THE NEW ZEALAND SOCIETY ON LARGE DAMS

NZSOLD

Dams - Consents and Current Practice

Proceedings of a
Symposium held in Wellington, August 2003

ipeNz
Engineers New Zealand

Proceedings of Technical Groups

Volume 30, Issue 2 (LD)

ISSN 0111-9532

THE NEW ZEALAND SOCIETY ON LARGE DAMS

***IPENZ Proceedings of Technical Groups* Volume 30, Issue 2 (LD)**

ISSN 0111-9532

Edited and produced by
Geoff Gregory, Word Therapy, Paraparaumu

Printed by
Otaki Print & Copy Centre, Otaki

Covers printed by
Graphic Press & Packaging Ltd, Levin

Binders by
Waikanae Plastics Ltd, Waikanae

Cover photo: Waitaki River valley, looking upstream from near Kurow. Existing hydroelectric lakes are impounded behind Waitaki and Aviemore Dams.

Photo GNS CN42818–20: D.L. Homer

Foreword

This volume contains the technical papers prepared for the one-day symposium *Dams – Consents and Current Practice* held at the Wellington Festival & Convention Centre on Tuesday 26 August 2003. The New Zealand Society on Large Dams (NZSOLD), a Technical Group of the Institution of Professional Engineers New Zealand (IPENZ), thanks you for your support and registration for the symposium.

Water is a resource needed for electricity generation, domestic consumption, irrigation or industrial use. Allocation issues represent a challenge for New Zealand, and the need for storage in reservoirs has been illustrated earlier this year, when electricity shortages over the winter months were being forecast. Over the three years since the last one-day symposium in November 2000, many power generation companies have been completing the resource consent renewal process. The intention of this seminar was to draw together experiences of both applicants and regulators in this process, and also to include an update on the status of dam safety legislation. Current practice aspects included papers on tailings dams, dam design construction and enhancement plus emergency management experiences and likely water needs for irrigation. The keynote address, by Professor Angela Arthington, of Griffith University, Queensland, focused on ecological aspects of river systems and impacts from dams and water storage.

The Organising Committee arranged for circulation of the papers in advance of the symposium to help stimulate active participation. At the symposium, presentation of the papers by the authors was intended to summarise and highlight main issues and was followed by discussion sessions of approximately 10 minutes after each grouping of 2–3 papers. Summaries of these discussions are included in this volume.

Peter Mulvihill	Stuart Read
Chairman	Chairman
NZSOLD	Symposium Organising Committee

Webpage: http://www.ipenz.org.nz/nzsold

NZSOLD

Dams - Consents and Current Practice

Support for the symposium is kindly acknowledged from

Tonkin & Taylor

Watercare services limited

Institute of Geological & Nuclear Sciences Limited

Meridian Energy

Riley Consultants

DamWatch

URS New Zealand

Meritec

TrustPower

Contact

MWH

Marsh

Mighty River Power

Contents

Opening address

Peter T Mulvihill

On behalf of the New Zealand Society on Large Dams and the Institution of Professional Engineers New Zealand, it is my privilege and pleasure to warmly welcome you here today. In particular, I would like to extend a warm welcome to our guest speaker, Professor Angela Arthington, who has made the long trek from Brisbane to be with us today. I am sure her address will provide us with a somewhat different view of the world regarding water allocation and management.

The focus of today's symposium is consents and current practice in the dam management field. Since our symposium in November 2000, dam owners have faced significant challenges when completing various resource consent renewal processes. Many of papers at this symposium draw together experiences of both applicants and regulators in this process.

In today's programme, we have several excellent technical papers covering current practice with regard to new dam construction, upgrades and tailings dams. On a dam safety theme, we also have a paper that gives us an insight into emergency management when things go wrong.

Despite our belief after the last symposium that dam safety legislation was unlikely to be enacted in the near future, government has been working over the past 19 months towards clarifying regulatory responsibility with regard to dam safety. We understand that the publication of the draft Building Amendment Bill is imminent. This Bill includes specific provisions regarding dam safety and is the subject of several presentations later in the day.

With the issue of long-term energy security in New Zealand at the forefront of government thinking, along with the increasing demand for irrigation water, water allocation issues present a major challenge to sustainable resource use in New Zealand in the future. The construction of new dams and reservoirs provides one of the alternatives to meet these demands, but for these options to be viable we must in some way address the environmental effects and negative public perception of such projects. I look forward to the papers later in the day that pick up on these issues.

On behalf of NZSOLD I would also like to thank our sponsors, who are publicised in these Proceedings, as well as the people who took time to write and present papers, and last but not least our organising committee. With the pressure of work commitments, it is becoming harder these days for individuals to allocate voluntary time to organising such symposia, and I would like to thank Stuart Read and his committee personally for the hard work they have put into doing this for us.

We encourage you to participate as much as possible in today's programme and hope you have ample free time during the breaks to meet and discuss relevant issues with fellow professionals. I am sure you will leave at the end of today with something that will enhance your professional knowledge with regard to dam engineering.

In conclusion, I declare the 2003 Symposium open.

Ecological impacts of dams and flow regulation in rivers

Angela H. Arthington[1]

Dams, weirs and flow regulation have changed water volumes and patterns of variability in many rivers around the world, with largely undesirable consequences for ecological systems and loss of the goods and services associated with healthy rivers. The provision of environmental flows has become the main approach to the mitigation of flow regulation impacts in rivers.

In Australia and other countries, the 'pre-scheme' environment of a regulated river (if known), or the condition of a similar unregulated river, is commonly used to guide the design of environmental flows in river restoration projects. In such projects, the baseline for evaluation of the ongoing effects of a dam or scheme and the regulated flow regime is the condition of the 'existing environment' with the scheme in place and operational.

Acceptance of similar definitions and approaches as part of the resource consents process in New Zealand could avoid conflicts about the interpretation of 'existing environment'. These conflicts suggest the need for a national protocol or guideline that all parties can accept and adhere to in the consenting process.

Keywords: *Impacts of dams, flow regulation, river ecology, environmental flows, resource consents, 'existing environment'*

Introduction

There is a massive world literature on the ecological impacts of dams, weirs and flow regulation in rivers and their associated floodplains. Recently, a group of ecologists from the USA, Europe and Australia set out to distil this literature down into a series of guiding principles linking hydrology and the biodiversity and ecological functioning of rivers and riparian systems. Four principles were developed to relate key features of river flow regimes and aquatic biodiversity. These principles are briefly outlined as an introduction to the substance of this paper, that is, the mitigation of the downstream effects of dams and flow regulation.

The provision of environmental flows has become the main approach to the mitigation of flow regulation impacts in rivers. The main types of methodology used to define environmental flows are briefly described, and examples of their use are outlined, especially for the class known as 'holistic methodologies'.

In New Zealand, the provision of environmental flows is one aspect of the process of obtaining resource consents and re-consents. Differing interpretations of 'existing environment' have complicated the re-consenting process and suggest the need for a national protocol or guideline that all parties can accept and adhere to in the consenting process. Experiences in other countries may be helpful in this context. The approach being taken in Australia is briefly outlined as a possible model for New Zealand to consider.

Hydrology and river ecology

In many parts of the world there is growing awareness of the pivotal role of the flow regime (hydrology) as a key 'driver' of the ecology of rivers and their associated floodplains (see Richter *et al.* 1996, 1997; Poff *et al.* 1997; Puckridge *et al.* 1998; Naiman *et al.* 2002 for reviews). Every river system has an individual or 'signature' flow regime with particular characteristics relating to flow quantity, and temporal attributes such as seasonal pattern of flows, the timing, frequency and duration of extreme events (e.g. floods and droughts), rates of change and other aspects of flow variability (Poff *et al.* 1997; Olden & Poff 2002). Each of these hydrological characteristics has individual (as well as interactive) influences on the physical nature of river channels, sediment regime and water quality, biological diversity and key ecological processes sustaining

[1] *Centre for Riverine Landscapes, Griffith University, Nathan, Brisbane, Queensland 4111, Australia*

the aquatic ecosystem (Naiman *et al*. 2002). These processes govern the ecological health of rivers and underpin the ecosystem goods and services that rivers provide to humans (e.g. flood attenuation, water purification, production of fish and other foods and marketable goods).

In large part, recognition of the importance of flow has stemmed from ever increasing evidence of the negative impacts of flow regulation on riverine ecosystems. Water resource development and flow regulation are often claimed to be the most serious and continuing threat to ecological sustainability of rivers and their floodplain wetlands (Naiman *et al*. 1995; Ward & Standford 1995; Kingsford 2000). Dams, weirs and flow regulation have changed water volumes and patterns of variability in major world rivers on three temporal scales – the flood pulse (days to weeks), flow history (weeks to years) and the long-term statistical pattern of flows, or flow regime (decades or longer). To summarise world literature on the impacts of such changes, Bunn & Arthington (2002) suggest that four guiding principles link hydrology and aquatic biodiversity and can be used to illustrate the impacts of altered flow regimes (Figure 1). There can be little doubt that these principles apply just as well to New Zealand's regulated rivers as they do in other countries.

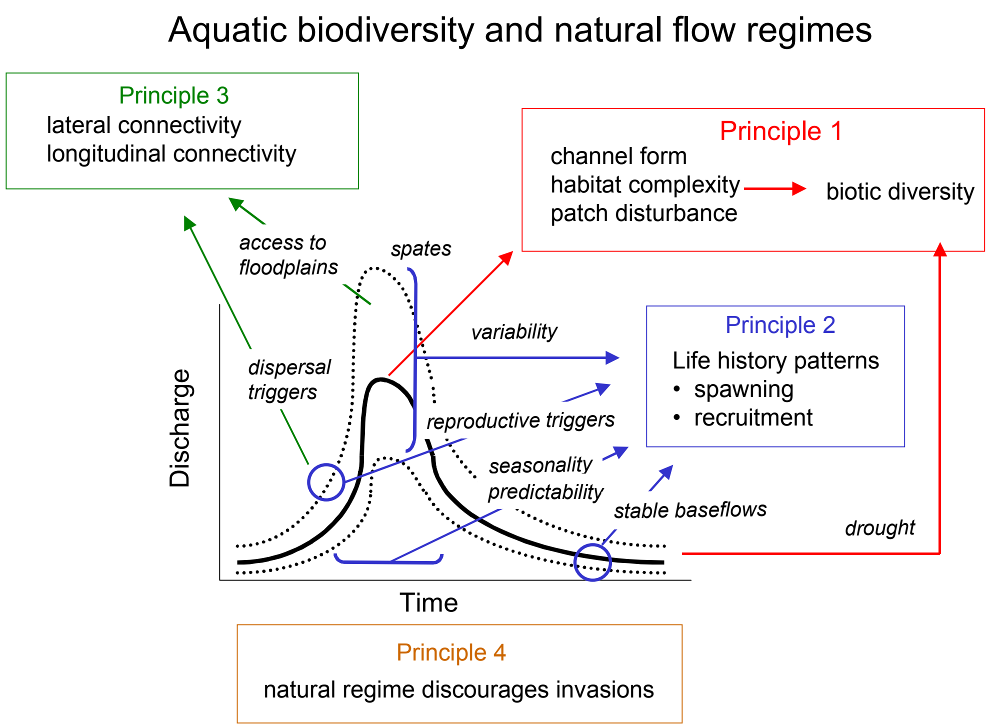

Figure 1. Links between aquatic biodiversity and river flow regimes (from Bunn & Arthington 2002).

The principles are:

1. Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition.
2. Aquatic species have evolved life history strategies primarily in direct response to natural flow regimes.
3. Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species.
4. The invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

The natural flow regime of a river influences aquatic biodiversity via several, inter-related mechanisms that operate over different spatial and temporal scales (Bunn & Arthington 2002). The relationship between biodiversity and the physical nature of the aquatic habitat is likely to be driven primarily by large events that influence channel form and shape (Principle 1). In addition, droughts and low flow events also play a role by limiting overall habitat availability (Newbury & Gaboury 1993; Pusey *et al*. 2000). Many features of the flow regime influence life history patterns (Milton & Arthington 1985; King *et al.* 1998; Pusey *et al*. 2001), especially the seasonality and predictability of the overall flow pattern (Junk *et al*. 1989), but also the timing of particular flow events (Principle 2). Some flow events trigger longitudinal dispersal of migratory aquatic organisms, and other large events allow access to otherwise disconnected floodplain habitats (Principle 3). Catchment land-use change and associated water resource development inevitably lead to changes in one or more aspects of the flow regime, resulting in declines in native aquatic biodiversity via these mechanisms (Bunn & Arthington 2002). Invasions by introduced or exotic species (e.g. plants, fish) are more likely to succeed at the expense of native biota if the exotics are adapted to the modified flow regime (Principle 4).

Naiman *et al.* (2002) summarise the implications of these guiding principles in terms of the management responses required to take cognisance of them, and to manage river flow regimes in ways that will avoid or mitigate the major impacts of flow regulation. The provision of environmental flows has become one of the most prominent management responses to flow regulation impacts in rivers.

Environmental flows

Environmental flow assessments (EFAs) address how much (and which specific temporal characteristics) of the original flow regime of a river should continue to flow down it and onto its floodplains in order to maintain specified features of the "riverine ecosystem" (Arthington *et al*. 1992). An EFA produces one or more descriptions of possible modified hydrological regimes for the river, the environmental flow requirements (EFR) or environmental water allocation(s), each modified regime linked to a predetermined objective in terms of the ecosystem's future condition (King & Tharme 1994).

The scales at which EFAs are undertaken vary widely, from entire large river basins that include a regulated main channel and/or several regulated tributaries, to a flow restoration project for a single flow-impacted river reach or even for a single fish species. Different methodologies are appropriate at each particular spatial scale as well as in relation to typical project constraints including the time frame for assessment, availability of data, technical capacity and finances (Tharme 1996; Arthington *et al.*1998, 2003). Methodologies accordingly range from rapid, reconnaissance-level approaches for regional, national or basin-wide water resources planning, to resource intensive methodologies for highly exploited, individual river sites subject to multiple uses, or single species of high conservation significance.

Tharme (2003) has recognised four relatively discrete types of environmental flow methodology, namely (1) hydrological, (2) hydraulic rating, (3) habitat simulation, and (4) holistic methodologies. Each of these is briefly described below, with reference to the main literature sources that provide access to further details and/or case studies.

1. Hydrological methodologies

These represent the simplest set of techniques where, at a desktop level, hydrological data in the form of naturalised, historical monthly or average daily flow records are analysed to derive standard flow indices which then become the recommended environmental flows. Commonly, the EFR is represented as a proportion of flow, often termed the 'minimum flow', e.g. Q_{95} – the flow equalled or exceeded 95% of the time. This minimum flow is intended to maintain river health, fisheries or other highlighted ecological features at some acceptable level, usually on an annual, seasonal or monthly basis. In a few instances, secondary criteria in the form of catchment variables, hydraulic, biological or geomorphological criteria are also incorporated. Hydrological methodologies are generally used mainly at the planning stage of water resource developments, or in situations where preliminary flow targets and exploratory trade-offs are required (Arthington *et al.* 1998; Tharme 2003).

2. Hydraulic rating methods

Hydraulic methods use changes in simple hydraulic variables, such as wetted perimeter or maximum depth, usually measured across single, flow-limited river cross-sections (e.g. riffles) as a surrogate for habitat factors known or assumed to be limiting to target biota. Environmental flows are determined from a plot of the hydraulic variable against discharge, commonly by identifying curve breakpoints where significant percentage reductions in habitat occur with decreases in discharge (Jowett 1997). It is assumed that ensuring some threshold value of the selected hydraulic parameter at a particular level of altered flow will maintain aquatic biota and thus, ecosystem integrity. These relatively low-resolution hydraulic techniques have been superseded by more advanced habitat modelling tools, but they continue to be improved and are still being applied, often as part of holistic approaches (see below).

3. Habitat simulation or microhabitat modelling methodologies

Habitat simulation methods also make use of hydraulic habitat-discharge relationships, but provide more detailed, modelled analyses of both the quantity and suitability of physical stream habitat available to target biota under different discharges. Environmental flow recommendations are based on the integration of hydrological, hydraulic and biological response data (Jowett 1997). Flow-related changes in physical microhabitat are modelled in various hydraulic programs, typically using data on depth, velocity, substratum composition and cover and, more recently, complex hydraulic indices (e.g. benthic shear stress). This information is collected at multiple cross-sections within each study river reach. Simulated available habitat data are then linked with habitat suitability index curves representing the habitat conditions used (or preferred) by target fish or invertebrate species (or life-history stages). The resultant outputs, in the form of habitat-discharge curves for specific biota, or extended as habitat time and exceedence series, are used to derive optimum environmental flows for a species or life history stage. The habitat simulation modelling package PHABSIM (Bovee 1982; Stalnaker *et al*. 1994) is the pre-eminent model of this type widely used in the USA and many other countries. A modified version of this package known as RHYHABSIM is often used to develop minimum environmental flows for New Zealand rivers (see Jowett 1997).

4. Holistic methodologies

Over the past decade, river ecologists have increasingly made the case for a broader approach to the definition of environmental flows to sustain and conserve the river ecosystem (Arthington and Pusey 1993; Sparks 1995; Poff *et al*. 1997). From the conceptual foundations of a proposed “holistic approach” (Arthington *et al*. 1992) at least 16 so-called “holistic methodologies” (*sensu* Tharme 1996, 2003) have been developed and applied in Australia, South Africa and the UK. This type of approach is founded on the assumption that if certain features of the natural hydrological regime can be identified and adequately incorporated into a modified flow regime, then, all other things being equal, the extant biota and functional integrity of the ecosystem should be maintained (King & Tharme 1994). Reasoning along similar lines, Sparks (1995) suggested that “rather than optimizing water regimes for one or a few species, a better approach is to try to approximate the natural flow regime that maintained the entire panoply of species.”

Holistic methodologies aim to address the water requirements of the entire riverine ecosystem rather than the needs of only a few taxa (usually fish or invertebrates). These methodologies are underpinned by the concept of the “natural flows paradigm” (Poff *et al.* 1997), and basic principles guiding river corridor restoration. They share a common objective – to maintain or restore the biophysical components and ecological processes of in-stream and groundwater systems, floodplains and downstream receiving waters (e.g. terminal lakes and wetlands, estuaries and near-shore marine ecosystems).

Ecosystem components that are commonly considered in holistic assessments include geomorphology, hydraulic habitat, water quality, riparian and aquatic vegetation, macro-invertebrates, fish, and other vertebrates having some dependency upon the river and its riparian habitats (e.g. amphibians, reptiles, birds, mammals). The flow requirements of each of these components can be evaluated using data derived from field studies, modelling and desktop techniques (see Arthington & Zalucki 1998 for a review of such methods particularly those used in Australia), and/or by accessing expert opinion. The requirements of each component for particular volumes and timing of flows are then incorporated into the EFA recommendations.

Holistic methodologies currently represent around 8% of the global total of some 200 environmental flow methods (Tharme 2003). Although predominantly developed and used in South Africa and Australia, recently holistic approaches have begun to attract growing international interest in both developed and developing regions of the world, with strong expressions of interest by some 12 countries in Europe, Latin America, Asia and Africa (Tharme 2003). At least 16 methodologies based on the holistic principles now exist, and they can be described (see Arthington *et al.* 1998) as either ‘bottom-up’ methods (designed to ‘construct’ a modified flow regime by adding flow components to a baseline of zero flows), or ‘top-down’ methods (addressing the question: “How much can we modify a river’s flow regime before the aquatic ecosystem begins to noticeably change or becomes seriously degraded”?).

The South African Building Block Methodology or BBM (King *et al*. 2002) was the first structured approach of this type. It began as a bottom-up method, more recently incorporating the Flow Stress-Response Method. In this modified form it is legally required for intermediate and comprehensive determinations of the South African Ecological Reserve (Tharme 2003). Other bottom-up methodologies include several expert and scientific panel methods developed and applied in Australia (see reviews in Arthington 1998 and Cottingham *et al*. 2002).

Examples of top-down methods are the Benchmarking Methodology (Brizga 2000; Brizga *et al.* 2002) used routinely in Queensland at the planning stage of new developments to assess the risk of environmental impacts due to future water resource development, and DRIFT – Downstream Response to Imposed Flow Transformations (King *et al*. 2003), also designed to predict the probable ecological impacts of various scenarios of flow regime change. The fish component of DRIFT has been described in detail by Arthington *et al*. (2003). In contrast to DRIFT and Benchmarking, the Flow Restoration Methodology (Arthington *et al*. 1999, 2000) is a bottom-up approach designed to analyse how an existing regulated flow regime could be modified to capture more of the ecological characteristics of the river in its pre-regulation state. It involves modelling a range of possible scenarios of environmental flow releases and then undertakes a simple top-down appraisal of the probable ecological consequences of restoring (or not restoring if there are real constraints) certain elements of the pre-regulation flow regime. The Flow Events Method is a rather similar approach providing hydrological and hydraulic analyses of particular thresholds of ecological response as part of a broader scientific panel approach (Cottingham *et al*. 2002). Additional holistic methodologies developed and applied elsewhere include the River Babingley Method developed in England, and the Adapted BBM-DRIFT methodology developed in Zimbabwe.

Applications of holistic methodologies to date have focused almost entirely on surface water systems, with most effort addressed to the main river channel and its tributaries. It is only relatively recently that specialist methods have been proposed to address the freshwater flow requirements of downstream receiving waterbodies (e.g. large floodplains and terminal lakes in arid-zone rivers), and estuaries (see Loneragan & Bunn 1999). Methods and protocols to integrate the dynamic interactions of surface and groundwater systems into existing holistic methodologies are at a fairly immature stage of development, with none routinely applied as part of the holistic assessments described above.

Environmental flow assessments may include evaluation of a range of other mitigation measures, for example, how to restore longitudinal and lateral connectivity by providing fish passes or altering the configuration of levee banks on a floodplain. Management of storage water levels may also be examined and recommendations made on the benefits of more, or less, stable water levels. Some of the holistic methodologies described above (e.g. the Flow Restoration Methodology) also take into consideration the influence of threatening processes and disturbances unrelated (or less directly related) to flow regulation, and advise on possible mitigation measures such as riparian and habitat restoration, or the management of invasive vegetation and fish.

The most recent innovations in environmental flow assessment methods are reviewed by Tharme (2003), and further information on recent world developments can be found in *River Research and Applications* Volume 19 (2003) containing selected papers from the International Working Conference on Environmental Flows for River Systems and the Fourth International Ecohydraulics Symposium (held in Cape Town, South Africa, March 2002). A special edition of the *Journal of Water Resources* (Volume 5, 2002) also describes recent developments in Australian EFA methods and studies.

Over 50 countries now use environmental flow assessment as a water management tool. Moreover, the requirement to provide environmental flows to protect and restore river ecosystems is increasingly appearing in national legislation – in Australia as part of recent water reforms (Comonwealth of Australia 1996; Arthington & Pusey 2003), in South Africa associated with the new water laws (King *et al.* 2003; Tharme 2003), and in Europe in response to the European Water Directive.

New Zealand Resource Consents

Dams – Management and Best Practice (NZSOLD Symposium 2000) and papers for the 2003 NSOLD Symposium provide insight into the requirements and procedures involved in obtaining resource consents for new dams and re-consents for existing schemes. Foster & Amos (2000) have described guidelines for resource consents and associated activities prepared by Optus International Consultants assisted by four Regional Councils and four dam owners. These guidelines set out a logical framework for preparing an Assessment of Environmental Effects (AEE) and consent application for dam development. Foster & Amos (2000) point out that while every dam proposal will be different, there are commonalities, and they suggest that consent conditions and associated activities should address the following issues – environmental limits such as residual flows and contaminant levels in receiving waters (for discharges), mitigation requirements for environmental effects, monitoring requirements related to environmental effects, requirements for dam safety, requirements for appropriate emergency management procedures and plans, and a review of condition allowing the consent authority to review the exercise of the consent.

Environmental effects are further discussed by Lilley (NSOLD Symposium 2003) with regard to TrustPower's re-consenting processes, and by McQuarrie *et al*. (NSOLD Symposium 2003) who include a broad range of environmental issues in their discussion of the upgrade of Cosseys Dam.

Part of the consenting process is the definition of 'existing environment', or baselines against which the ongoing effects of a water resource scheme can be evaluated. Interpretations advanced by stakeholders have included, but have not been limited to:

- The 'Pre-scheme' approach, where it is argued that the consents must be processed by considering the river and its environs as if the scheme did not and had not ever existed;
- The 'Recent History' approach, where the existing environment is defined in terms of recent scheme operations;
- The 'No Consents' approach, where the scheme structures are permitted to exist, but the right to divert, store or utilise any water is withdrawn (i.e. the river is released back along the river course).

Differing interpretations of the definition of the 'existing environment' have emerged from the re-consenting process around New Zealand, suggesting the need for a national protocol or guideline that all parties can accept and adhere to in the consenting process. Experiences in other countries may be helpful in this context.

In Australia, every State and Territory is required to evaluate the water requirements of 'water-dependent ecosystems' (aquatic, riparian, floodplain, wetland) and to provide water allocations to 'sustain' and where possible 'restore' the ecological values of these ecosystems (Commonwealth of Australia 1996). Water allocation strategies must be reviewed after 5 or 10 years, when it is anticipated that monitoring data will be available to guide re-adjustments of the flow regime to more closely approximate the desired ecological outcomes.

When the requirement is to 'restore' ecological values, the strategy is generally to re-instate particular features of the pre-regulation flow regime that are known or presumed to 'drive' particular ecological outcomes (e.g. certain within-channel or floodplain flows may be provided to mimic the frequency, timing and duration of historical flows that achieved fish or bird breeding). The best available information about the linkages between pre-scheme flows and ecological responses is used to guide the flow restoration strategy. It is very rare for a restoration project to attempt full restoration of the prior natural flow regime. Weir removal is under active consideration in several areas of Australia but to date, dam removal has not come onto the water reform agenda, for fairly obvious reasons (most dams have ongoing value to society and cannot be removed unless new sources of water can be provided to meet society's needs). Therefore, flow restoration projects tend to have much more constrained objectives involving only partial restoration of some aspects of the river's historical hydrology, or some approximation of this.

In every case known to this author, the baseline for comparison of the ongoing effects of a dam or scheme and the regulated flow regime is the condition of the 'existing environment' with the scheme in place and operational. The monitoring strategy therefore involves quantitative documentation of this existing condition, followed by a planned sequence of monitoring activities designed to record how particular ecological features of the river respond over time to the flow manipulation.

In other words, the pre-scheme environment (if known) or the condition of a similar unregulated river may be used to guide the design of environmental flows, but the existing environment with the scheme in place provides the baseline against which the ongoing effects of the scheme and the regulated flow regime are evaluated.

The Flow Restoration Methodology (Arthington *et al.* 2000) describes the entire sequence of flow restoration for a large Queensland dam, from evaluation of the existing environment, through definition of the actual flows to be restored (and what they are expected to achieve for each component of the river ecosystem) through to the design of a monitoring program. Other environmental flow methodologies also address monitoring strategies (e.g. Benchmarking, Brizga 2000; DRIFT, King *et al.* 2003).

Given that there have been differing interpretations of the definition of the 'existing environment' during the re-consenting process around New Zealand, a review of issues and arguments for and against various positions could be useful. From this review, and with reference to procedures followed in other countries, a best-practice guideline for New Zealand could be developed. Such a guideline could be endorsed by the Department of Conservation and/or other relevant national bodies, thereby reducing the potential for conflicting viewpoints and unrealistic expectations about the likely future state of rivers that are already regulated and likely to remain so. The overall goal should be to mitigate every possible environmental impact of existing water resource schemes, and to strive towards design improvements that will minimise the likelihood of undesirable environmental impacts of any new dams and water resource schemes in the future.

Conclusions

River management to achieve ecological sustainability as well as access to water resources for human uses is now the goal of many nations, and environmental flows, as well as other strategies (e.g. integrated catchment management, water quality standards, biodiversity agreements) are the approaches being applied to achieve sustainability. There are four major types of environmental flow methodology, with the most recent innovations involving hydraulic habitat modelling and holistic methodologies. The latter aim to protect as much as possible of the historical riverine ecosystem or to restore ecological values to regulated systems within the constraints of dam design and operations.

In New Zealand, differing interpretations of 'existing environment' have complicated the re-consenting process and suggest the need for a national protocol or guideline that all parties can accept and adhere to in the consenting process. Experiences in other countries may be helpful in this context. In Australia, the 'pre-scheme' environment or the condition of a similar unregulated river may guide the restoration of flows in a regulated river, but the 'existing environment' with the scheme in place provides the baseline against which the ongoing effects of the scheme and the regulated flow regime are evaluated. Acceptance of similar definitions and approaches as part of the resource consents process in New Zealand could avoid conflicts about the interpretation of 'existing environment'.

References

Arthington, A.H. 1998. Comparative Evaluation of Environmental Flow Assessment Techniques: Review of Holistic Methodologies. *LWRRDC Occasional Paper 26/98*. Land and Water Resources Research and Development Corporation, Canberra.

Arthington, A.H., Pusey, B.J. 1993. In-stream flow management in Australia: methods, deficiencies and future directions. *Australian Biologist 6*: 52–60.

Arthington, A.H., Pusey B.J. 2003. Flow restoration and protection in Australian rivers. *River Research and Applications 19* (in press).

Arthington, A.H., Zalucki JM. (eds). 1998. Comparative Evaluation of Environmental Flow Assessment Techniques: Review of Methods. *LWRRDC Occasional Paper 27/98*. Land and Water Resources Research and Development Corporation, Canberra.

Arthington A.H., Brizga S.O., Kennard M.J. 1998. Comparative Evaluation of Environmental Flow Assessment Techniques: Best Practice Framework. *LWRRDC Occasional Paper 25/98*. Land and Water Resources Research and Development Corporation, Canberra.

Arthington A.H., King J.M., O'Keefe J.H., Bunn S.E., Day J.A., Pusey B.J., Bluhdorn D.R., Tharme R. 1992. Development of an holistic approach for assessing environmental flow requirements of riverine ecosystems. Pp. 69–76 *in*: Pigram, J.J., Hooper, B.P. (eds) Proceedings of an International Seminar and Workshop on Water Allocation for the Environment. Centre for Water Policy Research, University of New England, Armidale.

Arthington, A.H., Brizga, S.O., Kennard, M.J., Mackay, S.J., McCosker, R.O., Choy, S.C., Ruffini, J.L. 1999. Development of a flow restoration methodology (FLOWRESM) for determining environmental flow requirements in regulated rivers using the Brisbane River as a case study. Pp. 449–454 *in*: Proceedings of Hydrology 1999, the 24th Hydrology and Water Resources Symposium. Australian Institution of Engineers, Barton, ACT.

Arthington, A.H., Brizga, S.O., Choy, S.C., Kennard, M.J., Mackay, S.J., McCosker, R.O., Ruffini, J.L., Zalucki, J.M. 2000. Environmental flow requirements of the Brisbane River downstream from Wivenhoe Dam. South East. Queensland Water Corporation and Centre for Catchment and In-Stream Research, Brisbane.

Arthington, A.H., Rall, J., Kennard, M.J. 2003. Environmental flow requirements of fish in Lesotho rivers using the DRIFT methodology. *River Research and Applications 19* (in press).

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. *Instream Flow Information Paper 21*. FWS/OBS-82/26. US Department of Fisheries and Wildlife Services,Washington DC.

Brizga, S.O. 2000. Burnett Basin water allocation management plan: proposed environmental flow performance measures. Volumes 1 and 2. Department of Natural Resources, Brisbane, Queensland.

Brizga, S.O. Arthington, A.H., Pusey, B.J., Kennard, M.J., Mackay, S.J., Werren, G.L., Craigie, N.M., Choy, S.J. 2002. Benchmarking, a 'top-down' methodology for assessing environmental flows in Australian rivers. ENVIRO FLOWS 2002. Proceedings of the International Conference on Environmental Flows for River Systems, incorporating the 4th International Ecohydraulics Symposium. Southern Waters Ecological Research & Consulting (Pty) Ltd., Cape Town.

Bunn, S.E., Arthington, A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management 30*: 492–507.

Commonwealth of Australia 1996. National Principles for Provision of Water for Ecosystems. *Occasional Paper SWR No. 3*. Agriculture and Resource Management Council of Australia, and Australia and New Zealand Environment and Conservation Council, Canberra.

Cottingham, P., Thoms, M.C., Quinn, G.P. 2002. Scientific panels and their use in environmental flow assessment in Australia. *Australian Journal of Water Resources 5*: 103–111.

Foster, P.F., Amos, P.D. 2000. Guidelines for resource consents for dams. In: Dams – Management and Best Practice. Proceedings of NSOLD Symposium 2000. *IPENZ Proceedings of Technical Groups 26 (1(LD))*: 7–12.

Jowett, I.G. 1997. Instream flow methods: A comparison of approaches. *Regulated Rivers: Research and Management 13*: 115–127.

Junk, W.J., Bayley, P.B., Sparks, R.E. 1989. The flood-pulse concept in river-floodplain systems. *In*: Dodge, D.P. (ed.) Proceedings of the International Large River Symposium (LARS). *Canadian Journal of Fisheries and Aquatic Sciences Special Publication 106*: 110–127.

King, J.M., Tharme, R.E. 1994. Assessment of the Instream Flow Incremental Methodology and initial development of alternative instream flow methodologies for South Africa. *Water Research Commission Report No. 295/1/94.* Water Research Commission, Pretoria. 590 pp.

King, J.M., Cambray, J.A., Impson, Dean N. 1998. Linked effects of dam-released floods and water temperature on spawning of the Clanwilliam yellowfish *Barbus capensis*. *Hydrobiologia 384*: 245–265.

King J.M., Tharme R.E., De Villiers M.S. (eds) 2002. Environmental flow assessments for rivers: manual for the Building Block Methodology. *Water Research Commission Technology Transfer Report No. TT131/00*. Water Research Commission, Pretoria.

King, J.M., Brown, C., Sabet, H. 2003. A scenario-based holistic approach to environmental flow assessments for rivers. *River Research and Applications 19* (in press).

Kingsford, R.T. 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology 25*:109–127.

Lilley, P. 2003. TrustPower's re-consenting process – the highs and lows. *In*: Dams – Consents and Current Practice. Proceedings of NSOLD Symposium 2003. *IPENZ Proceedings of Technical Groups 30 (2(LD))*: 77–83.

Loneragan, N.R., Bunn, S.E. 1999. River flows and estuarine ecosystems: implications for coastal fisheries. *Australian Journal of Ecology 24*: 431–440.

McQuarrie,W. Davies, A. Bell, J. 2003. The upgrade of Watercare's Cosseys Dam – project implementation and consenting. *In*: Dams – Consents and Current Practice. Proceedings of NSOLD Symposium 2003. *IPENZ Proceedings of Technical Groups 30 (2(LD))*: 11–20.

Milton, D.A., Arthington, A.H. 1985. Reproductive strategy and growth of the Australian smelt, *Retropinna semoni* (Weber) (Pisces: Retropinnidae), and the olive perchlet, *Ambassis nigripinnis* (de Vis) (Pisces : Ambassidae), in Brisbane, south-eastern Queensland. *Australian Journal of Marine and Freshwater Research 36*: 329–41.

Naiman, R.J., Magnuson, J.J., McKnight, D.M., Stanford, J.A. 1995. The Freshwater Imperative: A Research Agenda. Island Press, Washington, DC. 165pp.

Naiman, R.J., Bunn, S.E., Nilsson, C., Petts, G.E., Pinay, G., Thompson L.C. 2002. Legitimizing fluvial ecosystems as users of water. *Environmental Management 30*: 455–467.

Newbury, R., Gaboury, M. 1993. Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour. *Freshwater Biology 29*: 195–210.

Olden, J.D., Poff, N.L. 2002. Redundancy and the choice of hydrological indices for characterising streamflow regimes. *River Research and Applications 18*.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.l., Richter, B.D., Sparks, R.E., Stromberg, J.C. 1997. The natural flow regime a paradigm for river conservation and restoraton. *BioScience 47*: 769–784.

Puckridge,, J.T., Sheldon, F., Walker, K.F., Boulton, A.J. 1998. Flow variability and the ecology of large rivers. *Marine and Freshwater Research 49*: 55–72.

Pusey, B.J., Arthington, A.H., Bird, J., Close, P. 2001. Reproduction in three species of rainbowfishes (Melanotaeniidae) from rainforest streams in northern Queensland, Australia. *Ecology of Freshwater Fish 10*: 75–87.

Pusey, B.J., Kennard, M.J., Arthington, A.H. 2000. Discharge variability and the development of predictive models relating stream fish assemblage structure to habitat in north-eastern Australia. *Ecology of Freshwater Fishes 9*: 30–50.

Richter, B.D., Baumgartner, J.V., Powell, J., Braun, D.P. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology 10*: 1–12.

Richter, B.D., Baumgartner, J.V., Wigington, R., Braun, D.P. 1997. How much water does a river need? *Freshwater Biology 37*: 231–249.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and floodplains. *BioScience 45*: 168–182.

Stalnaker, C., Lamb, B.L, Henriksen, J., Bovee, K., Bartholow, J. 1994. The Instream Incremental Methodology. A Primer for IFIM. *Biological Report 29*. US Department of the Interior, National Biological Service, Washington, DC.

Tharme, R.E. 1996. Review of international methodologies for the quantification of the instream flow requirements of rivers. Water Law Review: final report for policy development, South African Department of Water Affairs and Forestry. Freshwater Research Unit, University of Cape Town, Pretoria. 116 pp.

Tharme, R.E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications 19*: (in press).

Ward, J.V., Standford, J.A. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated Rivers Research and Management 11*: 105–119.