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Article

Integrated Management in Large River Basins: 12 Lessons from the Mekong and Murray-Darling Rivers

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with 3 figures

Abstract: Although every large river basin is unique, we identify 12 broadly applicable lessons related to integrated management which river basin managers should bear in mind. These are: the size of a river basin has an important influence on the complexities of management; decision makers tend to give priority to stakeholders seeking to gain short term personal benefit; river basin managers often fail to learn from the experience of others, or even from past mistakes in their own river basin; preventing river basin degradation is far cheaper than repairing damage; a basin plan does not replace a basin planning process; basin plans and their implementation must strike an appropriate balance between stakeholders; sound knowledge is essential in evidence-based decision making, but decisions are ultimately political and involve value judgments; technical work must be peer reviewed to ensure quality; the emphasis on the fishery in basin planning is often unrelated to the importance of the fish to human subsistence; asset-based management approaches are very complex in large river basins; large scale developments attract a lot of planning attention, but basins are often degraded through numerous small scale impacts.

Keywords: large rivers, river management, Mekong, Murray-Darling

Introduction

The Mekong (south-east Asia) and Murray-Darling (Australia) river systems are two very large river basins encompassing multiple jurisdictions. The basin managers in each case share many common problems, but there are also substantial differences. The suite of commonalities and differences means that many of the lessons that have been learned in the process of improving the management of these two huge river systems may be relevant to managers of large river basins elsewhere. This paper provides a discussion of 12 key lessons arising from our personal experience in the management of the two rivers.

The Mekong and the Murray-Darling Rivers are similar in a number of ways. Both have very large river basins – approximately 1 million km^2, and extend over a number of jurisdictions. For the Mekong the jurisdictions are six sovereign countries, while in the case of the Murray-Darling they are four of the six States that formed the sovereign country of Australia in 1901. However, as with the United States of America, the Commonwealth of Australia has only limited powers. The States still retain many of the powers critical to integrated river basin management.

The differences between the Mekong and the Murray-Darling are also important. The first critical difference is

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that the Mekong flows through countries or parts of countries, which are very poor in terms of per capita GDP (Campbell 2009a). By contrast Australia is a relatively wealthy country in terms of GDP per capita. Second, the Murray-Darling has been severely impacted by human development (particularly agriculture) over the past 150 years, with a number of consequent issues including over allocation of water and salinisation being widely recognized by governments and communities in the basin (MDBA 2010, 2011a). In contrast the Mekong has, until recently, been far less impacted by human activity. Dams on the mainstream are relatively recent and, so far, restricted to the upstream regions and the fishery has been impacted by a decline in the abundance of large fish species, and, although overall catch does not appear to have declined (MRC 2010), the catch per individual fisher almost certainly has (Baran & Myschowoda 2008, MRC 2010). However, the flow of the Mekong remains largely unaltered, water quality is still good except for the delta (Campbell 2007b, Ongley 2009) and it supports the world's largest inland fishery (Hortle 2009).

The Mekong River Basin

There are several publications that describe the physical, biological, social and political features of the Mekong River Basin (Hori 2000, Osborne 2000, MRC 2003, Hook et al. 2003, Campbell 2009, Molle et al. 2009). The Mekong River (Fig. 1) drains a basin of about 795,000 km^2, which has been estimated as the 22nd largest river basin globally (Campbell 2009a). The mean annual discharge is estimated at more than 475 x 10^9 m^3, with relatively little variation from year to year (Adamson et al. 2009). The population of the lower basin was estimated at 55 million in 2003 (MRC 2003) with rapid population growth (Hook et al. 2003). The population density in the upper Mekong is lower, so the overall population of the total basin now exceeds 60 million people. The basin is shared by 6 countries: PR China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam.

Fig. 1. Location map of the Mekong River Basin. Note the unusual "panhandle" basin shape and six countries sharing the basin.

The relatively large human population, and a long history of large-scale human settlements and states for over 2000 years (e.g. see Hall 1991), has extensively altered the ecology of the Mekong Basin. Much of the forest remaining in the Lower Mekong Basin is secondary forest (Rundel 2009), which, although it still plays an important role in supporting biodiversity, has a lower diversity than the original primary forest. The most notable features of the biodiversity of the Mekong are the extraordinary diversity of fish species (Valbo-Jorgenson et al. 2009) and the high diversity of freshwater snails (Attwood 2009), together with the presence of a number of iconic species such as giant fish species, including the Mekong giant catfish (Valbo-Jorgenson et al. 2009) and the freshwater Irrawaddy dolphin (Beasley et al. 2009).

Another feature of the Mekong River, together with many other rivers in developing regions, is the intensive and extensive subsistence use of the river and its water. The fisheries of the Mekong and its floodplain provide the main source of protein and micronutrients for the people of the Lower Mekong (Hortle 2009). In addition to fish and other aquatic animal foods, such as crustaceans, molluscs and insects, the annual Mekong flood has traditionally supported rice agriculture, which was formerly a rainfed or flood recession crop, or facilitated by small-scale irrigation. Increasingly rice cropping has been managed by large-scale poldering in the Delta or through large-scale irrigation development in upstream areas, with fairly mixed outcomes (Hoanh et al. 2009, Nesbit et al. 2004). A consequence is that development which has the potential to alter flow volumes or flood heights, and consequently the riverine biota, also has the potential to directly impact the livelihoods of hundreds of thousands or even millions of people. Projects that bring short-term social and economic benefits can also bring very large long-term social, economic and environmental losses.

As a consequence of the high population density and intensive subsistence use, management of the Mekong River Basin has a huge and often unappreciated social dimension. The number of people potentially directly impacted by changes in water resource allocation is very large, and the impact per individual on those who derive all or most of their subsistence from the river may also be very large. In addition many of the subsistence users are poor, not formally educated and with limited skills beyond those directly needed to support themselves and their families. As a result they are very vulnerable to changes in river basin or water resources management.

The Murray-Darling River Basin

The Murray-Darling Basin is Australia's most iconic river system. There are many publications that describe its physical, ecological, socio-economic and political features (e.g. Mackay & Eastburn 1990; Young 2001, MDBA 2010, MDBA 2011 a-c, Rogers & Ralph 2011). The catchment has an area of around 1 million km^2 (or 1/7 area of Australia) and is located in south-eastern Australia (Fig. 2). The system is divided by climate into northern rivers (Darling system) and southern rivers (Murray system) (Fig. 2). The Darling system is more influenced by tropical weather patterns with most rainfall occurring in the

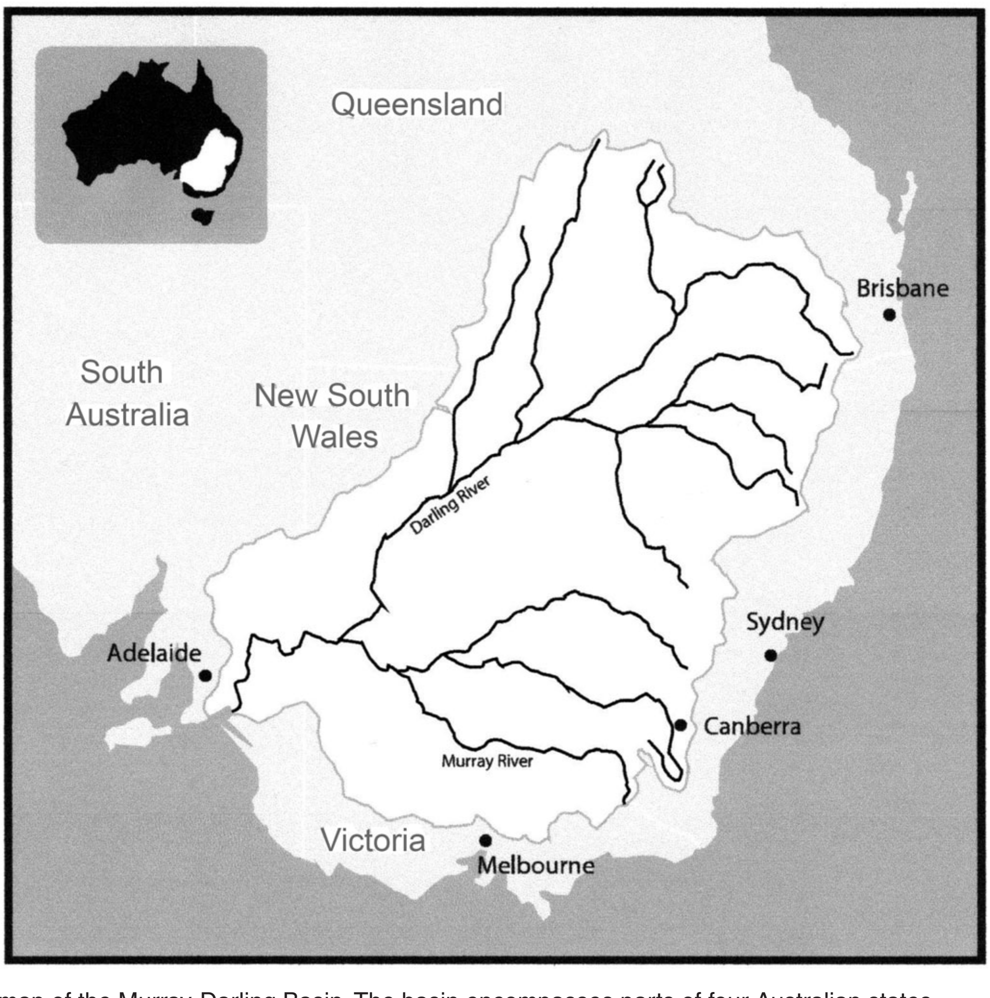

Fig. 2. Location map of the Murray-Darling Basin. The basin encompasses parts of four Australian states.

summer, while the Murray system is more winter-spring rainfall dominated.

Most of the flow in the Murray-Darling system originates from the Australian Alps that run essentially north to south down the eastern side of the catchment. And while the Alps dominate the rainfall and runoff, by far the greater proportion of the Basin is made up of extensive plains and low undulating areas, mostly no more than 200 m above sea level. A consequence of the extent of the Basin is the great range of climatic and natural environments; from the rainforests of the cool eastern uplands, to the temperate woodland savannah country of the south-east, to the inland sub-tropical areas of the north, and to the hot, dry semi-arid and arid lands of the western plains.

The Murray-Darling Basin has been home to Aboriginal people for at least 50,000 years, sustaining their cultural, social, economic and spiritual life. There are now over 2 million people living within this Basin and dependent on its water resources. Outside the Basin a further 1.3 million people are dependent on its water resources, most living in the city of Adelaide.

Although the Basin covers a large area, runoff is very low compared with other major river systems around the world. Inflows to the rivers of the Basin have ranged from 118 x 10^9 m^3 in 1956, a wet year, to less than 7 x 10^9 m^3 in 2006, a dry year. Prior to significant human changes in the Basin, about 32 x 10^9 m^3 yr^{-1} (or 6% of average annual rainfall) occurred as run-off and flow into rivers and streams. Additionally, on average, an additional 1 x 10^9 m^3 yr^{-1} is transferred into the Basin from external sources for an annual mean of 33 x 10^9 m^3 yr^{-1}, but unlike the Mekong the year to year variations in the Murray-Darling system are very large.

The Murray-Darling Basin is one of the most productive agricultural regions in Australia, representing 20% of Australia's total agricultural land area, but contributing almost 40% of the annual gross value of agricultural production in Australia (MDBA 2011c, 2012b). Irrigated agriculture is the major user of the Basin's water resources (currently around 40%) and contributes around 37% of the Basin's agricultural output. Key agricultural products in the Basin include fruit and nuts, vegetables, table and wine grapes, dairy, rice, cotton, grain, sheep and beef cattle.

The Basin has a large area of floodplain forests and wetlands, with 16 of the wetlands being Ramsar listed. It also supports a great diversity of nationally and internationally significant plants, animals and ecosystems, many of which are now threatened, vulnerable or degraded. The degradation of floodplain River Red Gum forests, native fish populations, water bird populations and the Coorong coastal lakes at the end of the system, are now well documented (MDBA 2010, 2011b). Much of this degradation has been caused by the increasing regulation of the Murray-Darling river system for consumptive use over the past 100 years.

In the early 1990s it was recognized that there was an urgent need to reform water resource management in the Murray-Darling river system. This has led to considerable change to the management of the Basin's water resources. In 1995, Basin governments agreed to impose a cap on surface water use, and in 2004, the National Water Initiative was adopted with the aim of phasing out overuse of water, reforming the water entitlement system and developing an active water market. Then, in 2007, the Federal Government passed a new Water Act (Aust. Govt 2009), with Basin State governments agreeing that the Australian Government take a larger coordinating role in integrated management of the Basin's water resources. The Federal Government coupled this new Act with a proposal to invest around AU$ 10 billion in purchasing water entitlement for the environment and in modernizing the existing irrigation infrastructure.

The Water Act (2007) established a new independent Murray-Darling Basin Authority, with a mandate to rebalance water allocations between the environment and consumptive uses, through the development and implementation of a Basin Plan. The development of this Basin Plan is now complete; it was approved by Federal parliament in November 2012 (MDBA 2012a). Implementation of this first plan will occur over the period 2013–2019.

Purpose of the paper

In trying to identify possible management strategies that may be broadly applicable to large river basins, it is useful to compare management issues common to basins that are as different as the Mekong and the Murray-Darling. Issues common to these two basins, with their different histories and physical, political and cultural environments are likely to be issues relevant to all large river basins. Similarly, possible solutions and approaches to management, which appear to be succeeding in these two, are worth considering elsewhere, while management failings can act as cautionary warnings for other river basins.

In this paper we identify 12 key lessons from our experience in the management of both the Mekong and Murray-Darling river basins, and where possible suggest solutions to the problem or issue identified.

Lesson 1: Size matters – challenges for river basin management authorities

Increasing size in river basins correlates positively with increasing complexity in decision-making. However, the relationship is not linear, but more like a power function, with a very rapid increase in complexity in larger sized basins, for three reasons.

First, there is an increasing level of physical and ecological complexity in large river basins. Large basins that extend east-west, such as the Amazon, are entirely in one climate zone (tropics), while basins that extend north-south, such as the Mekong and Murray-Darling, will span many climatic zones; in the case of the Murray-Darling from sub-tropical to temperate and for the Mekong from temperate to tropical. In addition many of the large basins span a great altitudinal range. For example, the Mekong rises at an altitude of approximately 5,200 m in the Himalayas and flows to the sea, while the highest headwaters of the Murray rise on the upper slopes of Mt Kosciusko, Australia's highest mountain, at an altitude of about 2,000 m. Both rivers rise above the tree line and flow through a range of vegetation biomes in their respective regions. The water temperature changes dramatically, from close to freezing to above 30°C, and water chemistry also changes along each river, with increases in salinity and turbidity downstream (Campbell 2007b, Shafron et al. 1990).

Second, there is a range of different human communities spread through the basin. They range from urban dwellers living in large cities, to rural farmers and fishers. In large basins, people in one area of the basin often have a narrow perspective on the basin as a whole, and difficulty in appreciating the perspectives of communities elsewhere. There are usually upstream-downstream tensions. Often the downstream communities, which are usually amongst the earliest river users, fear that their use of the river is threatened by upstream users.

In the Murray-Darling, people from downstream South Australia frequently express the view that excessive upstream water use threatens the Coorong, a RAMSAR system of estuarine lakes at the mouth of the river (Paton 2010). Similarly, the lower Mekong countries, Cambodia and Vietnam, are concerned that Chinese dams will cause problems of increased saline intrusion or interfere with fisheries in the lower Mekong. On the other hand, the Chinese have been unwilling to have their hydropower development constrained by the real or perceived needs of the downstream countries.

Third, the number of jurisdictions inevitably increases as the size of the river basin increases. Jurisdictions may include governments at the local, regional and national level. The Murray-Darling basin lies within a single nation-state, however, parts of the basin are controlled by five independent State and Territory governments and numerous lower level jurisdictions, including local governments and catchment management authorities. The Mekong flows through 6 nations.

Interestingly, the need to manage such large river basins as single systems has been recognized for both systems. In Australia, issues around the management of the Murray River and tributaries arose prior to Federation and the (then) independent colonies of New South Wales, Victoria and South Australia had a number of meetings at least as early as 1863 to discuss improving navigation on the river through the construction of locks. At Federation, when Australia as a nation was founded in 1901, a number of clauses were included in the constitution specifically to address Murray-Darling River issues. In 1915 the Australian Government signed an agreement with the State governments of Victoria, New South Wales and South Australia to establish the River Murray Commission which had, as its main role, ensuring that the three states received their agreed share of the Murray River water (Eastburn 1990, also http://www2.mdbc.gov.au/about/history_mdbc.html). So the initial drivers for establishing a river basin management organization were navigation and the need to equitably share the water resource.

In 1985, in response to a growing range of environmental concerns including increasing salinity in the water and increasing land salinization the riparian states and the Australian Government signed the Murray-Darling Basin Agreement – and established the Murray-Darling Basin Commission. The new Commission had a broader remit than the previous commission, especially in the areas of water quality and quantity (Eastburn 1990). However, while the Commission was able to progress the integrated management of the Basin, it became obvious that this was not enough since ecological degradation continued to occur. The response was to establish an independent national level Authority (Murray-Darling Basin Authority – MDBA) in 2009 to 'ensure that the Basin water resources are managed in an integrated and sustainable way … and in the National interest' (Aust. Govt. 2007, MDBA 2011a).

In the Mekong, efforts towards managing the river basin as a whole did not begin until the 1950s (Campbell 2009a). In part this reflected a lesser need to manage the basin as there was less development and thus less demand and competition for water. A Committee for Coordination of Investigations of the Lower Mekong Basin was established in 1957 by the United Nations Economic Commission for Asia and the Far East (ECAFE), and this committee proceeded to undertake investigations and develop plans to harness the water resources of the Mekong. Several projects identified on the tributaries of the Mekong were implemented, but none of the main-stream projects identified by ECAFE were implemented. The activities of the committee were inhibited by war and politics with three member countries ceasing participation in 1976 and Cambodia continuing as a non-participant until 1992. Following Cambodia's decision to recommence participation in the Mekong Committee, the four Mekong Countries negotiated a new agreement and in 1995 the Mekong

River Commission (MRC) was established outside the ambit of the United Nations. The new agreement, while still maintaining the important principles around cooperation to promote and support development, also included objectives to '*protect, preserve, enhance and manage the environmental and aquatic conditions and maintenance of the ecological balance'* (MRC 1995).

As with the Murray-Darling, the initial driver for establishing a river basin management organization was the perceived need to ensure equitable sharing of the water resource, but unlike the Murray-Darling there was an external facilitator, perhaps reflecting the greater complexity in managing international relationships.

Lesson 2: Decision makers tend to give priority to those seeking to gain or maintain short-term personal benefit

In any public debate about the use of community resources, such as water or forests, those in the community who are seeking to gain or maintain short-term personal benefit usually have the loudest voices. This occurs because these community members have a strong motivation to speak out and are often those most willing to invest resources – time and money – into ensuring that their views are made known to decision makers.

In environmental debates in Australia, for example, the timber industry (including large forestry companies and mill operators as well as small-scale contractors) has been prominent in debates about forest management, and the irrigation industry (including National Farmers Federation and the NSW Irrigators Council – see www.nswic.org.au) has been prominent in the debate about water usage in the Murray-Darling Basin. It is not surprising that such groups, who frequently already have industry organizations, and who often have a shared viewpoint, should gain considerable media coverage, and should gain a disproportionate amount of the attention of politicians.

Other groups who may have differing views on resource utilization are often less unified in their views. Local communities, for example, generally encompass a wide range of viewpoints. Recreational natural resource user groups, including recreational fishers, water sports participants and campers tend either not to have organizational representation, or to be weakly organized, and for environmental groups, river management is often just one of many issues they deal with.

One difference between the Murray-Darling and the Mekong has been the role of international players in resource utilization debates. Financing and donor organizations, such as the World Bank and bilateral aid agencies have been influential in the Mekong, in a developing region, but not in the Murray-Darling. Multinational resource users have been prominent in both regions in recent times. In the Murray-Darling these tend to be within the agricultural industries, while in the Mekong the hydropower industry has been more prominent. International environmental organizations such as World Wildlife Fund (WWF) and the International Union for the Conservation of Nature (IUCN) have played significant roles in both basins, although the mix has differed somewhat.

This lesson highlights the need for public participation and consultation processes to be well designed and extensive to ensure that the full range of stakeholders has an opportunity to have their views considered. The MDBA, in developing the Basin Plan for the Murray-Darling, embarked on a series of consultations throughout the basin. These included round-table meetings and town hall meetings with communities within the basin as well as consultations with key lobby groups such as the National Farmers Federation, the NSW Irrigators Council, the Australian Conservation Foundation and others. At the end of the consultations the final plans are unlikely to give any of the stakeholders all that they would ideally want, but if the consultations have been genuine and transparent there is often an acceptance that the outcome is a reasonable tradeoff.

Within the Mekong there have been national players as well as other transnational and subnational potential beneficiaries. The dam building and hydroelectric interests with potentially large short-term profits to gain have certainly been loud and persistent lobby groups. The insistence of the Lao Government to build the Xayaburi Dam regardless of environmental consequences (Wongruang 2011) suggests that those seeking short-term benefits also have the ear of Mekong governments.

Lesson 3: We don't learn from other people's experience

While scientific literature has become increasingly borderless, and global communication is increasingly easy through email, the internet and VOIP telephony, there is still often a resistance to learning lessons from experience elsewhere. There are two perceived parts to the problem – one is a lack of knowledge of practice elsewhere, and the other is a failure to learn from, and apply, knowledge from elsewhere.

Lack of knowledge has been the most tractable aspect of the problem. It has been addressed by a number of means. Making information widely available through publication either physically or through websites at least makes it possible for those seeking knowledge, and who have the right tools (literacy in the appropriate language, access to libraries or the web) to be able to find it. But there are other solutions such as supporting stakeholders to participate in appropriate national and international meetings, through study tours and through the use of knowledge brokers. The latter are specialists whose role is the keep in touch with scientific and technical developments and present the information in appropriate form to non-specialist stakeholders. That may involve translating between languages, or translating from technical to everyday language, or translating to audiovisual media.

All these options have disadvantages. In developing countries, access to published information is difficult. River basin management organizations should be employing at least some staff with the skills and resources to access the international technical literature, but that is not always the case. Study tours and travel to conferences have sometimes been abused, and are often perceived within organizations or by the press as unjustified expenses – not much more than holidays for the fortunate recipients. Consequently, they are used less widely than should be the case. Finally, knowledge brokers are not yet widely recognized and are expensive. Organizations find it easier to justify employing technical specialists such as hydrologists, or specialized press officers (frequently with a purely media background) than technical communicators.

Ensuring that we learn from, and therefore that we apply other people's experience, is more difficult. In an Australian context there has been a strong tradition of querying to what extent Australian ecosystems differ from those elsewhere (e.g. see Dodson & Westoby 1985) and what that may mean for natural resource management. The implication being that overseas information is not relevant.

Too frequently, experience from elsewhere is either discounted out of hand because 'our system is different', or filtered so that key lessons are lost in translation. Clearly experience from elsewhere will often not be directly transferable to a particular basin, due to biophysical or political differences, but much can be. Unfortunately, much river basin management involves 'reinventing wheels'.

One approach being applied by the MDBA and some other agencies is a requirement that the 'best available science' be employed in decision-making. This is a requirement within the Water Act (2007) that established the MDBA. An approach to best available science has been formally developed over the past decade or so (Moghissi et al. 2010), with a primary focus on requirements of environmental and regulatory agencies in the United States. A formal process for identifying best available science will improve transparency in decision-making, making the scientific basis of technical decision-making clearer. But this approach is not a panacea (e.g. Richards undated), and, of course, many of the lessons in river basin management relate to issues other than technical decisions.

The best available science approach (Moghissi et al. 2010) includes a classification of science, an assessment of the reliability of science and procedures for scientific assessment. A key to the assessment of the science is a peer review process, and this is discussed further below. But it needs to be noted that a peer review process will not necessarily lead to lessons from elsewhere being incorporated into the knowledge base of a basin management agency. Peer reviewers will frequently be selected from the local scientific community, because they are convenient and known to the organization, and thus may be no better informed about lessons from elsewhere than the original program basin managers.

Lesson 4: We don't learn from our own experience

The process of learning from experience in natural resource management is the central tenet of adaptive environmental management (Walters 1986). The underlying philosophy of adaptive management is that we rarely have sufficient technical understanding to manage most natural resources, but that we cannot wait until we have a full understanding to make management decisions. Indeed, there will always be uncertainties in our understanding of the system being managed. Consequently, a logical path to proceed is to make management decisions based on our best present understanding, monitor the consequences of those decisions, and use the outcome of the monitoring to improve our understanding and to revise the management as necessary. This is often referred to as 'learning by doing'.

It is now almost mandatory to include 'adaptive management' in any plan for river management, e.g. see the proposed Murray-Darling Basin Plan (MDBA 2012a). But the successful implementation of adaptive management is quite rare (Eberhard et al. 2009). There are a number of steps required in successful adaptive management (Figure 3): (a) establishing an appropriate management structure, (b) assessing the resource to be managed, (c) understanding the resource and predicting future changes under a number of scenarios, (d) setting management targets, (e) developing the management strategy, (b) implementation of the appropriate management actions, (c) monitoring and assessment of the actions and the system's response, (d) feedback from the monitoring to the management decisions, and (e) a system or process for changing the management structure and strategy if needed.

The initial decision-making to develop a river management strategy is usually done well, as is the implementation of appropriate actions, but the process frequently breaks down thereafter. Two of the most common breakdowns are a failure to monitor and assess the system appropriately, or even at all, and a failure to implement feed-

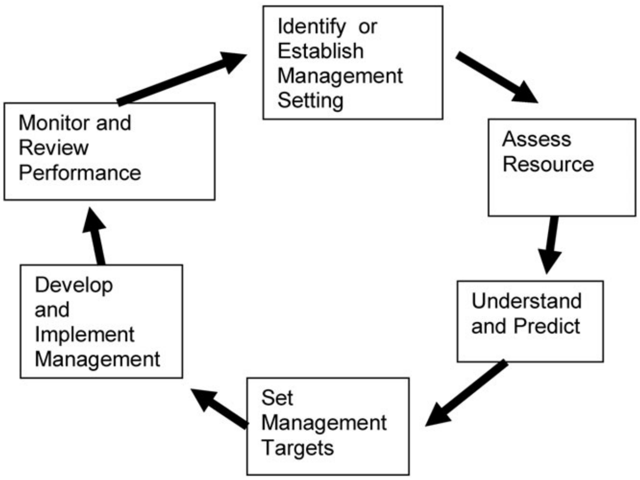

Fig. 3. A representation of the adaptive management cycle. Key aspects include understanding and predicting how a resource may change under a variety of future scenarios, (including climate and population change as well as management actions) implementing management and monitoring system change, and then ensuring that there is feedback to improve system understanding and evaluate management structures and management actions.

back from the monitoring to the decision-making process to permit necessary changes to be made. The same problems reoccur in river basins throughout the world (O'Donnell & Galat 2008).

In the Mekong River Basin the agreement to establish the Mekong River Commission in 1995 affirmed the need to manage and maintain the aquatic environment (MRC 1995). Under Article 3 of the Agreement, the member countries agreed to 'protect the environment, natural resources, aquatic life and conditions, and ecological balance of the Mekong River Basin from pollution or other harmful effects resulting from any development plans and uses of water…'. However, although chemical water quality monitoring has been conducted basin-wide by all four member countries since 1993 (Campbell 2007b, Ongley 2009), basin-wide monitoring of the aquatic life did not commence until 2004 and was only continued for 4 years (Campbell et al. 2009). The fish catch at the Tonle Sap river dai or bag net fishery has been monitored annually since 1997, but there are concerns that the pre-2000 data are not reliable (Kent Hortle pers. comm. 2011). The fishery as a whole is so large and diffuse that annual monitoring is impractical (see Hortle 2009).

Overall, the Mekong provides an example of a large river basin where there is no adequate ecological monitoring program. A reasonably reliable hydrological monitoring network exists, and monthly data on chemical water quality, but little else. The nature and extent of this monitoring is not sufficient to support adaptive management.

The example of the Mekong is not unique. In Australia, while there are large-scale monitoring programs for water quality and river health operated by state agencies and the MDBA (MDBA 2009), many of these monitoring and assessment programs have been poorly conceived and coordinated and have led to few changes in management strategies. This lack of adequate monitoring and assessment has been recently highlighted in attempts in Australia to show that the additional environmental water (environmental flows) allocated to rivers and wetlands has been beneficial (NWC 2012). A recent global review of environmental water management also concluded that within the USA most projects to restore environmental flows had not been followed by adequate monitoring, and in many cases by no monitoring at all (Campbell et al. in press).

This lack of monitoring has also been highlighted in several reviews of river restoration works in the Murray-Darling Basin (Stewardson et al. 2002) and by several catchment management authorities in the Australian state of Victoria (Brooks & Lake 2007). Both these reviews found that monitoring was carried out in very few cases following river restoration works.

Obviously, the concept of adaptive management of natural resources has much to commend it. However, unless there is robust monitoring of both the management actions and the system responses, managers will remain uninformed about the effectiveness (or otherwise) of their management activities, and will lack information on whether the management strategy is appropriate or needs to be changed.

There is an extensive scientific literature on the design of monitoring programs for rivers (e.g. see Downes et al. 2002). Scientists have tended to emphasize the need for statistically sound monitoring designs, and this is certainly an important issue. However, in our experience, a failure to monitor at all is an even more widespread problem, especially in developing countries.

Lesson 5: Prevention is better than the cure

The restoration of ecological systems has recently become a vibrant field of ecological research (e.g. see Falk et al. 2006, Clewell & Aaronson 2008, Perrow & Davy 2008a) and river restoration has been a significant contributor to both the theoretical discussion (e.g. see Janssen et al. 2005, Lake 2005, Palmer et al. 2005, Lake et al. 2007) and a source of practical examples (Perrow & Davy 2008b, Howson et al. 2009). However, the restoration of rivers, or any other ecological system, is still a challenging task. There is as yet no agreement on what constitutes success in river restoration or how it should be measured (Wohl et al. 2005, Palmer et al. 2005, Janssen et al. 2005).

Clearly, without a clear articulation of what constitutes success (i.e. the ultimate objective), it is difficult to know whether the objective has been achieved.

It is now well appreciated that restoration of rivers is far more expensive than the initial modifications to the system. For example, the Kissimmee River in Florida was modified between 1962 and 1971 in order to reduce flooding (Koerbel 1995). A meandering channel and floodplain was converted into a 90km long large capacity straight channel intended to conduct floodwaters more rapidly to Lake Okeechobee. That project was completed at a cost of US$ 29 million, but in 1976 a decision was made to restore the fish and wildlife habitat by restoring the river to its original meandering condition, together with a restored floodplain, at an estimated cost of US$ 980 million (SFWMD 2010). We are not aware of any systematic assessment of the benefits of the project.

River, or river basin, restoration is not only expensive and technically difficult with uncertain outcomes, but it is also socially challenging. There are two sets of challenges: first there is usually some part of the community that will suffer costs or be disadvantaged as a result of the restoration project, and second, it may be difficult to achieve community agreement of the desired restored condition.

There are a number of obvious groups within communities who may suffer losses when rivers are restored. These may be people who own land on a floodplain that may be flooded more frequently. They may be people or enterprises that have been discharging wastes to the river and will now have to treat the wastes to a higher standard or find an alternative disposal method. They may be people or enterprises that will have reduced access to water diversions. And finally they will include fishers, or other users of aquatic resources, who may have their catch or activities limited. All of these groups may need to be convinced of the need for restoration, and possibly be compensated as well.

River restoration is most commonly required where a river flows through a landscape that has been substantially modified by human activity. As a consequence it is not realistic, and usually not possible, to restore the river to a ‘natural’ condition. So before restoration work can sensibly commence there must be a decision about the river condition that is to be the goal of restoration. In countries such as Australia and the US the goal has usually been some improvement in ecosystem function, which needs to be more specifically defined on a case by case basis. In some European countries reduction of flood hazards has been a major goal. In the Mekong both ecosystem function to support the fishery and flood risks are important river management drivers. This may be a difficult decision for a community to reach with various community members having widely differing visions. For example, the vision expressed by the MDBA in the draft Murray Darling Basin Plan is for a ‘healthy working basin … that supports strong and vibrant communities, resilient industries, including food and fibre, and a healthy environment’ (MDBA 2011a).

Preventing degradation is far preferable to restoration, from an environmental, social, economic and political viewpoint, and this is now broadly accepted at least among large river scientists (e.g. see Bloesch 2005)

Lesson 6: Basin plans are often mistaken for basin planning

River basin planning is a complex and should be a continuous process. Planning can never finish because river basins are never static. Even if a plan is achieved which is near perfect at a particular time, within a few years the situation will have altered and the plan will need to be revised.

The changes that occur in river basins are biophysical, social, economic and cultural. Physical changes can occur rapidly, but many occur over long time scales, social changes occur over decades (both within and between generations), and economic changes can occur on time scales of a few years to decades.

Physical changes include changes such as variations in rainfall, which can take place from year to year, or over decades. There are wet years and dry years, there are wet periods and dry periods such as those associated with El Nino and La Nina events (Pidwimy 2006), and there are longer term changes in climate, natural and human-induced, which will occur over decades to centuries (e.g. Pant 2003). Plans, and even models and scenarios, developed during wet periods may need revision if a long-term drought occurs. Increasingly, planning is explicitly including consideration of climate variability and climate change. This is the case in south-eastern Australia where, largely as a result of the ‘Millennium Drought’ between 2000 and 2010, most Water Authorities and Catchment Management Authorities now include a consideration of climate change and variability, and consequences for river and water supply management (NWC 2011).

Biological changes can occur in basins as a result of the introductions of alien plants and animals intentionally or accidentally. The spread of plants such as giant mimosa (Braithwaite et al. 1989) in northern Australia and the Mekong delta required rapid attention in land-use management plans. The introduction and spread of European carp (*Cyprinus carpio*) in the Murray-Darling basin from the early 1960s caused major alterations to the commercial and recreational fisheries (Koehn et al. 2000).

Societies change over time which triggers changes in societal values and priorities. Examples include the increase in environmental concern that has been evident in many countries since the mid 1960s in developed countries and more recently in the developing world. Further examples include the dramatic political changes that are continuing to occur in many countries, for example the 'Arab spring' and the fall of apartheid in South Africa. Those often lead to major changes in water resources allocation and river basin planning. South Africa provides a spectacular example with the post-apartheid water law (King & Pienaar 2011).

Finally, changes in the economic environment can also impinge dramatically on river basin planning. The impacts may arise through changes in demand for particular crops, through growth and movement of human populations, from growth or collapse in demand for hydropower for example. The changes may occur within a country, but may also arise through changes in neighboring countries or trading partners. For example, the possible consequences of free trade agreements on national patterns of agriculture, and subsequently on the environment, have been one area of discussion in the international literature (e.g. Maya & Bonilla 1997, Minot et al. 2007)

Consequently, while the development of a widely accepted basin plan is a challenging achievement, which may be an important milestone in basin planning, it is no more than that. The plan still requires implementation, and within a relatively short time the plan will require updating and revising. In fact, many Australian jurisdictions now have legislation that mandates the review of water resource plans or strategies after 5–15 years (NWC 2012). Additionally, it should be recognized that this review process will be facilitated if the community is engaged and kept involved in the basin management plan.

Lesson 7: Basin plans must strike an appropriate balance

Biophysical, social, cultural and economic differences between river basins mean that the imperatives in every river basin planning process are different. In developed countries, many of the major rivers are overallocated, and the river basins overdeveloped. However, in many developing countries the common perception is that further development of rivers is required to support poverty reduction.

In overdeveloped river basins, water resources are often overcommitted with insufficient water flowing in rivers to even meet the entitlements of legal abstractors. Examples include parts of the Murray-Darling river system in Australia (e.g. Kamal & Siddiqui 2009) and a number of river basins in South Africa (Muller 2009). In such places there is often strong community support for reducing abstraction rights and providing additional environmental water to restore ecosystem services to the river and its floodplain.

Interestingly, in the debate over the Murray-Darling Basin Plan, much of the push for more environmental water was from people based in the major capital cities, all outside the basin, while the major socio-economic impacts that may result from a rebalancing of water from consumptive (e.g. irrigation) to environmental uses will be incurred by people living in the basin (MDBA 2011c, 1012b).

In many less developed countries there is a perception that increased water resources development can play an important role in poverty alleviation. However, in these countries it is often a fact that the water resources are already intensively used by poor subsistence users. Such is the case in the Mekong. The challenge here is to identify development trajectories that enhance the economic conditions of the poor, a situation that will rarely be the case if subsistence use of the resource is ignored.

In each river basin an appropriate balance between consumptive and environmental uses and a development trajectory must be identified, and these will often be different between different river basins. The development trajectory should consider the need for poverty alleviation wherever appropriate, taking into consideration the need for equity. In most regions where poverty is widespread there is also a great inequity in personal wealth – with a small number of very wealthy individuals and a much larger number of poor people. Those wealthy individuals are often well positioned within society to take advantage of large-scale water resource developments, whilst subsistence water users are rarely able to claim a fair share of the benefits.

In international basins the inequities may occur not only between sectors of the community, but also between riparian countries. For example economic analyses of proposed hydroelectric developments in the Lower Mekong invariably demonstrate that Lao PDR will benefit economically, because it has the most suitable terrain for building large dams. However, the analyses also demonstrate that Cambodia will bear the brunt of the costs, because that country is flat and unsuitable for building large hydropower dams, and the Cambodian population is heavily dependent on the fishery, which would be substantially impacted by such development.

A major challenge in basin management is managing the trade-off between the basin communities, some of whom will lose out and some of whom will gain when water resources are reallocated. Achieving the trade-off may require provision of suitable compensation for the losers. In some cases that compensation may need to be between countries, which will add a second level of challenge to ensure that the compensation reaches those, often poorer members of the community, who are most directly affected.

Lesson 8: Science helps but the decisions ultimately require judgments to be made

Science plays an important role in river basin management. Decisions based on inaccurate or incomplete understanding of the river basin are likely to be poor. Good science is a necessary component of effective monitoring programs, and can help to develop predictions and scenarios, through modeling or other techniques that can inform the community and the decision makers. It is important to understand the hydrology, geomorphology, water quality and ecology of the river (the ecosystem function), as well as the fishery and the other users to develop management options and understand their consequences.

However, even if the technical understanding is perfect, and it never will be, in the end the community must still make a decision about trade-offs – between the condition they want for the river and the other uses they have for the river and its resources – water, fisheries and recreation, for example.

As the concept of 'river health' has become more widely used there has been a great deal of discussion in the literature about the appropriateness or otherwise of the human health analogy to the ecological condition (e.g. see Wiklum & Davies 1995, Suter 1993, Meyer 1997). In many respects we think it is a useful analogy, because as with human health, river health is not a categorical variable. That is, people have a range of healthy states: human health is not binary – we do not consider ourselves as having only two possible states – either healthy or unhealthy.

So also with rivers – river health forms a continuum from a perfectly health pristine stream to an entirely modified concrete drain flowing through a completely paved catchment. As a result of acid rain and global warming there are probably no streams on earth completely uninfluenced by humans. But we are prepared to accept some loss of river health to obtain other benefits from the river. The size of the loss we will accept depends on the size of the benefits, who will benefit, and our own personal value systems. Some people value wild rivers while others do not. Some people enjoy fishing, while others do not.

The challenge in river management is to find the best possible community agreement on what the condition of the river should be. That agreement must be informed about the benefits and costs – economic, social and environmental.

Some of the recent developments in environmental flows approaches, particularly in South Africa, have made the trade-offs in river management explicit. So the application of the DRIFT (downstream response to imposed flow transformation) method for environmental flows determination (King et al. 2003) produces a series of scenarios each of which includes the consequences for river condition, subsistence use and water extraction for community consideration. These scenarios can then be considered by the community in a transparent process in reaching a decision.

Lesson 9: Technical work must be peer reviewed to ensure quality

River and river basin management agencies are increasingly dependent on outside expertise for technical analysis and advice. The model adopted almost universally is for management agencies, and other government agencies for that matter, to maintain a small core staff and contracting out much of the specialist work to universities and consulting companies. There are advantages and disadvantages of this model.

Advantages include management agencies not having large numbers of redundant specialist staff if their operational emphasis changes. It is potentially a better use of highly skilled specialists if their skills are made available across a number of agencies or river basins or countries rather than being retained in one.

Disadvantages may include the lack of technically competent staff in the agency to be able to develop appropriate terms of reference, to manage consultancies, or to pick up on potentially valuable new technical developments.

One significant disadvantage that we have observed is a lack of understanding of the process of science. Often program managers have no scientific or other appropriate technical training, or have never worked as scientists or technical specialists. As a consequence they have no appreciation of the need for peer review of scientific or technical work. The review process needs to be conducted at a number of levels. At the highest level questions such as 'is the overall program designs scientifically or technically sound?' need to be answered. Also reviews need to be conducted at more detailed level, right down to the level of major technical reports preferably prior to acceptance by the agency, and certainly prior to publication.

In developing a protocol for the use of 'best available science' Moghassi et al. (2010) include a discussion of scientific review processes. These include independent peer review, a transparent process carried out by suitably qualified independent reviewers, which is appropriate to evaluate a document or manuscript and an independent scientific assessment which is appropriate for the critical evaluation of a topic. Most of the processes they identify are equally applicable, and equally important, to non-science technical fields, such as economics or governance.

Lesson 10: The emphasis on the fish is inversely related to their importance

This lesson has a number of parallels to Parkinson's original 'Law of Triviality' (Parkinson 1958). Parkinson argued that the time spent on any particular item on the agenda of a finance committee meeting will be in inverse proportion to the sum of money involved. He suggested that where the sum of involved money is large, such as, for example, allocating funds for the building of a nuclear reactor, the issue is complex and poorly understood by many committee members who are thus reluctant to comment. However, where the sum of money is small and the issue is simple, such as the nature of the refreshments served at Welfare Committee meetings, every committee member feels qualified to comment, and since many feel guilty because they didn't comment on the previous agenda item about building the nuclear reactor they now feel obliged to comment at length on this item.

The major inland fisheries in the tropics occur in locations where there are often large water bodies together with large human populations to harvest the fish. It is interesting that most of the world's largest rivers and the largest inland fisheries are located in developing countries (Campbell 2007a). Unfortunately, most developing countries have small research budgets, and fisheries, usually subsistence fisheries, are often not viewed as high priority by government decision makers. Large subsistence fisheries are complex to understand and difficult to manage. They are difficult to tax and not important sources of export revenue.

Subsistence fisheries are difficult to value, and are often undervalued economically. This has been well illustrated in the Mekong Basin. The difficulty in valuation arises because much of the catch either does not pass through markets, or passes through numerous small local markets. For large commercial fisheries with a relatively small number of operators and a few large markets, collection of catch data is simpler. However, collection of subsistence fishery data is logistically more difficult, and in countries where there are numerous informal taxes, official catch data tend to substantially underestimate the catch. In the lower Mekong when the MRC began to use consumption survey data to estimate the catch rather than government fisheries department data, estimates of the annual catch size increased more than threefold to 2.2 million tonnes (Jensen 2000).

In developed countries, inland fisheries tend to be less important as a food source, and more valued as a recreational industry and because of the conservation significance of fish. Recreational fishing and species conservation are relatively easy concepts to understand and to manage. The recreational industry is also easily taxed in a developed country. The annual economic value of the recreational fishery in the Murray-Darling Basin has recently been estimated at AU$ 1,350 million (Ernst & Young 2011) and employs almost 11,000 people. However, much of the government expenditure on fisheries in the Murray-Darling basin has focused on improving fish passage, and is most often justified in terms of maintaining or increasing populations of fish species considered to be of conservation significance (e.g. MDB native fish strategy, see http://www.mdba.gov.au/programs/nativefishstrategy).

Lesson 11: Asset-based environmental water management is difficult in large river basins

Asset-based (or values-based) management has been a significant development in environmental management (Pannell 2009). It requires explicit management goals to be identified, and enables the success (or otherwise) of management to be readily assessed. The goals are maintenance or restoration of the assets identified, and the success is judged by whether the assets are maintained or restored. The management process begins by identifying the assets or values which are to be protected or restored, then identifying the factors or processes which put the assets or values at risk, and managing by minimizing the risks.

Within the Murray-Darling basin, the water-based assets include particular sites – such as the icon sites (MDBA 2009), which are nationally recognized, but also an increasing number of additional sites – which include river reaches, riverine wetlands, floodplain forests and the estuary (e.g. Coorong). There are now over 2,500 key assets identified within the basin (MDBA 2011b).

When the number of assets was small, for example restricted to the 6 icon sites, environmental management was primarily bottom up. That is each asset was considered more or less independently, and management plans were developed largely in isolation. The overall environmental management of the basin was largely the net effect of a large number of small decisions, the strategy being that managing the key sites, at least with regard to environmental watering, would by default manage other less charismatic sites. As the number of sites to be managed increased there were increasing opportunities to use water destined for one site to water additional sites on the way, or after use, and with increasing pressure on limited water resources this became necessary. So water provided for the city of Adelaide and the systems in the lower Murray, if sourced from Eildon Reservoir, can also be used to provide beneficial environmental flows in the Goulburn River while in transit. However multi-site watering can also prove problematic (e.g. see http://www.mdba.gov.au/draft-basin-plan/supporting-documents/ewp/ewp_ch5). If the water needed for Adelaide must transit the Goulburn River at a time when river flows should be low it may have a negative ecological impact on the Goulburn River. The more sites there are to manage, the more difficult it becomes to model and manage the system.

The Mekong is not using such an explicitly asset based approach. The fishery is viewed as an asset by most of the community, but because it is a diffuse asset site specific management has not been viewed as appropriate. The Mekong dolphin population is the best known example of a site specific asset, and there have been approaches to develop and implement management plans for at least some of those locations (Beasley et al. 2009). Khone Falls, near the Lao-Cambodia border, is another iconic asset.

Lesson 12: The big issues are only half the story

Big issues in environmental management, such as the construction of large dams, large-scale water diversions and identifiable pollution sources, tend to gain a lot of attention through the media and political processes. Consequently, there is often a great deal of effort and resources focused on trying to resolve them.

Within the Murray-Darling Basin, examples of such issues in the past have been large-scale cotton irrigation at Cubby Station in Queensland, and construction of Dartmouth dam in Victoria. In the Mekong examples are the large dams being constructed in the Chinese section of the river (Daming He et al. 2009) and the proposed series of dams on the mainstream in the Lao PDR (ICEM 2010)

Large projects are important, and can have major and often unforeseen impacts on the riverine environment. The Aswan Dam on the Nile River provides one of the most spectacular and best known examples (e.g. George 1973, Kassas 1973) but there are many others including the Ord River Dam in northwestern Australia (Stanley1975) and Pak Mun Dam in Thailand (Roberts 1993, Foran & Manorum 2009).

But the less spectacular environmental impacts – small in scale but numerous – are at least an equal threat in terms of overall impact and often far less tractable for environmental managers. This includes pollution from diffuse sources rather than point sources – urban and agricultural runoff rather than factory pipes (e.g. Hart 1982). It also includes the increase in fishing pressure from an increasing population and improved capture technologies, such as monofilament nets. Another example is the increase in small-scale extractions of water from the river, or even the proliferation of small farm dams on drainage lines which trap runoff before it reaches the river (SEWPaC 2002) or small scale hydropower systems which can create fish barriers and alter flow regimes.

Effective river basin management needs to manage both the large-scale projects and more abundant small-scale impacts. The large-scale projects in river basins are often handled through political processes under a media spotlight. Managing the smaller scale activities that impact the river is more difficult. For the most part it cannot be managed simply through legislative change or policing, but requires education and a change in community values.

Changing the widespread small-scale impacts often requires a change in long standing cultural practice. As populations increase and the size or condition of the shared resource decreases, practices that served communities for generations may no longer be effective. For example, there is no need for fish conservation areas or bag limits (limits on the number of fish each fisher can catch per day) when the population of fishers is small and the river large and in good condition. But when water extraction, channelization, degraded water quality and dams reduce the area of habitat suitable for fish, the population of fisher's increases and fishing technology improves, a formerly sustainable fishery can rapidly become unsustainable.

Reinstating a sustainable fishery is impossible unless there is a widespread understanding amongst the fishers of the necessity for change. Even then it may be necessary to assist subsistence fishers to find alternative livelihoods, and for the fishers to be confident that changes to the fishery are being implemented in a transparent and equitable fashion. Because recreational and artisanal fishing is a diffuse activity often conducted at small scales over a large area, legislation and enforcement, while necessary, will not be sufficient to bring about change. Enforcement itself is often best conducted in a participatory manner at the community level rather than being imposed by governmental agencies.

Conclusions

The management of large river basins poses a broad range of technical and governance challenges. In both fields each large river basin has some unique characteristics and needs, but managers can also learn many lessons from the management of other river basins.

Every large river basin has a unique governance context. This is a product of the international and national context, the governance history, the specific suite of stakeholders, national and sub-national agencies and civil society groups, and the balance of political influence between them. However, governance in each river basin must resolve a similar set of challenges: limited resources of water, land and other assets to be managed, limited resources of people, time and money with which to manage them, and a diverse suite of stakeholders with conflicting goals and objectives.

Every large river basin also presents a unique set of technical challenges. Each has a specific combination of climate, catchment landscape and geophysical environment, hydrology and biota. The interactions between the biophysical environment and the stakeholders also differ between basins. For example, not only is the fish fauna different in every basin, but the ecological requirements of the fish species differs and the significance of the fish to the stakeholders differs. In some cases fish support livelihoods directly, as a food source, in some cases fish support livelihoods indirectly, as a recreational resource, in other cases they are primarily a conservation asset. But, as with governance, there is a common suite of technical principles that apply across all river basins. General technical understanding can come from other river basins, but it is critical to have a solid understanding each specific basin to be managed. The solid understanding must be based on applied research which is peer reviewed and publically available.

River basin management requires both technical decisions and value judgements, and management decisions can never satisfy the interests of all the stakeholder groups. However, decision making is always likely to be better when it is based on publically available peer reviewed science, and reached through trade-off processes which are explicit and transparent.

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