costs of operation. These present values are determined by discounting the flows, using an appropriate discount rate[2]. The difference

2 The discount rate is the higher of the interest rates at which the asset owner can use funds, acquire them, or dispose of them on the market. This is true of a commercialised public sector owner as much as it is of one from the private sector. In the case of a non-commercialised public owner, the determination of the appropriate discount rate is complicated by arguments that public rates should be less than market rates. Most such public bodies are spared agonising over this issue by the nomination, by the Treasury, of the rate to use.

between them is called the net present value (NPV) of the asset. NPVs vary through time. Some weirs, such as those used for stock and domestic purposes, may have declined in value because of the secular decline in the livestock industry they support. Similarly, some town water supply weirs may have declined in value, and developed excess capacity, because of population loss in the relevant town. On the other hand, a weir may increase in value due to the introduction of a more profitable water using activity, such as cotton[3].

If it were costless to do so, the rational asset manager would continually monitor alternative uses of the asset, and the associated NPVs, in order to be alert to the scope for adjusting its use in response to changing circumstances, and to maintain its value at its maximum. Such adjustment could involve changing the rate of use, or switching to an alternative use with a higher net present value[4]. Monitoring of some weirs has clearly led to the conclusion by their owners that the best strategy is abandonment. This decision, if rationally made, would pay no attention to external costs and benefits warranting, from the viewpoint of society as a whole, investment in demolition of the abandoned weir. This would seem to be the case with Wellington Dam.

In most cases, the cost of continuous monitoring is too high. Instead, compromises are made between that cost and the alternative of missing opportunities as a result of infrequent monitoring. In the final analysis, however, sound asset management requires on-going monitoring of the status of assets and of investment options with the frequency being a matter of judgment or legal compulsion.

Widening the View - Measuring Benefits and Costs

This section is concerned with the identification of relevant benefits and costs and the determination of their values. Benefits and costs are classified as 'direct', 'indirect' and 'un-priced'.

Direct Costs and Benefits

These are the costs and benefits stemming from the use of the asset to pursue the objectives of its owner. As long as the objectives are clearly comprehended by the operator, direct benefits and costs should be readily identified. The costs include operation and maintenance, capital charges for depreciation[5], refurbishment and, if justified, replacement. They also include an opportunity rate of return on the value of the asset. This is the rate of return from the next best alternative use of the weir, or which would be obtained if it were liquidated and the proceeds invested in their next best alternative use. If, as may well be the case, a weir has no alternative use, or there is no market for it, then the opportunity rate would be zero. In this case, the value of the asset is determined by its value in use. Weirs having no alternative use, no market on which they can be sold, and whose value in use does not exceed the cost of their operation[6], have zero capital value. The rational decision for the owner of such a weir may be to abandon it. Once again, the external benefits of such action may justify intervention by the state to modify or demolish it.

Usually, direct benefits are readily identified and quantified. Their valuation, however, is not necessarily so straightforward. From the point of view of those concerned with the efficiency rather than the financial outcome of the use of the asset, prices should be net of transfer payments, such as taxes and subsidies. For those concerned with assessing financial outcomes, however, all cash outgoings and incomings should be counted. In this case, transfers would be taken into account. Private and commercial operators would be interested in financial BCAs; while Treasuries would be interested in both: the efficiency, because it indicates the efficient outcome from the point of view of society as a whole, and the financial

3 Risk is an important consideration ignored in this discussion. Its recognition involves using expected values or the probability distributions of benefits and costs. This is not always easy and typical studies rely on the use of sensitivity analysis of a range of values of key variables instead.

4 This is the opportunity cost of the asset – the value of the asset in its next best alternative use. The concept of opportunity cost is one of the more useful contributions of economics to the art of decision-making. The value of an asset is determined by its market value, its opportunity cost or its value in use, whichever is the higher. The historical cost of the asset is irrelevant. It is a 'sunk cost'.

5 Depreciation is a contentious area with a variety of views ranging from support for traditional historical cost depreciation to advocacy of the use of renewals annuities. This is unfortunate as the value of capital costs will vary depending on the approach adopted.

6 That is, there is no surplus, after meeting operations and maintenance costs.

because it indicates the financial viability of the project and throws some light on its distributional consequences. Clearly, a number of different BCAs may be undertaken, each one reflecting the differing objectives of those commissioning the study. Analysts need to indicate clearly the methodology they are adopting and the reasons for it.

Indirect Costs and Benefits

There are two classes of indirect cost and benefit. First, are off-site effects on regional or overall economic activity (usually called multiplier effects or secondary benefits and costs) and effects on government taxation revenue. Second, are the off-site effects commonly known as externalities. As already indicated, externalities are important in weir management. Inclusion of the first class in a BCA is normally not accepted, but inclusion of externalities is. In the case of small weirs, the first class is likely to be minor.

The reason for exclusion of the first class of indirect benefit or cost is that the resources involved would be expected to have the same impact on taxation receipts and economic activity, regardless of whether they are employed in the project in question, or not. This, and the fact that taxes are transfer payments, means that a special case for their inclusion is needed in an efficiency analysis. Rarely can such a special case be made for taxation impacts of projects. Acceptable cases can be made for multiplier impacts if they can be demonstrated to have impacts on overall activity, which would not otherwise be achieved. That is, the impact flows from the project, and from it alone. The ultimate test of the legitimacy of the inclusion of a benefit or cost is the so-called ‘with and without principle’.

The With and Without Principle

According to this principle, only costs and benefits, over and above those which would be incurred in the absence of the project, should be included in the BCA. While seemingly simple, the principle, in practice, provides a most important discipline for BCA practitioners, particularly for those assessing public sector projects having to cope with stakeholder advocacy. In the event of debate as to whether a particular cost or benefit should be included in the BCA, the question to ask, according to the principle, is ‘would that cost or benefit be expected to be incurred, even if the project did not go ahead?’ If the answer is in the affirmative, then the cost or benefit should be ignored in the BCA. Thus, if investment in a weir causes output to go up or down, care should be taken to ensure that only the change net of on-going secular trends in output, which can be attributed to the project, should be included in the analysis. While seeming to be common sense, application of the principle calls for discipline and application on the part of the analyst. Further, estimation of what might happen in the absence of the project is often no less difficult than estimating what will happen with it.

Use of the principle can, however, cause debate where indirect economic impacts are involved. Thus, in the case of Mildura Weir, lowering the weir height, in order to gain environmental benefits as a result of diminution of the groundwater mound, will have a direct negative impact on up-stream irrigation activity, and perhaps on the tourist industry. These declines in economic activity may have a flow-on, negative effect on associated regional economic activity. The former would be a direct cost of the action in question. From the viewpoint of the economy as a whole, according to the with or without principle, the latter would not, because the resources involved are assumed to be mobile and capable of being fully employed, for the same return, elsewhere in the economy. This position may not be acceptable to those with a narrower regional point of view.

Such a conclusion might, however, be debated because resources are not always mobile, and the local decline in economic activity could leave them stranded with resultant unemployment and capital losses. Even where resources are mobile, their movement may involve dislocation costs, which, arguably, could be debited to the project. In most BCAs, such issues are either ignored, or presented separately from the results of the analysis. The latter practice is usually followed in the analysis of public projects when ‘social impacts’ of concern are expected

Externalities

Externalities arise because of inadequate property rights resulting in asset operation creating benefits or imposing costs, which are not credited or debited to the owner. They seem to underpin many weir ‘problems’. The degradation of Gol Gol

Swamp and Gol Gol Lake are external costs of Mildura Weir. As with direct benefits and costs, externalities are not difficult to take into account if they can be readily identified and measured[7].

For example, the Mildura water mound contributes to a high water table in an adjoining irrigation area. Any yield reduction this causes is an external cost of the weir. If a modification of the operation of the weir impacts on the mound and changes yields for better or worse, compared with what was achieved prior to the modification, then the value of that external cost or benefit should be included in an evaluation of the modification. Providing the science is good enough, and valid price predictions can be made, the value of these crop impacts should be capable of calculation.

In principle, externalities should not constitute a problem in BCA. For example, the external impacts of modification of Mildura Weir, seem to be readily identifiable. If, however, specification of how the water mound will behave, or how the Gol Gol Swamp ecosystem will respond to the contraction of the mound, is not possible, or if values cannot be established for the resultant environmental benefits or amenity losses, then there is a problem. Such a difficulty can, of course, also arise in the case of direct benefits. In fact, un-priced costs and benefits present a serious problem in BCA.

Un-priced Costs and Benefits

Because of the significance to weir policy of environmental impacts, these are a most important consideration in the context of this Conference. Most environmental benefits and costs are un-priced, and, so, do not lend themselves to ready inclusion in the benefit cost calculus. In the case of weirs, examples include the status of the fish population, other ecosystem components, and water quality. The value of the ecosystem of Gol Gol swamp is a particular example.

Un-priced costs and benefits are not restricted to environmental effects alone and include such things as amenity and recreational impacts. The significance of many weirs to the quality of life and the culture of Indigenous people illustrate this point well. The Mildura Weir provides an excellent example of the provision of significant intangible amenity and recreational benefits to a major country town. The weir at Brewarrina, which is built over traditional fish traps in the Barwon River, appears to have significant cultural implications for the local Indigenous people.

Un-priced values would seem to be particularly important in the case of weirs. Not only are environmental, recreational and amenity impacts significant, but so too are consumption impacts, not just in terms of quantity but also quality. While there is considerable information on the cost of supplying water, the same cannot be said for the willingness of consumers to pay for different quantities of water, let alone varying quality.

This is a major difficulty for BCA of weir policy because there is every indication that consumers can be quite responsive to the price and quality of water. Once they get beyond the threshold for health and nutrition, urban consumers are able, and apparently willing, to vary their consumption in response to opportunities for use, quality and price. Similarly, irrigators can switch between crops and can vary irrigation intensities. To the extent that this is true, reliance on the simplifying assumption that consumers have a fixed need for water may give a biased assessment of the comparative value of weir management options. On the other hand, if the consumption of a commodity is unresponsive to price, and other variables such as quality, then the single valued needs approach is appropriate[8].

Economists have put considerable effort into trying to find ways of determining values for intangible benefits and costs. A variety of

7 This discussion focuses on physical or non-pecuniary externalities. Pecuniary externalities arise when the project impacts on price levels. While of less importance in weir management, the possibility of their occurrence should not be ignored.

8 When the output of weir management is expressed in single-valued or needs terms, such as water consumption per head of a stable urban population, then conventional BCA is not really relevant. An alternative approach known as cost effectiveness analysis (CEA) can be used. This approach consists of assessing the costs of alternative ways of meeting a fixed need. While less powerful than a BCA, CEA can be a useful decision aid and is widely employed to select least cost ways of meeting fixed targets. One needs to be always wary, however, that the fixed, or inelastic target assumption is warranted.

techniques have been developed, including hedonic valuation for amenity impacts, the travel cost method for recreational impacts, and stated preference techniques, such as contingent valuation and choice modeling, for a variety of environmental effects. Not all of these developments have received universal acceptance. The reasons for this are several and include failure to establish credibility, mainly as a result of examples of inappropriate or improper application, and, in the case of some, the expense and complexity of their use.

Whatever the reason, estimation of un-priced values is rarely attempted on a routine basis in Australia. A low cost alternative is to use values estimated for similar phenomena in other locations. In order to facilitate such 'benefit transfer' the NSW Environment Protection Authority has collected a range of estimates in a database called ENVALUE. To date, use of these values appears to have been limited. Another approach is to use 'threshold values'.

Threshold Values

A 'threshold' value is the opportunity cost of the diversion of resources to produce an un-priced benefit. If the diversion goes ahead the value of the un-priced benefits to the decision maker is deemed to exceed the threshold value. It is a measure of what is given up, in monetary terms, in order to obtain the un-priced benefit. For example, if weir operation is modified to enable an improvement in environmental flows with a resultant loss in irrigation output, then the decision makers can ask themselves whether, in their opinion, the environmental gains are greater or less than the monetary value of the foregone irrigation. In the case of Mildura Weir, lowering the weir level in order to obtain environmental benefits will impose measurable costs on the irrigation and tourist industries. These costs provide a threshold value which, to be accepted, the environmental benefits must be deemed to exceed. The use of threshold values can provide a useful focus and structure to debate when un-priced values are involved.

Conclusion

BCA is undoubtedly a useful management tool for commercially oriented weir owner/operators. It is also useful, but not to the same extent, to policy makers with a wider social and environmental remit. For them, external and un-priced effects, along with distributional and equity concerns, despite the availability of formalised procedures to handle such situations (such as multi-criteria analysis), typically mean that the determination of the best policy must be through the customary process of political debate. This is the way we usually resolve complex, multi-faceted, highly inter-dependent problems. Weirs policy presents us with such problems. Externalities are many and varied, social and cultural impacts cannot be ignored, while the interdependencies between weirs can be such that they can only be dealt with satisfactorily on a system-wide basis. BCA, along with other techniques of social and bio-physical analysis can inform such debate, but they cannot take its place. Even so, those who use the technique in the assessment of such multi-dimensional problems, as has been the case with the land and water management plans in New South Wales, find that it provides a structure and discipline for the process which facilitates attainment of satisfactory outcomes through relatively less fraught decision processes.

Even casual acquaintance with the weir problem leads to the conclusion that, in most cases, it should not be left to the owners to resolve independently of each other, and of government. The widespread incidence of externalities, un-priced effects and significant interdependencies, means that resolution must typically be pursued in the form of a partnership between stakeholders, driven by the State, on a cost-sharing basis. The BCA philosophy provides a basis for structured, consultative and transparent discourse, which informs and facilitates negotiations about cost shares, as well as the economic merits of the available options. To those familiar with the strengths of the technique there can be no argument but that it should be a basic procedure in any review of weirs, such as is currently being undertaken in New South Wales. Those with an interest in a successful and fair outcome of such a review, in the overall public interest, should seek to ensure that this is the case. If it is not, they should satisfy themselves that an alternative decision process with, at least, equivalent strengths, is being employed.

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Biography

Warren Musgrave is a self-employed consulting economist. He was Professor of Agricultural Economics at the University of New England from 1971 to 1995. From 1990 to February 1995 he was Dean of the Faculty of Economics, Business and Law at that University. In 1995 he joined the NSW Government where he was briefly Catchment Assessment Commissioner and then Special Adviser – Natural Resources in the Premier's Department. He is a member of the Independent Pricing and Regulatory Tribunal for its reference on bulk water pricing. In February 2000 he left the Premier's Department to take up his present activities. He is a member of the Scientific Advisory Committee of the World Wide Fund for Nature (Australia). At the University of New England he was Director of the Centre for Water Policy Research from 1988 till 1995. During his time with the Government he was Chair of the Land and Water Management Planning Assessment Team and of the Independent Advisory Committee on Socio-Economic Analysis. He continues to hold the former position.

Beyond Palliative Care: Removing Weirs in the Upper Nepean River through a Whole System Approach

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Abstract

The independent inquiries undertaken by the NSW Healthy Rivers Commission highlight several key principles that are central to securing healthy riverine ecosystems and sustainable patterns of resource use (HRC 2000). These principles involve the need to manage rivers as whole systems, to treat rivers as productive assets requiring careful management, to fashion more rigorous and directive strategies that create obligations on the entities that possess powers and resources to manage rivers, to create government and community partnerships based on unambiguous statements of their respective responsibilities and to apply an adaptive approach.

Applying these principles is crucial to reinstating critical natural ecological processes in the upper Nepean River. In particular, applying a 'whole system' approach is central to addressing the adverse impacts of multiple weirs. This demands action to remove many of these structures, rather than applying various palliative measures to alleviate the symptoms of river health decline. This, in turn, creates obligations to recognise and find ways to address the needs of existing river extractors.

Introduction

The adverse impacts of weirs on river health are now well recognised. These structures often provide a secure water supply for various consumptive water uses, including towns, industry and agriculture. However, weirs can have significant impacts on riverine ecosystems. For example, weir pools often create still water conditions that favour exotic and some native aquatic plant and animal species, induce stratification of a water body with consequent water quality problems, inhibit or prevent the movement of fish and cause erosion of river beds and banks.

A range of management responses, including the construction of fishways, installation of destratification systems, and measures to protect river flows, have attempted to mitigate those impacts. However, decisions about such measures are often made in isolation, with the result that these are often little more than 'palliative' actions, affecting one, or at best a few, of the symptoms of river health decline, while at the same time deflecting attention away from the underlying and fundamental problem. The result has often been to exclude serious consideration of innovative alternatives with a whole system focus, entrenching the retention of weirs, at considerable ongoing expense to river health.

This paper examines the potential ecological and economic benefits of applying an alternative, whole system approach to managing weirs and its implications for the delivery of public sector programs. Key aspects of the past approaches, and possible alternatives, are demonstrated with reference to the twelve weirs on the upper Nepean River. The impacts of those weirs on river health, and management options for them, were examined in the course of a Healthy Rivers Commission Inquiry into the Hawkesbury Nepean system undertaken in 1998 (HRC 1998). Government responses to the Commission's recommendations included a decision to conduct a review into the number of weirs on the upper Nepean River, with a view to removing as many as possible, subject to addressing the needs of existing water users (Debus 2000).

The Upper Nepean Weirs: Management Challenges

Numerous dams, weirs and other structures have been constructed on the streams in the Hawkesbury Nepean catchment. A recent survey conducted by the Department of Land & Water Conservation (DLWC) identified approximately 500 structures that are believed to adversely affect riverine ecosystems in the catchment (DLWC undated). Eighty one of these structures have been identified as having a major impact on fish passage (Marsden & Gehrke 1996).

Notably, a number of the structures in the Hawkesbury Nepean catchment appear to have become redundant in relation to the purposes for which these were originally built. Some have become important for other purposes, such as recreation, scenic amenity, heritage values and, in some cases, as valuable modified ecosystems.

This is thought to be the case, in varying degree, for the twelve weirs along much of the length of the upper Nepean River.[1] Most of these were built earlier last century, following construction of major water storages in the upper tributaries of the river system to supply Sydney's urban demands. Several were constructed as 'compensatory' weirs, their purpose was to provide secure supplies to agricultural water users along the river.

A number of typical palliative measures have been suggested and/or implemented to partially mitigate the adverse impacts of these weirs on riverine ecosystems. These include constructing fishways, modifying structures to enable the water level in upstream pools to be varied, destratifying water bodies behind structures, applying stringent controls on nutrient inputs (to the limited degree that this is now possible and/or effective), flushing weir pools by releasing greater volumes of water from upstream storages (than may otherwise be necessary for environmental flow purposes), 'harvesting' excessive aquatic plant growth in weir pools and constructing erosion control works. Such measures are additional to the engineering difficulties and substantial ongoing costs of maintaining multiple weirs in a sand dominated river system (SWC 1995)[2].

The estimated costs are typically high. For example, modifying seven of the weirs on the upper Nepean River is estimated to cost between about $900,000 and $2.0 million in order to improve fish passage alone (NSW Fisheries, pers. comm.). At this stage, two new rock-ramp fishways have been constructed at Theresa Park and Mount Hunter weirs on the Nepean River at a cost of about $120,000 and $150,000 (DLWC, pers. comm.).[3] Other financial costs to destratify weir pools, modify weir structures to provide variable water levels, control nutrient inputs, flush weir pools and harvest aquatic plants have not been quantified, but are widely expected to run into millions of dollars in capital and operating terms. Similarly, the ecological costs of such measures are likely to be substantial. In particular, releasing larger volumes of water from upstream storages to flush weir pools (than may otherwise be required for environmental flow purposes) would add to other pressures to bring forward the construction of Welcome Reef Dam on the Shoalhaven River to protect the security of Sydney's urban water supply.

The expenditure of scarce public and/or private funds on such actions demands rigorous scrutiny, not least because there is unlikely to be much support for the removal of such structures after the expenditure of substantial funds on palliative measures. That is, such expenditures are likely to entrench the retention of weirs, and lessen both the incentive and the opportunity for relevant agencies, water supply authorities and irrigators to implement alternative arrangements for securing the water supplies of those users who are presently dependent on the weirs. As the actions are unlikely to re-establish, fully, the natural ecological processes that prevailed in a free flowing riverine ecosystem (notwithstanding the benefits of

1 These structures are Maldon, Douglas Park, Menangle, Bergins (collapsed), Thurns (bypassed by bank erosion), Camden, Sharpes, Cobbitty, Mount Hunter, Brownlow Hill, Theresa Park and Wallacia weirs.

2 A number of the weirs failed and were replaced at a cost of about $3.7 million in 1986-87 (SWC 1995).

3 The investment in these experimental structures is warranted, given the evident research value and potential to refine and apply such technology in other appropriate locations. However, this should not preclude the potential to remove these weirs in the future.

creating healthier still-water conditions), the net result is, at best, inefficient use of the limited funds available for river protection and restoration.

It is arguable that these problems are attributable to the fragmented nature of agency responsibilities and programs that are involved in managing rivers. The management of weirs in the Upper Nepean (and elsewhere) is typical of other aspects of river management, in that there is a significant fragmentation of agency responsibilities and programs in relation to these. Inquiries undertaken by the NSW Healthy Rivers Commission have found that there is seldom sufficient, if any, assessment and response to river health problems on a whole system basis (HRC 2000). That is, the powers and financial resources available for river management are distributed among a large number of different agencies, each of which has responsibility for some particular aspect(s) of river or catchment management. There is a constant risk that inconsistent goals will be pursued and that opportunities for activities to be mutually reinforcing will be missed because system problems cannot be readily aligned with the responsibilities of any individual agency (HRC 2000).[4]

It is therefore unsurprising that weirs are typically treated as a 'fish passage problem', 'environmental flow problem' or 'water quality problem', thereby beckoning fragmented responses. Decisions about the management of each separate aspect are then often justified on the presumption that weirs cannot be removed without adversely and permanently affecting the security of irrigation water supplies.

Such an approach is not confined to the management of weirs. For example, in the upper Nepean River, the treatment and disposal of sewage effluent has in the recent past been viewed solely as a water quality problem (HRC 1998, Hurst 1999). This has typically limited consideration of the range of options available for treatment, disposal and / or reuse of effluent to the application of more complex and costly treatment processes and / or creating new demands for the sewage effluent, such as establishing and irrigating wood lots (SWC 1997). This has tended to exclude testing of more innovative options, such as using highly treated effluent in the make-up of environmental flows and / or to provide an alternative water supply to existing river users (HRC 1998, Hurst 1999)[5].

In short, much remains to be done to achieve the improvements in river health that are promised by the concept of integrated natural resource management.

A Whole System Approach to Weir Management

In developing an optimal strategy for addressing the impact of weirs on river health, some fundamental questions regarding river health require prior consideration. These include:

- How significant are the environmental and / or economic aspects of the weir(s)?
- What are the values of the modified environments created by the weir(s), and how should / may those valued be assured?
- Are the original purposes of the weir(s) still relevant, and does the weir (group of weirs) still serve those purpose(s)?
- Are there cost-effective alternative means of serving the original purposes, and what are the environmental and institutional / legal implications of any such alternatives?
- Are there other actions in train to improve river health, such as measures to improve environmental flows, whose effectiveness would be impaired by the existence of the weir(s)?

4 Recognition must, of course, be given to the need to maintain centres of expertise and to reduce tasks to manageable proportions, via specialist agencies. However, such realities strengthen the need to develop and apply strategies to integrate the efforts of multiple players, including resolving differences between competing interests.

5 The NSW Government endorsed the Healthy Rivers Commission's recommendation to set up, for the first time, the concept of an integrated effluent management strategy for the Hawkesbury Nepean River (Debus 2000). Efforts initially will focus on the feasibility to transfer up to 160 megalitres per day of highly treated sewage effluent from sewage treatment plants in the South Creek catchment to the lower Nepean River, via the Penrith Lakes Scheme, to make-up environmental flows in the river system. See HRC (1998) or Hurst (1999) for greater detail of this concept.

Consideration of such questions in the case of the upper Nepean River, leads to the conclusion that a 'whole system' approach[6] to improve river health would involve releasing sufficient flows from upstream storages for environmental flow purposes, removing many of the weirs, and implementing a number of measures to offset negative impacts on irrigators (HRC 1998). Important amongst those mitigation measures would be providing (directly or indirectly) highly treated sewage effluent from local sewage treatment plants and/or marginal increases in water releases from upstream storages to provide for irrigation purposes. Figures 1 and 2 show a schematic comparison between the palliative and whole system approaches.

Figure 1: *Palliative Care Approach*

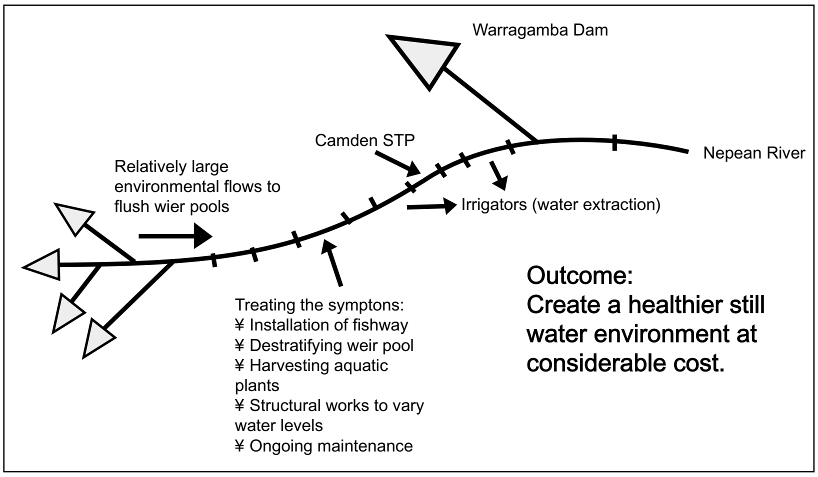
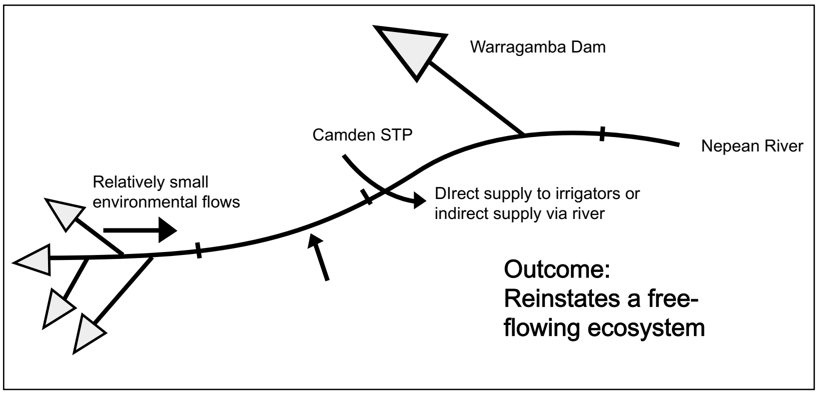


Figure 2: *Whole System Approach*



With regard to the use of sewage effluent, it is notable that average dry weather discharges from a local sewage treatment plant at West Camden is forecast to increase to about 23 megalitres per day by 2021 (SWC 1996). Such a volume would satisfy a substantial proportion of the water requirements of existing irrigators (Webb McKeown 1996, HRC 1998)[7]. In the past, that alternative has not been perceived as cost-effective because the relatively high costs of adequately treated sewage have been compared with the lower costs to farmers of direct extraction of river water, via weir pools. However, such comparisons have been based on certain assumptions that are no longer appropriate.

Previously, the costs at which the supply authority would make treated sewage available would reflect only the costs of treating the effluent to the necessary level, (in addition to any reticulation/delivery costs). Now, however, operators of sewage treatment plants are increasingly being required to reflect a broader range of river health considerations into their decision making. That is, they are obliged to ensure that sewage disposal involves not only appropriate treatment, but also its release in appropriate patterns and locations. The new costs will enter into the determination of the prices at which effluent would be delivered to agricultural (or other) users, tending to decrease that price. At the same time, as the real value of river flows is understood and increasingly recognised in the

6 A whole system approach is akin to the public policy concept of 'backward mapping' (Elmore 1980). That is, management effort is directed toward addressing the primary cause(s) of a problem from a holistic perspective, rather than its symptoms.

7 Provisional estimates of water extractions in the whole upper Nepean catchment range between 15 to 40 megalitres per day, based on values derived from users' water returns and remote sensing techniques (Webb McKeown 1996). Note that careful assessment is warranted to determine the feasibility and type of sewage treatment required for the irrigated crops grown in the area, although preliminary analyses undertaken by SWC (1997) indicate suitability subject to some additional treatment.

rules governing farmers' access to river water, the attractiveness of the alternative secure supplies will increase. In summary, then, a full system approach would lead to the conclusion that the preferred option would be the removal of the weir(s), rather than retention with associated maintenance and palliative measures.[8]

Conclusion

Much remains to be done to achieve the improvements in river health that are promised by the concept of integrated natural resource management. A critical step is applying the principles for securing river health demonstrated in this paper.

This is particularly true for the management of weirs, generally, and for those along the upper Nepean in particular. A major finding of the Healthy Rivers Commission's Inquiry into the Hawkesbury Nepean was that a healthier riverine ecosystem and a sustainable pattern of resource use could be achieved at a tolerable cost to resource users. Removal of some weirs, and improved management of those remaining are, potentially, key mechanisms through which that outcome will be reached.

In its response to the Commission's Hawkesbury Nepean Inquiry, the NSW Government has stated its intention to pursue such an approach in the upper Nepean River. The challenge to carry through the Government's decision has been assigned to the NSW Weir Review Committee, which must now examine options of the type outlined in this paper.

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8 See HRC (1998) for further discussion of how full internalisation of real costs may alter the perceived cost effectiveness of various river management options.

Biography

Anthony Hurst is presently engaged as a Strategic Policy Analyst with the NSW Healthy Rivers Commission, in which he is currently managing the Independent Inquiry into Coastal Lakes. Anthony previously led the Commission's Inquiry into the Clarence River and preparation of a report on strategic issues relating to all coastal rivers.

Anthony has a diverse background in managing riverine resources, which includes experience in the areas of environmental flows, coastal floodplains and estuaries, fluvial geomorphology and greenhouse strategies. He previously worked for the former NSW departments of Water Resources and Public Works. Anthony's undergraduate studies focussed on fluvial and coastal geomorphology and he recently completed a Master of Management in public policy.

The Future of Weir Management in the Murray-Darling Basin: Towards a Rational Approach

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Introduction

Along the Murray, the drought of 1902 was a culmination of a series of dry years that commenced in 1895 – only eight years after the establishment of Australia's first large scale irrigation developments at Renmark and Mildura. The rest is history – at the 1902 Corowa conference, Australia's first Prime Minister, Edmund Barton, noted that the conservation and distribution of River Murray water would be one of the "first fruits of federation". Fifty-five years of weir and dam construction followed in the Murray and Darling River systems, commencing with Lock 1 at Blanchetown in 1913. As the riverboat trade continued to decline throughout this period, the motive is often today assumed to be primarily increased security of irrigation, stock and domestic supplies. However low river levels were also seen as denying public benefits such as fishing and hunting and threatening public health – the "sluggish" flow and "insignificant" volume of water in the polluted Murrumbidgee River were reported to the 1902 Royal Commission as threatening Balranald with an epidemic of typhoid.

The same variable nature of climate and river flows in the Basin still exists today, but with an even greater dependence on security of supply, due to the growth of industries and their dependant communities both within and outside the Basin. Consequently, the rivers of the Southern Basin are highly regulated. The total volume of "government owned" storages is about three times annual consumptive use and more than double the average natural flow to the area (Fig. 1).

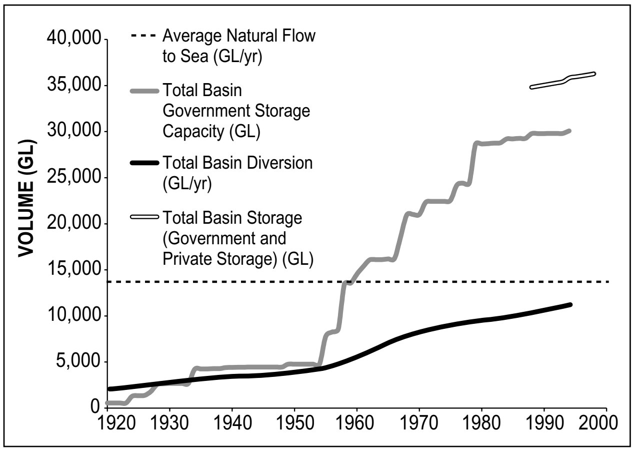

Figure 1: *Growth in diversions and river regulation, Murray-Darling Basin*

Outline of the Scale of the Issue in the Basin

An interstate database on barriers to fish migration, funded by the Commission, identifies more than 3,600 structures within the Murray Darling Basin that provide some form of barrier to fish movement. The area of backed up water for the 237 "major" dams and weirs in the Basin have a combined surface area of 180,000 hectares. Together with the area of backed-up water of the remaining 3,400 medium and small sized weir pools, it can be readily understood why there are large-scale impacts from weirs. These impacts include:

- habitat conversion from flowing to still water, with attendant changes in biodiversity and problems such as elevated algal growth and favouring of exotic species;

- impediments to movement, particularly of fish;
- direct mortalities, particularly of vegetation and fish;
- groundwater elevation and increased surface salinities;
- increased evaporative losses; and
- a build-up of sediment and nutrients.

And, this is on top of the impact of regulated flow, particularly in the southern rivers of the Basin, such that:

- there are "unnatural" high summer flows and low winter flows;
- the incidence of small to medium range floods and drought has been removed;
- there is cold water pollution downstream of major structures; and
- many floodplain wetlands have been alienated from the rivers by levees and development.

On the other hand, management of weirs can bring benefits to the riverine environment, such as:

- allowing re-regulation of releases from upstream storage;
- creating small-scale flow variations at preferred times of year; and
- providing refuge habitat in times of drought.

Managed Sustainability

There is current enthusiasm for weir removal with wide reporting of celebrated cases in North America and Europe. The logical and rigorous review process under way in New South Wales has identified about 100 structures to be considered for decommissioning. However, this is only one element of an effective program to rehabilitate the riverine environment and will provide only a small proportion of the benefits that can be achieved through structural and operational changes in weir management.

The Commission's focus is on existing structures, and their refurbishment and management as part of the solution. So often now, in the face of major degradation issues, we have to manage our way to sustainability because "letting nature take its course" is no longer an option capable of getting results. And in doing this, there are increasing challenges in making decisions to balance environmental, economic and social outcomes.

Nevertheless, there are options for changes to structures and their operations:

- re-introduction of downstream flow variations and weirpool level variations;
- increased periods of weir removal;
- judicious (and harmonic) offtakes for algal bloom control;
- fishway installation;
- automation of release gates and releases; and
- enhanced offtake structures.

A scan of the research literature and investigations reports shows that there has been a considerable amount of work done, but that action has not been commensurate with the knowledge and recommendations put forward. Continued research will be required, but also close monitoring and adaptive management on the structures under consideration.

Commission Operated Structures

Future management of weirs is a major and growing issue for the Commission. It owns and operates assets 70 to 80 years old, some of which have already experienced failure, with the probability of wider failure continuing to rise until the risk is unacceptable. In terms of a planned program for replacement of weirs (Fig. 2), it is anticipated that the economic, social and environmental benefits and costs associated with each structure would be reviewed on a case by case basis, and decision options will include alternatives to current structures.

Regarding weir operation and refurbishment there is a program of investigations, feasibility studies, design principles, capital works, changed operations and review. From the Murray Mouth to

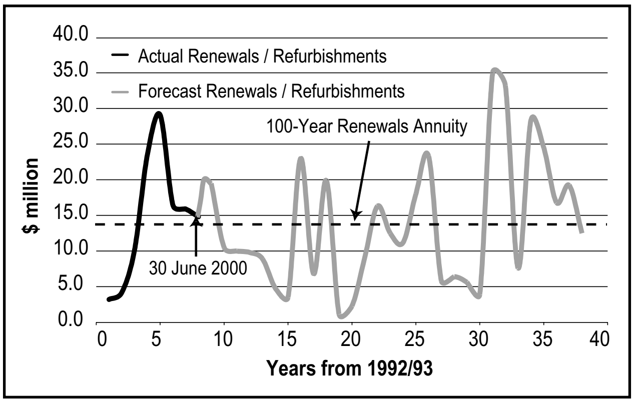

***Figure 2:** Forecast expenditure for refurbishment or replacement of structures, Murray-Darling Basin*

Dartmouth Dam and Menindee Lakes, changes are under way to improve environmental outcomes. In summary:

Barrages: A feasibility study is to evaluate automation of their operations to improve occupational safety and flow management for sediment control and to provide fish passage. At the same time a specific study is examining the potential causes of migratory bird decline on the Coorong which may be related to sediment sorting, and a much larger study is looking at future management of the lower lakes.

Locks and weirs: For occupational health and safety reasons, alternative structures to the navigable passes are being evaluated. This will be a major refurbishment. As each structure is upgraded, fish passage will also be provided, with options ranging from passage through the lock to a purpose built fish ladder. Design principles and cost estimates are being prepared.

Yarrawonga Weir: In 1998 dead fish were found at the inlet of the hydro power station raising concerns that the adjacent fish lift may have been responsible. While research into the possible cause continues, six options are under evaluation to improve the operation of the fishway.

Hume and Dartmouth Dams: The Operations Review is now being implemented, with a focus on a conservation management plan for the downstream river reaches. Specifically, the option of adding a variable offtake to the high level outlet at Dartmouth has been assessed. Options for limiting the cold water problem from Hume are under consideration.

Weir pool management: Preliminary work is underway for a weir drawdown trial, possibly to be conducted at Euston Weir. This experimental design stage involves:

- identifying physical constraints to weir operations;
- identifying attainable environmental objectives;
- providing specifications for trial drawdown;
- specifying methods for monitoring ecological responses; and
- undertaking an environmental, economic and social analysis of the impacts.

Environmental flow and water quality management for the River Murray: A much larger project is now well under way, with the goal of an interstate agreement on future management of the whole length of the Murray, to improve environmental outcomes. This raises all kinds of issues in management of dams, locks and weirs but also beyond them – to other impediments such as alienation of the floodplains and the impacts of human activity on the river. There is no shortage of highly competent scientific and technical reports, with a strong focus of re-introducing flow variability. The challenge is building a community and government consensus around the trade-offs involved.

Towards a Rational Approach for the Basin

With the weir review underway in New South Wales, and activities in other Basin states such as fishway programs, asset management and review programs, improved water use efficiency programs, the question is whether the aggregate of State actions will amount to the best outcome for river environments of the whole Basin. Priorities will differ for individual actions, depending on the scale of work attempted, and the outcome may not be sufficient to provide for fish migrations, for example. But is there a need for a Basin-wide process of weir review that would give consistency of approach and therefore more certainty of beneficial outcome?

There is a community expectation that the Commission should lead strongly on broad environmental issues in the Basin. Although the Murray-Darling Basin Agreement provides the authority necessary to protect the water quality and quantity in the Murray-Darling system, it is done in a prescribed way – by agreement. Its Ministerial Council decides on policy and the Commission implements strategies, in areas where interstate co-ordination is required and where its program adds value to what the partner governments are capable of doing in their own right. This principle applies to weir management.

The Commission will facilitate states developing policies in weir management and fish passage, supporting them with knowledge. To the extent that the scope of such policies range across state borders there is a role for the Commission. Certainly, for the “shared rivers” – the River Murray and the Darling River below Menindee Lakes there is a Commission responsibility. Further any proposed development anywhere in the Basin likely to impact on the “shared rivers” – such as a new weir – is referable to the Commission for assessment and advice to the decision authorities.

In summary, a rational approach to weir management in the Basin has the following features:

- a logical and rigorous process for weir removal is beneficial but a small part of the solution;
- there needs to be a pro-active and resourced program of structural and operational changes to weir management;
- the Commission is doing this for structures on the Murray and Darling Rivers, through a knowledge driven process and changes to structures as they “fall due” under capital replacement requirements; and
- the Commission can facilitate, particularly through better knowledge, a Basin-wide approach while presiding over accountable management of structures on the River Murray and Lower Darling.

Over the next year or two, the Commission will be embarking on two policy initiatives that can work in tandem with improved weir management to benefit the riverine environment:

- the Sustainable Rivers Audit; and
- the Native Fish Management Strategy

Biography

Kevin Goss holds the position of General Manager, Natural Resources with the Murray-Darling Basin Commission, having spent his earlier working life in Western Australia. He holds an MA (Communication) from Michigan State University and a BSc (Agriculture) Hons from the University of Western Australia. Kevin’s job in the Commission is to manage the ‘Basin Sustainability’ component of the Murray-Darling Basin Commission (MDBC), across the spectrum of water resource allocation, integrated catchment management and riverine environment protection. Also, he is the Commission’s Deputy Chief Executive, and has a broader policy development role.

Kevin Goss’ professional career began as an agricultural extension officer in the WA Department of Agriculture (1970). His involvement in natural resources management came relatively late (1989) when he led the Department of Agriculture’s Western Australia Landcare program, which culminated in the joint appointments of Commissioner of Soil and Land Conservation (1993) and Executive Director Sustainable Rural Development (1995). Kevin lists among his recent achievements the writing in part of the inaugural Western Australian Salinity Action Plan and the administration of clearing controls and remnant vegetation protection in that State.

Engineering Solutions for Alternative Water Supply for Small Towns

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Abstract

In New South Wales over 4,000 weirs and dams have been installed in rivers for various purposes including irrigation, transport, recreation and/or water storage. A proportion of these structures provide security of water supply to communities along the river whereby water is extracted from the weir pool and fed to households following some form of treatment. PPK was commissioned by the World Wide Fund for Nature to investigate five sites in central western NSW, with a view to demonstrating that alternative water supply solutions exist that enable the affects of barriers to be significantly reduced or removed entirely.

The five sites selected that currently use river water from weirs as their primary source of town drinking water, were Louth, Tilpa, Pooncarie, Yeoval, and Glen Innes.

A range of possible alternative water supply options are discussed in this paper, including modification to the existing weir structures, groundwater as an alternative source, in-stream storage of river water, off-stream storage of river water, increased rain water storage, all combined with demand management strategies. The engineering and non-engineering factors influencing choice are discussed, including site specific environmental, hydrogeological, economic and social considerations.

Introduction

This paper investigates alternative town water supply options for small towns in central western New South Wales (NSW) which currently use river water from weirs as their primary source of town drinking water. It is based on a study that was undertaken for the World Wide Fund for Nature that included an assessment of five weirs at Louth, Pooncarie, Tilpa, Yeoval and Glen Innes. Weirs that solely supply water for the town were chosen. Weirs providing irrigation supply were not examined.

Providing water to towns by methods other than from weir pools can help address issues regarding water quality, water availability and habitat created by weirs. These problems are not discussed in this paper. Rather, the paper focuses on one of the original five case studies, Louth weir on the Darling River, to demonstrate alternative water supply options.

The case study involves both a desktop assessment and a site visit. The existing condition of the weirs was investigated, and feasible alternative water supplies formulated.

Alternatives were evaluated according to engineering, environmental and economic aspects. The ecological assessment was desktop based with no qualitative or quantitative data. In general, alternative options were selected on the basis that they would encourage the removal or modification of the weirs, and the re-establishment of more natural fish passage. Water supply options were also evaluated against practical feasibility, available yield, capital costs, renewal costs, operational and maintenance costs, treatment, social issues, environmental benefits and disbenefits.

The Role of Weirs as a Water Supply

Historically, weir pools have supplied storage for town water by filling with river water. River flow is provided either by natural run-off or regulated by releases from upstream dams. Water is generally pumped from the weir pool to temporary storage tanks from where it is reticulated to consumers, either with or without treatment. Weirs provide sufficient security of supply during prolonged dry weather by ensuring adequate water is available throughout drought periods before being replenished during wet weather. The size of storage depends on the size of community it serves and the security of supply required, which is governed by historic rainfall frequency.

Alternatives to Weirs — Engineering Details

Alternative water supply options must provide similar security for prolonged periods of drought. There are a number of generic options worth considering as water supply alternatives to the traditional small weirs used for small town and village water supply. The engineering details and environmental consequences of these options are detailed following. Combinations of the options are also considered. All options should be considered in conjunction with a demand management strategy and increased use of rainwater storage to minimise reliance on the town supply source.

Water Demand Projections and Water Security

In developing alternative options, typical water supply demands were used to size alternatives. Typically, demands can vary as shown in Table 1 below.

Table 1 indicates that average demand can be as low as 110L / day / person. The rural areas under consideration, however, appear to have an outdoor demand well above average which may in part be due to domestic irrigation of gardens. To account for this, while at the same time allowing for improvements in domestic use due to demand management, a target average demand of 367L / day / person is considered reasonable for this exercise.

Alternative water supply options investigated in this paper consider only the town water supply requirements, and do not include any demands from stock. This is because there is no evidence that the weirs have any measurable effect on stocking rates in drought times, as these are generally limited to the availability of feed and not water (Department of Water Resources 1989).

Three to twelve months storage is usually sufficient security (Engineering and Water Supply Department of SA 1987), but should be evaluated on a case by case basis, depending on rainfall patterns, river flow, available finances and end-use requirements. This will vary according to population and capital required to provide an appropriate off-stream storage. In general, where finances permit, it is considered that in sizing water supply headworks for small communities a

Table 1: *Supply Level Guidelines (WSAA 1999)*

		Min. Supply Level[2]	Basic Supply Level	Desirable Supply Level[3]
Total average day residential demand	(L / day / house)[1]	330	715	1,100
	(L / day / person)	110	238	367
Total peak day residential demand	(L / day / house)[1]	500	1,500	3,000
	(L / day / person)	167	500	1,000

1 For per house usage an occupancy ratio of 3 has been adopted.

2 Where water resources are very limited and no allowance is made for outdoor demands.

3 Where increased supply can be provided at reasonable cost.

reasonable level of water supply security can be based on the following conditions (Department of Primary Industries and Energy 1989): the frequency of water restrictions should not exceed once in 3 years on average; the duration of restrictions should not exceed 10% of the time; and the severity of restrictions should be such that 70% of normal demand can be supplied through a repeat of the worst historical drought starting at the time restrictions are first applied. No such detailed analysis of security requirements has been undertaken for this paper. Twelve months was assumed as a preliminary estimate for Louth.

Water loss through either evapotranspiration and/or ground infiltration should be allowed for in sizing of storages. Weir pools and turkeys nest dams lose water through evapotranspiration, while both dams and aquifer storages lose water through infiltration into the ground. For sizing alternative storage options, the depth of the storage has been increased to allow for losses of 2,000mm/year or 500mm/3 months. This includes an allowance for evapotranspiration of 1,700mm/year, and an infiltration rate of 10mm/month has been adopted, as recommended by the Environment Protection Authority (EPA) Draft Environmental Guidelines The Utilisation of Treated Effluent by Irrigation (EPA NSW 1997). These values will vary depending on the local climate, soil type and the existing groundwater regime.

Modification to the Existing Weir Structures

If retained, structural changes to weirs can help to reduce their environmental impact.

For fixed weirs (no moving parts), weir modifications that could be undertaken to reduce impacts on the aquatic environment include: reducing the crest level and pool storage volume to the minimum level; installing a larger outlet to allow the release of environmental flows or water level variation; installing dropboards or gated openings to allow free flow when storage is not needed; or constructing a fishway.

For regulatory weirs, where flows downstream of weirs may be modified by sluice valves (gates that control the flow of water) or flood gates, examples of weir modifications are: achieving water level variations; ensuring that discharge over weir and drawdown of the weir storage mimics the natural variation of water level within and downstream of the weir; and raising gates fully when a water storage is not required.

Groundwater as an Alternative Source

There are three groundwater options that can be considered as potential water supply options. Option 1 involves the use of a naturally occurring low salinity groundwater resource, Option 2 involves using artificial recharge of an existing groundwater resource, and Option 3 involves using artificial groundwater recharge to create a resource. All groundwater options should ensure that aquifers are a safe distance from any town septic systems. The groundwater options are considered in more detail following.

Option 1 relies on the natural characteristics of the underlying rock formations to provide satisfactory groundwater storage for water supply. At some sites, where towns and villages are close to major creeks and rivers, and where floodplain sediments have been deposited, there is some potential for shallow groundwater supplies. In cases where these shallow deposits are not present, exploration into the underlying rock formations is the only other alternative groundwater supply. Available supplies and groundwater quality are extremely variable for both alluvial and fractured rock aquifer supplies. The groundwater potential of each weir site needs to be assessed on a case by case basis.

Option 2 involves maintaining or improving the reliability of an existing low salinity resource in an aquifer. This option may be possible at some locations where it is feasible either to develop a larger aquifer storage of low salinity groundwater, or to improve aquifer storage quality by displacing brackish or marginal quality groundwater. The latter may be applicable in alluvial areas with shallow aquifers located some distance from the river. Low salinity surface water harvested from the river (when available) would be used to artificially recharge the shallow aquifers using different methods.

The methods vary from excavated trenches and pits, to formed earthen basins and weirs on the floodplain and along flood-runners. The stored water permeates through the ground to the aquifer. In some instances, groundwater injection boreholes are preferred, where water is injected under pressure. The selection and detailed design of these structures can only be determined after extensive site investigations. Dedicated weirs are commonly used for recharge in Queensland and there are a few examples of earthen weirs in New South Wales. Basins and injection boreholes are rarely used because of clogging and maintenance problems.

Option 3 is to create a low salinity aquifer system using the void spaces in the underling formations above the naturally occurring water table. In effect it is to fill the unused airspace in the formation to create an artificial aquifer system. The physical characteristics of the rock formations and the formation salinities need to be suitable for such a scheme to be feasible.

The engineering techniques required are the same as those described for the second option. There are no known examples of aquifer storage and recovery in eastern Australia, although the technology is used in South Australia and Western Australia.

In-stream Storage of River Water

In-stream storage can be large, natural depressions in a river which will normally retain water beyond the no-flow periods of the river; natural flood-runners connected to the river; or man-made modifications to a river such as excavation or weir modification which increase the capacity of in-stream storage.

A flood-runner is an abandoned river channel on a flood plain that takes high to medium level flows during floods. Where flood-runners are used as off-stream storages by constructing a weir care should be given to ensure that the weirs do not result in the permanent flooding of natural wetland and riparian environments.

Off-stream Storage of River Water

Off-stream storage involves pumping water from a small depression in the riverbed to a man-made dam or existing natural oxbow lake or billabong. Water is stored in these structures and then pumped to the town. The pump could be a submersible type in a protective housing structure or raised and lowered into the river on rails, and would operate when river flows permitted.

The off-stream storage would be sized for approximately a 3-12 month storage capacity, depending on site specific level of drought security that is required. Off-stream storages are sized to accommodate the demand and natural losses from evaporation and exfiltration. Evaporation can be controlled by the installation of covers or filling the structure with sand/gravel. Neither of these control options have been considered for the sites, as they cannot be justified economically.

Increase Rainwater Storage

Rainwater is a highly valued water resource owing to its excellent quality (potable quality) and availability. Rainwater is especially valuable in areas where other forms of water supply are high in salts, particularly bicarbonates, iron or sulphates. Rainwater can supply a significant proportion of household water needs even in areas of unreliable rainfall.

A full rainwater supply for all internal household needs is possible with a large enough roof area and tank capacity. This can be provided by a large shed or purpose-built roof structure connected to a tank. Such a system could supply 400L per day at 90% reliability in arid areas. A full rainwater supply system such as this can be a cost effective alternative where other water supplies are not available or of very low quality (Engineering & Water Supply Department 1987).

Demand Management Strategy

In all cases, a water demand strategy should be developed and implemented to conserve water. Encouraging water efficiency is an inexpensive and successful way of conserving water. Upgrading appliances that use water using modern technologies, or the practise of water harvesting, are ways of achieving water use efficiency.

Potential improvements that may reduce the demand from existing and alternative supplies are dual flush toilets (or simply putting a brick in the cistern); improved gardening and watering practices; planting trees adapted to dry conditions; charges for excess water use; contour banks encouraging surface water storage thereby enhancing terrestrial absorption; wind reduction techniques; recycling greywater from the bathroom and laundry or kitchen wastewater, for use on garden areas; wastewater treatment systems can provide irrigation water in public areas, replacing traditional methods of disposal of septic tank effluent; and leak detection and minimisation.

Water Treatment

Usually only the more basic treatment processes are applicable to small rural communities as both operational skill requirements and costs become prohibitive. Depending on the quality of source water, treatment is generally limited to processes such as aeration, sedimentation, filtration, pH adjustment and disinfection. Disinfection with chlorine to maintain a residual in the distribution system may be appropriate. Some of the specific processes that can be included, where necessary, are activated carbon dosing for toxin or blue-green algae removal, sedimentation in storage assisted by chemical dosing to improve the quality of highly turbid surface water, and microfiltration using filter membranes with microscopic holes to screen out particles as well as parasites such as Cryptosporidium and Giardia.

Rehabilitation of Environment after Weir Removal

Areas of environmental degradation caused by the impacts of weirs upstream and downstream of weir pools should be rehabilitated where possible. Where silt has built up behind the weir, managing the removal or modification of the weir should ensure that the silt does not cause degradation of water quality downstream. Examples of impacts that need to be determined at an early date (American Rivers 1999) are: the presence of pollutants in the river; the volume of sediment upstream of weir and potential impacts of sediment downstream; and potential hazards and blockages in the weir pool that could become exposed with dam removal.

The effect of lowering the level above the weir removal site must be evaluated. Specifically, susceptibility to erosion or movement of materials in and near the river bed. Some important hydrological impacts of the removal of a weir are: increased flow velocities upstream and downstream of the weir, resulting in higher erosive capacity of the river; local scouring around the weir site due to removal of bank vegetation arising from weir construction and flooding of the weir pool; higher flow depths and flood capacity downstream of the weir; and lower flood capacity upstream of the weir.

Case Study of Louth Weir (Darling Weir No. 21)

General

The town of Louth is located on the Darling River some 106km south west of Bourke, NSW and has a population of approximately 40 people. The weir is located approximately 20km (road distance) downstream of Louth and is currently used to provide town water supply for Louth and some local stock supply. Darling Weir No 21 was built in 1979 and is a fixed type weir constructed from sheet piles, concrete and stone and includes a submerged orifice fishway – a box culvert. The weir is considered ineffective by the NSW Fisheries Research Institute. Before it was constructed in 1979, river water was pumped directly from the Darling River when flows allowed.

The level of the weir is such that water backs up to Louth where it is pumped from the river to elevated holding tanks. River water is supplemented by groundwater pumped from a local bore located to the east of the Louth river crossing. Rainwater tanks are also used by several Louth households to provide additional alternative supply. River water and bore water is pumped to, and held in, separate elevated holding tanks which feed two separate reticulation systems that serve the community.

The local operator of the town water supply reported that the groundwater bore is able to meet current demands of the whole Louth community without the use of river water. However, the bore water is considered by some of the community to be of poor taste and is high in iron, which has caused operational problems with some household goods such as evaporative air conditioners. An additional groundwater bore was drilled on the western side of the Louth river crossing and commissioned to supplement river water supply during the major blue-green algae outbreak of 1991. This bore, although originally successful, has since proved an unreliable source and has thus been abandoned. During the 1991 blue-green algae outbreak all river water taken for town water supply was pumped to holding ponds and chemically treated for at least 24 hours prior to being filtered through carbon and sand filters. Following this treatment the water was held in the elevated tanks prior to being fed to the reticulation systems. The holding ponds and filters are not currently in use.

The local operator indicated that water use averages approximately 91kL/day or 33ML/year (for domestic use and some stock). From preliminary calculations the weir's upstream storage is of the order of 500ML which by itself is well in excess of the existing domestic water demands of the town.

Riparian Environment

Land to the north west of the weir is well wooded with eucalypt woodland lining the banks. The south eastern bank has been cleared and now consists of scattered eucalypts and pasture. The south eastern bank is covered with loose rock, which could be easily eroded in times of flood. There is little riparian vegetation, and the vegetation on the banks is now dominated by pastoral grasses. Little remains of the riparian vegetation that would have existed prior to the introduction of domestic stock and, perhaps the construction of the weir.

Both the banks are being cut in part, with the north western bank undergoing major geomorphological change. Just downstream of the weir, the banks have been actively eroded. Works have been undertaken to batter the eroding banks. At the time of the site visit the water in the weir was cloudy and water was freely flowing over the weir. It is unknown as to whether or not the weir undergoes periods of no flow.

Geology and Hydrogeology

Louth is located on Quaternary floodplain alluvium deposited by the Darling River and its ancestral streams. Ordovician rock outcrop occurs immediately north of Louth in the area known as Dunlop Range. Department of Water Resource's drilling at Louth during the Blue Green Algae Emergency in 1991 (Department of Water Resources 1992) indicated there was around 15m of alluvial sediments (clay and sand) above silcrete and weathered shale/coal bedrock. At this bore site (#39477), immediately west of Louth, alluvial clay extends from surface to around 13m depth with a thin sand aquifer to 15.5m depth. The silcrete and ironstone horizon extends to 24m, with weathered and solid rock to the final depth of 29m. There are no other rock or sediment outcrops in the vicinity of Louth. In the area of weir #21 downstream of Louth, Devonian sandstone bedrock is likely to occur. The depth of alluvium is uncertain but 29m of alluvium was intersected at the Milpa River Well emergency bore site (#39481) located about 15km to the south.

The hydrogeology of the Darling Basin is described on the Australian Geological Survey Maps (AGSO, 1995). Alluvial thicknesses are up to 130m and the sediments are generally considered to be a two aquifer system. The deeper aquifer below 40m (where present) contains saline water generally in the range 30,000 to 50,000mg/L TDS (total dissolved solids)[1]. The shallow aquifer less than 40m has variable salinity between 200 and 8,000mg/L TDS. Areas close to the river generally have salinities less than 1,000mg/L TDS. In the vicinity of Louth, fresh and slightly brackish water can be expected close to the Darling River and flood-runners. The yields from these alluvial aquifer systems are largely unknown but are expected to be in the range of 0.5 to 10 litres per second (L/s). The hydrogeology of the bedrock Ordovician shales is expected to be high salinity groundwater with low yields less than 0.5L/s. The potential of the Devonian sandstones is unknown but the formation probably contains brackish to slightly saline water with low yields less than 5L/s.

Alternative Water Supply Options

In determining alternative options and their approximate sizes, it is assumed that water for stock use is independent of weir storage, water demand is approximately 367L/day/person, and storage for 3 to 12 months has been assumed. Hence alternative water supply storage volume in the order of 2 to 16ML is required, including allowances for evaporation and ex-filtration losses.

1 Acceptable salinity levels (measured as Total Dissolved Solids) are as follows (AGSO, 1995):

TDS (mg/L)	Accepted Uses
<500	All purposes, domestic and irrigation
500-1,000	Most purposes
1,000-1,500	Most purposes, upper limit for drinking (accepted in remote areas)
1,500-3,000	Limited irrigation, all livestock

Costs

A breakdown of estimated costs are provided in Table 3. Non tender costs are included in these estimates with the exception of the preparation of environment impact statements as the need, at this stage, is unknown.

Table 2: *Louth – Alternative Water Supply Options*

Weir Modification	Louth weir could be modified by reducing storage volume to suit demand by lowering the weir crest level; by installing a deep outlet notch in the weir with a drop board (or a combination of both); or by constructing a fishway through the notch or to the side of the weir.
Weir Removal	
Naturally occurring groundwater resource	As mentioned previously, the local operator of the town water supply reported that the groundwater bore is able to meet current demands of the whole Louth community without the use of river water, but that the bore water quality is not entirely adequate. An option is to use the existing treatment facility of carbon and sand filters, which is used typically for algae outbreaks, for the daily potable supply from the existing bore. If this is not sufficient, improved supplies may be possible about 1km to the north west close to the Darling River and in the vicinity of the abandoned river meander/flood-runner, however confirmation of this would require a geophysical investigation and/or an extensive test drilling program. (Note that the underlying bedrock shales near Louth have no groundwater potential and should not be considered for potable supply.)
Naturally occurring groundwater resource which has been alluvial formation.	A low level weir on a flood-runner west of Louth and selected excavation to expose shallow sands (if present) would be an ideal site for artificial recharge of the shallow alluvial formation. However, the shallow stratigraphy, depth of alluvium and existing groundwater quality in the area must be assessed with a test drilling program prior to serious consideration of a recharge scheme at this site. (Note that the bedrock aquifers are unsuitable for artificial recharge).
Artificial ground water resource	The water table depth at Louth is around 11 to 12m from surface. The shallow alluvial aquifer is fully saturated and the overlying sequence appears to be entirely clay. Based on this assessment, there are no prospects of creating an artificial groundwater system and providing for aquifer storage and recovery. Similar conditions are expected to exist immediately upstream and downstream of Louth.
In-stream storage	A low level weir on a flood-runner with excavation if necessary to provide sufficient storage volume, for example 1mx20mx132m for three months storage, or 3mx20mx264m for 12 months storage. Filling of storage would be by gravity if levels permit, otherwise by flood harvesting. Town supply would be pumped from the weir pool to the existing treatment facility.
Off-stream storage of river water	The local pump operator has indicated that river flow (without the weir) would be sufficient most of the time to allow pumping from the river to an off-stream storage. Flood harvesting from a natural or excavated depression in the river to an off-stream reservoir near the township would be appropriate. For example, a reservoir size 2.5mx26mx26m for three months storage, or 4mx73mx73m for 12 months storage. This would be in the form of an earthen dam created in a natural depression or a turkey's nest.

Table 3: *Louth - Summary Costs of Weir Alternatives*

Weir and alternative	Running Costs[1]	Capital Cost $ Assuming 3 Months Storage	Capital Cost $ Assuming 1 Years Storage	Capital Cost $ Rainwater Supply
Louth				
Modification to existing weir	L	87,000	87,000	
Groundwater source	L	1,655,000	1,655,000	
Storage on flood-runner	M	1,410,000	1,410,000	
Off-stream storage	M	1,090,000	1,245,000	
Full household rainwater supply[2]	L	-	-	583,000-875,000

1 For comparison purposes, running costs are either L (low), M (medium), or H (high).

2. Costs taken from Table 2.8 Water conservation measures for rainwater supply plus 20% for non-tender costs and contingencies.

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Biography

Tahmina Smyth has worked as a Civil Engineer for four years, is a member of the Institution of Engineers Australia and is a Registered Professional Engineer. Tahmina's engineering experience has encompassed work both in construction and consulting. Her design work has been primarily in the geotechnical and water and wastewater fields. Work in these fields has involved design from initial feasibility studies to completed detailed design. Recent projects include small town water supply and sewerage systems; biosolids and effluent re-use systems; and a study of water supply options for small towns. She has also undertaken environmental assessments and community consultations as part of her consultancy work, and enjoys the variety of skills these jobs require. This is also reflected in a background of both Civil Engineering and Science studies at university.

To maintain a balance with areas outside her work and keep herself informed, Tahmina enjoys work she has undertaken as a volunteer for environmental groups. She is very interested in the ongoing debates revolving around inland rivers, and enjoys finding out about parallel yet different experiences from all over the world.

Developing Trust to Enable Partnerships to Develop: Partnerships Can Lead to Success

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Abstract

How many times have I heard the saying "Community and government working together for clean healthy and productive rivers?" or "there are trade offs".

Most of the slogans that have been used for the last six years have been just that, slogans.

The hardest process of all is giving ownership of a concept, a problem or a solution if they have not been given the dignity of considering it, discussing it and feeling it beforehand.

This is even more pronounced if the salesman lives in some other world.

Contrary to some peoples' belief, 99.9% of the members of the community that I meet want to see their environment managed well, with an absolute minimum requirement of halting degredation as the prime goal.

There are at least two major impediments to better management of our environment, they are fear of change and cost.

To overcome the fear of change it is essential that there is trust between all parties involved.

Once trust has been established and demonstrated, it becomes easier to manage and distribute cost.

Fear of change and the issue of cost are the agenda items that all Governments and their Agencies fail to manage at all well.

Many community groups also fail to realise the significance of the depth of feeling and effects of not managing them well.

All good Partnerships are formed on the basis trust, so let's look at Trust.

Introduction

Caring for the environment is not a new idea or ethic for large numbers of Australians. Our nation is fortunate to be wealthy enough to afford an extremely high standard of living, with support structures for the less fortunate in our society. We have taken great pride in, and indeed many have taken for granted, our stable and democratic way of life.

Governments and organisations have recognised that to really make an impact on past mistakes of management of our natural resources there needs to be a more strategic or global commitment of effort to addressing the issues involved.

In most instances we have collectively broken through the impediment of apportioning blame for management in the past that has led to such huge change to the natural environment throughout Australia.

There is real evidence that there are many groups and individuals that have been disenfranchised by the process so far.

It does not matter if this is reality or perception, because in the end there will be major difficulties and challenges that will have to be dealt with before real and continuing environmental gains are achieved.

There must be a review of the processes that are in place to capitalise on the gains already made, and ensure that individuals are not disadvantaged or dispossessed for the common good.

Many governments have used legislation as the tool of change, and paid the price later, demonstrated in the ballot box or through failure to achieve the desired outcome despite the legislation.

Before proceeding further it would be prudent for government and interest groups to revisit some fundamentals.

The Fundamentals

- Is there true ownership of the issues we feel need addressing?
- Have we got the “global” support required from federal, state and local government?
- Are the projections we are making in the public arena inclusive or exclusive?
- Have we addressed transitional arrangements required to facilitate change?
- What about attribution of cost and its relationship with “blame”?
- If an individual is to be expected to bear the cost, what are the social issues in the local community, and in the broader community?

It is valuable to consider recent examples of reforms that are creating difficulties for communities.

Let us look at global support.

There is growing concern about “the level playing field” approach of Australian Government to international trade. Why?

Attribution of cost to individuals, lack of transitional arrangements, social issues in local communities and most importantly lack of ownership of the issues at an international trade level.

The NSW government has been having difficulties with vegetation and water reforms. Why?

There are problems with ownership.

The global support is not demonstrably strong in that the proponents can blame or make excuses by claiming “this is an MDBC issue”, “this is a state sovereign rights issue”, “this is out of my hands, it’s a political issue”, “we have international treaty obligations” and the list goes on.

Much of the presentation of policy has been exclusive, some of it grossly misleading, and there have been great examples of the “consultation process” lacking integrity and equity.

Transitional arrangements have in some instances been ignored or not considered.

Attribution of costs has been so poorly handled that it has alienated large sections of the community, much to the detriment of us all.

Specific targeting of individuals to bear the cost (as an example the groundwater issues in the Namoi Valley) has been clearly rejected by large sections of local communities, and has been the catalyst for the involvement of Local Government.

Much has been made by government and its agencies about productive partnerships, announced to all and sundry with grand statements and glossy brochures.

“Community and Government working together for healthy, clean and productive rivers” or “there will be trade-offs required” are delivered by agencies as foregone conclusions that alienate the very audience that they are trying to involve.

Government and its agencies in many instances have lost the trust of the community that they serve. This creates major problems.

Goals for Better Environmental Management

There are many opportunities for better environmental management being lost by government and therefore our communities, because the reality checks have not been done. The checklist is:

- ownership;
- global support;
- inclusivity;
- transitional arrangements;
- attribution of costs; and
- social and economic issues for local communities.

Many communities have difficulty with change. To deal with that fear there needs to be a demonstration of integrity and trust by the proponents, followed by strategies that clearly demonstrate the roads of change, including cost and benefit to the whole and individually.

In some areas of resource management there have been some really good results.

Lessons Learnt

The Catchment Management Committees, recently disbanded by government, managed to set the scene for progress. The processes were slow and cumbersome, with a lot of quite vigorous debate, especially by some of the agencies involved, but there are many examples of meaningful outcomes.

The reason for the successes was in the process. There was time for process, demonstration and there was money from the Natural Heritage Trust (NHT) to sow the seeds of change and ease the burden of cost to individual landholders.

Landcare Groups encouraged inclusivity, and many of us noticed there were few ambit claims, or mischievous statements made in the media about their direction or activities.

Despite some statements of late, there has been a real gain made in Total Catchment Management. For instance, in the Liverpool Plains, with better management of the rising water tables and the resultant discharge of saline water into the system.

This success has not been easy.

What are some of the lessons that we can learn from these people in the Plains?

- They actively sought ownership, and were able get it.
- There was global support.
- Local valley community, State government and the Federal government of course, with NHT funding.
- Inclusivity: through Landcare groupings, and representation to the “outside community”.

Transitional arrangements are continuing as long as NHT or Salt Action funding continues. It is hoped that recent developments at the national scale will help.

Attribution of costs continues: in this case it must be remembered that environmental gains paid for by farmers are the property of these farmers in the first instance, as non-productive areas on the farm return to full production.

Similarly, the social and economic issues are a positive, not only for the individual landholder, but also for all downstream.

The positive effects for the downstream environment have helped to gain support for whole of community funding to help alleviate the growing dryland salinity problem.

It is interesting to note that there was no need for outside people or government to tell these people how to set up their structures, but some of them now would feel strange to see some of the statements by government and others about dryland salinity. Many of the statements are negative and many are based very loosely on fact.

Their success did not happen by accident, it happened with process.

The Weir Review Process is relatively new, and there is no doubt that it is long overdue.

The State Weir Review Committee has had a difficult job trying to work its way through to a process that will deliver good outcomes for everyone who lives in the immediate environment, and those that like to visit the more wide open spaces of this country of ours.

It is really great to see agency people who are fired up, and with confidence stocktaking the issues (physical review of the weirs) to enable us to proceed with the next phase of the task.

The next step will be critical.

There are reality checks that must be done.

Under the current conditions of resource management in this state it could be demonstrated that the hard part is yet to come.

Ownership. Who owns the problem? An amateur fisherman at Murray Bridge? An Aboriginal at Wilcannia? An irrigator growing tomatoes at Tamworth?

Global Support. What is the support structure from other signatories of the Murray-Darling Basin Agreement? At government level? At agency level?

Inclusivity. Is this process truly inclusive? Who needs to be included? At what level?

Transitional Arrangements. These must be developed. At what level? Catchment? Basin? Reach?

Attribution of Costs. Is this a similar issue to dry land salinity? Can the Irrigation Industry become a willing partner? Are there trade-offs that can have positive outcomes for those involved?

What are the social and economic issues involved? Catchment? Local Government? Basin?

The message is that we will need to earn the trust of all "stakeholders" to be able to form the partnership that will achieve the outcomes required for better environmental management of our river systems. Nationally.

Biography

Jerry Killen has been involved with agriculture nearly all his life. Sheep, cattle, grain farming and cotton growing have been his main pursuits. He commenced irrigation in the Namoi Valley at Narrabri in the mid '60s. Observation of the arid zones of far south west corner of Queensland 1960-1963, with it's decline from heavy sheep grazing led to an interest in resource management issues. Since 1981 he has been involved with representing irrigated agriculture to the community and Governments.

Jerry Killen is a director and Deputy Chair of the NSW Irrigators Council, and past President of the Namoi Valley Water Users Association, presently the Executive Officer of the this Association. He was a community representative on the "Scientists on Safari" panel that surveyed the Barwon Darling Rivers in 1995/6. Recently he was appointed to the Namoi Catchment Board and was a member of the North West Catchment Management Committee.

He sits on the Namoi Regulated River Management Committee.

He represents the Irrigators Council on the State Weir Review Committee.

Challenges for the Darling Anabranch: Water supply options and the future of weir pool structures.

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Abstract

The Darling Anabranch is a major watercourse in the far west arid region of NSW. Seventeen structures retain water in the river channel, creating a series of weir-type pools along the entire length. Issues include blue-green algae, salinity, siltation, the proliferation of carp, reduced floods and lake-bed cropping. Finding suitable options for water supply and delivery for the Anabranch community is a highly complex interaction between social, economic, political and practical issues. The Darling Anabranch Management Plan seeks to resolve these issues whilst still providing secure, good quality water for landholders.

Introduction

The Great Anabranch of the Darling River, also known locally as the Darling Anabranch, is a special feature of the Western Division in New South Wales (Fig. 1). Breaking away from the Darling River below Menindee Lakes, the Darling Anabranch winds its way through some 400km of red-soil and clay landscape, reaching the Murray River just below Wentworth. Landholders and visitors admire and love this oasis with its towering river redgums and large fringing ephemeral lakes. Bird watching, yabbying and camping along the riverbank are all popular past-times. The Darling Anabranch is also an important area for its Aboriginal and European cultural history.

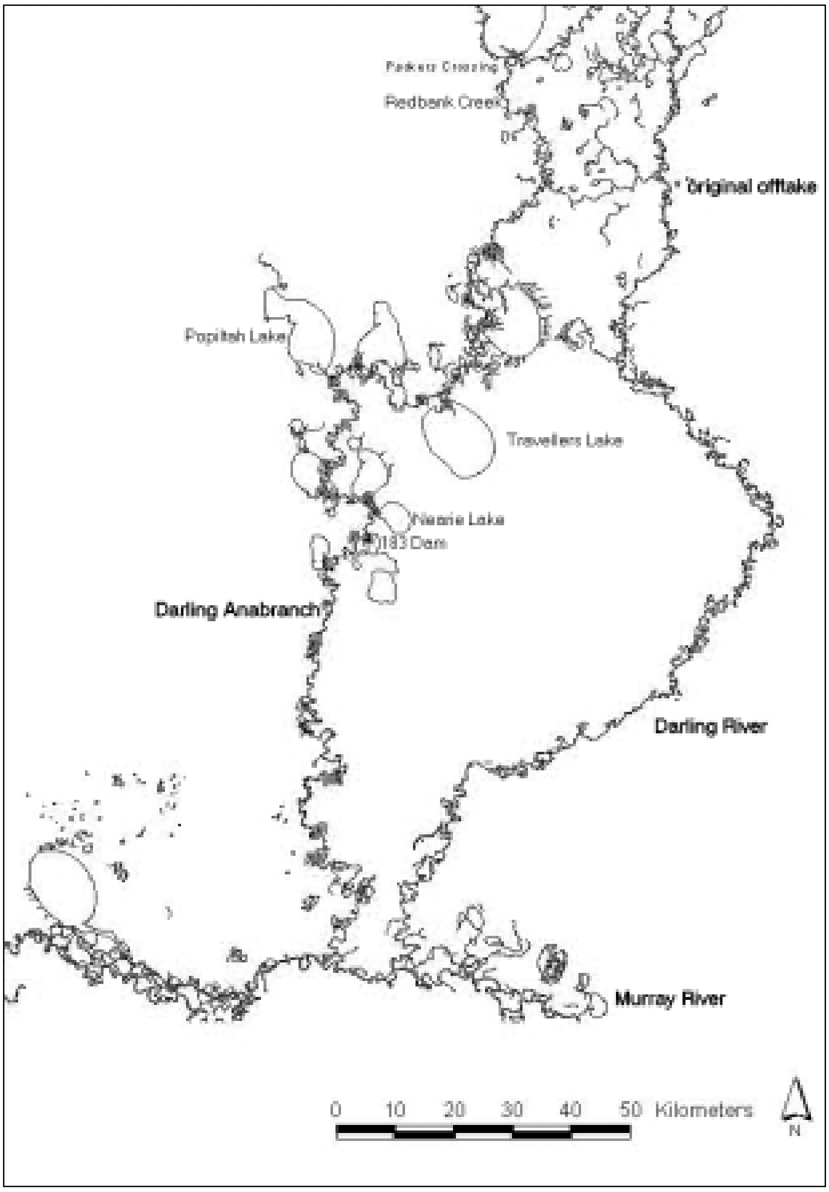
In 1997, the Anabranch Water Trust (AWT) successfully applied for Natural Heritage Trust (NHT) funds to develop the Darling Anabranch Management Plan (Table 1). In 1998, a steering committee was established with representatives from local landholders, government agencies and industry to determine the future of the Darling Anabranch. Community consultation and ownership of the plan will be the key to its acceptance and success.

Management Structure

The Darling Anabranch is operated by The Great Anabranch of the Darling River Water Trust "Anabranch Water Trust" (AWT) formed under the *Water Act*, 1912. The Trust initially managed the erratic flood overflows from the lower Darling River into the Anabranch. When the Menindee Lakes Systems was developed in the 1950s and 1960s, a regular supply of water (50,000ML) from Lake Cawndilla was made available to the Anabranch each year for primarily stock and domestic use. This annual 'replenishment flow', combined with regulation along the Anabranch, provides a more predictable and dependable water supply.

The Anabranch Water Trust consists of two Anabranch landholders and a representative from the Department of Land and Water Conservation (DLWC). The Trust is empowered with the construction, maintenance and operation of regulators, block banks and bywashes along the Darling Anabranch. A 'Memorandum of Understanding' exists between the Trust, DLWC and NSW National Parks and Wildlife to determine water flows into the Nearie Lake Nature Reserve.

Figure 1: *Structures on the Anabranch*



There are 17 'weir pools' located along the Darling Anabranch which pond the annual replenishment flow. Weir structure varies from earthen banks, some with a pipe and regulator, to concrete banks with pipes and regulators. Pipes through weir pools vary in diameter from ~74cm to 1.5m. Pools are designed to store water for 2-3 properties and allow flows to pass downstream and to lakes during floods. There are also 17 bywashes along the Anabranch, comprised of earthen block banks, which protect structures in times of high flow by providing an extra flow passage, 'bypassing' the structures. There are also 10 block banks, most with regulators on the inlets to lakes. Regulators on lakes prevent the replenishment flow going into lakes to enable enough water to fill the Anabranch channel and to prevent loss by evaporation and soakage. Some of these lake inlet regulators are also on roads, i.e. Stony Crossing (or Nearie Lake), Popiltah Lake and 183 Dam. Most of the regulated structures across the main channel are also roads for access to homesteads or properties that are on both sides of the Anabranch.

Hydrology

The flood regime of the Darling Anabranch has been significantly altered since the first European settled in the region. Prior to the development of the Menindee Lakes scheme, significant flows down the full length of the Anabranch only occurred in large floods (DWR 1994). During floods, the northern lakes fill, capturing large volumes of water. From 1890 to 1961 the water flowed the full length of the Anabranch to the Murray River nine times (Withers 1994). From 1895 to 1972, Nearie Lake (midway along the Anabranch) flooded about one in every ten years. Water commenced to flow into the Anabranch when the river level reached 5.48m at Menindee, and it reached the Murray River when it was above this level for 3 months (Withers 1994). The Darling River at Menindee ceased to flow 48 times between 1885 and 1960, and the river did not flow for 364 days in the 1902-3 drought (Lloyd 1992).

In 1961 the Menindee Lakes Storage Scheme was completed and an outlet regulator and channel at Lake Cawndilla designed to "provide periodic flush flows to extend through the full length of the Anabranch to replenish storages" (Withers 1994). Water is released annually from Lake Cawndilla and flows to the Darling Anabranch via a 12km channel to Tandou Creek and then into Redbank Creek. This flow is then released through Packers Crossing regulator which operates at roughly 500ML/day and has a maximum release rate of 800 to 1,000ML/day.

Floodwaters enter the Darling Anabranch when flows at Menindee exceed 10,000ML / day. Water flows to the Anabranch along 'the cutting', or the main Anabranch channel, (Harriss *et al.* 1991). At flows of 20,000ML / day, water passes naturally to the Anabranch via Tandou Creek.

The modifications to the Anabranch water regime due to the operation of Menindee Lakes and the annual stock and domestic flow are compounded by abstractions in the Barwon-Darling River. Up to 81% of flows along the Barwon-Darling River pass through nine major headwater impoundments and 15 weirs (Thoms *et al.* 1996). In the Barwon-Darling River system median annual runoff is reduced by 42% (Thoms and Sheldon 1998) and diversions above Menindee are now equivalent to 60% of the natural flow at Menindee (Thoms *et al.* 1996). The lower Darling River diverts 215GL of water annually, and of this 14GL is used from Menindee to Burtundy, 65 at the Lock 10 Pool, and 136GL by the Darling Anabranch and Tandou (Thoms *et al.* 1998).

The Future of the Darling Anabranch

The steering committee recently appointed a major consultancy company to examine water supply and options for the Anabranch. Water supply and delivery options were first developed by the steering committee with extensive community consultation. Five major options were then identified for further evaluation. Some early analyses of these options are provided below, with comment provided on the likely implications for the weir structures. It is stressed this is only a preliminary analysis with its focus being primarily technical, rather than social or political.

Large on-farm storages

This option suggests that the replenishment flow would be released every two years down the Anabranch, then held in the weir pools and pumped into large on-farm storages. Some of the technical difficulties identified so far include the lack of suitable ground for large storages, declining water quality within the storages that cannot be flushed out, and on-going maintenance. Fencing off the Anabranch is also a significant issue because the Anabranch is the official boundary between most of the properties.

This option is unlikely to lead to removal of most of the weir structures because water would still need ponding, if only temporarily. At all other times, however, structures could be left open. Lake regulators would have to remain to restrict water to the main channel.

Abandon the replenishment

This option would see the replenishment flow abandoned altogether and the system returned to 'natural' with residents left to source their own water. This is a radical option and certainly not supported by the residents. The recreational and primary productivity that results from the regulation of the Anabranch unites the community and most would be reluctant to abandon such a lifestyle. Further, medium and small floods no longer flow down the Anabranch channel due in part to abstraction of water in the Barwon Darling and Menindee Lakes. Returning the Anabranch to 'natural' could potentially result in environmental degradation of the channel if there is no provision made for an allocated environmental flow.

Most of the structures could probably be removed, but some block banks near residents' properties, and structures on road crossings would still be required.

Pipe the water from either the Darling or Murray River, and introduce an environmental flow

A piped water supply would provide security of supply and improve the quality of source water. A pipeline system would have to be integrated with the current extensive water infrastructure. Other major considerations include significant capital and maintenance costs and fencing. Such a scheme would probably also result in a major restructure of the Anabranch Water Trust, and on-going sinking funds would be needed. It is possible that funding for such a scheme could arise from the sale of 'saved' water (~5,000ML of water is used for stock and domestic, but ~50,000ML is used for conveyance). A specific environmental flow for the channel itself would be needed but structures should remain until the flow has been tried and monitored.

Many of the weir structures could be removed, or left open. Some structures would be needed to protect roads and houses during flooding. Some structures may be needed to manipulate an environmental flow, especially if backwaters and lagoon areas were to be filled. Lake regulators would remain to restrict water to the main channel during an environmental flow.

A removable weir across the Darling River below the Anabranch off-take

A removable type weir would be placed across the Darling River below the Anabranch off-take to raise the Darling River. The water would then run down the original course of the Anabranch. The weir is then removed after the replenishment is completed. This option would mean better quality water being supplied. There is also concern about the effect on the Darling River environment and so such a scheme would have to prove to be of no disbenefit. Given the State Weirs Policy, it is likely that a trade-off would also be required, whereby some of the structures on the Anabranch would have to be removed before a new one could be put in.

Some reduction in weir structures required, but many remain because the replenishment pools are still used for stock and domestic use. Lake regulators would also have to remain.

A continuous flow

Water would be released continuously but at a lower level. This might improve water quality and therefore allow flow into the Murray River. Suggestions have been made to combine a continuous flow with Option 4 above, but this would mean the weir would have to be permanent. Objections to a continuous flow include the likely proliferation of cumbungi, changes to channel morphology, and little water savings. It is unlikely this option will satisfy the requirements of government, which is to restore more natural flows wherever possible.

Without adequate hydrological modelling of this option, it is difficult to determine whether structures would need to remain. Lake regulators would have to remain to confine water to the channel.

Conclusion

Plotting the future of the Darling Anabranch and its community involves complex interactions between landholder, government, politics and the needs of the environment. Securing water of good quality is generally regarded as the top priority by landholders and there is also an expectation within government that some structures on the Anabranch can be removed or upgraded once water supply is secured. However, there are diverse opinions on how such an aim can be realised and an appropriate environmental monitoring program is needed before any structures are removed. The Darling Anabranch Management Plan seeks to resolve the issues that surround the options for the water supply and delivery, and provide a strategy for moving forward.

Biography

Deborah Nias has spent the past two years working for the Darling Anabranch Management Plan steering committee, developing a management plan for the Darling Anabranch. This is a three year NHT funded project, initiated by the Anabranch Water Trust. Deborah is the project manager for the plan and is employed as a Scientific Officer within the Department of Land and Water Conservation at Buronga, New South Wales.

Immediately prior to this position, Deborah was completing her PhD at Monash University, which examined the ecology and carbon dynamics of a temporary floodplain wetland.

Conference Summary

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The serious degradation of Australia's riverine ecosystems has finally received wide recognition. Means to both understand and address that degradation are now accepted as urgent environmental management priorities. However, the causes are complex and the relevant participants in remedial action are both numerous and disparate in nature.

The Inland Rivers Network is to be congratulated on initiating and organising this Conference, which brings together the many relevant players involved in one important cause of riverine degradation – the modification of water flow by dams and weirs.

In the opening address to the Conference, the Hon Dr Sharman Stone, Member for Murray in the Federal Parliament and Parliamentary Secretary to the Federal Minister for the Environment, provided a graphic (and depressing) first-hand portrait of serious degradation in watercourses in her local area over her lifetime. She also set the scene for positive outcomes from the Conference by stressing that "there is now a different attitude in Australia", such that the degradation she has witnessed in her home area could no longer happen, and the time is right, both in terms of recent legislative and institutional changes, and the new public attitudes, for degradation to be reversed.

One important cause of degraded watercourses, and the topic of this Conference, is the impact of the many installations that alter the flow of rivers. Dr Stone noted that many of these structures are well past their use-by date in terms of safety, and the environmental costs may well outweigh the social and economic benefits for many more.

It is now time that the environmental impacts and the costs and benefits of retention of dams and weirs, be given serious attention. This was the topic of this Conference.

Impact of Dams and Weirs

Session 1 of the Conference considered the impacts of dams and weirs through five papers.

The overall message from these papers was that it is now clear that dams and weirs lead to a series of deleterious changes to riverine and associated floodplain ecology. These involve complex interconnections between the river, its floodplain and the full range of other human-made changes to the area. While the impacts are clear in a general sense, good understanding of the effects in particular areas requires detailed site-specific study. There is still much work to be done at this level.

Keith Walker set the scene with an excellent overview of the effects of weirs on the River Murray, emphasising the change to the hydrological 'signature' of the river and the wide range of flow-on effects from this. In essence, the very erratic 'natural' flow rhythm of the river, which was the basis of its ecosystems' functions and of the community diversity and structure, has been dampened. Seasonal flows are much more stable than before, while the discharge at the mouth of the Murray is now only 20 percent of its long-term natural flow. The important functional connection between the river and its floodplain has been severed as a result of this changed flow. The floodplain is now wet or dry, rather than wet and dry, with species types and abundance altering in response. Weir pools have been invaded by wetland species, riverine species are in decline and exotic species are becoming dominant, while algal blooms have been promoted. Keith Walker summed up the changes by saying that while the 'icons' of the old Murray were the river red gum and the Murray cod, they are now the willow and the carp. Moreover, the weirs have also made a substantial contribution to the input of salt to the Murray; 25 percent of the salt now entering the Murray is a consequence of the weirs.

Duncan Leadbitter described a range of similar effects from weirs in the fresh water reaches of coastal rivers, but noted that to these should be added the impacts of acid sulphate soil disturbance. In the saline reaches of coastal waterways the movement of tidal waters and efforts to provide barriers to this, creates an added dimension of complexity.

Sandra Brizga and Angela Arthington added an extra level of detail of both physical and ecological impacts of weirs, by drawing on research on three weirs that collectively impound 30km or 25 percent of the lower Pioneer River in Queensland. Physical impacts occur both upstream and downstream of weirs, in addition to direct effects of the barrier of the weir. They involve not only disruption of the hydrological regime, but also changes to sediment inputs, to the riparian zone, to the extent of open water in the landscape and to water quality and temperature stratification. Ecologically, impacts are similarly distinguished upstream and downstream of the weirs, and by virtue of the presence of the barrier, and can be linked to the physical impacts. Angela Arthington described the development of conceptual models linking the physical effects with impacts on ecological processes and community diversity and structure. She stressed that reversing the ecological impacts requires management of water flow to mimic the 'natural' water level fluctuations, and questioned whether it was possible to do this with weirs in place.

John Koehn added further detail by examining the impacts of weirs on fish. The decline of native freshwater fish populations has been substantial and importantly, for the public, provides a key indicator of the success or otherwise of river management. In essence the changes in water flow brought about by dams and weirs have benefited exotic fish species at the expense of native fish. With regard to dams and weirs as an impediment to movement, Koehn noted that the ability of native fish to have free passage within rivers is acknowledged even though not all reasons for, and patterns of, movement are understood. Most attention has been paid to the blocking of upstream fish movement by weirs and the need to install ladders to deal with this, but important downstream movements have not been given necessary attention. Similarly, attention has focused on adult fish, but there are also key impacts of weirs on eggs and larvae. Research is needed to better understand fish movement and its functions.

Reducing the Environmental Impacts of Dams and Weirs

While many of the impacts of dams and weirs have been known for a long time, the 'conventional wisdom' has been that the benefits justified their existence. This Conference is perhaps evidence of the 'different attitude in Australia' referred to by Sharman Stone. The large attendance at the Conference and the varied mix of stakeholders present shows that we are prepared to seriously address how the impacts of dams and weirs can be lessened, and to consider the removal of certain of these structures as one way of dealing with the impacts.

Sessions 2–4 considered, respectively, whether weir operations can be altered to reduce environmental impacts, how weirs may be removed or modified, and how we might think laterally about water supply and management, in order to lessen the need for water retention structures.

Many speakers revealed the enormous potential extent of the problem by citing figures for the number of installations – more than 10,000 weirs and related structures in south eastern Australia according to John Harris. John Harris also noted that we don't really know how many weirs and related structures there are in south eastern Australia, although the recent Weir Review by NSW Fisheries will help to resolve this gap in knowledge. Duncan Leadbitter described the great variety of barriers associated with rivers – including large to small dams, weirs, road crossings, fjords, culverts, floodgates and levees. Others noted that there is no such thing as a typical weir; they have been built for different purposes, may be operated differently (with consequent differences in impact), are situated in different environments and range in present utility from current high benefit to no longer useful.

It seems clear that a case-by-case basis is necessary to address the problems caused by weirs and associated structures and how best to manage these.

A further clear message from the Conference was that although it may be timely in terms of public acceptance to seriously address reduction of impacts of weirs and similar structures, and indeed to consider removal in specific cases, it is most important that we 'get this right' – ecologically, in engineering terms, socially and economically. The message from the United States speakers, Stephanie Lindloff, Gordon Russell and Bill Kier, who each have had experience in dam / weir removal, was that we won't quickly get a second chance if major remedial actions are seen as failing in any of these areas. This was reinforced by Allan Lugg from NSW Fisheries who outlined the difficulties associated with the removal of an unused water supply weir on a tributary of the Shoalhaven River, and the lessons learnt from this. In contrast, Ian Dinham from the Clarence River County Council shared the successful experience of multi-agency and community cooperation in the Clarence Floodplain Project, which introduced new floodplain management techniques for the operation of floodgate structures, resulting in significant environmental improvements in the Clarence estuary and floodplain.

Reducing Environmental Impacts Through Altering Weir Operations

Many weirs and related structures may be judged indispensable, for social, political and / or economic reasons. The second section of the Conference provided numerous suggestions as to how we can practically minimise the damaging effects of such structures.

A clear message from these papers was the need for good site specific data in order to tailor-make any impact-minimising solutions. For example, fish ladders are perhaps the best known devices to minimise impacts of in-stream obstructions. Yet according to Cameron Lay of NSW Fisheries, even with fishways it remains necessary to emphasise the need to avoid a 'one fishway fits all' mentality, to draw on past lessons from fishway design and maintenance, and to seek new and lower cost designs to achieve desired outcomes.

Papers in this session by John Harris, Glenn Wilson, Helen Keenan, Liz McNiven, Cameron Lay, Joanna Kuswadi, Ian Webster and Bryce Skarratt, together provided a very good picture of the need for careful and detailed analysis of a wide range of factors in designing ways to minimise impacts of weirs.

For example, Glenn Wilson, from the Murray Darling Freshwater Research Centre, drew attention to the wide variation in environmental effects from differential timing and patterns of 'drawdowns' as a means to restore more variability ('naturalness') in flows, in turn aimed at providing ecological conditions more suited to native species. He also noted that Australian rivers have a very wide range of growth forms and exposure tolerances for macrophytes and riparian vegetation, adding further complexity to attempts to use drawdowns to restore more natural conditions. As well there are likely to be a range of operational constraints related to the functions provided by the weirs and their individual forms. This set of complexities further emphasises the need for a case-by-case assessment of actions to minimise environmental impacts of weirs.

Similarly, Ian Webster, described the complex relationships between weir design (shape, size), water flow and water column stratification, and the effects of this on blue-green algae outbreaks and the downstream movement of larval fish.

Bryce Skarratt's paper, which discussed assessment of weir impacts pre-construction in Queensland, was useful in emphasising the need for holistic assessment covering interactions between the river and its catchment, environmental flows, water use requirements, benefit-cost analysis, social impacts, site selection and a wide range of physical and ecological impacts. As well, operational requirements need to be addressed, including design to manipulate flow when necessary through, say, variable level outlets, monitoring of effects, management plans for weir maintenance and possibly self-cleaning systems to maintain sediment movement, and so on. Anthony Hurst's analysis of the degradation of the Upper Nepean rivers system in New South Wales, in Section 4 of the Conference, similarly emphasised the importance of 'whole system' analysis and additionally stressed the need for clear obligations on those entities managing river systems which should include government and community partnerships.

Helen Keenan from the NSW Department of Land and Water Conservation (DLWC) provided details of DLWC operational systems on the

Murrumbidgee River aimed at dealing with thermal stratification, a major cause of environmental impacts of dams and weirs. These include the use of monitoring of water quality information and provision of the information ‘back-to-base’ so that operational protocols can be remotely tailored to deliver maximum environmental benefits at minimum cost. There seems to be considerable potential in using continuous monitoring devices coupled with ‘back-to-base’ information delivery to modify a whole range of physical parameters and consequently to lessen ecological impacts. Again site-to-site assessment is required and careful cost-benefit analysis of such systems is a necessary basis for decisions on their installation.

In sum, the papers in this section revealed much potential for mitigating the impacts of dams and weirs, but as John Harris noted, except for fish ladders, means to assess environmental benefits of weir modification (both structure and operations) is in its infancy – much more research is needed.

Nevertheless, it is clear that in some (many?) cases, the potential benefits of modification will not outweigh the costs (either of residual damage, or of putting the modifications in place) and environmental costs may be such that weir removal needs to be considered. Discussion of weir removal formed the third section of the Conference.

How Can Weirs be Removed or Modified?

Since the issue of environmental problems caused by dams and weirs is now widely acknowledged in Australia, actions to reduce these problems by either modification or removal of weirs and other obstructions is becoming the focus of discussion.

Craig Copeland’s (NSW Fisheries) discussion of the State Weirs Policy for New South Wales and the recent Weir Review is evidence of this new focus. While the major recommended action from the Weir Review was ‘no action’; for a significant number of weirs, some modification was recommended (e.g. build fishways or manage gating), and for some 100 weirs decommissioning and removal was recommended.

The three papers in this section from the visitors from the United States of America provided many valuable lessons on how best to go about decision-making regarding the future of specific dams/weirs. In essence, they demonstrated that apart from the obvious technical considerations and cost-benefit analysis of retention with repair or modification versus removal, weir removal as part of river management is a highly charged issue which requires a sophisticated public participation program that starts at the earliest stages of discussion of the issue, and continues after removal, with monitoring and continuing public involvement in restoration.

Stephanie Lindloff from the Small Dams Program, River Alliance of Wisconsin, outlined experience in Wisconsin which has showed that while dam or weir removal is not appropriate in all situations, for many rivers dam removal is the most important thing that can be done to restore the health of the river, and at the same time may make the most sense economically. She noted that despite this many dam decisions end in repair even though repair may be more costly than removal. Experience in Wisconsin shows that repair costs are typically underestimated and removal costs overestimated (sometimes by 5 or 6 times), yet on average repair costs 3-5 times as much as removal.

The River Alliance has produced a citizens’ guide to decision-making on selective dam removal and has used computer simulations to show people what the landscape would look like after removal.

Gordon Russell from the US Fish and Wildlife Office in Maine described the intricacies and the innovative solutions used to bring together a range of interested parties to successfully remove a large hydro dam. The lessons from this example were about careful planning of process to bring parties together in a collaborative ‘win-win’ setting, and the search for innovative economic and institutional means to achieve this. Bill Kier brought similar lessons from experience with large dam removal in California. Both Gordon Russell and Kevin Goss (Murray-Darling Basin Commission) identified re-licensing of structures as an opportunity to drive decision-making for change.

While these experiences from North America are not necessarily directly transferable as applicable models for decision-making processes in Australia, they bring some very useful generic lessons about the need for careful design of decision-making process and stakeholder involvement. Study of the full papers on these North American experiences is likely to be very useful for all involved in the current process of dams and weir assessment in Australia.

Importantly, we need to develop criteria, relevant to the Australian situation/s, for decision-making on the future of specific dams and weirs. Considerations in such decisions will need to include:

- Is the dam/weir fulfilling a useful social function? How broadly shared are the social benefits?
- Is the structure in need of repair? What are the risks of the structure to human life and property? If repairs are needed, and/or regular maintenance, what will it cost?
- What are the ecological impacts of the structure? How good is our information on this? Can we put a cost figure on these impacts?
- Can modifications in structure or operations significantly reduce the ecological impacts to an 'acceptable' level? If so, at what cost? (Warren Musgrave discussed the important role benefit-cost analysis can play in development of weir policy, but warned that benefit-cost analysis may tilt attention to the 'measurables' and neglect those environmental and social matters that are not readily costed in dollars);
- What are the relative costs of repair/modification versus removal?
- Are there other ways of fulfilling the social/economic needs provided by the dam/weir (for example, Tahmina Smyth discussed alternative engineering solutions to avoid dams/weirs in providing water supplies for small rural towns; Deborah Nias considered alternative options for communities along the Darling Anabranch); and
- Is removal justified on ecological, economic and social criteria?

We also need to be sure that the decision-making processes we put in place are transparent and follow a process agreed by all key stakeholders. Meaningful community participation is necessarily a key part of that process.

A decision to repair or remove a dam or weir is not the end point. A number of speakers including Stephanie Lindloff from the US and Kevin Goss from the Murray-Darling Basin Commission, stressed the importance of good riverine management, including community involvement, in the post-removal period for showing that the decision has produced environmental and social benefits. Failure to follow through to post-removal management is a fast way to lose public support.

In Sum

- The ecological impacts of dams, weirs and other watercourse barriers, are clear in a general sense and seen to be significant.
- The 'time is right', both in terms of recent institutional and legislative changes and new public attitudes, to put in place actions to reverse degradation to river systems caused by dams and weirs.
- However, we need to use this opportunity with care. It is important that the decisions made are seen as bringing benefits – socially, ecologically and economically. Bad planning for decision-making may squander the present opportunity for a widespread review of dams and weirs and consequent action on recommendations.
- Such review needs to consider a range of possibilities: Do specific dams still fulfil a useful function? Are they, nevertheless in need of repair? Would the cost of repair be justified in terms of the social benefits produced? Can such dams/weirs be modified in structure or operations to reduce environmental impacts? Are specific dams/weirs redundant? Should they be removed?
- How should such decisions be made? This is of high importance. What considerations are relevant?
  - decisions must be based on good data – scientific, social and economic;
  - but recognise the complexity and need for site-specific, case-by-case analysis;
  - recognise also the need for holistic analysis – take a whole of catchment

approach and consider cumulative effects;

- include adaptive management and monitor and learn from results;
- involve benefit-cost analysis, but remember to take account of the matters which are not readily costed;
- think laterally and imaginatively about alternative means for providing the needs met by dams / weirs;
- use / encourage ‘smart’ engineering solutions where weir retention is required;
- remember the importance of quality control in maintenance and operations;
- plan for decision-making carefully; involve all relevant stakeholders from the earliest stage and ensure meaningful public participation;
- develop agreed criteria for decision-making;
- agree on a decision-making process including the roles of all stakeholders in this; make sure the process is transparent;
- seek ‘win-win’ solutions and productive partnerships;
- remember that if a dam / weir is removed the post-removal management of the river, and community involvement, is vital in setting the scene for successful future decision-making on river management; and
- above all, learn from experiences. Consider the US experience in dam / weir management decisions to date and put this into an Australian context. Document and draw lessons from Australian experiences as they become available.