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Challenges and commonalities in basin-wide water management

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Abstract

Water managers around the world are facing challenges when trying to manage water resources sustainably, particularly when confronted with increasing water scarcity. This article examines four river basins in Africa, Asia and Australia, with wide-ranging histories, politics and hydrology, to consider some of the key common challenges faced in very differing hydroclimatic conditions and the approaches being taken in response. It is proposed that elements in common between these basins can provide knowledge for use in other situations. A comparison of these elements suggests that many basins face difficulties due to geopolitical situations and that problems meeting competing demands, particularly in the context of water scarcity, will be exacerbated by climate change. In response to these challenges and in moving to manage water resources sustainably, water managers should consider: co-operation, trust-building mechanisms and political will; stakeholder engagement; reliable data and monitoring; co-operative benefits; and flexibility between multiple uses in water allocations.

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Keywords: governance; water management; trade-offs; integrated water resource management; water scarcity

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1. Introduction

The sustainable use of water resources is a global challenge that manifests at regional, national and local levels. Within these spatial scales the interplay between growing demands from multiple users, the issues inherent in transboundary co-operation and the management of a variable water supply pose common challenges for water managers. In this paper we explore the different management approaches in four complex and contrasting river basins to extract the common principles used in dealing with these challenges.

The studies showcase a diverse range of hydroclimatic contexts and geopolitical situations. The Rokel–Seli Basin in Sierra Leone demonstrates the approaches being taken to water management at a local level in a country rebuilding in the aftermath of a civil war. The Murray–Darling Basin (MDB) is examined to provide an insight into how Australia tackled these challenges across domestic jurisdictional boundaries against a background of water scarcity in one of the country's most important river basins. The nexus between water and energy security and how this could influence water management in the Zambezi region is explored, while the Mekong River Basin highlights the regional challenges involved in managing a transboundary basin.

The key challenges, proposed responses and lessons learned are outlined for each basin and summarized in Table 1. By comparing the practical experiences from these contrasting basins, similarities are identified to inform recommendations on 'essential ingredients' or principles for sustainable water management, and will contribute to the growing body of literature addressing basin-wide water management. Given that the level of development, political climate and physical and social contexts in each of these basins are wide ranging, we anticipate that principles that are common to all four will also be relevant to many other basins globally.

Table 1. Comparison of challenges, successes and constraints in basin management in the four river basins in the case study.

	Rokel–Seli	Murray–Darling	Mekong	Zambezi
Basin challenges: **Balancing competing demands** **Transboundary co-operation**	• Hydropower/mining/ agriculture/urban • Upstream/downstream • Rebuilding after the Sierra Leone civil war – taking management experience from a local to national level	• Agriculture/ environment • Upstream/downstream • Crosses one territory and four state jurisdictional boundaries within the federal nation of Australia	• Hydropower/fisheries • Upstream/downstream • Crosses the boundaries of six sovereign nations	• Hydropower/agriculture/ environment • Upstream/downstream • Crosses the boundaries of eight sovereign nations
Variable inflows	• High inter-annual seasonality	• High inter-annual seasonality	• Seasonal – monsoons	• Variable rainfall between upper and lower basin countries • High inter-annual flows
Success factors/proposed solutions **(in order of importance)**	• Broad stakeholder engagement • Capacity-building of local staff • Investment in data collection and monitoring • Local level trials • Political will – strengthening policy, law and practice	• Whole-of-basin approach • Data collection and science balanced with social/economic/environme ntal needs • Active interstate water market • Funding • Political will/social licence provided by a crisis (drought) drove the reform • Enforceable regulatory regime	• Co-operative benefits through the Mekong River Commission • Political will to co-operate, but tempered with a tradition of non-interference and lack of experience in trade-off negotiations	• Importance of water, food and energy nexus regionally (beyond the basin) • Co-operative benefits from trading in surplus hydropower through a regional power pool • Variable assurance of supply to cope with drought • Conjunctive management of hydropower/irrigation
Key constraints	• Lack of funding and limited institutional capacity • Time allowed for change to be achieved on a national scale	• Lack of stakeholder engagement in the early stage of reform • Sufficient time needed for reform to be implemented/ understood	• Time required for trust-building amongst riparians • National opportunities that create conflicting uses in a transboundary context • Strong sense of sovereign rights–lack of experience in negotiations and compromises	• Time required for trust-building among riparians • Sovereign water, food and energy concerns • Shared benefits are strategic and not immediately apparent

2. Rokel–Seli River Basin, Sierra Leone

The Rokel–Seli River rises in the highlands between Sierra Leone and Guinea, draining a basin area of 8,000 km^2 before discharging north of Freetown, the capital of Sierra Leone. The Rokel–Seli Basin is one of the country's most strategic river basins, producing most of the nation's hydroelectric power and providing water for a number of major industries. There are future plans to use it to supply water to Freetown. In various ways, this river basin presents a microcosm of Sierra Leone's water security issues.

2.1. Key challenges

Although Sierra Leone is a well-watered country, there are growing pressures on the quantity and quality of its water resources (Akiwumi, 1997). Small-scale abstractions for rural and town water supplies, as well as large-scale requirements for hydroelectric power production, mining, irrigated agriculture and urban water supply, all compete for a finite quantity of water. Discharges from these uses threaten to pollute aquifers and watercourses, affecting downstream users. As the population grows and the economy matures, it is anticipated that these pressures will increase. The Ministry of Water Resources (MoWR) has recognized that measures taken now can help to mitigate future risks.

While there is a commitment to manage Sierra Leone's water resources to realize water security, there are major challenges that must be overcome if this is to be achieved. First, much of Sierra Leone's water monitoring infrastructure was destroyed during the country's civil war from 1991 to 2002. Institutional capacity (skills, knowledge and resources) remains weak. A capacity-building programme that re-establishes hydrogeological monitoring and rebuilds human capacity and skills is an essential first step. Secondly, the country experiences high inter-annual seasonality. Rainy season precipitation varies from 85 to 97.5 per cent of the annual total (Gregory, 1965). Thirdly, Sierra Leone still faces repeated shocks and threats; for example, the 2014 Ebola health crisis has highlighted the fragility of central and local government institutions that have a low capacity to cope.

The Encyclopedia of the Earth includes this telling comment: "As water resources have never been a serious constraint to development in Sierra Leone, no base exists for their management (except for the water supply and sanitation sector)." Against this backdrop, different stakeholders have different concerns about the quality and quantity of water resources, as the basis of supply, or the recipient of discharges. The challenge is to ensure that individual water requirements do not undermine collective water security.

2.2. Responses to challenges

The Sierra Leone Water Security Project established in 2012 was led by the MoWR and Bumbuna Watershed Management Authority, with direct technical support from Adam Smith International. The project aims to establish effective water resource monitoring and data collection as a basis for decision-making related to improved water management. Key to achieving this aim is the establishment of institutional arrangements for data collection, storage and publication, and for dialogue and decision-making among stakeholders.

The project has four main objectives:

- to gain experience of *what does* and *does not work* regarding practical hydrometeorological monitoring,
- to build the government's capacity to monitor and manage water resources,
- to obtain enough data to develop a better understanding of the surface water and groundwater hydrology of Sierra Leone,
- to promote the importance of sound water resources management.

Project monitoring was carried out with the support and co-operation of district councils, paramount chiefs, villages, schools, government and industry. Technicians from the MoWR and the Bumbuna Watershed Management Authority were trained to programme and install monitoring equipment and retrieve data. They also undertook field visits to understand the impacts and water demands of mining and commercial agriculture projects. Training workshops and meetings were also held with a diverse range of local stakeholders.

2.3. Lessons learned

The Water Security Project has revealed that the freshwater resources of Sierra Leone have been historically overestimated, primarily due to an underestimation of evapotranspiration rates. This has highlighted the need for reliable hydrometeorological monitoring networks. Without these, water resources cannot be managed for the benefit of people, food and energy production, and industrial development.

Other project findings are:

- A general approach of 'starting small' and 'learning by doing' should be pursued in preference to adopting de facto solutions for water resources management. Local level trials and lessons learned should be used to inform national strategy and policy.
- Schools and local communities can play an important participatory role in monitoring water resources, acting as voluntary observers. This will increase ownership in the water monitoring at a local level and encourage learning and interest.
- Training, support and institutional strengthening are required to ensure effective data collection.
- The scale of national monitoring networks must be proportional to the capacity of government institutions to support them sustainably.
- More support will be needed over many years to take the early learning experiences of the Water Security Project to a national scale.

The challenges in the Rokel–Seli Basin may be common to many river basins in the early stages of development that experience hardship and competition for financial resources after a natural disaster or civil war, as in this case. Establishing reliable water monitoring networks is an essential first step and best use of funding, and they can gain acceptance through commencement at a local level. As networks are established, the primary consideration is to bring all river basin stakeholders together to understand collective water demands and build good relations and trust. Over time, and with experience, negotiations between participants must be informed by the outcomes of hydrological monitoring.

3. Murray–Darling River Basin, Australia

The MDB is Australia's largest river system and has very variable annual and seasonal flows. It covers an area of over one million km^2 and crosses four state boundaries. The basin is highly productive, generating 40 per cent of the total national agricultural output (Australian Bureau of Statistics, 2013), with irrigation being the largest water consumer by using 83 per cent of the water extracted (Bureau of Meteorology, 2014). The basin also supports many large, diverse floodplain wetlands of international environmental significance.

3.1. Key challenges

For decades there was growing evidence of unsustainable use of water resources. This attracted widespread public debate in the 2000s with the worst drought on record highlighting ongoing risks to both the consumption and conservation of water. Agriculture, tourism, recreation, cultural practices and the environment were all impacted as river flows dropped almost 40 per cent below previous record lows (MDB Authority [MDBA], 2011a). The challenge for the Federal Government was how to find a better balance between consumptive and environmental water users.

3.2. Responses to challenges

In 2007, the Federal Government announced a major reform in response to this challenge. The 2007 Water Act (Commonwealth of Australia, 2007) established the MDBA with a mandate to rebalance water sharing through the development of a basin plan. This reform would not have been possible without the alignment of a number of factors:

- A severe drought, which provided a trigger for the Federal Government to take action (major policy reform is often driven by a crisis).
- Political commitment, with the Prime Minister driving the process, backed by substantial funding.

- Decades of water reform that could be drawn upon, for example, a developing water market.

However, the reform was not an easy process. It took five years of negotiations from the passing of the Water Act to reach agreement on the 2012 Basin Plan.

3.3. Lessons learned

3.3.1. Whole-of-basin approach

The Basin Plan required the development of science-based, legally enforceable limits on the use of surface and groundwater across the MDB. Managing the basin as a single system meant that environmental requirements could be considered holistically, regardless of state boundaries.

3.3.2. Rebalancing water use to improve sustainability

When the Basin Plan is fully implemented, approximately 25 per cent of the surface water that was being consumed will be redirected back to the environment (MDBA, 2011b). To achieve this:

- Good data and sound science and judgement need to be balanced with social, economic and environmental needs.
- Water recovery must occur through a combination of government investment in irrigation infrastructure upgrades and purchasing water licences in the market. Water rights are not expropriated from irrigators.
- Arrangements must be put in place to manage the environmental water recovered.
- An enforceable regulatory regime must underpin the work.

3.3.3. Active water market

The redistribution of water use as outlined above would have been near impossible without a water market to buy and sell water licences – this trade allows water to be redistributed among users and can be either temporary or permanent. There has been trading in the MDB since the 1980s; however, it wasn't until the mid-1990s that the water market experienced a strong growth in activity. In 1994–95, water shortages caused water trades to increase significantly in terms of volume, especially for temporary water allocations. In 1995 a cap was introduced that placed an upper limit on surface water diversions. By limiting the total number of water licences available, trading of these licences has increased as users wanted to source more water (MDBA, 2014). Interstate trade is possible in the MDB between certain states where the system is connected. It began in 2006 and has been growing strongly since (National Water Commission, 2014). The benefits of an effective water market enable the water available in a given year to go towards its most productive economic use and be purchased for the environment.

3.3.4. Community engagement

To achieve any lasting reform, the process must genuinely involve those affected by the reform. The MDBA learned this lesson the hard way. A lack of genuine engagement in the early days of the development of the Basin Plan led to significant misunderstandings and community backlash in a number of towns in areas heavily dependent on irrigated agriculture. Since then, the MDBA has made a concerted effort to understand the views of communities across the basin, and to involve them in the implementation of the Basin Plan.

The recent Australian experience with water reform also highlights that substantial time is required to reach agreement among riparian states and for communities to adjust to significant policy reform. Internationally, other river basin organizations should consider the substantial time and funding required to undertake significant reform.

4. Mekong River Basin, South-East Asia

The Mekong River flows for 4,800 km from Tibet through China, Myanmar, Lao People's Democratic Republic (PDR) (Laos), Thailand, Cambodia and Vietnam via a delta into the East Sea, draining a basin area of 795,000 km^2.

The flow from the Lancang–Upper Mekong Basin contributes 16 per cent of the average annual flow in the Lower Mekong Basin, but up to 30 per cent of the dry season flow. There is a large difference between wet and dry season flows caused by the Southwest Monsoon, which generates the wet and dry seasons. Inter-annual variability is large in terms of river discharges, flooded areas, and the start and end of the wet and dry seasons.

4.1. Key challenges

The Mekong River is still relatively unexploited but has the potential to provide sustained benefits to its riparian countries. Vietnam's Mekong Delta is the region's rice basket and is key for agriculture. Cambodia's inland fishery in the Tonle Sap (Great Lake) is not only unrivalled in the region but globally, comprising approximately 2 per cent of the world's inland fisheries (Lieng Sopha and Van Zalinge, 2001). Lao PDR is developing hydropower with a view to exporting energy to its neighbours, while for Thailand, the basin is home to about one-third of the country's population. Therefore, it is critical for Thailand that the region develops to provide its people with opportunities. Consequently, the national transboundary nature of the Mekong River creates many challenges in balancing these competing interests, as well as exploring opportunities for shared benefits.

4.2. Responses to challenges

4.2.1. The Mekong River Commission

To meet the challenges of development and find ways to share the benefits of the shared river basin amicably, Cambodia, Lao PDR, Thailand and Vietnam established the Mekong River Commission (MRC). Created by treaty in 1995,[1] the MRC is the institutional mechanism that encourages co-operation in the sustainable development and use of the Mekong River Basin. The MRC comprises country representatives who make decisions about the Mekong's future. Importantly, the MRC's mandate does not infringe national sovereign rights, but commits parties to co-operate and recognise each other's rights. It also stipulates objectives and principles for co-operation. For instance, the agreement outlines areas of co-operation that include maintaining minimum flows (Article 6), basin development planning (Article 2) and promotion of freedom of navigation (Article 9). There are provisions for addressing impacts and protecting the environment (Article 3), promoting reasonable and equitable use (Article 5), dealing with damaging impacts (Articles 7 and 8) and ensuring co-operation in the case of emergencies (Article 10). Finally, the sovereign status of the signatories is recognized (Article 4).

For ten years the MRC worked intensively to finalize protocols and procedures, which resulted in a detailed framework for co-operation that is crucial to the management of a transboundary river. One important mechanism is the Basin Development Strategy (BDS), which sets out the framework for basin planning and management (MRC, 2011). It was agreed by members in 2011 and is operational until 2015. This is of great significance because it is the first time the countries have agreed to a common strategy. Under the BDS there are action plans for national and regional work, which are funded by USD 1 billion provided by the MRC Secretariat, development banks, bilateral donors and the national governments (MRC, 2013). However, its success is dependent on member countries using the strategic priorities and actions to shape national social and economic development plans.

4.2.2. International co-operation

Political support for co-operation in the Mekong River Basin exists at the highest level, exemplified by signatories of all four Heads of Government to the Ho Chi Minh City Declaration (MRC, 2014). However, increased pressure on the resources might pose a risk to the scope of this co-operation in the future. Trust and transparency between members is generally improving, but the different political systems are a complicating factor. The large difference in socio-economic development between member countries also makes co-operation more difficult and therefore it is even more crucial.

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[1] Building on co-operation since 1957 under the United Nations-supported Mekong Committee, and the Interim Mekong Committee.

4.3. Lessons learned

The stage is set for success – at least a sufficient level of success – in sustainable management of the Mekong River Basin, created by the work of the MRC and co-operation between member countries. The key future priority (building on existing processes) is to ensure enduring trust and understanding of the mechanisms created. Once such trust is established, the scope for co-operation may extend beyond the water sector.

5. Zambezi River Basin, Southern Africa

The Southern African Development Community (SADC) covers a region characterized by varying water availability in terms of both space and time. The southern river basins in this region face physical water stress, have the largest *per capita* storage and support the region's strongest economies with the highest water and energy demands. While the northern basins are better watered, they have little storage and support smaller economies but are still subject to considerable variability. Addressing this spatial and temporal variability is key to managing the Zambezi River Basin and building regional climatic resilience.

Hydropower and irrigation using surface water are rapidly expanding in the basin. However, while the Integrated Water Resources Management (IWRM) plan (SADC, 2008) notes only 20 per cent of mean annual runoff is allocated for use, a severe drought in the early 1990s reduced energy production, which cost the economies of the riparian countries USD 100 million (Bielfuss, 2012).

5.1. Key challenges

The Zambezi River Basin hosts some of the world's fastest growing economies, with water and energy demands expected to grow substantially over the coming years. From a regional perspective, 67 per cent of the SADC's economy and 85 per cent of electricity generation is driven by 5 per cent of the region's water coming from four of the southern basins (Climate Resilient Infrastructure Development Facility, CRIDF data). These basins are rapidly approaching closure, i.e. the water in the basin cannot cater for all the needs for part of the year (Falkenmark and Molden, 2008), but must still provide basis for the continued development of the largest regional economies.

The predominant climate change predictions in the SADC region are that the southern basins will get drier, while the areas north of the Inter-tropical Convergence Zone (ITCZ) will become wetter. The Zambezi River Basin's position straddling the ITCZ means that runoff is likely to become more variable. Climate change is expected to cut hydropower production by 43 per cent, and average power by 25 per cent (World Bank, 2010; Beilfuss, 2012).

Maintaining water security in the face of these growing challenges will be key to maintaining regional economic growth.

5.2. Response to the challenges

Typical responses to water variability are storage and transfer schemes. However, the capacity to supplement water yields from additional storage in the southern basins is limited, while costs of large north–south water transfers would make water prohibitively expensive and storage and transfer schemes pose significant ecological risks. Alternatively, the following options could be explored.

5.2.1. Trading in surplus hydropower

The riparian countries are aiming for sovereign electricity security through hydropower, in spite of the demonstrated benefits of co-operative generation. Firm[2] hydropower generation projections are 30,000 GWh/a, with an average of 55,000 GWh/a (World Bank, 2010). Therefore, on average, 25,000 GWh/a could be available for sale

[2] Firm power is the power that can be guaranteed for supply and is usually determined by the availability of water in severe droughts.

into the Southern African Power Pool (SAPP). The World Bank (2010) estimates this has an average sale value of USD 116 million/a.

If purchased by the energy-constrained south, the savings in thermal generation costs could be twice that – approximately USD 230 million/a (Ham, 2012). The amount of water saved would be 8 million m^3/a – 2.5 per cent of the water used to produce thermal power in South Africa. While not significant in terms of total water use, these ‘savings’ could be significant during periods of drought. The CO_2 emission saving is about 5.5 million tons of carbon, 2.4 per cent of South Africa’s power utility’s total annual emissions (the South African power company ESKOM reports an emission factor of 1 kg/kWh (The Eskom Factor, 2011)).

These preliminary estimates indicate a huge potential for regional water, economic and carbon benefits if the riparian countries co-operate.

5.2.2. Introducing variable assurance of supply

The economies of the Zambezi River Basin countries are heavily dependent on agriculture, and expansion of irrigated areas is a key component of most countries’ national development plans. Agricultural exports from these countries have a high ‘blue water’ content value (CRIDF data). Irrigation users in the Zambezi River region typically receive a 90 per cent assurance of supply. However, reduced assurance of supply to key irrigation sectors in droughts could increase the volume of water that can be allocated to users without further impacting environmental flows (Quibell et al, 2013). The contribution irrigation can make to the economies of the wetter SADC states can be increased by developing these principles through corporate water stewardship.

5.2.3. Conjunctive management

Plans for irrigation expansion in the Zambezi River Basin will affect the hydropower sector and is expected to result in a 21 per cent reduction in firm and 9 per cent reduction in average power generation (World Bank, 2010). Despite this, the riparian countries are largely developing their irrigation and hydropower expansion unilaterally. In dry years difficult trade-offs would be required to maintain the viability of all users.

While the financial benefits of electricity trading are substantial, the value of agricultural products produced through irrigation could be even more significant. Zambia’s agricultural exports earn USD 880 million, with an 8 per cent ‘blue water’ content, and a ‘blue water’ value of USD 3.70/m^3 (CRIDF data). However, energy shortfalls can cost the economy even more, which, in turn, affects the ability to irrigate. Conjunctive management of hydropower and irrigation is therefore beneficial, with operational decisions on curtailments made depending on the availability of surplus power in the SAPP, and the expected reduction in yields due to irrigating at a lower volume.

5.3. Lessons learned

Variability in runoff across both space and time can significantly constrain economic growth nationally and regionally. Dealing with this problem and building climatic resilience requires a regional approach. In the SADC region, energy trading through the SAPP provides a possible solution, avoiding the environmentally and politically costly alternative of physical water transfers. Similarly, managing trade-offs across the water and energy nexus both nationally and regionally increases climatic resilience, builds co-operation and strengthens economic growth. However, politically, given the immediate and significant needs for water, food and energy security in each basin country (and in the region as a whole), it may be difficult to forego immediate benefits for these long-term strategic gains.

6. Commonalities and discrepancies in managing complex river basins

First, it should be noted that all river basins are unique. The physiographic, hydroclimatic, socio-economic and geopolitical situations in a particular basin will determine how its water and other resources can be best managed. There is no ‘one-size-fits-all’ basin-wide management solution. It is a challenging task for riparian countries to agree to the best way to manage the resources. Nevertheless, there are some overarching principles rising above the technical decisions that are common to the basins examined in this paper. These should be considered by water managers, policy-makers, scientists and decision-makers when undertaking water resource management on a basin scale to achieve sustainable use in a changing environment.

Table 1 (see section 1) outlines three challenges common to each of the basins: balancing competing demands, transboundary co-operation and variable inflows. Our analysis demonstrates that there other important challenges but as these are applicable to four basins from different parts of the world, it is anticipated that they may apply to other basins. We also reviewed whether there were any common success factors or constraints that managers should consider in responding to the challenges. Analysis of Table 1 supports the assertion that there is no 'one-size-fits-all' response. Each management solution incorporated a range of strategies and assigned importance to differing issues. However, we can determine that political will to co-operate and take action is a necessity, and that co-operative benefits are important but need to be balanced with sovereign concerns. This issue is crucial and is explored further in section 6.2. A common constraint across the four basins is time. Building trust among parties to co-operate and to implement a reform can take decades. River managers who are frustrated by lengthy negotiations should be assured that to achieve lasting reform, this time investment is essential.

6.1. Climate change

Of fundamental importance to basin-wide water management are the challenges driven by climate change, which, in general, are expected to lead to: increased rainfall variability; increased intensity of extreme events with an increased risk of floods and flash floods; changes to seasonality such as the onset and length of monsoon rainfall periods; and increased length and severity of dry spells and droughts (IPCC, 2014). In the basins studied, this will lead to increased water scarcity and stress that will intensify the need to juggle water demand and trade-off between sectors and across political boundaries.

Along the Zambezi, the climate is predicted to become considerably drier – the region has already seen delayed rainy seasons, longer dry spells and fewer rainy days over the past 50 years (Tadross et al., 2009), putting higher stress on the water resources and their management. In the Zambezi River Basin, challenges linked to climate change-driven stress on water resources may prompt consideration of innovative mechanisms, such as energy trading and variable assurance of supply to deal with increased water variability and competing demands.

In West Africa, including Sierra Leone, annual rainfall does not show strong trends of change (Niang et al., 2014), but higher temperatures will increase evaporation and, subsequently, reduce 'blue water' generation (Rockström and Falkenmark, 2015). This, in combination with increased rainfall variability, including dry spells punctuated by intense rainfall events, will put constraints on water availability in the Rokel–Seli basin.

In the Mekong region, the climate will generally become warmer and wetter, but the size of the basin means that a range of changes in climate will be experienced, resulting in floods, droughts and salinity intrusion in the delta. The impact will be significant, but should be seen in conjunction with other drivers of change, particularly infrastructure development linked to, for example, energy and food production (Keskinen et al., 2010). The challenges here need to be met with a diversity of response mechanisms implemented in a water–food–energy nexus (Bach et al., 2014) with a strong collaborative dimension among riparian countries.

In Australia the severe drought experienced during the early 2000s and resulting stress on water availability have clearly shown what future climate on the continent may look like (Reisinger et al., 2014). It provided a turning point in political awareness, highlighting the unsustainable level of extraction from the river compared with the need of water for sustained ecosystem services, and triggered the Federal Government to take action. The resulting institutional arrangements and basin plan have begun to address this.

6.2. Geopolitics

One of the common complexities in the river basins considered is the geopolitical context that determines if and how effective co-operation within a basin can be reached (Cascão et al., 2013; Zeitoun and Jägerskog, 2009, 2011). This is particularly cumbersome when several nations share a basin. However, it can be equally challenging where the river crosses political boundaries *within* a nation, such as states or provinces. In this respect, the MDB could be considered as politically complex domestically as, for example, the transboundary country basins in the Mekong and

Zambezi. One of the key lessons from the MDB was the agreement to confer some water management powers to the Federal Government, allowing for a whole-of-basin approach.

In many cases, geopolitical constraints can be reduced through international or regional agreements, or the establishment of river basin organizations (RBO) where a common platform for co-operation can be shaped by the riparian countries (Granit, 2010). The Revised Protocol for Shared Watercourses in the SADC has been instrumental in establishing a common legislative framework, while basin-specific agreements have fostered closer co-operation between riparian countries. In the Mekong River Basin, the MRC has played a similar role in promoting sustainable development in the lower Mekong region for the benefit of its member countries.

Although there is no single solution to addressing geopolitical challenges, these case studies demonstrate that particular consideration of the institutional arrangements – including formation of an RBO – can be useful in a transboundary context. However, while they provide a useful framework for co-operation, a common understanding of transboundary water treaties is critical to their implementation (Falkenmark and Jägerskog, 2010).

6.3. Co-operation and political will

As well as facing common challenges, a number of common responses can be gleaned from the cases examined. Trust between parties and political will are essential to progress towards co-operation and subsequent effective basin-wide sustainable water management. Co-operation may be between different nations or other governance bodies, or between different sectors competing for use of the same resource. In all cases, it is crucial to allow ample time for trust to be developed in order to trigger substantial joint co-operation. Trust-building can be facilitated by promoting collaboration on less sensitive matters, such as technical solutions for flood management. To promote increased co-operation among partners in a given basin, it can be useful to find areas or values of sufficient common interest to act as an incentive (Granit, 2010). This can be, for example, the development of hydropower or other energy sources, agricultural production and trade, flood management or common cultural and spiritual values. To this end, it is important to remember that for riparians to co-operate within transboundary basins, the benefit of co-operation must be perceived to be greater than the net benefits of non-co-operation, and the distribution of these net benefits must be perceived to be fair (Sadoff and Grey, 2002).

There must be political will to stimulate co-operative action. For example, the Prime Minister and Federal Government drove the essential reforms in the MDB, and similar high-level political commitment has been demonstrated in the Mekong. The establishment of the MRC has led to interstate discussions and joint development processes that can be very time consuming, but this is advantageous as trust is gradually developed between the partners over time, which is important for future joint decision-making. In Sierra Leone, the conclusion of the civil war has motivated the government to address water management challenges as a priority. In contrast, the Zambezi River Basin demonstrates that the strategic nature of water and energy in driving the economy underpins a drive for sovereign water, food and energy security, perhaps to the detriment of optimal regional solutions. However, the eight countries along the Zambezi have come a long way with the formation of the Zambezi Watercourse Commission (ZAMCOM), by forming a joint RBO to facilitate future development of the basin. It took 20 years of trust-building before the political will was strong enough to form the ZAMCOM agreement, which shows the time needed to secure progress in such processes. Nonetheless, in the absence of wider economic integration, its parties continue to focus on sovereign water, food and energy security. It is necessary to demonstrate to riparians that sovereign security will be best served by a basin or, in the Zambezi example, a regional perspective across all three issues. Few nations in a developing context will be entirely secure across the nexus, so co-operative management can help to achieve this.

It is important for water managers in any basin to understand that whatever the level of development, time must be allowed for trust and goodwill to be built among stakeholders and riparians, and any opportunity to stimulate co-operative action must be recognized – never waste a crisis! The drought in the MDB, the energy crisis in the SADC region and rapid hydropower development in the Mekong are stark examples of such crises triggering further co-operation.

6.4. Stakeholder engagement

Irrespective of the size of the basin or the nature of the challenges faced in order to undertake significant reform in the water sector, it is essential to involve the local community and any stakeholders likely to be impacted by the change (Kranz and Mostert, 2010). This was demonstrated in the case of the MDB, where the major reform (although backed by political will, funding, science and good data) encountered significant problems because of a lack of community engagement in the early days when many communities had no clear understanding of what the reform was trying to achieve. The project in the Rokel–Seli has implemented this principle by holding meetings with a range of stakeholders, including paramount chiefs, schools, affected villages and industry, and actively involving them in the monitoring process. This is more likely to result in an enduring solution to the challenges faced.

6.5. Data monitoring and sharing

As the challenges linked to water variability increase, the need for robust monitoring of water resources and reliable data about them becomes increasingly important. This is another principle common to our four case studies. In the Rokel–Seli Basin the need for an improved water resources monitoring system is urgent and being prioritized under the Sierra Leone Water Security Project. The gradual investment in the monitoring infrastructure is being paired with capacity-building of technicians and institutions to measure, store and analyze data. Similarly, in the MDB and the Mekong, reliable data were essential to bringing credibility to the basin plans. However, it is acknowledged that monitoring is resource-intensive. Therefore, to be effective in the long term, financial sustainability of the networks must be ensured. Data are of no use unless they are accessible to those who can act on them. Data monitoring and storage must be followed by analysis, and where there is a risk of emerging extreme events (droughts or floods), warnings have to be issued and communicated to communities that could be affected (via early warning systems) (Eriksson, 2012).

In transboundary settings, these important mechanisms are more cumbersome. Nevertheless, it is crucial, and often of life-saving importance, that riparian countries sharing a basin agree on mechanisms for distributing data and information on water resources to minimize the adverse impact of hydroclimatic hazards. This matter is currently being addressed by the MRC in the Mekong River Basin.

Reliable data collection, storage and dissemination is an essential first step and a worthy investment of time and funds for water managers to enable future planning, particularly where rainfall and climate are becoming increasingly variable.

6.6. Co-operative benefits

An important principle providing incentives for countries to co-operate over shared water resources is the potential for additional benefits to be gained in other sectors. For instance, in the Zambezi River Basin the SAPP provides a platform for the trade of energy produced by hydropower in the basin. Since it is more cost-efficient to transfer energy in the region rather than transfer water to the areas in need of energy, the necessity of attaining energy security becomes an incentive for increased co-operation over water resources (Cascão et al., 2013). A similar development can be seen in the Mekong River Basin where, for example, development of hydropower at a national level in Lao PDR may also result in gains for other countries in the region, perhaps outside the water sector, which could offset any impacts associated with hydropower development. The Procedures for Notification, Prior Consultation and Agreement implemented by the MRC can perform this role. In the Zambezi area and SADC region as a whole, the ZAMCOM and the SAPP could provide similar functions.

Unless there are clear advantages to transboundary co-operation, countries will put national interests first, just as states or provinces will prioritize their needs above the national interest. Therefore, the benefits that can be accrued from co-operation must be made relevant to the national or sovereign interests, outweigh the costs of co-operating, and be perceived to be fairly distributed among the interested parties (Grey et al., 2009). For example, in the MDB, decades of competition for water between states led to significant environmental consequences. This was partly addressed by the Federal Water Act 2007, which brought the national interest and benefit of having a healthy river system to the fore. After lengthy negotiations, the states agreed to the new arrangements, which included the transition from the MDB Commission to the MDBA and the states benefiting from federal funding for various initiatives, including irrigation infrastructure upgrades.

In the Mekong, the Procedures outlined above aim to provide a measure of protection for environmental flows and downstream users. However, the implementation of these has been hampered by the fact that the benefits and costs are not perceived to be fairly distributed, combined with the fact that the MRC doesn't have enforcement powers – its remit is to encourage co-operation. An emerging perspective from the Procedures suggests that they exist not to control the countries, but to be used as tools to avoid, minimize and mitigate, as far as is reasonably practical, potential impacts and to identify emerging concerns and propose options to address these.

In the Zambezi region, despite the World Bank's Multi-Sector Investment Opportunity Analysis demonstrating the significant hydropower benefits to optimal irrigation development and conjunctive management of the hydropower, the riparian countries have still opted to proceed with sovereign interests. The analysis of the Zambezi demonstrates that there are substantial benefits to be gained across the region, even outside of the basin. These benefits can accrue to each country, and sovereign security and economic growth can be found in the regional water, food and energy nexus. Therefore, rather than focusing on the apparent disadvantage that RBO's don't have 'a stick' (or enforcement powers), managers should consider highlighting the 'carrot' (or incentives) through demonstrating the sovereign advantages that can accrue from co-operation, which will be different in each basin.

7. Conclusion

Despite the many contrasts between the river basins discussed in this study, there are a number of overarching common principles that are essential for water management decisions in these basins and which may also be applicable to other basins. Challenges include competition for limited water resources leading to over-extraction, and complicated or ineffective management arrangements arising from the transboundary nature of rivers, often linked to regional geopolitics. These challenges are exacerbated by the impact of climate change, particularly in nations vulnerable to extreme weather events such as droughts, floods and flash floods. However, they may also provide a trigger for increased collaboration. Furthermore, so far basin wide management has mainly focused on surface water. Increasingly, the importance of also taking ground water resources into account is being acknowledged and we will probably see more efforts in this respect in future basin wide water management approaches.

Similarities in many of the management responses to common challenges are evident. These cases demonstrate that a 'trigger' provides an opportunity to stimulate action towards reaching a solution. However, this will only be achieved through collective involvement of the riparians that has been established over time using trust-building mechanisms. The riparians (at whatever spatial level) will only be convinced to pursue actions that result in collaborative benefits if it can be demonstrated that they will also advance sovereign interests that will be distributed fairly. The case studies also highlight the necessity of both understanding the resource to be managed and providing an effective monitoring network to inform management responses. These are fundamental prerequisites to effective water resource management. Without a reliable information base, management decisions lack credibility and are unlikely to endure or be accepted by society. The importance of involving a wide range of stakeholders, including the local community, has been identified as an essential part of any management response. This alone may determine the success or failure of improved, more sustainable basin-wide water management.

References

Akiwumi, F. A. (1997). Conjunctive water use in an African river basin: A case study in poor planning. IAHS Publication, 240, 495-502. *Sustainability of Water Resources under Increasing Uncertainty* (Proceedings of the Rabat Symposium S1, April 1997)

Australian Bureau of Statistics (2013). Gross value of irrigated agricultural production (GVAP) *(*catalogue no. 4610.0.55.008). Retrieved April 8, 2015, from the Australian Bureau of Statistics. Web site: www.abs.gov.au/ausstats/abs@.nsf/Lookup/4610.0.55.008main+features52011-12

Bach, H., Glennie, P., Taylor, R., Clausen, T. J., Holzwarth, F., Jensen, K. M., Mejia, A. and Schmeier, S. (2014). Cooperation for Water, Energy, and Food Security in Transboundary Basins under Changing Climate. Mekong River Commission, Lao PDR, 2014. 97 p.

Beilfuss, R. (2012). *A risky climate for southern African hydro: assessing hydrological risks and consequences for Zambezi Basin Dams*. International Rivers. Retrieved April 8, 2015, from www.internationalrivers.org/files/attached-files/zambezi_climate_report_final.pdf

Bureau of Meteorology (2014). National Water Account 2013. Canberra: Bureau of Meteorology.

Cascão, A., Jägerskog, A. and Earle, A. (2013). Transboundary water cooperation: a Rubik's cube. In: A. Jägerskog, T. J. Clausen K. Lexén and T. Holmgren (Eds.) 2013. *Cooperation for a water wise world – partnerships for sustainable development. Report No. 32*. Stockholm: Stockholm International Water Institute (SIWI).

Commonwealth of Australia (2007). Commonwealth Water Act. Canberra: Commonwealth of Australia.

Eriksson, M. (2012). Early warning systems for water in agriculture. In: A. Jägerskog and T. Jønch Clausen (Eds.) *Feeding a thirsty world – challenges and opportunities for a water and food secure future. Report No. 31.* Stockholm: Stockholm International Water Institute (SIWI).

Falkenmark, M. and Jägerskog, A. (2010). Sustainability of transnational water agreements in the face of socioeconomic and environmental change. In: A. Earle, A. Jägerskog and J. Öjendal (Eds.) 2010. *Water without borders: from rhetoric to practice in transboundary water management*. London: Earthscan.

Falkenmark, M. and Molden, D. (2008) Wake up to realities of river basin closure. *International Journal of Water Resources Development*, 24:2, 201-215.

Granit, J. (2010). Identifying business models for transboundary river basin organisations. In: A. Earle, A. Jägerskog and J. Öjendal (Eds.) 2010. *Water without borders: from rhetoric to practice in transboundary water management.* London: Earthscan.

Gregory, S. (1965). Rainfall over Sierra Leone. Research Paper No. 2. Liverpool: Department of Geography, Liverpool University.

Grey, D. Sadoff C. and Connors G.(2009). Effective cooperation on transboundary waters: a practical perspective. In: A. Jagerskog and M. Zeitoun (Eds.) 2009. *Getting transboundary water right: theory and practice for effective cooperation. Report No. 25*. Stockholm: Stockhom International Water Institute (SIWI).

Ham A. (2012). Cost of Power. Retrieved April 8, 2015, from www.probus.org.za/cost-of-power.html

Intergovernmental Panel on Climate Change, IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Keskinen, M., Chinvanno, S., Kummu, M., Nuorteva, P., Snidvongs, A., Varis, O. and Västilä, K. (2010). Climate change and water resources in the Lower Mekong River Basin: putting adaptation into the context. *Journal of water and climate change*, 1(2), 103–117.

Kranz, N. and Mostert, E. (2010). Governance in transboundary basins – the roles of stakeholders; concepts and approaches in international river basins. In: A. Earle, A. Jägerskog and J. Öjendal (Eds.) 2010. *Water without borders: from rhetoric to practice in transboundary water management.* London: Earthscan.

Lieng, S. and Van Zalinge, N. (2001). Fish yield estimation in the floodplains of the Tonle Sap Great Lake and River. In: *Inland Fisheries Research and Development Institute of Cambodia* (*IFReDI) Fisheries Technical Paper Series, Volume III* (pp. 23-26). Cambodia: IFReDI.

Mekong River Commission (MRC) (2011). *Integrated Water Resources Management-based Basin Development Strategy*. Vientiane: MRC. Retrieved April 8, 2015, from www.mrcmekong.org/assets/Publications/strategies-workprog/BDP-Basin-Dev-Strategy-2013-Eng.pdf

Mekong River Commission (MRC) (2013). *MRC Basin Action Plan* Vientiane: MRC Secretariat. Retrieved April 8, 2015, from www.mrcmekong.org/assets/Publications/strategies-workprog/MRC-Basin-Action-Plan-May2013.pdf

Mekong River Commission (MRC) (2014). *Ho Chi Minh City Declaration*. Ho Chi Minh City: MRC. Retrieved April 8, 2015, from www.mrcsummit.org/download/HCMC-Declaration-V5-4Apr2014.pdf

Murray–Darling Basin Authority (MDBA) (2011a). The proposed environmentally sustainable level of take for surface water of the Murray–Darling Basin: method and outcomes. Canberra: MDBA.

Murray–Darling Basin Authority (MDBA) (2011b). Plain English summary of the proposed basin plan – including explanatory notes. Canberra: MDBA.

Murray–Darling Basin Authority (MDBA) (2014). History of water licences in Australia. Retrieved April 8, 2015, from MDBA. Web site: www.mdba.gov.au/what-we-do/managing-rivers/water-trade/history-of-water-licenses

National Water Commission (NWC) (2014). Australian water markets: trends and drivers 2007–08 to 2012–13. Canberra, NWC.

Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014). Africa. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (Eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1199–1265). Cambridge, UK; New York:. Cambridge University Press.

Quibell, G., Le Quesne, T. and Speed, R. (2013) Basin Water Allocation Planning: International Experience and Lessons. WWF, Gland. (In press)

Reisinger, A., Kitching, R. L., Chiew, F., Hughes, L., Newton, P. C. D., Schuster, S. S., Tait, A. and Whetton, P. (2014). Australasia. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (Eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1371–1478). Cambridge, UK; New York:. Cambridge University Press

Rockström, J. and Falkenmark, M. (2015). Increase water harvesting in Africa. *Nature,* 519, 283–285

Tadross, M., Suarez, P., Lotsch, A., Hachigonta, S., Mdoka, M., Unganai, L., Lucio, F., Kamdonyo, D. and Muchinda, M. (2009). Growing-season rainfall and scenarios of future change in southeast Africa: implications for cultivating maize. *Climate Research,* 40, 147–161.

Southern African Development Community (SADC) (2008). Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin. Retrieved April 8, 2015, from SADC. Web site: www.icp-confluence-sadc.org/documents/integrated-water-resources-management-strategy-and-implementation-plan-zambezi-river-basin

Sadoff, C. and Grey, D. (2002). Beyond the river: the benefits of cooperation on international rivers. *Water Policy*, 4, 389–403.

World Bank (2010). *The Zambezi River Basin. A multi-sector investment opportunities analysis*. World Bank. Retrieved April 8, 2015, from siteresources.worldbank.org/INTAFRICA/Resources/Zambezi_MSIOA_-_Vol_1_-_Summary_Report.pdf

Zeitoun, M. and Jägerskog, A. (Eds.) (2009). Confronting power: strategies to support less powerful states. In: 2009. *Getting transboundary water right: theory and practice for effective cooperation. Report No. 25.* Stockholm: Stockholm International Water Institute (SIWI).

Zeitoun, M. and Jägerskog, A. (2011). Addressing power asymmetry: how transboundary water management may serve to reduce poverty. Report No. 29. Stockholm: Stockholm International Water Institute (SIWI).