Water Resources Development and Management

World Water Council *Editor*

Global Water Security

Lessons Learnt and Long-Term Implications

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Preface I

Join Hands to Meet Water Security Challenges and Promote Global Sustainable Development

Water is the foundation of life, the origin of civilisation, and the cornerstone of ecology. Water security and human fate are closely intertwined. To bring the concern and attention of the international community to the issue of water security, build global consensus on water governance, and boost exchange and sharing of water governance experience and technologies, the Ministry of Water Resources of the People's Republic of China and the World Water Council have co-sponsored the compilation of this academic report on world water security. After more than one year of joint efforts by many experts and staffers, this report is now available for publication. I would like to extend our gratitude to the World Water Council and other related parties for their close cooperation in the publication of this report; to Honorary President Loïc Fauchon for his great attention, long-term research, and insightful opinions on water security issues; to President Benedito Braga for the important leadership and advocacy role played by the World Water Council under his eminent leadership; and to our experts, scholars, and staff members for their hard work.

At present and for the foreseeable future, due to global population growth, economic development, and accelerated urbanisation and industrialisation, coupled with the intensifying impact of climate change, water security problems will become increasingly prominent, posing a major challenge to global sustainable development. *In terms of water infrastructure,* countries across the world are facing common problems such as lagging infrastructure development, ageing and disrepair of waterworks, insufficient funds for maintenance and repair, inadequate investment and financing capacity, and poor response to flood and drought disasters. According to some estimates, the needed investment in the water sector will exceed 1 trillion USD by 2025. With the global economy continuing to experience great uncertainty, the lack of water investment and financing will become increasingly salient. *In terms of water and sanitation,* more than 1.1 billion people lack access to safe drinking water and 2.6 billion people do not have access to sanitation facilities at the time of the publication of this report, and 650,000 children die of water-borne diseases every year. *In terms of water and food,* it is expected that by 2050 global grain output will need to increase by 60% and agricultural water use by 55% to meet the food demand of the growing world population. Owing to worsening water scarcity, global food security is exposed to significant risks. *In terms of water and ecology,* over the past 100 years, the total area of wetlands in the world has shrunk by nearly half, and 40% of the rivers on earth have suffered from various degrees of pollution. Untreated wastewater currently affects the lives of 1.8 billion people. *In terms of water hazards,* climate change is increasing the frequency and severity of catastrophic events. Natural disasters such as floods, waterlogging, droughts, hurricanes, and storm surges have severe impacts. Globally, floods kill more than 7000 people annually, on average. In future, adverse impacts of water hazards will loom further on the horizon. *In terms of water governance,* competence in water resources development, utilisation, conservation, and management vary enormously between countries, with capacity-building facing a major shortfall. Promising approaches such as integrated water resources management and river basin management have yet to be practised extensively. Global capacity in water governance is in urgent need of further improvement.

In recent years, the topic of water security has attracted close attention from the international community, thanks to vigorous and enthusiastic appeals and promotion by international organisations such as the United Nations and the World Water Council. In September 2015, the United Nations Sustainable Development Summit adopted the 2030 Sustainable Development Agenda, incorporating water as a dedicated goal. It emphasised universal access to water and sanitation and set up explicit targets for drinking water security, wastewater treatment and recycled use, water use efficiency and integrated management, ecological system restoration, and water-related disaster management. It fully demonstrates the importance of water security in the context of global sustainable development and embodies the strategic consensus of the international community on the need to respond to water challenges and safeguard water security.

With its large population and limited water resources, plus uneven distribution of water resources in time and space, China is the developing country facing the most arduous task of water governance. The Chinese government attaches great importance to the issue of water security. In response to people's aspirations for a better life, China upholds the concept of the harmonious coexistence of humankind and nature, pursues green development with ecological integrity prioritised, incorporates safeguarding water security into the overall layout of its modernisation drive, places it atop the agenda of ecological civilisation development, and has researched and developed a national strategy for water security. Thoughts, concepts, and policy measures on water governance and management with Chinese characteristics have taken shape.

(1) *Insist on prioritising water saving and toughen management of water resources*. China enshrines water conservation as a national strategy, has launched national water conservation actions, is implementing the most stringent water resources management system, and follows the principle of determining water demand, urban development, and production output in line with water resources availability. Among other measures, China has intensified the strict control of water resources by means of the Three Red Lines: capping total water use, improving water use efficiency, and restricting the pollution load in water functional zones. As a result, China practises dual control of water consumption in both quantity and intensity, strictly curbs new water use by industries with redundant capacity, is scaling up high-efficiency irrigation at the regional level, and promotes industrial and domestic water saving, in a bid to build a water-saving society on all fronts.
(2) *Stick to joint prevention and control to promote the protection of the water environment*. All walks of life will be involved in improving the water environment and addressing water environmental issues at their roots. Specific interventions include implementing the Action Plan on Control of Water Pollution, improving the mechanisms for water environment monitoring and early warning, tougher regulation of water function zones by level and category, strict quantitative control of pollution discharge into rivers and lakes, and stronger protection of drinking water source areas. Efforts are being made to coordinate treatment of pollution on land and in water, to practise basin-wide joint prevention and control, and to adopt such measures as treating pollution sources, curtailing pollution discharge, diverting clean water for dilution purposes, cleaning up and dredging polluted river courses, and applying biological technologies, to reinforce comprehensive and all-round water environment harnessing.
(3) *Uphold systematic governance and accelerate restoration of the water ecology*. China has redoubled its efforts to better manage and protect river headwaters, ecologically sensitive areas, and water source nurturing areas, pushing forward water and soil conservation initiatives, toughening control over the usage of water bodies and shorelines of rivers and lakes, turning once-reclaimed farmland back into lakes and wetlands, and expanding the ecological space of rivers and lakes. In addition, groundwater utilisation is under strict management, and areas of groundwater over-exploitation are subject to integrated harnessing, with a view towards gradually restoring the balance between extraction and replenishment. Low-impact development and urban ‘sponge’ construction are being promoted, and water ecological civilisation is being advanced in both urban and rural areas.
(4) *Adhere to scientific planning and improve the network of water facilities*. China has formulated national medium- and long-term water resources development plans, as well as special planning relating to water utilisation for different purposes. Steps have been taken to develop water resources in a scientific

manner, optimise the layout of water engineering projects, and boost support for water programmes in poverty-stricken regions. China has also sped up the construction of major waterworks, key water-control projects, rural water infrastructure, and engineering systems for flood control, drought relief, and disaster reduction. In the meanwhile, we are pushing forward water-system connection of rivers, lakes, and reservoirs, and establishing modernised networks of water facilities.

(5) *Persist in reform and innovation to improve water governance mechanisms.* The 'river chief' system, in which government officials at every level are fully responsible for the protection of rivers and lakes in their jurisdiction, is being rolled out across the country. Dedicated policies are being formulated for every river to improve its management and protection. Among other measures, China has increased input from public finance and attracted investments of financial and social capital in water conservancy. We have built more robust water-pricing mechanisms and water-saving incentives, introducing block tariff and escalating-tariff systems for water use above allowed quotas. China has also sped up the development of water rights and water markets, established an ecological compensation mechanism, perfected the water legal framework, and fostered innovation in water science and technology to promote the progress of 'smart water conservancy'.

(6) *Encourage public participation and pool resources from the whole society.* In this regard, China has refined the government responsibility system by evaluating its competence in water management. By incorporating indicators such as consumption of water resources, damage to the water environment, and benefits for the water ecology into the system for comprehensive assessment of economic and social development, China is promoting a new pattern of green development. Through public communication and education on water resources, China intends to create a civilised social trend of saving water, protecting water, and loving water, and foster synergy across the whole society to value and develop water. Thanks to persistent efforts, China has ensured the food security of 21% of the world's population, with 6% of the world's freshwater resources and 9% of its arable land resources, and safeguarded the country's medium-to-high-rate economic growth with only a marginal increase in total amount of water consumption. This itself is a major contribution to global sustainable development.

Addressing the issue of water security is a very complicated systematic endeavour that requires concerted efforts from all countries around the globe. Our world is confronted with many tough challenges in achieving the water-related targets on the 2030 Sustainable Development Agenda. With the experiences of China and other countries in mind, I believe we should focus our efforts on the following aspects.

(1) *Develop national strategies to ensure robust top-level designs for safeguarding water security*. Water security strategy deserves an important place in the overall national development strategy. The interdependence between water security, food security, ecological security, flood control security, and energy security should be taken into comprehensive consideration, in order to develop forward-looking, integrated, targeted, and coherent water policies. Stronger political will is required to build a consensus among various stakeholders and turning commitments into practical actions.
(2) *Further develop water conservancy to reinforce the foundation for socio-economic development*. Water conservancy, as an important foundation for socio-economic development, requires scientific planning, general design of and allocation of resources to specific programmes. Speeding up the construction of water infrastructure will enhance the capacity for safeguarding water security. Thus, the international community should assign infrastructure construction a larger share in their aid programmes and help developing countries gradually overcome their deficiencies in water infrastructure.
(3) *Advocate water saving and promote the formation of green development patterns*. It is imperative to assign a prominent status to the conservation and protection of water resources; to promote the formation of spatial layouts, industrial structures, production modes, and consumption patterns that are conducive to the conservation and protection of water resources; and to facilitate the adaptation of socio-economic development to the carrying capacity of water resources, water environment, and water ecology.
(4) *Augment financial input to the water sector and establish a sound and multi-source water investment and financing regime*. As water is foundational and *pro bono* in nature, the government needs to allocate more public finance to the water sector. In the meanwhile, we should make full use of market mechanisms, actively explore the trading of water rights and financing models such as public–private partnership and build–operate–transfer, and broaden water investment and financing channels, in order to increase the effective provision of public goods related to water.
(5) *Insist on comprehensive implementation of policies and measures and accelerate the fulfilment of key water development targets*. The resource, environmental, and ecological functions of water should be taken into comprehensive consideration. Domestic, production, and ecological water use should be provided for in a coordinated way. All stakeholders should be engaged in the greater participation and stronger support. Synergetic efforts should be made to promote achievements of those targets on the 2030 Sustainable Development Agenda that are related to water use efficiency, drinking water safety, wastewater treatment, ecological restoration, river basin management, and water disaster prevention and mitigation.
(6) *Strengthen international cooperation and improve the global water governance system*. It is vital to actively organise multi-level policy and strategy dialogues in extensive areas. We should push forward pragmatic cooperation between government departments, research institutes, water companies, and relevant

international organisations, so that all parties can learn advanced ideas, experience, and water governance technologies and management from each other, and accelerate the formation of a global water governance system that is green, safe, efficient, circular, and conservation-oriented.

This report brings together water security cases from ten countries and regions, reflecting major challenges to water security under different natural and geographical circumstances, at different stages of economic development, and with different endowments of water resources. Profound thinking triggered by such challenges, responses undertaken by various stakeholders, and success stories from different continents are available in this book. As such, it is an important source of reference and inspiration for actions by countries around the world to raise public awareness of water crisis, encourage public participation, upgrade the capacity for scientific water governance and management, and address water security challenges effectively. I am confident that this report will be well received by readers from all walks of life. To address water challenges, enhance water governance, and safeguard water security is a major task that all humankind will need to face in the process of sustainable development for a long time to come. China is more than happy to work with other countries and international water organisations to expand the breadth and depth of water cooperation, compare water experiences, share water wisdom, and maintain water security, in order to enable water to become an inexhaustible resource to nourish the shared future of the entire human community.

Chen Lei
Minister of Water Resources, People's Republic of China

Preface II

Global Water Security: Strategies and Policy Implications

The need for strategies and policies to enable water security across the globe is more pressing than at any time in history. Recent years have seen many regions suffer more water scarcity, more extreme droughts, and more extreme floods. Water issues underlie famines, migration, epidemics, inequalities, and political instability. The Organisation for Economic Co-operation and Development's Environmental Outlook to 2050 estimates that by mid-century more than 40% of the world's population is likely to be living in river basins under severe water stress and 20% of the population will be at risk from floods.

Yet, although reliable, safe water supplies and sound defences against droughts and floods are vital for social and economic prosperity, few countries pay enough attention to strategies and policies for water security. Strategies and policies for water security are urgently required to protect populations, cities, economies, and ecosystems from water-related risks—risks from droughts, floods, pollution, unsafe drinking water, inadequate sanitation, and degraded ecosystems. Population growth, urbanisation, the rising global demand for food, and climate change make strategies and policies for water security imperative. One of the greatest challenges ahead is to meet global demand for energy and food, which is expected to grow by more than one-third by 2035, while providing adequate water to households.

Water security is critical in both developed and developing countries. Although water-related risks mainly threaten developing countries, floods and droughts cause enormous damage to economies and communities in developed countries as well. By 2050, the value of assets at risk is expected to triple to around US$45 trillion. Recent estimates from the High-Level Panel on Water indicate that US$650 billion is required every year from now until 2030 to assure the infrastructure necessary to achieve water security. Althouth current investment falls far short of global needs and the impacts on communities, economies and the environment are significant.

Recognition is growing that water security is key to cross-sectoral sustainable growth. Investing in water security reduces risks faced by society and economic sectors associated with water and can have a positive effect on economic growth and inclusiveness. The policy agenda for water must proactively build water-wise policies across sectors. Water security, business security, and the well-being of the planet depend on joined-up thinking and working together. We need to reach out to all sectors.

Mainstreaming water security means catalysing knowledge to develop sustainable, bankable projects that are risk-resilient and will provide returns on investment. It means mobilising political will for developing policies and strategies that will create an enabling environment for the investment in multi-purpose infrastructure. As water is often under-valued and underpriced, there are opportunities for investing in higher value uses of water. Policy interventions can lessen the risks and improve the returns of investments in water, thus encouraging a shift towards higher value uses. Technological and business innovations can make investing in water more attractive and need to be scaled up. Blended finance is a promising way of financing large water infrastructure projects on viable terms. In the face of an uncertain future, strategies to integrate individual investments and projects in basins can build resilient, cost-effective water infrastructure that delivers multiple benefits.

Developing strategies and policies for financing water infrastructure is a priority for achieving water security. The World Water Council has a history of addressing the need to scale up investment in water, seeking to improve understanding of investment risks and encouraging more investment in water infrastructure worldwide. The partnership on water and finance between the Organisation for Economic Co-operation and Development, the Government of the Netherlands, and the World Water Council was a key to launching the Roundtable on Financing Water in 2017. This group leverages policy, economic, and financial expertise and shares its findings with leaders in the private sector, government, regulatory institutions, academia, and civil society. The Roundtable contributes to the work of the High-Level Panel on Water on developing policies and incentives to meet the challenge of financing the world's needs for water infrastructure.

In this collection of studies, the World Water Council with the generous support of the Government of China has drawn on worldwide expertise. The prospects for a water-secure world that meets the demands of increasing populations and growing economies are surrounded by complexity and uncertainty. Most analyses to date have been theoretical or have examined water security in a particular sector, such as agriculture or energy. The governments we task with developing policies and strategies for a sustainable future have little practical guidance on best bets for building and managing water systems that will deliver water-secure development.

Crops that fail because of droughts or floods, cities that face water restrictions, economies with insufficient water supplies to grow, and millions of livelihoods at risk mean that it is imperative to gear up policies and strategies to ensure greater water security—and to gear up now. This book, in discussing real-life policy, management and governance decisions across food production, energy, ecology, finance, industry, climate, and disaster-resilient issues, provides insights on what can be done towards greater water security, the trade-offs, the short- and long-term implications and the lessons learned. The Council hopes that the studies offer fresh perspectives on strategies and policies for water security and that the recommendations offer constructive advice.

Benedito P. F. Braga
President, World Water Council

Preface III

Water Security—Worldwide, for Us All, and by Us All

The world is lurching from crisis to crisis. Political tensions are flaring, while military and diplomatic pressures are rising. The climate is changing at an alarming pace. Energy and water are becoming increasingly scarce resources. People are facing growing threats to their health, as well as to vital food supplies. Billions of people all over the world are suffering from the accumulated effects of such crises.

As our economies and societies become more and more interdependent, as demographic growth and urbanisation reach unprecedented levels, as news spreads ever faster, and as people's hopes for a better quality of life are raised, this suffering is becoming more intense and more brutal. Yet, at the same time, it also strengthens calls for peace and human dignity.

Peace and dignity, and a fairer world, depend in the long term on two things: access to development opportunities and protecting the natural world. To develop *and* to protect nature, we need to act with mutual respect and find a sustainable balance between the use of our increasingly coveted natural resources and the need to protect them.

Water is one of these resources. And it has become a rare commodity, in terms of both quantity and quality. Despite our household, industrial, and agricultural uses of water, and even its ecologically friendly use, the water in our rivers, boreholes, water tables, dams, and reservoirs is rapidly being depleted. As the demand for water increases, the supply is stagnating, at the local scale and at the global scale. Our lives depend on water being available. If we fail to manage its availability, we condemn entire populations to be excluded from development and the enjoyment of fundamental human rights.

Collectively and individually, this is our responsibility, or rather, these are our responsibilities. We must ensure water security, worldwide, for us all, and by us all.

To secure water use, we first need to secure the availability and protection of the resource itself. We have to find the right balance between *water now* and *water in the future*. That means a balance between the demand for water and the restrictions that come with water stress. Securing resources means finding the additional water resources needed to meet the demand and establish that balance. To achieve all this, we can rely on human ingenuity and the ability to constantly innovate and come up with new solutions.

This begins with technical solutions. In the future, we will need to drill for water more deeply, transport it over longer distances, store it for longer, and purify it more efficiently. We will develop new, cheaper, and more advanced solutions, such as the wider use of desalination and wastewater reuse. These will give us a fantastic source of freshwater for agricultural and industrial use. Technological advances will enable us to speed up the roll-out of new, smarter, more efficient, more environment-friendly, more sustainable, and fairer solutions.

But apart from human ingenuity, there is also the need, indeed the obligation, to take political action. The politician's job is to take the lead, to implement and oversee the use of water. We can think of water management as a house supported by three pillars: governance, finance, and knowledge. These three pillars need to be well built, to ensure that every drop of water is used as productively as possible.

To improve efficiency, we now need to go beyond the concept of integrated water resource management, which is a vertical approach to the short water cycle. It needs to be combined with a horizontal approach, based on the fundamental links between water, energy, food, health, and education—the 'five fingers'. This is a new approach, one which finally enables development policies to be implemented at national and local levels without segmentation or isolation, and without opposing any of the five 'fingers' against the others, seeing them as implicitly interrelated, rather than conflicting. Thus, expanding a city, or building a school, must answer to each of these five basic factors simultaneously, rather than focusing on one to the detriment of the others. It is an approach exemplified in the slogan 'Water and energy, fighting for the same cause'.

With these emerging needs, we see that water security is now one of the key strategic challenges faced by our planet, along with climate security, nuclear security, and maritime security. Water scarcity makes human societies more vulnerable and leaves some states and communities in an extremely fragile situation.

Global water security has now become an integral part of every country's national security and foreign policy. Which brings us to the need to develop 'hydro-diplomacy'. Hydro-diplomacy is the art of building peace based on this most vital resource for mankind. It should operate not only through joint management of cross-border basins, but also in climate mitigation and adaptation negotiations. Hydro-diplomacy is also needed to set up the effective and fair debt refinancing mechanisms linked to water (and energy) for the world's poorest nations.

However, in the last few years, we have seen that governments no longer have a monopoly on such a strategic vision. Ensuring water security, for the present and, above all, for the future, will be in the hands of parliaments, local authorities, and user communities. This is because the best people to ensure water security are, as always, those closest to the ground, who can state the rights and duties of all, with a careful eye on ethics and transparency in political action. The right to water, so easily proclaimed yet so difficult to enforce, will be the common thread running through collective action and policy on water security.

So, how are we to proceed, in a world where everything needs doing yesterday and instant communication is often more important than long-term action? To advance water security, we need a pact, or, to be more precise, a series of pacts, starting with a global pact that makes water the priority in the Sustainable Development Goals, in climate negotiations, and in the financial commitments made by development agencies and banks.

We need a global pact that commits international institutions and states to making water a key priority, transposed into laws and decisions made by the international community under the aegis of the United Nations. Added to this, we need local pacts, at the level of river basins, metropolises, and rural communities, in which political leaders and business and social players will publicly commit, in concrete terms, to making water and water security central to their regular public policies.

As for climate change, water security can only be ensured sustainably if everyone, everywhere, makes an unwavering commitment to achieve it.

This work sets out to promote some of the different initiatives and experiences worldwide which set an example in the struggle to ensure water security. The idea for this book was developed in liaison with my dear friend, Chen Lei, Minister of Water Resources of the People's Republic of China. Chen Lei is a great leader of the water community, and the recent advances accomplished in China under his responsibility have been extraordinary.

I would like to thank him for his vision, his leadership, and his contribution to the cause of ensuring access to water. Without his determination and commitment, this book would not exist. I would also like to thank the people who work with him and, more generally, all those who have been involved in writing this book. I hope that it will make a significant contribution to ensuring, in time, water security, worldwide, for us all, and by us all.

Loïc Fauchon
Honorary President, World Water Council;
Chief Executive Officer, Société des Eaux de Marseille

Contents

Chapter 1
Towards Global Water Security: A Departure from the Status Quo?

Cecilia Tortajada and Victor Fernandez

Abstract Water resources are, and have always been, a multidimensional resource that crosses all social and economic sectors. Globally, growing population and urbanisation have increased the pressure to meet the water, energy, and food demands of larger populations with higher expectations. As a result, both developed and developing countries seem to be racing against the clock to respond to the needs of societies in which inequalities continue to grow. Water resources are scarcer and more polluted; their management, governance, and development increasingly depend on decisions that are made in other sectors, many times without sufficient coordination; and their availability is more than ever threatened by issues, such as climate variability and change, that impose nothing but uncertainty. These factors have led to water resources being seen through the lenses of risk and security. The security of water resources necessitates a departure from the status quo, to an innovative system that is able to understand and appreciate how different natural, policy, and political variables interact and affect each other. This system requires a wholesome perspective that is able to propose alternatives that consider complexity and that are adaptive to an uncertain future. A departure is necessary because the status quo has proven unable to respond to the present needs and expectations, much less to future ones.

1.1 Introduction

Water security is broadly defined as the availability of an adequate quantity and quality of water to sustain socio-economic development, livelihoods, health, and ecosystems (Grey and Sadoff 2007; United Nations University 2013). Water, as a multidimensional issue, is a prerequisite for human security. Its scarcity has impacts at all levels of society, often exacerbating poverty and holding back socio-economic

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development. As has been extensively discussed, factors such as population growth, urbanisation, land-use change, changing lifestyles and social expectations, economic activities, and lately climate variability and change and associated extreme events, have far-reaching effects on global human and natural environments (Biswas and Tortajada 2009; van Beek and Arriens 2014; Vörösmarty et al. 2010).

Water use is estimated to have grown sixfold due to global population growth during the twentieth century (Bogardi et al. 2012), putting enormous pressure on available resources. However, not all countries display this trend, for example, the largest world economy. In the United States, total water use declined between 2005 and 2010 in all sectors including public supply, industrial, thermoelectric power, and irrigation. Only mining and aquaculture had larger withdrawals in 2010 than in 2005, but they are comparatively small and did not offset the larger overall reduction from the other uses, calculated at 54 billion gallons per day (US Geological Survey, n.d.).

Poor quality of water is greatly responsible for water insecurity and has large social and economic consequences (World Bank 2007). The most significant sources of water pollution are inadequately treated municipal discharges and inadequately managed and treated industrial and agricultural wastes.

Data and information on water use are essential for a broad understanding of water availability. In most cases, however, data are not available and, when collected, are incomplete and sparse, lacking the temporal and spatial resolution required for an understanding of trends, frequency, timing of shortages, and times of peak use (World Bank 2017).

From the non-traditional point of view, water security has implications at the political and military levels (Zeitoun 2011). From this perspective, water insecurity has resulted in 'explosive conditions' that have even destabilised political regimes (Reed 2017). In the United States, the intelligence community has expressed concern that water problems may contribute to instability in countries important to US national security interests. In general, the risks might include social disruption due to water shortages, greater poverty, social tensions, environmental degradation, and poor governance; depletion of groundwater, which could threaten national and global food markets; and serious negative impacts on important trading partners due to water shortages and pollution (Office of the Director of National Intelligence 2012). Local risks have the potential to escalate to the global level due to scarcity and deterioration of natural resources. This makes it crucial to understand the relation between societies and their political, human, and natural environments (Andrews-Speed et al. 2013; Brauch et al. 2009), as well as the role environment and natural resources play in promoting peace, stability, and human security (Tortajada and Keulertz 2016).

The water outlook differs significantly between OECD and non-OECD countries. Non-OECD countries will experience higher rates of population growth, and dramatic growth in demand for water. On the other hand, in the OECD countries, total water demand is projected to decrease from 1000 km^3 in 2000 to 900 km^3 in

2050. This will be driven by efficiency gains (conservation measures and technological innovations) and a structural shift towards service sectors that are less water-intensive (OECD 2013). In all cases, however, the impacts of water scarcity are most severe for the poorest sectors of society (United Nations 2007) because they face greater exposure to water risks, are more vulnerable, and have more limited access to alternative sources of water and related services (OECD 2013).

1.2 Water Security, Its Dimensions and Risks

Following the sustainability paradigm that proposes equal prioritisation of social, economic, and environmental issues, water security has the same three dimensions: social equity, economic efficiency, and environmental sustainability.

As discussed by van Beek and Arriens (2014), the social dimension is about ensuring equitable access to water services and resources for all sectors of society, through robust policies and legal and regulatory frameworks, as well as governance practices. The economic dimension refers to increasing water productivity and conservation in all sectors. Economic efficiency is essential because increasing water productivity is key to addressing present and future water security. Water productivity could certainly be optimised in both the agriculture and energy sectors, since, at the operational level, water use for energy, and water consumption for irrigation, are largely unquantified. This will require more efficient practices and also closer coordination among local, regional, and national institutions. Without further improvements in water efficiency and productivity, water use for domestic, agricultural, and industrial activities may continue increasing to unsustainable levels in the long-term (United Nations 2007). Last but not least is the environmental dimension: managing water sustainably as part of a green economy.

Addressing water security concerns requires more comprehensive planning, policy and management, technological innovations, and closer collaboration across sectors, communities, and political borders (European Commission 2015; United Nations University 2013; Zeitoun 2011). It also requires mitigating water-related risks, because water is not only vital for humans, but also the economic foundation for millions of businesses, farms, power plants, and manufacturers, which all depend on a supply that is reliable in both quantity and quality (Kane 2017).

Water insecurity as it relates to climate variability and water-related disasters can be addressed by managing risks and reducing vulnerabilities (Asian Development Bank 2016). The objective is to understand how societies can cope with variability by prioritising thresholds of acceptable level of risks both at present and in the future.

As a risk-based approach to water security, the OECD (2013) has proposed a framework that combines technical risk assessments with contextual factors, such as risk perceptions and risk evaluation (Fig. 1.1). The OECD proposes that increasing water security means achieving and maintaining acceptable levels of risk in the following water-related areas: water shortages, inadequate water quality, excess

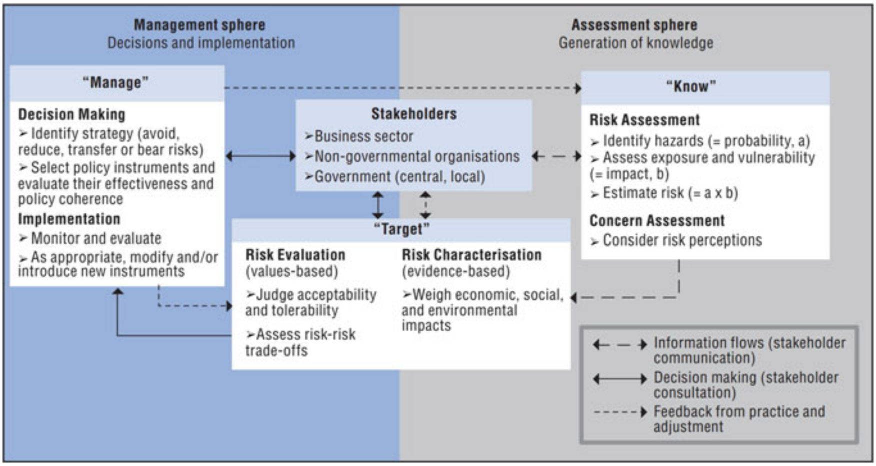

Fig. 1.1 A risk-based framework for water security. *Source* OECD (2013)

water, and weakened resilience of freshwater bodies. Since these risks are interrelated and influence each other, their management should focus on events that have as many positive impacts as possible (OECD 2013). The framework proposes that management of risks, as well as risk evaluations, are in the 'management sphere', which is about decision-making and implementation instruments. On the other hand, risk assessment, characterisation, and concern assessments are in the 'assessment sphere', which is about generation of knowledge.

According to this framework, the first step is *knowing* the risk (labelled 'know' in the diagram)—that is, identifying the main drivers of water-related risks and projecting their long-term trends. Drivers of water risks include policies and institutions, socio-economic trends, water resources (quantity and quality), and natural events. Building an adequate information base to inform decisions about water risks requires scientific risk assessment. It also requires understanding the risk perceptions of the actors who are affected (Grafton et al. 2012; OECD 2013).

The second step, *targeting* the risk ('target' in the diagram), identifies the possible responses and which ones would be the most appropriate. Based on the risk appraisal, evidence, and value-based judgments, this step considers the acceptability of the risk, which can be categorised as acceptable, tolerable, or intolerable. The process is characterised by potential trade-offs, given that the efforts to reduce water risks for a given population, ecosystem or activity may affect each other, or may result in other water risks. The level of acceptability of the water risk for society and the environment should, at least theoretically, depend on the balance between economic, social, and environmental consequences as well as the costs and trade-offs of ameliorating them (OECD 2009, 2013; van Beek and Arriens 2014).

In the third step, *managing* the risk ('manage' in the diagram), decision-making on the appropriate response to water risks and its implementation takes into consideration all the previous steps. The objective of this step is to avoid, reduce, transfer, or simply accept the risk, by attempting to manage its drivers or by limiting exposure of populations, ecosystems, and activities to negative impacts or making them less vulnerable. In general, a risk-based approach has the potential to develop a more holistic approach to water security, better assessment of policy priorities enabling preventive action, and more informed decision-making (OECD 2013). In all cases, the countries, regions, and basins that are more prepared to manage the different risks and respond to them will be those with the most functional, accountable, and inclusive institutions (Rüttinger et al. 2015).

From the governance viewpoint, one of the most contentious tasks is that of identifying risks as acceptable, tolerable, or intolerable. Here, the so-called traffic light model is often used: green if risks are acceptable, yellow if further management actions are necessary, and red if risks are intolerable (Klinke and Renn 2012). In this model, risks are ranked and prioritised based on their likelihood and their consequences. A risk is acceptable if it is highly unlikely and would have only slight consequences. A tolerable risk is one with occasional serious impacts, for which risk reduction measures are necessary. A risk becomes intolerable when there is a high probability of catastrophic consequences (Fig. 1.2).

Risks can be deemed more or less acceptable from the socio-economic and environmental viewpoints depending on their magnitude, consequences, and cost of amelioration. In Fig. 1.3, the magnitude, consequences, and costs of specific risks are presented on the horizontal axis, and their probability on the vertical axis. Water management is usually effective only when events have acceptable risk, for example, events of moderate impacts with low probability. Larger events with higher probability can have very large, very expensive impacts on water resources, making them very difficult to manage. One of these events is climate change, which could increase water risks to very high levels (OECD 2013).

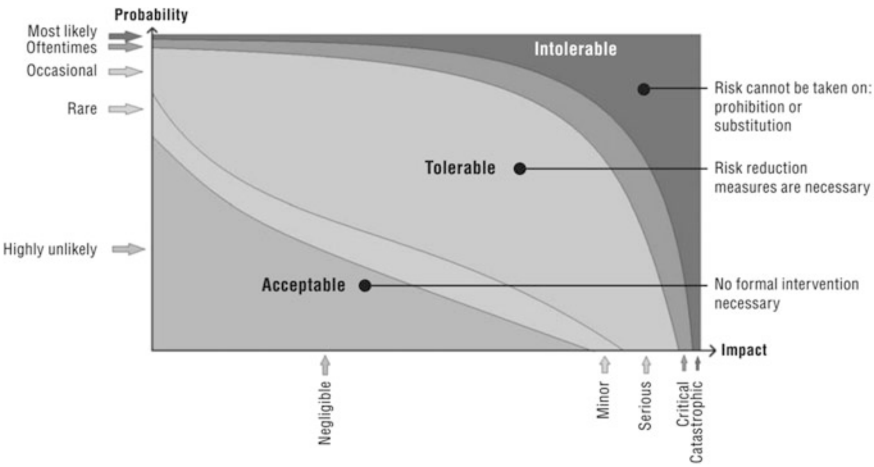

Fig. 1.2 Acceptable, tolerable and intolerable risks. *Source* Klinke and Renn (2012)

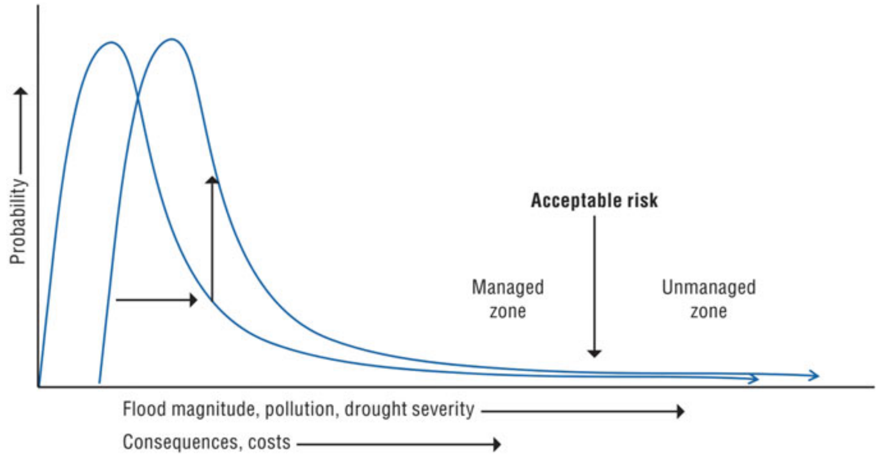

Fig. 1.3 Setting the acceptable level of risks. *Source* Prosser (2012)

1.2.1 Water and Climate-Related Risks

Water management and climate change and variability have numerous interlinkages. These interlinkages, in addition to their numerous hydrologic, economic, social, environmental, and political impacts over time and space, make policy alternatives, management, governance, and development decisions, as well as investment choices on mitigation and adaptation strategies, most challenging under the best of circumstances (Tortajada 2016).

Climate change has increased the complexity of managing water resources (World Bank 2010). It presents numerous challenges to the traditional water management paradigm of stationarity or historical variability for estimating and managing risks (Milly et al. 2008). Since these principles are no longer valid, water resources have to be managed in different ways, and water systems have to be optimised in different ways. As discussed by Milly et al. (2008) and further explained by the World Meteorological Organization (2012), the extent of anthropogenic impacts on the means and extremes of precipitation, evapotranspiration, and rates of river discharge makes it essential to identify new non-stationary probabilistic models of the relevant environmental variables.

Confidence in stationarity in the face of climate change is low in many countries in the developing world, where institutional capacities, legal and regulatory frameworks, and infrastructure development to cope with non-stationarity are historically low (Weaver et al. 2013). Water managers at the basin scale and at the municipal level face numerous difficulties when trying to make decisions that involve climate change risks, even with qualified management and technical capacities (Conway 2013).

Climate variability and change will have and are already having, direct consequences for water security. The majority of the impacts will be on the water cycle, resulting in higher climatic and hydrological variability. More frequent and more intense droughts, floods, and other extreme events are expected (Tortajada 2016; United Nations University 2013). This will vary depending on the location of countries, cities, and basins (United Nations University 2013), but also on the policies, institutions, governance and management practices, investment funds available, and, overall preparedness for change (Tortajada et al. 2017). Even if climate change proves to be neutral in some places, major increases in water scarcity are expected. People in countries that already suffer from water shortages, poor institutional capacities, and inefficient services will face the most difficult situations (United Nations 2007). In the medium and long-term, climate variability and change are very likely to increase the number of people living under water scarcity conditions globally, making them more vulnerable and less secure (World Bank 2015).

1.3 Instruments to Address Water Security

Addressing water security concerns is necessary, mainly due to the extent of the impacts on the social and natural environments. Even if complete water security cannot be achieved, policy instruments should be developed to move towards better water security and better preparedness. These instruments may include institutional reforms, governance and management aspects, market-based instruments, water pricing, capacity building, and information and data sharing (United Nations University 2013; OECD 2013; World Bank 2015). The ever-changing physical, economic, and social conditions, which require continuous adaptation of natural and social systems, make these instruments more relevant (van Beek and Arriens 2014).

According to the Asian Development Bank (2016), strategies have been proposed at the international level for countries, regions, and cities to improve their water security. One example is the 'integrated water resources management' paradigm. The bank submits that one reason this paradigm has been unsuccessful is that individual governments have tried to adopt it without considering that their own stage of development, needs, and capabilities differ from those for which the paradigm was initially proposed. (For in-depth discussion of the practical limitations of this paradigm, see Biswas 2008; Giordano and Shah 2014).

The Asian Development Bank (2016) explains that the water economies are not homogeneous: they are at different evolutionary stages. And the conditions necessary to improve water security regarding financial aspects, institutional reforms, capacity building, water instruments, and management of impacts on ecosystems are different in each stage. In Table 1.1, water economies are indicated by the percentage of users in the formal sector: Stage 1 is completely informal (less than

Table 1.1 Priorities for improving water security in water economies at different stages of evolution

Evolutionary stage	Stage 1: completely informal	Stage 2: largely informal	Stage 3: formalising	Stage 4: highly formal water industry
Users in formal water economy (%)	5–15	15–35	35–75	75–95
Examples	Afghanistan, Bhutan	Bangladesh, Pakistan	People's Republic of China, Indonesia, Thailand	Australia, Republic of Korea
Capacity building	Invest in techno-managerial capacities for creating affordable infrastructure and services	Build capacities for efficient management of water infrastructure and water service provision	Build local capacities for catchment/river basin-level water resources management	High-level techno-managerial capacity for water and energy-efficient water economy
Policy and legal regime	Effective policies for water supply and food security Create a regulatory framework for bulk water users	Establish basic water policies and water laws consistent with local institutions and customary law	Introduce policy and legal regimes for a transition to basin-level water governance	Policy and regulatory frameworks for a modern water industry and transboundary water governance
Investment priority	Establish and improve water infrastructure for consumptive and productive use by entire population, including disadvantaged groups	Invest in infrastructure modernisation for improved service delivery and water use efficiency	Invest in infrastructure for basin-level water allocation and management, including interbasin transfer and managed aquifer recharge	Technologies and infrastructure for improving water and energy efficiency
Managing ecosystem impacts	Create broad-based awareness of aquatic ecosystems Regulate water diversions and pollution by corporate consumers	Proactive management of water quality and ecosystem impacts at project level Invest in low-cost recycling	Focus on water quality and health management Urban wastewater recycling Control of groundwater depletion	Zero or minimal discharges Reduce carbon footprint
Water pricing and subsidies	Minimise perverse subsidies Make subsidies smart Rationing to minimise waste	Volumetric water pricing for bulk users Partial cost recovery for retail consumers Targeted subsidies for the poor	Full financial cost recovery of water services Metered water supply Ninety per cent of population covered by service providers	Full cost recovery of water services, including costs of impacts on ecosystems

Source Asian Development Bank (2016). Adapted from Shah (2016), 'Increasing Water Security: The Key to Implementing the Sustainable Development Goals', TEC Background Paper No. 22, Global Water Partnership Technical Committee, Stockholm

15%); Stage 2 is largely informal (15–35%); Stage 3 is when the sector is formalising (35–75%); and Stage 4 represents a highly formal water industry (over 75%).

Lack of capacity related to water, not only institutionally but financially and technologically, is a major hindrance to achieving water security. Better water security depends on the quantity and quality of water available but also on the institutional and governance capacities to implement plans and policies that have been agreed to. Regarding financial aspects, the mobilisation of domestic capital, such as from banks, capital markets, pension funds and insurance companies, is necessary and requires extensive credit capacity to support utilities, introduce the opportunities to the water sector, and try to remove legal or policy obstacles to mobilise funds (United Nations University 2013; World Bank 2015).

It is known that market-based instruments provide incentives such as water taxes, like abstraction and pollution taxes, and tradable permit systems. They provide incentives for users to improve their practices. It is proposed that the advantage of taxes, compared to regulatory instruments, is that they are often less demanding in terms of the information public authorities require for them to be environmentally effective and economically efficient. Water taxes can also have relatively low administrative costs. Regarding tradable permit systems, 'caps', as well as promotion of direct investment in environmentally beneficial outcomes, contribute to the achievement of water security goals. A caveat is that the transaction costs associated with some trading systems can be very high and affect the net social gains that could be realised from trading. Overall, it should be kept in mind that economic efficiency alone is not sufficient to address water security problems and that environmental and social goals need to remain the main priority (OECD 2013). These goals make governance (or decision-making by multiple actors with numerous and dissimilar interests, and the formal and informal institutions they form) particularly relevant for water security.

From the point of view of governance, countries require institutional and legal frameworks that are prepared to respond when situations are different, with management structures that can be adapted to local, regional, and national contexts, new forms of relationships, and multilayered models capable of integrating the complexity of natural and social dimensions (United Nations University 2013). Closer institutional coordination among sectors that depend on water resources (such as energy and agriculture) will strengthen water policy, management, and development (World Bank 2017).

Good governance is thus proposed as an enabler of water security. Using a water security index (ADB 2013) and a governance index, Makin et al. (2014) argue that countries with good governance have achieved higher levels of water security compared to those countries where water governance is still a limitation (Fig. 1.4). As discussed elsewhere (e.g., Biswas and Tortajada 2016), this supports the argument that water scarcity and insecurity are related more to poor governance than to the physical scarcity of water resources.

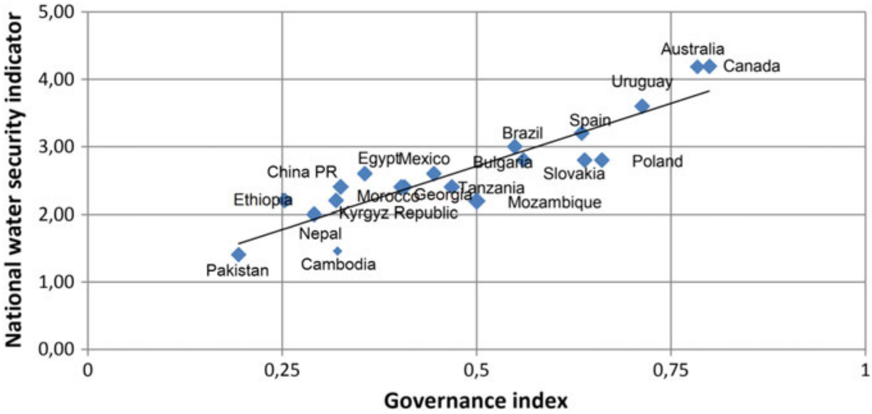

Fig. 1.4 National water security index against governance index. *Source* adapted from Makin et al. (2014)

1.4 Implementation of the Water Security Paradigm

This book includes case studies of countries, regions, and cities with different water security challenges, each in its own socio-economic, political, and environmental contexts. An effort has been made to make these analyses policy-and-practice-oriented so that the lessons learnt are based on actual experiences. The case studies are on Australia, China, Singapore, and Central Asia in the Asia and Pacific region; Morocco and Southern Africa in the African continent; France in Europe; and in the Americas, Brazil, California, and Latin America as a whole.

In the case study on Australia, it is explained that water resource planning is calibrated to scarcity. As Horne (2018) discusses, the microeconomic reform in the 1990s started the contemporary process of strengthening water security in both urban and rural areas. In 2004, the National Water Initiative further emphasised the importance of strengthening water security. The National Water Initiative took place during the Millennium Drought, which lasted from 1997 to 2009 in the south-east of the country. It aimed at improving the governance framework and encouraging change of behaviour (Council of Australian Governments 1994). Shortly after, in 2006, the national government introduced a National Plan for Water Security. It focused on governance reforms in the Murray-Darling Basin, strengthening agriculture sustainability and water markets, and enhancing the quality of information (Howard 2006). At present, even though there has been enormous progress on water security, it remains on the agenda, although with a much lower profile. Large investments in climate science and in upgrading water information systems are an indication of the priority they represent for the country when considering climate change. Horne also mentions that in spite of the overall successful management of water security, there are still two serious concerns: the poor water security in remote and regional communities of the country, such as in small towns in the state of Tasmania and indigenous settlements in the Northern Territory; and the trade-offs between public benefit and private profit, unresolved issues at the policy level.

The case study on China (Ministry of Water Resources 2018) points out that rapid urbanisation and industrialisation have led to increasingly acute conflicts between water supply and demand. Background contributing factors include limited water resources per capita, uneven distribution of precipitation in time and space, and the intensification of the impacts of global climate change. Also effects are excessive growth of water demand, increased wastewater discharges with no appropriate treatment, inadequate water supply infrastructure, soil erosion, deterioration of water bodies, and shrinkage of rivers, lakes, and wetlands. More than 400 cities suffer water shortage to varying degrees. This has resulted in water security becoming a matter of national interest. Flooding and waterlogging constitute the most hazardous and damaging natural disasters. Approximately two-thirds of the country and more than 90% of the people are exposed to flood threats to different degrees, and losses from floods and waterlogging represent 70% of the aggregated loss caused by all kinds of natural disasters. In response, the government has implemented a national flood control and drought relief command system, which is expected to be a nationwide and multilevel system for monitoring rainfall and water regimes, as well as forecasting floods. Also, to address increasing water demand, the government has implemented the policy of 'three red lines': total control of water use, improvement of water use efficiency, and restriction of water pollution in water functional zones. Looking towards the future, the Chinese government plans to uphold the new development concept of innovation and coordination to improve water security. Implementation of these policies has the objective to improve the conditions of the human and natural environments.

The case study on Singapore points out that historically, the city-state has strongly pursued the objective of being water-secure (Tortajada and Wong 2018). Today, in terms of planning, the aim is to be fully water-secure and self-sufficient by 2060. The country's limitations of having no natural water resources, being dependent on water, energy, and food from outside sources, and having no hinterland, have been overcome with long-term comprehensive planning, sound policies, and innovation in all sectors. The strategies that have ensured that Singapore can successfully meet present and projected requirements have included diversification of water supply sources within and outside the city-state, cleaning-up of rivers and waterways, protection of water catchments, water conservation measures, wastewater treatment and disposal, production of high-grade reclaimed water for potable and non-potable purposes, and desalination (Tortajada et al. 2013). It is expected that by 2060, Singapore's demand for water will double. To cope with this, the government has put in place long-term strategies, including increasing the proportion of the land used for water catchment to 90%, and doubling the production capacities of high-quality reclaimed wastewater (NEWater) and desalination by 2030. The latter two sources are expected to supply up to 85% of Singapore's water requirements by 2060 (Parliament of Singapore 2016). In the future, to augment its water resources and provide clean water to all users and for all uses, Singapore will have to develop an even more comprehensive strategy focusing much more on water demand, public engagement, and pricing instruments.

Central Asia is the last case study from Asia (Xenarios et al. 2018). The Central Asian countries are among the most water-intensive economies in the world, with mean water withdrawals of 2200 m^3/y per capita and nearly 90% of water diverted for irrigation purposes (Sehring and Diebold 2012). As Xenarios et al. (2018) explain, Tajikistan and Kyrgyzstan, the two upstream countries, are rich in surface water, with 81% of the region's water. Since they are poor in hydrocarbon resources, for them, water security is mainly interpreted as energy independence, reduction of disasters stemming from water, and sufficient water for irrigation and pastoralism. The downstream countries (Uzbekistan, Turkmenistan, and Kazakhstan) have abundant hydrocarbon resources. The first two have 23 and 44%, respectively, of the region's natural gas deposits, while the third is one of the world's top 20 oil producers. But all three of them face severe water scarcity. For them, water security mostly means intensified agriculture, fisheries and pastoralism, and reduction of water scarcity incidents. Despite local frictions, all the Central Asian states have recently agreed to set up regional organisations to adopt water management decisions by consensus. In the last decade, a river basin management approach was gradually introduced in each of the Central Asian countries in an attempt to improve national water use and allocation plans on the principle of the European Union's Water Framework Directive. River basin management plans have gradually been developed in three countries. However, there is still a notable lack of coordination, monitoring, and assessment of these interventions, mainly due to overlaps between too many governmental authorities. As discussed in the chapter, water security is a multidimensional concept that is perceived differently by each country in the region. Looking towards the future, it is expected that the common goal of improving socio-economic development will also result in better water security at the regional level.

In the case of Morocco, Ait Kadi and Ziyad (2018) explain that, despite being endowed with extensive groundwater resources, including 32 deep aquifers and more than 46 shallow ones, the country is enduring a changing climate, with decreasing precipitation and rising frequency of droughts. The risks to water security resulting from these challenges as well as from population growth, increasing urbanisation, and growing water scarcity, have driven the country to implement major policy reforms in its water management system. These have included the adoption of a long-term strategy for integrated water resources management, using the National Water Plan as its framework; the development of a new legal and institutional framework to promote decentralized management and increase stakeholder participation; economic incentives in water allocation decisions through rational tariff and cost recovery; and monitoring and control of water quality to reduce environmental degradation. Other policies implemented that have contributed to securing the supply of water in Morocco include the rapid construction of dams, from 16 in 1967 to 140 by 2016; an extended water transfer system between 13 basins; major infrastructure projects that aim to capture most of the remaining surface runoff by the year 2020; and development of wells and boreholes for groundwater extraction, which today contributes about one-third of the country's drinking water supply, a percentage that can reach 90% in rural areas. Current threats to water security in Morocco are the decline in available water resources, the increase in frequency of extreme events, the decrease in annual total rainfall, a positive trend in the maximum number of consecutive dry days, and a change in the hydrological regime that is lower average runoff and higher frequency and intensity of flash floods. Current climate change projections also suggest higher frequency and intensity and longer durations of droughts, with substantial impacts on the food, water, energy, and health sectors. Therefore, all policies and management and governance-related instruments continue to be strengthened.

The case study on Southern Africa discusses that the first challenge for water security in the region is economic, and that investments in infrastructure for storage and transmission have the objective to address water resources variability and unequal spatial distribution. As Muller (2018) explains, Southern Africa is a region with an area of 6.6 million km^2 and a population of 155 million. While there are pockets of prosperity, most people in the region live in poverty. In spite of the impact of water scarcity in the several countries in the region, the physical availability of water is not the main impediment to water security. While the situations in the countries vary, in general, the main constraints are financial and institutional, followed by a high level of inequality: people in urban areas are more likely to have access to clean drinking water and sanitation compared to rural areas. Today, water security in Southern Africa derives primarily from the economic capacities of the households, communities, and countries concerned. Improving institutional capacity is the second-most important priority to break Southern Africa's cycle of underdevelopment.

In the case study on France, it is explained that in the French public policy realm, the expression 'water security' is not commonly used (Tardieu 2018). Water security is not perceived as a critical issue, mainly for two reasons. First, France enjoys abundant water resources. Since almost all of the catchment areas of the major French rivers are on its national territory, the country depends little on other countries for water resource availability. Second, the country invested heavily in the governance of water resources in the past, starting in 1964, when the river basin was taken to be the relevant scale for water management, and the focus of water management was shifted to shared governance and dialogue among stakeholders. Despite the abundance of water and the apparently strong water governance, there are still challenges to water management in France. These include adapting to climate change; combating diffuse pollution, in particular agricultural pollution; and urban water supply and sanitation in overseas territories. In the country, the need for security in regard to floods has remained relevant. Floods have caused on average €650–800 million of annual damage over the last 30 years. The State has overall responsibility for preventing and combating flooding through the adoption of a national flood risk management strategy, the coordination of measures to anticipate floods and manage crises, and the gradual establishment of flood risk prevention plans. Nonetheless, local authorities or regroupings of municipalities now have some responsibilities for aquatic environment management and flood protection.

The general abundance of water has not prevented seasonal difficulties and local conflicts, particularly during dry summers. Water conflicts exist due to droughts, and partly due to climate change, which has increased environmental imbalances in south-west France and around Paris. And droughts have had cascading effects, including lower flows and levels in rivers, but also lower groundwater levels. The State has implemented several measures to improve water management during droughts, including promoting water-savings awareness campaigns, the implementation of flow control systems, better monitoring and control of irrigation activities, and even more drastic measures such as water use restrictions.

The case study on Latin America focuses on infrastructure development (Carrera et al. 2018). Latin America is the most urbanised region in the world. The urban population is projected to reach 585 million by 2030. Today, 80% of the population lives in cities, most of which have grown on top of the informal occupation of urban areas with inadequate urban services. Water supply coverage in urban areas has increased from 40% in 1950 to more than 90% in 2010, but the quality of services is still low. In most Latin American countries, water is abundant in less populated areas. For example, in Peru, 70% of the population and 90% of the economic output are located along the Pacific coast, which has only 1% of the country's endowment of water. Furthermore, the seasonal distribution of rainfall is quite uneven during the year. In Mexico, for example, 68% of the rainfall takes place in the four months from June to September, and only 16% in the months from November to April. Urban water management is complex, and it is generally handled in a rather segmented way, separating three distinct and linear components: water, sanitation, and drainage. This is very different from the natural hydrological system, which is closed and circular. Development of water infrastructure in the region has been insufficient to consolidate water security. According to the Development Bank of Latin America, this prospect could change. In 2011, the bank showed that annual investments equivalent to 0.31% of 2010 GDP would suffice to close the gap of water and sewerage services, expand water sources and drainage infrastructure, and treat almost two-thirds of the sewage that is collected. These investments would total USD250 billion over the period 2010–2030. Looking towards the future, even if large investments are made to close the infrastructure gap and achieve universal service, it will not be enough unless countries improve their weak institutions and governance practices and improve the administration and efficiency of water services (Mejia 2012).

The case study on Brazil presents an overview of water security at the national level in general, and São Paolo and Ceará in particular (Souza Filho et al. 2018). Brazil, the largest country in Latin America, is known for having the greatest availability of water on the planet, yet the unequal distribution of water across its territory is also well known. The north holds 65% of Brazilian water, but has only 5% of the population. The north-east has only 4% of the water resources, but 30% of the population. The south, responsible for 60% of the country's output, has 40% of the population but only 6% of the water. The case study explains that water security has become more relevant in Brazil due to the severe droughts that have affected the different regions in the country. Among the different droughts that have affected the country in recent years, the ones in the states of São Paolo and Ceará have been the most extreme. According to Souza Filho et al. in São Paolo, during the severe 2014–2015 drought, rainfall averages were well below historical records, the outflow rate from the state reservoir system was the lowest in 85 years, and practically the entire flow of surface water was being used. However, the state opted not to implement rationing in light of the possible negative outcomes, including health risks, and having to interrupt the supply of essential services. Instead, it implemented various water conservation measures, among which was reduction of water consumption through a bonus programme. In the aftermath of the crisis, water security has assumed greater importance in the political agenda of the state. As a consequence, technical and operational innovations, and investments in infrastructure, have been carried out. As for Ceará, it has faced multiannual droughts from 2012 onwards. The four years following 2012 were among the 10 driest years since 1950, and probably the most severe in the last 50–100 years. The initiatives implemented by the state government to cope with the drought have included the strategic expansion of water infrastructure, planning and management measures, and emergency actions for water security at specific moments. Thanks to these measures, a large proportion of the impacts have been minimised.

The last case study is on California (Lund and Medellin-Azuara 2018). If California were to be considered as a country, California would be one of the largest economies in the world, with high population and economic growth. The state has managed to successfully guarantee water security to most of its territory, overcoming to some extent the threats of water shortages and floods and being relatively efficient in balancing human, economic, food production, and ecosystem goals. The water management system in California has been in constant evolution. Water resources were initially managed by individual landowners and businesses, and later by local organisations, mainly to address local flood control problems and for the construction of local irrigation infrastructure. More recently, larger agencies were established to address the more challenging scarcity of water resources and the more severe threats of floods and droughts. The globalized nature of the state's economy has contributed considerably to its water security by supporting overall economic prosperity and providing substitute inexpensive food supplies normally and in times of drought. California's mountainous terrain and extensive sedimentary geology provide unusual geologic opportunities for substantial surface water storage, significant hydropower production, and immense aquifer storage. In terms of innovation, one of the state's most featured policies is a portfolio management approach, where a wide range of water supply and demand management options are integrated, along with actions to provide support for the entities involved working together. Actions include improvements in water source availability, conveyance capacities, agricultural and urban water use efficiency, and incentive pricing and markets. The biggest threats to water security in California include possible groundwater overdraft in the San Joaquin Valley, pollution in the groundwater supply of some rural areas, ineffective implementation of ecosystem objectives (which becomes evident during dry periods), and the perennial threat of floods and water management conflicts in the Sacramento–San Joaquin Delta.

In all the case-study discussions, plans, policies, and management and governance practices have been developed to address water scarcity and thus water insecurity. The common denominator is the concern that the effects of water scarcity on global and local human and natural environments will be such that policies and institutions may not be robust enough to provide appropriate and timely responses; and that this, in turn, will result in economic, social, environmental, and political vulnerabilities that will expose humankind to risks of irreversible change (Carrao et al. 2016; Turner et al. 2013).

1.5 Initiatives and the Burden of the Status Quo

There are numerous local, regional, and global initiatives to address water insecurity. Some of the global ones are the World Economic Forum's Global Water Initiative; the World Bank's A Water-Secure World for All; the Global Water Partnership and OECD's Global Dialogue on Water Security and Sustainable Growth; The WWF's Water and Security Initiative; the Water programme of the Nature Conservancy's Global Solutions; and the Global Human Water Security Fund (Grafton et al. 2017). Each one is making efforts to improve the status of water resources locally, regionally, and globally.

From a more practical point of view, larger transnational companies are embracing and implementing the concept of sustainability, and becoming increasingly efficient in terms of water and energy use, generation of waste, greenhouse gas emissions, etc. Performance varies greatly among them, but the best example of efficiency so far is Unilever. With its Sustainable Living Plan, the company has established a new business model whose objective is to double the company's size but halve its environmental footprint, with concrete targets, by 2020. With its over 600 industrial sites (and its 400 brands used by 2.5 billion people), efficiency measures could have a truly global impact.

In the case of governments, many have not departed from the status quo and are unlikely to do so in the near future. Nevertheless, they are trying to improve water security from the management, governance, and development viewpoints, with the objective to encourage overall development, improve quality of life, and reduce poverty. Global initiatives such as the Millennium Development Goals for 2015, the Sustainable Development Goals for 2030, and those related to climate change and its impacts (with no end in sight) have added targets that have helped countries pursue more sustainable development. One only hopes that governments, private companies, academia, and society are willing and able to depart from the status quo and work towards development that is more sustainable.

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Chapter 2
Water Security in Australia

James Horne

Abstract This chapter provides a contemporary snapshot of water security in Australia today, and the key policy issues to maintain and strengthen it into the future. Its focus is on risks and their management. Policy and practice are gradually moving Australia towards more sustainable water use and effective management of scarcity and quality, but pressures from population growth, economic development, and climate change have been and are ever-present challenges. The chapter details water use in major urban areas, regional and remote towns, irrigated agriculture, rainfed agriculture, the environment, mining, and electricity generation. In addition to the well-known role of markets in the irrigated agricultural sector, innovation in all major water-using sectors is contributing to maintaining water security. Two areas where progress in improving water security has been slow are also discussed. The chapter concludes with lessons from the Australian experience that may be relevant elsewhere.

2.1 Introduction

Water security issues have been prominent in the Australian historical narrative since well before federation in 1901. Microeconomic reform in the 1990s started the contemporary process to strengthen water security in rural and urban Australia. A group of experts argued, and governments later agreed, that more efficient water use could boost economic activity and, at the same time, address adverse impacts on ecosystem health from over-allocation and overuse (COAG Working Group on Water Resource Policy 1994; Council of Australian Governments 1994). In 1995, Murray-Darling Basin (MDB) governments agreed to cap water extraction in the MDB, underscoring that extraction for irrigation had reached its sustainable limit (Murray-Darling Basin Commission 1995; Horne 2013). It signalled that for water security to be maintained, water access entitlements would need to be strengthened

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(including by permitting unbundling of land and water rights), and water management planning and the associated infrastructure would need to be upgraded. Water markets were seen as a way to allow water to move to higher-value uses. In urban areas, corporatisation of government business enterprises put pressure on key water service providers to raise prices, hence valuing water more highly. This first round of reforms made some progress over the following decade, but entrenched resistance to change left much work to do.

The 2004 National Water Initiative (NWI), agreed in the middle of the Millennium Drought (1997–2009) that affected southeast Australia, signalled further resolve by state and national governments to recommit to upgrading water security (Council of Australian Governments 2004). This was a multi-pronged effort to change both behaviour and the governance framework. Rural water security required secure water access entitlements, transparent statutory water planning, removal of barriers to trade in water to facilitate broadening and deepening the market (benefiting both agriculture and the environment), and clarity around assignment of risk arising from changes in availability of water (expected to result from climate change). All overallocated systems (both surface and groundwater) needed to be returned to sustainable levels of extraction, with statutory protection for environmental outcomes. Policy also needed to focus on improving water use efficiency in rural and urban areas (Council of Australian Governments 2004).

In 2006 the national government introduced a National Plan for Water Security. The plan focused on further governance reform in the MDB (including foreshadowing new basin-wide institutional arrangements), greater strengthening of water markets using oversight by the national competition policy regulator, strengthening the sustainability of agriculture by buying back water for the environment and investing in improving irrigation infrastructure, and enhancing the quality of water information to improve risk management by irrigators, environmental water holders, and policymakers (Howard 2006). The Commonwealth's Water Act 2007 and the MDB Basin Plan 2012 each contained one reference to water security: that one objective of the Basin Plan is to 'improve water security for all uses of Basin water resources' (Commonwealth of Australia 2009, 2012).

Now, a decade later, although much has been achieved, water security remains on the agenda, albeit with a much lower profile. In some quarters there is still considerable trepidation around the level of water security in Australia. In a 2016 water industry survey, only 46% of industry respondents and 36% of community respondents reported being 'very confident' or 'somewhat confident' that 'Australia currently had sufficient water security to meet all social, environment and economic needs' (Australian Water Association and ARUP 2016, p. 38). This survey showed a much more positive view of water security in large urban areas than in regional centres, with the most concern being expressed in rural areas. In a superficial way, this mirrors concerns being expressed internationally. In 2017, the World Economic Forum listed water crises as the number 3 global risk in terms of impact (World Economic Forum 2017). At this time in Australia, water security specifically no longer ranked among the list of issues of direct concern to the Australian public in more broadly based public opinion polls, although climate change continued to rank very highly (Roy Morgan Research 2017). This is not surprising given that most of Australia's major urban areas, where two-thirds of the population live, had significant unused supply capacity, and delivered water of a consistent quality that would be the envy of most urban areas around the world.

In 2017, the national government commissioned its independent research and advisory body, the Productivity Commission, to assess progress towards the objectives and outcomes of the NWI required by the Water Act 2007 (Commonwealth of Australia 2009; Productivity Commission 2017a). This report is not due to be completed until late 2017. Its issue report did not mention the term 'water security', but its draft report paid some attention to it, in particular in its discussion of urban water issues (Productivity Commission 2017b). While most stakeholder submissions submitted to the Productivity Commission as a part of this process did not focus on water security per se, an exception was that from the Australian Water Association (2017), which argued for 'a holistic framework to ensure long term water security for all Australians moving forward'. For many interest groups scarcity was well recognised: agricultural groups were well aware of the competitive tension between their interests and the environment—either in their being given greater access to water resources at the expense of the environment or through maintaining long-term average yields for water rights holders, even when there is evidence of declining runoff (National Farmers' Federation 2017; National Irrigators' Council 2017; Ricegrowers' Association of Australia 2017). This was at a time when the five-yearly national State of the Environment report presented a very mixed picture of the state of rivers and groundwater resources (Jackson et al. 2017). A similar comment applies to competition for available supply between miners and irrigators.

This chapter's contention is that Australian use of the term 'water security' does not have a single accepted meaning: its meaning is very much in the eyes of the beholder. Answers to the question of 'security for whom?' reflect that interest groups, not surprisingly, are concerned first and foremost with their own interests. The two most visible dimensions of water security are water availability and water quality, but each of those terms contains a number of elements. Water availability is about timeliness of availability as much as quantity, and water quality is about fit for purpose for the user in question. In an urban context, 'water security' is used in different ways to capture the risk around supply, sometimes denoted by the frequency of supply restrictions. In areas where water quality is an issue, it is sometimes used to describe the instances when supply fails to meet the Australian Drinking Water Guidelines. In recent years state governments and some urban water service providers have used the phrase in the context of a plan to assure water availability in a state or to an urban area.

In the spirit of much recent OECD work (for example, OECD 2013), this chapter explores the issue of water security in Australia with a focus on risks and the policy approaches pursued to manage those risks. It does this by providing a potted contemporary snapshot of the key policy issues in seven areas where water use is important (for a summary, see Table 2.1). The chapter then discusses how water security is likely to be affected in the future, particularly in light of the policy challenges from population growth, economic development, and climate change. Finally, the chapter draws out conclusions for broader consideration.

Table 2.1 Key water uses and water security policy issues

Water use	Significance of water use	Key policy issues
Large urban areas	Capital cities account for over two-thirds of the Australian population	Managing risks from extreme events such as droughts and floods. Managing population growth
Regional and remote towns	Small volumes used but critical for continuing viability of small towns, and the surrounding communities and regional economies	Remedying current poor water security in many regional and remote towns. Ensuring appropriate governance arrangements to achieve water availability and water quality yardsticks
Irrigated agriculture	Large volumes used in MDB and coastal Queensland, underpinning major agricultural industries, for example dairy, fruits and nuts, and vegetables	Ensuring full implementation of and compliance with the MDB Plan. Adjusting policy to reflect risks from climate change. Establishing the viability of irrigation in northern Australia
Rainfed agriculture	Rainfall underpins major agricultural industries, for example beef, grains, and wool production	Role of public/private research and development and its dissemination to ensure appropriate response to climate change, and disseminating information to the agricultural community
Environment	Declining access to runoff and groundwater, as other users increase demands, continues to adversely affect environmental outcomes	Managing ongoing conflict between environmental interests and all other water uses, but particularly agriculture and mining, and testing societal aspirations to protect the environment
Mining	Point-source use is significant. New mines potentially have very large footprints, with major impacts on groundwater resources	Ensuring that all mines meet basic environmental standards. Assessing risk from fracking for coal seam gas. Efficacy of using surplus water from dewatering to expand irrigation
Electricity generation	Relatively small user of water but some critical interdependencies	Ensuring access to good information on water availability and emerging risks from climate change

2.2 Urban Water Security

2.2.1 Water Security in Large Urban Areas

Australia is one of the world's most urbanised economies, with some 90% of its population living in urban areas—64% in its five largest coastal state-capital cities and its inland national capital. Water service organisations in its largest cities are in the main large, well-funded state-owned corporations delivering very high-quality water services. Over the past 20 years, and against the backdrop of growing populations in their service areas, most of these businesses have had to manage severe drought, and one of them, severe floods. Risks from population growth combined with these extreme weather events posed major challenges at the time, resulting in considerable introspection and, after a lag, significant redirection in policy and much strengthened water security.

Demand-side measures, including a significantly increased price of water, mandatory water use restrictions, and a national Water Efficiency and Labelling Standards scheme, helped moderate risk by reducing overall urban water consumption. Water conservation measures were applied in an increasingly sophisticated manner, with more thought being given to timing and appropriateness. In most cities, water conservation figured prominently in policy responses and in planning for the future (Horne 2016a; Australian Government 2017a).

Supply-side measures, including investment in expanded water distribution networking, large desalination plants, and an increase in water recycling, particularly by private corporations and water service providers, increased water availability and water use efficiency. Often-overlooked measures, such as optimising distribution system leaks, were prominent.

Not all responses were economically sensible. Politics drove key infrastructure decisions to build desalination plants in four out of five coastal state-capital cities. While the efficacy of some of these decisions can be debated (Horne 2016a), they have left each city with excess capacity in the short term, giving time to plan in detail responses to upcoming challenges. New dams played a significant role only in Canberra and in South East Queensland (as part of the South East Queensland water grid).

In parallel, investments in climate science and in upgrading water information systems assisted in enunciating the size of the future challenge (CSIRO 2013; CSIRO and Bureau of Meteorology 2015; Bureau of Meteorology 2017a). Climate change is likely to alter design rainfall events and the capacity of water infrastructure to manage them safely and effectively. National funding of the first new edition of *Australian Rainfall and Runoff* (Geoscience Australia 2016) in a generation was one of the critical first steps in assessing the likely risks from climate change for urban water infrastructure. These investments will be critical in underpinning water security in urban areas well into the future.

Over the past decade, there was another important departure from 'business as usual' affecting water security. State and regional water service organisations and government oversight departments began to morph from being essentially engineering departments/companies delivering water and sewerage services, to much more complex organisations, attempting to retain the confidence of their consumers by working with them to maintain and enhance water security. This process is far from complete, but an examination of recent annual reports and planning documents of water service providers illustrates that the process is well underway in most areas (see for example Sydney Water 2013, 2016a; Melbourne Water 2017; Seqwater 2017; Water Corporation 2012). Table 2.2 lists selected recent publications showcasing governments and water service providers addressing the water security needs of communities.

At the policy level in government and the planning level in water service organisations, the emphasis in the large capital cities has shifted from managing crises to managing the longer-term water security challenges. Many large urban

Table 2.2 Water security issues in policy and planning for major urban areas: some examples

Government	Focus	Document	Water security risks and approach
New South Wales (Metropolitan Water)	Major urban	2017 Metropolitan water plan: water for a liveable, growing and resilient greater Sydney	Risks: Managing drought and rising population/rising demand—models suggest that within a 50-year planning horizon, natural variability in rainfall is likely to have a greater impact on water security than climate change Approach: 'Water security we need at least cost'; 'risks will be adaptively managed'; investing in an 'economic level of water conservation'
Victoria	State-wide	Water for Victoria	Risks: Population growth; climate change impacts of increase in extreme events and a drier future Approach: strengthening the efficiency of water use, and the role of markets in rural and urban areas; strengthening regional water grids—identifies actions throughout Victoria to strengthen water security
Victoria (Melbourne Water)	Major urban	Melbourne water system strategy	Risks: changing and variable climate; growth Approach: adaptive approach to optimising the water grid and market, making the most of the water supply system, using water efficiently, and using diverse sources of water
Western Australia	Major urban and regional	Securing water resources for the Southwest	Risk: drying climate already apparent, and significant further drying a possibility, with impact on key groundwater resources Approach: water service providers to estimate future demand and work to achieve efficiency targets

(continued)

Table 2.2 (continued)

Government	Focus	Document	Water security risks and approach
Queensland (Seqwater)	Urban southeast	Water for life: south East Queensland's water security program 2016–2046	Risk: Impact of climate extremes and population growth Approach: introduces drought response triggers; looks at options for integrated responses beyond the next 20 years (where supply is relatively secure); envisages 'comprehensive and authentic stakeholder and community engagement'

Sources Metropolitan Water (2017), State Government of Victoria (2017), Melbourne Water (2017), Government of Western Australia (2015), Seqwater (2017)

water service providers have taken a wide portfolio of measures to improve water security per se, and to manage and reduce long-term risks.

2.2.2 *Water Security in Regional and Remote Towns*

By contrast, the current level of water security (around water availability and water quality) is much lower in a number of regional and remote areas of Australia, and also perceived to be much lower by communities and industry (Australian Water Association and ARUP 2016). For example, many small towns in the state of Tasmania have not had access to good-quality town water for long periods. Boil-water alerts indicating water quality below the Australian Drinking Water Guidelines have been a persistent problem and only begun to be addressed in recent years (TasWater 2016, 2017). A major part of the problem has been underinvestment in infrastructure, as local governments failed to raise water prices to sensible levels, and extracted large dividends from water service providers to underwrite local council base services. The Tasmanian state government has recently started to address these governance issues (Tasmanian Government 2017). In regional New South Wales (NSW), underinvestment and inadequate maintenance identified nearly a decade ago (Armstrong and Gellatly 2008) has also been a feature, resulting in heightened risk to water availability and water quality in many smaller towns. Here, the state government of NSW has recently committed significant resources to upgrade infrastructure with an eye also to address drought-future-proofing (New South Wales Government 2016).

There have also been persistent issues with water quality and water availability in dozens of small indigenous settlements in the Northern Territory, which is served by a subsidiary of the state-owned monopoly service provider (Power and Water Corporation 2016). The Northern Territory government has not yet adopted a long-term way forward that provides a level of water security that would be considered acceptable by the vast majority of Australians. These issues reflect poorly on governance and resourcing at the state and local government levels in this very large, sparsely populated part of northern Australia.

2.2.3 Urban Water Security and Climate Change

In large metropolitan areas, businesses are required to deliver a competitive return on capital and to achieve stringent licence condition outcomes, resulting in medium-to-high levels of water security. All these businesses, and the communities they serve, face growing climate risks to water security from an increase in extreme events such as flooding, severe droughts, bushfires in catchments, and increases in rainfall intensity (CSIRO and Bureau of Meteorology 2015). Table 2.3 outlines aspects of a changing climate likely to affect key population centres. All are well placed to address these risks.

By way of example, Box 2.1 briefly outlines some of the key risks posed by climate change that Sydney Water has identified. It is Australia's largest water service provider, with 4 million consumers.

Box 2.1: Water Security Risk Posed by Climate Change—A Sydney Water Perspective

- New risks come from changes in frequency, distribution, intensity, and duration of climate-related events
- 63 risks identified in 2013, including 37 higher-priority
  - Existing controls were not effective for 12 of these risks
- Risks include
  - Reduced fresh-water availability
  - Increased demand for water
  - Increased risk of severe bushfires in water catchments
  - Increased risk of algal blooms in dams
  - Increased risk of pipe corrosion and odours
  - More extreme storms that push treatment plants over capacity
  - Higher sea levels and more storms that threaten low-lying coastal assets
  - More pipe failures due to changes in soil structure and stability
  - More large-scale disruptions of electricity supplies.

Source: Sydney Water (n.d.; 2013)

Table 2.3 Climate projections for regions of key urban areas

Issue	Sydney	Melbourne	Brisbane	Perth	Adelaide	Canberra
Area	East Coast South—area encompasses important headwater catchments	Southern slopes Victoria West	East Coast North—area encompasses important headwater catchments	Southern and South-Western Flatlands West—Mediterranean climate	Southern and South-Western Flatlands East—Mediterranean climate	Murray Basin—relatively dry and temperate
Rainfall	Natural variability dominates in the next few decades; winter rainfall is projected to decrease (medium confidence)	**Natural variability dominates to 2030, but decreases for winter and spring (high confidence)**; decreases over western Victoria under high emissions	Impact assessment should consider risk of both drier and wetter climate; changes are possible but unclear	**Prolonged drying since 1970s**; continuation of the trend of decreasing winter rainfall (high confidence); spring rainfall decreases (high confidence)	**Prolonged drying since 1990s**; continuation of the trend of decreasing winter rainfall is projected (high confidence); spring rainfall decreases (high confidence)	**To 2030 natural variability dominates**; late in century, less rainfall in cool season (high confidence, warm season unchanged (medium confidence)
Rainfall intensity	**Extreme rainfall intensity is projected to increase** (**high confidence**)	**Extreme rainfall intensity is projected to increase** (**high confidence**)	**Extreme rainfall intensity is projected to increase** (**high confidence**)	Extreme rainfall intensity is projected to increase (medium confidence)	Extreme rainfall intensity is projected to increase (medium confidence)	Heavy rainfall intensity is projected to increase (high confidence)
Potential evapotranspiration	Projected to increase in all seasons (high confidence)	Projected to increase in all seasons (high confidence)	Projected to increase in all seasons (high confidence)	Projected to increase in all seasons (high confidence)	Projected to increase in all seasons (high confidence)	Projected to increase in all seasons (high confidence)

(continued)

Table 2.3 (continued)

Issue	Sydney	Melbourne	Brisbane	Perth	Adelaide	Canberra
Time in drought	Projected to increase (medium confidence)	Projected to increase (medium confidence)	Projected to increase (medium confidence)	**Projected to increase** (**high confidence**)	**Projected to increase** (**high confidence**)	Projected to increase (medium confidence)
Average temperatures	Continue to increase in all seasons (very high confidence)	Continue to increase in all seasons (very high confidence)	Continue to increase in all seasons (very high confidence)	Continue to increase in all seasons (very high confidence)	Continue to increase in all seasons (very high confidence)	Continue to increase in all seasons (very high confidence)

Source CSIRO and Bureau of Meteorology (2015); bolding added to highlight points of difference

Sydney Water was also at the forefront of a Water Services Association of Australia project involving most of Australia's large-scale water service providers developing national climate change adaptation planning guidelines covering their businesses (Water Services Association of Australia 2016), and in developing AdaptWater, a software tool that will 'assess and quantify the impact of climate change and extreme events on its water supply and sewerage assets, and compare adaptation responses' (Sydney Water 2016b, p. 1). Climate change imposes new risks to water security, but against a backdrop of a sound, well-performing system of water services provision, Sydney Water is in a position to develop detailed responses to these emerging risks. To varying degrees, similar comments could be made about all key water service providers in the six major Australian urban areas listed in Table 2.3. In large part, this is the outcome of a lengthy period of sustained reform in how state business enterprises operate, combined with the major shortcomings revealed during the Millennium Drought in eastern Australia, and the sharp and unmistakable decline in rainfall and runoff apparent in Western Australia. These events precipitated significant policy change that, although far from perfectly executed, has left the urban areas with moderate-to-high water security.

Again, by contrast, many regional and remote communities in Australia are not in a position to immediately address new or increased risks from climate change. First, they need to undertake the necessary remediation work to improve the performance of their existing water delivery systems, and only then can they sensibly work through the implications of climate change. Policy needs to address governance and resourcing shortcomings, which are substantial preconditions to moving forward to address future risks. Actions underway in NSW and Tasmania may well enable the two sets of issues to be dealt with together, but progress to date is insufficient to make an assessment.

2.3 Water Security in Agriculture

2.3.1 Water Security in Irrigated Agriculture[1]

Irrigated agriculture in Australia relies on both surface and groundwater, depending on location, and contributes a little over one-quarter of the gross value of agricultural production (Australian Bureau of Statistics 2016a). A little under half of this value originates in the MDB, with most of the remainder scattered around the coastal regions of Australia. Water security, referencing the risks to water availability (including its timeliness), varies significantly from region to region, and

[1]Parts of this discussion draw on an unpublished report: Horne and Stone (2017). Addressing Sao Paulo dry periods: water security, water allocation and water sharing mechanisms. Report arising from AWP engagement prepared for the Secretariat for Sanitation and Water Resources, Sao Paulo State Government.

within regions depending on the type of water entitlement held by the irrigator and the water allocation mechanism being used (National Water Commission 2011; Australian Bureau of Agricultural and Resource Economics and Sciences 2017a). In 2014–15, agriculture consumed around 60% of the water extracted from rivers and groundwater (Australian Bureau of Statistics 2016a).

For the most part, the level of water resource planning and oversight in Australia is calibrated to scarcity. If there are no scarcity issues, and if the environment is largely unaffected by consumptive use, there is little societal return from detailed planning processes. However, the more important the issue of scarcity, or the greater the conflict between uses, the more important water resource planning becomes. It is important not only from a societal perspective, but also for the water security of individual irrigators. Transparency and enforcement of a planning framework adds to delivery of equity and fairness. In most irrigation districts this appears to be high, but it has never been measured. However, as illustrated in a recent exposé in the unregulated Barwon Darling catchment in the north of the MDB, delivery of robust and fair planning frameworks requires effective enforcement. Without it, actual water security can easily be undermined (ABC Four Corners 2017).

2.3.1.1 Policy and Practice in the Southern MDB

In the southern MDB, active water markets give irrigators many options for sourcing water and for adjusting the implied level of water security. The level of water security sought by an irrigator will vary with the mix of agricultural products being cultivated and the water options available in the district. Price, level of security, and treatment of water allocations 'carried over' from one water year to the next may all affect choice of entitlement or allocation water sought (Grafton et al. 2015; Grafton and Horne 2014; Hughes et al. 2013). Cotton and rice, for example, are opportunistic crops that are widely grown in periods of high water availability. Other crops, such as citrus and nuts, require access to highly secure (hence more expensive) water. Grass production for dairy purposes is likely to swing from production by the farmer using allocated water held by the farmer or purchased in the market, if the price of water is low, to hay being purchased from another region and allocated water held by the farmer being sold into the market, if the price of water is high.

The level of transactions, and the percentage of irrigators participating in the market, suggest that restrictions on trade imposed by policy are no longer heavily impeding trading of entitlements or allocation water (Figs. 2.1, 2.2 and 2.3). Allocation trade flows through the Barmah Choke are often restricted due to hydrological limits, and irrigation infrastructure operators for their own purposes periodically impose restrictions on trading out of allocation water (Australian Competition and Consumer Commission 2017), but in principle the Basin Plan trading rules support trade without restrictions.

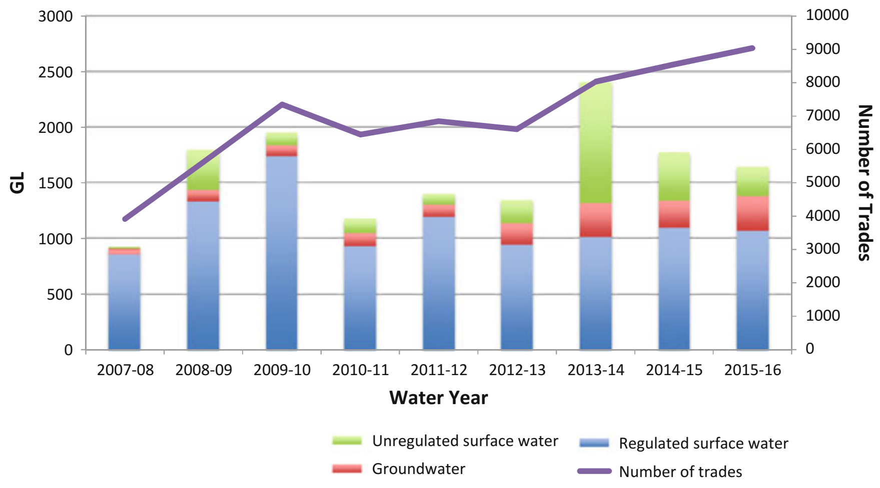

Fig. 2.1 Volume and number of water entitlement trades nationally, by source. *Source* Australian Bureau of Agricultural and Resource Economics and Sciences (2017b)

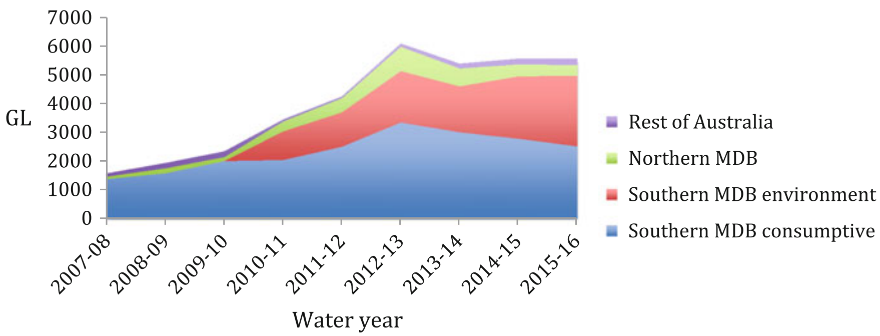

Fig. 2.2 Volume of surface water allocation trade, by region. *Source* Australian Bureau of Agricultural and Resource Economics and Sciences (2017b)

Key policy developments that have significantly improved water security for irrigators holding water entitlements, particularly in the regulated southern MDB, include:

- Following separation of water and land rights in principle in the 1990s, a gradual increase in the separation in practice; since 2009 there has also been the possibility of more direct ownership of water rights by irrigators operating within major irrigation districts—known as 'transformation' (Australian Competition and Consumer Commission 2017)
- Promulgation of the 2012 Basin Plan, and new governance arrangements in the MDB giving increased protection from arbitrary decision-making by state governments and irrigation infrastructure operators, encouraged by greater competition and transparency of information flows (Murray-Darling Basin Authority 2017)

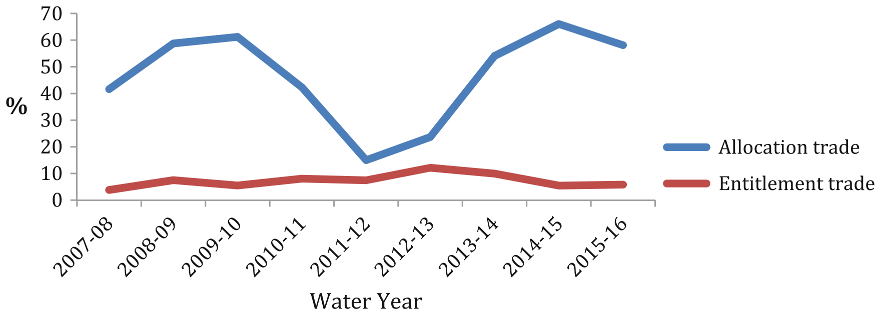

Fig. 2.3 Irrigation farms participating in the southern MDB water market. *Source* Australian Bureau of Agricultural and Resource Economics and Sciences (2017b)

- New trading rules and relaxation and (in some cases) elimination of restrictions by state governments on trading water between irrigation districts and between jurisdictions, increasing irrigator access to water markets (Murray-Darling Basin Authority 2016)
- Improvement in the technical capability of water registries, reducing transaction costs in water trading
- With many entitlements, greater flexibility in carry-over rules, which allows more allocation water to be held over from one year to the next (Hughes et al. 2013)
- Significant resourcing of Bureau of Meteorology information platforms, giving irrigators a stronger forward-looking information base for decision-making (Joyce 2016).

The policy changes have been buttressed by developments in information technology platforms and irrigator exposure to water markets, including:

- Better access to private-sector broking of water trades
- Growing irrigator experience in understanding the benefits of water trading for risk management in their businesses, which increases the value that can be extracted from water assets.

Reflecting the above developments, irrigators are now able to adjust their level of water security to suit their businesses by building a portfolio of water entitlements and accessing annual allocation water through the water market. Much of the ongoing debate in the basin and at the political level now focuses on the water shares embodied in the Basin Plan—to address questions such as how much water should be set aside for the environment, and how the share and absolute quantity available to irrigators should vary in the face of climate change. If, for example, climate change led to a reduction of runoff by 20%, how should this impact be distributed between irrigators and other water users, including the environment? While this issue was foreshadowed in a preliminary way in the 2004 NWI (see Council of Australian Governments 2004, clauses 48 and 49) and is being implicitly managed in the 2012 MDB Basin Plan (Neave et al. 2015), in practice the issue has been deferred to sometime in the early 2020s (Horne 2014). Peak farming groups continue to press their case for access to more water (National Farmers' Federation 2017). In a policy and political sense, these issues and the resulting levels of water security afforded each user will be continually revisited by society as it grapples, *inter alia*, with the relative value of ecosystem services on the one hand, and irrigated production on the other hand.

2.3.1.2 Policy and Practice in the Rest of Australia

Irrigation outside the southern MDB draws on both regulated and unregulated surface flows (for example, in the northern MDB, along the Queensland coast, in the Ord River scheme in northern Western Australia, and in Tasmania) and groundwater (for example, in southwest Western Australia and in the Gascoyne District of Western Australia). In all cases, water security is underpinned by reference to a basic policy principle embodied in the NWI concerning sustainable levels of extraction or use. In most areas, this principle has very gradually become more or less respected as a central tenet of policy, ongoing tensions notwithstanding.

2.3.1.3 Unregulated Surface Water

In unregulated districts, 'rules-based' water access dominates. The 'rules', based on the flow levels and flow rates in the river, can be simple or detailed depending on the level of demand relative to supply and the value/complexity of the environmental and social values being protected. Simple rules might involve restrictions on accessing water when water levels fall below certain values at a local staff gauge. The rules set out the water available for extraction (the 'consumptive pool') across the range of streamflow variability. In dry years the amount of water available for use will be restricted, with the water shared in accordance with the water access entitlements. In wet years there may be surplus water to that required for environmental water provisions and normal crop water needs. Rules could define access to this surplus water, with the water shared in accordance with the water access entitlements. Farmers need to take the risk of reduced water availability in dry years into account in their planning. They could mitigate this risk by, for example, building off-stream storages to store surplus water in wet years for use in dry years. But rules that allow high levels of harvesting of wet-year flows may actually undermine the water security of the environment, which depends on floods in much of the flood plain.

The Condamine–Balonne in southern Queensland is an example of a heavily used 'rules-based' river. Its resource operations plan uses a concept of continuous water accounting, which allows water extraction to be averaged over a number of years.

Water sharing and management rules are set out in detail (Department of Natural Resources and Mines 2015). Cooper Creek (which flows from Queensland into the neighbouring state of South Australia) is another example of a rules-based river, but in this case the river is set aside for the environment to a significant degree. Agricultural use is strictly limited. Its resource operations plan has an unallocated water reserve, which the government may at some future time choose to sell or allocate (Queensland Government 2016a). In Western Australia, there are few free-flowing rivers where farmers directly pump from the river for irrigated agriculture. Most of the rivers and streams reduce to little or no flow in summer and hence are not suitable for direct river pumping. There are exceptions reflecting the groundwater table, but with ongoing climate change, and groundwater levels sinking, the current levels of river pumping in summer are likely to be unsustainable in the medium-to-long term.

2.3.1.4 The Ord Scheme

In the regulated Ord Irrigation Scheme in the north of Western Australia, 10,400 GL Lake Argyle offers significant stored water suitable for irrigation. However, it only has an overall irrigation entitlement of a little over 400 GL, with less than 40% of allocations actually diverted in 2015–16 (Bureau of Meteorology 2017b). This compares with around 2100 GL used annually to generate the region's power. The Ord Scheme's extremely difficult history over the past 50 years (Ghassemi and White 2007) underscores the fact that far more than water security is required to attract irrigators and to establish an economically viable irrigation scheme. Against this background, the decision to add 8000 hectares of irrigation land to the scheme, plus a range of associated infrastructure, with national and state government funding of over AUD 500 million (Western Australian Auditor General 2016), is very difficult to understand in other than political terms (Dent and Ward 2015). Although the infrastructure was completed in 2014, it is not yet being fully utilised. A further expansion in the Northern Territory is on hold.

2.3.1.5 Northern Australia

Northern Australia receives an annual average rainfall of more than one million GL, nearly all falling in the wet season. Around 200,000 GL makes it into streamflow, mostly in coastal areas, and with a very small number of exceptions very little is captured by dams. Water security for the vast cattle herds and small pockets of population in most of Northern Australia depends on groundwater (Cresswell et al. 2009). Nonetheless, Northern Australia is still, to some protagonists, an undeveloped frontier that warrants major development (Australian Government 2015). In recent years, numerous studies have been undertaken to better understand the region, as a precursor to assessing its viability for further development, particularly expanding irrigation in quite remote areas (Petheram et al. 2014; CSIRO 2009, 2017; Dent and Ward 2015). The national government has even established the Northern Australia Infrastructure Facility to facilitate infrastructure projects (Australian Government 2017b). At this point few decisions have been made. The scientific studies undertaken thus far have not established viability. While a case may not be able to be made for any new dam construction, groundwater resources that have not yet been used to their full potential may provide the water resources necessary for limited-scale irrigation. The Great Artesian Basin is a huge resource where governments have spent the past decade attempting to undo damage done by earlier generations of pastoralists. Increasing extraction will require careful prior study if these errors are not to be repeated. While the drying trends likely to be seen in southern Australia are unlikely in the north, many factors additional to water security will need to be satisfied before viable projects can be established.

2.3.2 Water Security in Rainfed Agriculture

Experimental estimates by the Australian Bureau of Statistics (2013, 2016a) suggest that the volume of water used in rainfed agriculture is more than an order of magnitude greater than in irrigated agricultural production. Clearly, in a country with highly variable rainfall, and significant drying impacts (along with higher temperatures) likely to be felt from climate change, this observation has significant policy ramifications. The two largest rainfed agricultural industries illustrate some of the issues.

Production of meat cattle is Australia's largest agricultural industry. Much of the beef herd is grazed in northern Australia on large properties. Water security for these businesses has two central dimensions. First, cattle need ready access to daily water supplies, which commonly rely on rainfed dams and groundwater bores. Second, fodder for the cattle comes in the main from direct grazing of rainfed native vegetation. Artesian water security is well recognised as a key to maintaining production levels, but even if artesian water is plentiful, adequate rainfall is required for native pasture growth.

Cereal crops also figure prominently in Australia's rainfed agricultural production. Rainfed water availability is a critical factor in sustaining cereal yields in the long term. In the face of a drying climate, declining water security underscores the importance of developing and implementing new approaches to production systems and technology to maintain and increase productivity (Hochman et al. 2017). This has been a feature of rainfed agriculture: wheat yields per hectare grew significantly between the mid-1980s and early 2000s (Passioura 2013), at a time when, in some areas, rainfall was declining and temperatures increasing (Asseng and Pannell 2013; Hochman et al. 2017). This was achieved by farmers utilising an improved understanding of the cropping system, coupled with adoption of no-till agriculture, effective use of herbicides, better seeds, and management practices that allow the crop to better utilise soil moisture (Passioura 2013; Richards et al. 2014). Research and development, and adoption of new practices on the ground, are central to these improved outcomes.

These two examples underscore the importance of up-to-date information regarding all aspects of climate change impacts, including on rainfall, and the impact of changes in rainfall levels and within-year distribution on individual crops. They also underscore the importance of improved weather services from the Bureau of Meteorology both for the short term and for seasonal weather forecasts. This all contributes to matching water security to production decisions within the rainfed farming community. National investments in upgrading Bureau of Meteorology research and information services over the past decade, which have recently been extended for the medium term, point to the acceptance of these arguments by national policymakers (Bureau of Meteorology 2017a; Joyce 2016).

2.4 Water Security for the Environment

In Australia, as in nearly every other country, one of the most significant issues for water security and the environment is the ongoing tension between economic growth and the environment, seen in areas such as the competition for water resources between the environment and agriculture, urban water use, and mining.

In contrast with many other countries, policy measures taken in Australia at both national and state levels over the past decade have ameliorated some of this tension. Key developments are set out in Table 2.4. The extent that water resources are set aside for the environment is a social choice. Within Australia, the key national planning documents (the NWI and the Water Act 2007), and more detailed state water legislation, state planning documents, and water plans all contribute to the framework that underpins water security for the environment (for example, Council of Australian Governments 2004; Commonwealth of Australia 2009; Queensland Government 2016a, 2017b, d; State Government of Victoria 2016, 2017).

Table 2.4 indicates an activist national policy approach since the early 2000s, reflecting community concerns that the pressures of development were compromising water security for the environment (and in some cases water security for continuing agriculture). Each intervention ultimately involved both national and state action, and variable degrees of monitoring and enforcement. Judgments about the extent of 'progress' are difficult to make, and often depend on who is making the call. For example, the prominent Wentworth Group of Concerned Scientists dispute that the MDB Plan is improving water security for the environment in public utterances (Vidot 2017), but their detailed report (Wentworth Group of Concerned Scientists 2017) and reports of others (Commonwealth Environmental Water Office 2016; Jackson et al. 2017) suggest that progress is being made in many local areas. The Wentworth Group report should be regarded as an advocacy document, arguing that more water should be set aside for the environment, rather than assessing water security for the environment. This advocacy illustrates the ongoing tension between environmental and agricultural interests. All the policy actions listed in Table 2.4 have had substantial positive impacts on water security for the environment.

Table 2.4 Key recent developments in water security for the environment

Area	Major recent development	Comment
Murray-Darling Basin, covers around 1 million km^2	Promulgation of the MDB Plan in 2012 put sustainable diversion limits on surface and groundwater uses for the first time, requiring an overall reduction in use for agricultural purposes (Australian Government 2013). New sustainable diversion limits will go into force in 2018. Significant water entitlement portfolios already accumulated by the national environmental water holder, and more modest portfolios at the state level, provide significant opportunities to 'redress the balance'. Strengthened operation of water markets and more transparent annual allocation decisions strengthen water security for the environment, which previously was being squeezed by the operating-rules-based framework. Completion of new water resource plans consistent with the MDB Plan throughout the basin is an important next step	There is accumulating evidence that this enhanced water security for environmental water holdings is improving environmental outcomes (Commonwealth Environmental Water Office 2016). Overall, greater water security for environmental assets embodied in legislation and plans must be monitored and enforced. The national environmental water holder has delivered additional environmental water flows of over 1100 GL/y during the five years up to June 2017 (Australian Government 2017b). Important follow up-steps have yet to be completed
Great Artesian Basin, covers around 1.7 million km^2	Continuing national commitment for 2018–19, following the recent completion of stage 4, to further progress capping bores and replacing open drains with pipes, to restore water pressures in the basin and improve water security for both agricultural production and significant environmental assets relying on GAB water. Annual water savings from work so far now exceed 300 GL/y (total use is now around 500 GL/y). The new water plan for the Queensland part of the basin (covering around 1.2 million km^2) suggests a commitment to improving water use efficiency, and protecting key environmental assets relying on GAB springs (Queensland Government 2017b)	Significant investment of public resources is delivering water savings, but these savings now need to be converted into higher water pressures, delivering water to springs and associated environmental assets. The new Queensland GAB water plan explicitly identifies groundwater ecosystems to be protected (Queensland Government 2017b). Adequate oversight will be critical

(continued)

Table 2.4 (continued)

Area	Major recent development	Comment
Coal seam gas and coal mining regions	Amendments in 2013 to the Commonwealth EPBC Act 1999 to include a 'water trigger' have enhanced water security for environmental assets in the CSG and coal mining regions. Public pressure has resulted in statewide moratoria on 'fracking' in several states, limiting development of CSG resources. Reports by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (2017) have enhanced independent oversight. Bioregional assessments focusing on coal mining precincts in Qld, NSW, Victoria, SA, and the NT also provide transparent science-based assessments of environmental assets to be found in still relatively unexplored regions (Australian Government 2013, 2017a, b)	Reporting by the committee has considerably enhanced protection for regional water resources that underpin environmental assets. Bioregional assessments provide a new layer of understanding of interactions between water resources and the environment covering large parts of eastern and central Australia, and provide early-warning signals about projects that might affect water security for the environment
Major urban areas	Greater focus on demand management (notably the Water Efficiency Labelling Standards scheme and staged restrictions in times of reduced water availability) and climate-resilient water sources (notably desalination and water recycling) has reduced pressure from population growth and climate change on water sources near major urban areas. Higher water prices in urban use have also contributed to this outcome	Significant progress has been made in containing the growth of urban household and industrial water use, and in reducing pressures on traditional urban water supply catchments

Sources Joyce (2016), Department of Natural Resources and Mines (2017), Australian Government (2013, 2017a, b), Independent Expert Scientific Committee (2017), Commonwealth Environmental Water Office (2016), Queensland Government (2016b, 2017c), Metropolitan Water (2017), State Government of Victoria (2017)

2.5 Water Security for Mining

Mining is a significant economic activity in Australia. While agriculture contributes about 2% to Australian GDP and manufacturing around 6%, mining contributes about 7%. Overall, reported water consumption by the mining sector is estimated at 768 GL (Australian Bureau of Statistics 2016a). Even if this is an underestimate (as is likely), water used in mining is a very high-value use.

Mines are often located in arid areas of great water scarcity, and given the criticality of access to water to the ongoing operation of many mines, water security is of considerable importance. Historically, individual mines had small point-source impacts on the landscape, with relatively modest water demand. Mines could often access water oblivious to its broader impact. Today, however, not only do many mines require access to sizable water resources, their impact on the landscape can be considerable. For example, large coal mines can disturb the functioning of groundwater aquifers across tens of kilometres, as can fracking to extract coal seam gas (CSG).

A key principle of the NWI is that all water users be put onto the same footing, in the context of a regional water plan based on sustainable use. The importance of water security for mining can be seen in Clause 34 of the NWI (Council of Australian Governments 2004), which appears to contradict this underlying philosophy. It states:

> The Parties agree that there may be special circumstances facing the minerals and petroleum sectors that will need to be addressed by policies and measures beyond the scope of this Agreement. In this context, the Parties note that specific project proposals will be assessed according to environmental, economic and social considerations, and that factors specific to resource development projects, such as isolation, relatively short project duration, water quality issues, and obligations to remediate and offset impacts, may require specific management arrangements outside the scope of this Agreement.

This clause was included in the NWI at the behest of Western Australia to encourage it to become party to the overall agreement. Its aim was to address concern about the potential adverse impact of the NWI on mining in that state. Its inclusion gave Western Australia and other governments a mechanism to ignore the thrust of the NWI when it might adversely affect mining, should the relevant state jurisdiction consider it of overriding importance. Even with this clause, it was nearly two years after the agreement came into force before Western Australia signed it. And the tensions that existed in 2004 continue. In its submission to a review of the NWI in 2014, the mining industry continued to argue what it saw as the special case of the mining industry, and sought to have this clause retained (Minerals Council of Australia 2013).

The largest water issue for the mining sector remains managing community concerns regarding its impact on the water security of agriculture, the environment, or regional or remote townships (Western Australia Department of Water 2011; Queensland Government 2017a). This ongoing concern has resulted in a number of policy actions. With the growth of the coal and CSG industry in Queensland, the national government introduced new oversight of potential coal and CSG mining impacts on water resources, particularly from interference with groundwater aquifers and the impact of water co-production on sustainable groundwater use, through an amendment to its EPBC Act 1999 (Australian Government 2013). At the national level, all new coal and CSG projects with significant implications for water resources are now subject to scrutiny by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (2017) before approvals are granted. At the state level in Queensland, new governance arrangements manage conflict between mining and agriculture, with an aim of managing groundwater resources sustainably. Several state and territory governments have introduced moratoria on development of gas resources that require the use of fracking, effectively putting water security for others ahead of CSG production by mining companies. These moratoria are not based on risk assessment but in large part reflect political hysteria (Horne 2016b). In Queensland, which remains the only state with a large CSG industry, co-produced water is used both in agriculture and to bolster water security in nearby towns after it has been processed in a reverse osmosis water treatment plant (Gasfields Commission Queensland 2014). In Western Australia, dewatering of iron ore mines has led to water extraction beyond the needs of the mines, resulting in the potential to establish new irrigation schemes in the most unlikely places (Department of Water 2013, 2015). The ongoing issue is the need to monitor whether these activities have unintended impacts on the surrounding environment.

2.6 Water Security for Electricity Generation

While water security has not been the key policy issue confronting Australia's electricity markets, there are some critical interdependencies (Finkel et al. 2017). The electricity and gas industry accounts for a little less than 2% (or around 300 GL) of total water consumption from rivers and groundwater (Australian Bureau of Statistics 2016a). In 2015–16, over 90% of the electricity generated in the national energy market depended on water used in coal- and gas-fired generation or on water for hydroelectricity generation (Australian Energy Market Operator 2017). While the volume of water used is small in aggregate, this understates its importance to the national electricity market.

Water shortages in 2007 and more recently in Tasmania resulted in much-reduced generating capacity in the affected hydroelectric facilities. They also put coal- and gas-fired generators on notice of the heightened risk from extreme weather events (particularly drought). The industry has responded by paying more attention to water use efficiency and to managing these new risks. As the importance of wind and solar generating capacity grows, this interdependence will decline, but the risk will persist for decades.

As the water sector is a major consumer of electricity, an increasing incidence of extreme events also increases the risk to electricity generating and distribution, which could affect the capacity to deliver water services.

2.7 Discussion

2.7.1 The Present

Policy and practice are gradually moving Australia towards more sustainable water use and effective management of scarcity and quality, but pressures from population growth, economic development, and climate change have been and are ever-present dangers. They continue to necessitate policy directed at managing new and increased risks, and new and sometimes innovative policy action. Scarcity has been managed by the introduction of water planning throughout most of Australia, although the effort put into its use is dependent in part on politics, history, and the level of acuteness. Scarcity has not always been well managed, as areas of ongoing environmental degradation attest (Jackson et al. 2017). The use of water markets has grown dramatically, and with good effect, in the MDB and to a lesser extent elsewhere. In part, this reflects a sensible risk management approach and the cost of operating market infrastructure. Outside these market-based frameworks, the extent of water diversion is limited by regulation or not at all.

But progress in implementing water reform has been slow and in some cases reluctant. For example, the Northern Territory and Western Australia governments have, *inter alia*, not yet created statutory-based, clear and secure long-term water rights for consumptive uses, nor introduced best practice price-setting arrangements (Productivity Commission 2017b). In NSW, delivery of its own commitments to water planning renewal has not been achieved in a timely fashion. At this point, no jurisdiction has fully incorporated the likely full impact of climate change into limits on water diversions.

Despite its status as the parched continent, the above snapshot suggests that water security risks are for the most part being well managed in Australia today. There are two particularly problematic exceptions to this statement.

The first is the poor level of water security (in terms of both access to and availability of water consistently meeting Australian Drinking Water Guidelines, and adequately providing sanitation services) in remote and regional communities. Meeting these standards is necessary but not sufficient for improving health outcomes of indigenous communities in particular, but it would be a major initial step (Hall et al. 2017 provide a broad introduction to water and sanitation in indigenous health). State and local government areas are already effectively managing water security for some of these towns. But it is not universal. There is no reason policy reforms cannot resolve governance and resourcing issues effectively. This issue needs immediate attention.

The second is society's willingness to set aside sufficient water for the environment and ecosystem services. This trade-off between private profit (seen mainly in the agricultural and mining sectors) and public benefit remains a key battleground for policy. The debate can be seen in relation to water use in the MDB, and in the ongoing policy discussions around further developing northern Australia. It has been a 'live' debate for the past generation, with successive reports on the state of the environment in Australia since the late 1990s drawing attention to significant issues with water security and the environment, resulting in environmental degradation (Jackson et al. 2017). In each area, interests promoting development will seek public-sector subsidies to support opening up new agricultural districts or to support existing ones, or will want to undertake an activity regardless of the cost to the natural environment. At the core of this issue is that valuing the societal benefits from a sustainable environment is difficult, and subject to greatly differing views (see for example Atkinson and Mourato 2015). Each society will value these trade-offs differently. In Australia's highly urbanized society, with tourism accounting for 3% of GDP (Australian Bureau of Statistics 2016b), there is much concern about the state of the environment and the impact of climate change, and strong support for sustainability initiatives, even if this support ebbs and flows (Roy Morgan and Associates 2017; Australian Bureau of Statistics 2012). Agricultural and corporate interests regularly argue that these concerns should be put to one side.

2.7.2 The Future

Despite the significant emerging risks to water security from population growth, economic development, and climate change, the overall risks in the future can be effectively managed.

Increased water demand from population growth (which is concentrated in large cities) can be managed in coming decades by further increasing water use efficiency in corporations and households, and use of climate-resilient supply sources such as new desalination plants, or increasing water reuse where economic. New technologies being incorporated in all manner of household appliances will make a significant contribution to reducing per capita demand and maintaining water security in urban areas, as it has done over the past decade. Programs such as the national Water Efficiency and Labelling Standards scheme will continue to contribute to reducing water use. For many firms, reducing water use has become a more central part of brand management, and evidence that a corporation is operating 'sustainably'. New risks affecting supply continuity flowing from both a drying climate and a greater number of extreme events will need to be carefully and proactively managed. Enhanced information systems and greater use of climate-resilient water sources will contribute to maintaining the desired level of water security.

All industrial use should be limited to sustainable supply. This will cap, for example, agricultural and mining use. Growth opportunities will continue from water migrating to higher-value uses, greater use of climate-resilient supply sources, and in some cases increasing use from currently underutilized sources. Climate change risks appear high, but in some areas will present new opportunities. New risks to water security need to be managed proactively. Policy should be directed at setting out a clear framework for burden sharing of adjustment costs in areas facing reduced water availability. How this is determined will reflect the politics at the time, and evolving views on managing climate change impacts on the environment, economy, and society. Water consumption for electricity generation has peaked as the brown and black coal generation sector starts to shrink. Water security-related concerns in this sector from extreme events, including floods, will continue to need careful management.

The persistence of the two current problematic water security issues noted in the previous section suggests they will not be resolved rapidly. In the case of remote communities, and particularly indigenous communities, resourcing coupled with maintenance issues is central. A key broader question remains around the long-term viability of smaller communities, which is too large a topic for this chapter. In the case of water for the environment, judgments about the adequacy of society's willingness to underwrite adequate water security are likely to reflect the interests of the group making the call. Growing tourism and even higher urbanization as GDP per capita grows seem likely to increase demands for governments to look after the environment. But this has been the logic for an extended period, and the conflict still continues.

Specific water security problems will arise in all sectors from time to time, but particularly during and following extreme events. They will for the most part reflect specific policy, operational, or governance failure to manage known risks effectively. Events outside historical experience will occur, and those risks need to be embedded in emergency response plans. There is little doubt that the period 2020–2040 will throw up new risks. Some will be ignored until water security is adversely affected. Most will be addressed, and the past decade suggests that Australian governments and water users will learn effectively from such events (Horne 2016a).

2.8 Lessons

Water security is a global issue, but it must be managed at national and regional levels. Population growth, major migrations of people from rural to urban areas, economic growth, and climate change are key drivers affecting water security in many countries. Each country will be affected differently. And within a specific country, the risks will be different from region to region and use to use. Australia has had to address many issues affecting its water security over the past 20 years, and the policy responses at local, state, and national levels may provide insights for policy elsewhere. Seven lessons stand out.

First, managing water security is an ongoing task. Policy practitioners have actively pursued strengthening water security through strengthening governance and rights pertaining to and risk management of water use. But it is unfinished business, and key policy issues need to be kept under ongoing scrutiny. In Australia, climate change is likely to affect water security adversely in many ways. Population growth in key urban centres, coupled with a drying climate, means that without some other change the current supply/demand surplus will disappear. So efforts to reduce household use per capita and industrial use will need to continue. Good information and ongoing research are needed to proactively manage these issues. On the other hand, in some countries, there may be positives as well. Managing these impacts to the best effect also requires a proactive approach.

Second, there is considerable value in putting in place a water management framework to drive reform. Community buy-in is important, and commitment to follow through when problems emerge, as they will. Frameworks and planning alone are not enough. Australian governments have had to recommit to the principles in the NWI numerous times, and yet still there are cases of bureaucracies dragging their feet. Implementation is critical, as is a transparent, independent process to assess progress and draw public attention to perceived weaknesses in the framework and in its delivery by government and private-sector providers.

Third, 'fit for purpose' governance arrangements can contribute significantly to bolstering or maintaining water security. The Organisation for Economic Co-Operation and Development (OECD) Water Governance Initiative provides much useful, common-sense material (OECD 2016). In rural areas, improved governance has increased transparency around allocation decisions. Community consultation has also increased, along with a very stark realisation that consultation should avoid pressure towards lowest-common-denominator decision-making (or the worst of all worlds). In urban areas, service delivery models need to be reformed to achieve the high level of water security all users desire. Governments need to explore new models when old ones fail. In Australia, the issues around service provision to small regional and remote communities have been ignored in some states, resulting in unacceptable outcomes. Effective governance has been missing, resulting in inadequate capital and operating revenue, and inadequate access to trained maintenance personnel. In this case the evidence does not support the mantra that 'small is good'.

Fourth, political leadership is often critical in cementing paths to improved water security. Without it, established interests can derail reform, or slow its pace to ensure that it cannot be effectively implemented. It will need to be supported by public-sector administrators and policy advisers, and members of user communities with an interest in reforms.

Fifth, governments and policymakers may only act decisively when a crisis is present, but acting then brings risks of decisions being taken in panic mode. Water is often about contested use, with difficult trade-offs needing to be managed, particularly within a broadly agreed sustainability framework. Even when broad frameworks are agreed, there may be considerable conflict around details. Politics is important, and policy advisers need to consider carefully how that will impact outcomes. This again suggests that considerable weight should be placed on proactive development of options to tackle difficult and emerging problems.

Sixth, well-functioning water markets can add significant value, but developing them takes time and significant effort. The Australian experience in the MDB shows that the benefits can be substantial but that potential negative factors need to be and can be managed (Grafton et al. 2015). There are many circumstances when developing a market may not be appropriate, but in cases of emerging scarcity or a pressing need to manage water quality, water markets can offer cost-effective solutions to help address water security. Water markets are only as good as the regulatory framework in which they operate, so compliance, monitoring, and enforcement play a large part in determining how much markets can contribute to water security.

Finally, fit-for-purpose water information systems and scientific research can make very cost-effective contributions to water security. In Australia, the Bureau of Meteorology's upgraded water information system provides agriculture and environmental water managers with much-improved information to underpin water use decisions, while CSIRO, Bureau of Meteorology, and university research on climate change are helping agriculture and urban water service providers assess emerging risks to and impacts on water security. This is one area where many countries would do well to re-examine their level of public investment.

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Chapter 3
Addressing Water Challenges and Safeguarding Water Security: China's Thought, Action, and Practice

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Abstract This analysis provides an all-round description of the situation and challenges of water security in China, introducing the overall guiding thoughts, effective strategies formulated, and pragmatic measures adopted. The author analyses in detail the phased targets, policies unveiled, institutions and mechanisms established, and progress achieved of China's water security strategies. In the analysis, ten concrete cases are offered to exhibit the combination of policy and technology innovations in the implementation process, presenting China's solutions to the variety of water security challenges. The author concludes the discussion by calling for more international cooperation in the joint realisation of the water-related Sustainable Development Goals.

3.1 Overview of Water Security in China

3.1.1 Characteristics of China's Water Resources

China is in the south-east of the Eurasian continent. It straddles the north–south climate transition zone, with special geographical and climatic conditions and very complicated water regimes.

Low Per Capita Water Resources. China's water resources total 2.8 trillion m^3, ranking sixth in the world; its per capita water resources of 2100 m^3 are only 28% of the world average; and average water resources per hectare of arable land are about 21,600 m^3, about half of the world average.

Uneven Distribution of Water Resources in Time and Space. Precipitation in China follows a pattern of decreasing from south to north, from east to west, and from summer and autumn to winter and spring. Of the precipitation and river runoff, 60–80% is concentrated in the flood season. There are substantial interannual changes in precipitation. Several consecutive wet years or dry years often take

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place. Northern China, which accounts for 64% of the national territory, 46% of the population, 60% of the arable land, and 45% of the GDP, has only 19% of the water resources.

Complex River Systems. China has more than 23,000 rivers with a basin area of over 100 km^2 each and more than 2200 rivers with a basin area of at least 1000 km^2 each. Its 2865 natural lakes with individual water surface area of greater than 1 km^2 add up to an aggregate water surface of 78,000 km^2.

Frequent Floods and Droughts. Most areas in China are humid and rainy in summer, prone to frequent short-duration, high-intensity local rainstorms, occasional long-duration basin-wide rainfall, and varying degrees of flooding, waterlogging, and typhoon disasters every year. With approximately 53% of the national territory being arid or semi-arid, drought has become a major constraint on sustainable economic and social development.

3.1.2 The Difficult Situation of Water Security in China

A marked increase in extreme weather events makes disaster prevention and mitigation very hard. Due to the impacts of climate change and human activities, China's climate situation is becoming even more complex and variable. Local rainstorms, super-typhoons, unusually high temperatures, drought, and other extreme weather events are markedly on the rise, while water and drought hazards are growing in abruptness, abnormality, and uncertainty. At the same time, climate change has led to the accelerated melting of glaciers and rising snow levels, adversely affecting the overall situation and future trend of water resources.

Faster industrialisation and urbanisation are leading to increasingly acute conflicts between water supply and demand. The annual national water shortage exceeds 50 billion m^3. More than 400 cities suffer water shortage to varying degrees. Some areas are caught in acute water stress; some cities only have one water source; and some small towns and medium-sized cities lack a reliable safeguard for water sources. Thus, it is imperative for China to improve the capacity for safeguarding water supply and making emergency responses in both urban and rural areas.

The combined problem of population growth, land reduction, and water shortage is intensifying, while the development of farmland water conservancy lags behind. Nearly half of the arable land in China has no irrigation-and-drainage system, and some parts of China have obsolete farmland water conservancy facilities. The farmland irrigation water use coefficient in China is below the international advanced level of 0.7–0.8. China urgently needs to build capacity to combat natural disasters and boost comprehensive agricultural production. It is also imperative that China raise the productivity of land and water use.

Economic development mode remains water-intensive, and protection of the water ecological environment remains difficult. Pollutant discharges into some rivers and lakes exceed their pollution absorption capacity, leading to the problem of black odorous water bodies in both urban and rural areas. Overexploitation of water resources in some localities has caused drying-out of river courses, drying-up of lakes, shrinking of wetlands, land subsidence, and other ecological problems. The area of soil erosion nationwide remains extensive, and the groundwater overexploitation problem has yet to be corrected in a fundamental way.

3.1.3 China Has Raised Water Security to the Level of National Strategy

The Chinese government has always attached great importance to water security. Since the founding of the People's Republic of China, and especially since reform and opening up, the Chinese government has released a series of policy documents on accelerating the reform and development of the water sector, stating that water conservancy is critical not only to flood control security, water supply security, and food security, but also to economic security, ecological security, and national security, giving strong policy support to reform and development of the water sector. Since the 18th National Congress of the Communist Party of China in 2012, China has made a series of major decisions and deployments to safeguard national water security from a strategic view of the overall national situation, and explicitly put forward guiding principles for water work in the new era: 'prioritising water saving, spatial balance, systematic governance, and simultaneous functioning of both hands (government and market mechanisms)' (NPCSC 2016a). Thus, China has raised water security to a national strategy. The Chinese government insists on the development concept of 'innovation, coordination, green, open, and sharing'. It regards water conservancy as a key area in the construction of an ecological civilisation, assigns it the first place in the development of infrastructure networks, and incorporates it as an important aspect of deepening supply-side structural reform. In particular, China has formulated the planning for 172 major water saving and water supply projects, implemented the Most Stringent Water Resources Management System and the Action Plan for Control of Water Pollution, practised dual control of both the quantity and the intensity of water consumption, promoted agricultural water saving on a large scale, and focused on building a water security safeguarding system commensurate with the establishment of a moderately prosperous society across all metrics.

3.2 Constantly Improving Flood Control, Drought Relief, and Disaster Mitigation Capacity

3.2.1 Main Challenges to Flood Control Security in China

Flooding and waterlogging constitute the most hazardous and damaging natural disasters in China, and pose significant risks to China's economic and social development. Floods and waterlogging in China are:

Extensive in Impact. Two-thirds of the national territory and more than 90% of the population of China are exposed to flood threats to different degrees. The middle and lower reaches of the seven major rivers, including the Yellow, the Yangtze, and the Huai, where over half of the national population, more than a third of the national arable land, and over three-quarters of the national industrial and agricultural output value are concentrated, are prone to the most severe flood impacts.

High in Frequency. To take the Yellow River as an example, in the 2540 years from 602 BC (when the earliest historical record of flooding is available) to 1938, the river experienced 1590 dyke breaches and 26 major alterations of its course. Statistically speaking, the river witnessed two dyke breaches every three years and one alteration of its course every century. Since the foundation of the People's Republic of China in 1949, the seven major rivers have seen more than 50 major floods.

Various in Type. Due to natural conditions, a considerable proportion of land in China is seriously affected by disasters. It is prone not only to basin-wide catastrophic floods along major rivers, but also to other disasters such as flash floods, debris flows, landslides, typhoons, and ice jams. Furthermore, floods along small and medium-sized rivers and urban waterlogging have exhibited a trend of growth in recent years.

High in Economic Costs. Direct economic losses arising from floods and waterlogging make up more than 70% of the aggregate loss caused by all kinds of natural disasters. From 1990 until now, the average annual direct economic loss caused by floods and waterlogging has accounted for 1.37% of the GDP for the same period, and this could increase further in years of basin-wide catastrophic floods.

3.2.2 Main Measures to Safeguard Flood Control Security

The Chinese government insists that ensuring the safety of people's lives is the primary task of flood prevention and is firmly committed to the concepts of risk management and integrated disaster reduction. In practice and at all times, it combines prevention, defence, and rescue efforts, with a focus on prevention, integrates normal disaster reduction with extraordinary disaster relief, and makes comprehensive use of structural and non-structural measures to ensure flood control security.

Reinforcing the Implementation of Flood Control Responsibilities. In accordance with the Flood Control Law of the People's Republic of China (NPCSC 2016a), China has established organisation and command systems for flood control and drought relief at national, basin, and local levels. The State Flood Control and Drought Relief Headquarters (SFCDRH) is responsible for organising and leading the national flood control, drought relief, and typhoon response efforts. A deputy prime minister of the State Council serves as its commander-in-chief, the minister of water resources and several other agencies as its deputy commanders-in-chief, and heads of relevant national authorities and the armed forces as its members. Major basins such as the Yangtze River Basin, Yellow River Basin, Huai River Basin, Hai River Basin, Pearl River Basin, Songhua River Basin, and Taihu Lake Basin have all established their own flood control and drought relief headquarters, which consist of basin authorities and local governments. Local governments above the county level have also set up flood control and drought relief headquarters. Some areas suffering severe floods and droughts even extend their local flood control and drought relief headquarters to grass-roots levels such as townships and rural communities (Fig. 3.1). China has instituted a flood control responsibility system under which government administrators are held accountable for their duty performance. Each year before the flood season, the SFCDRH publishes a list naming the administrative heads in charge of flood control for the major rivers, large reservoirs, and medium-sized reservoirs that are the priority targets of flood control, the main flood detention and storage areas, and the key flood control target cities nationwide, so that these administrative heads will be subject to public scrutiny. Local areas and various departments also designate persons responsible for flood control at their corresponding levels in various categories, and publicise their names.

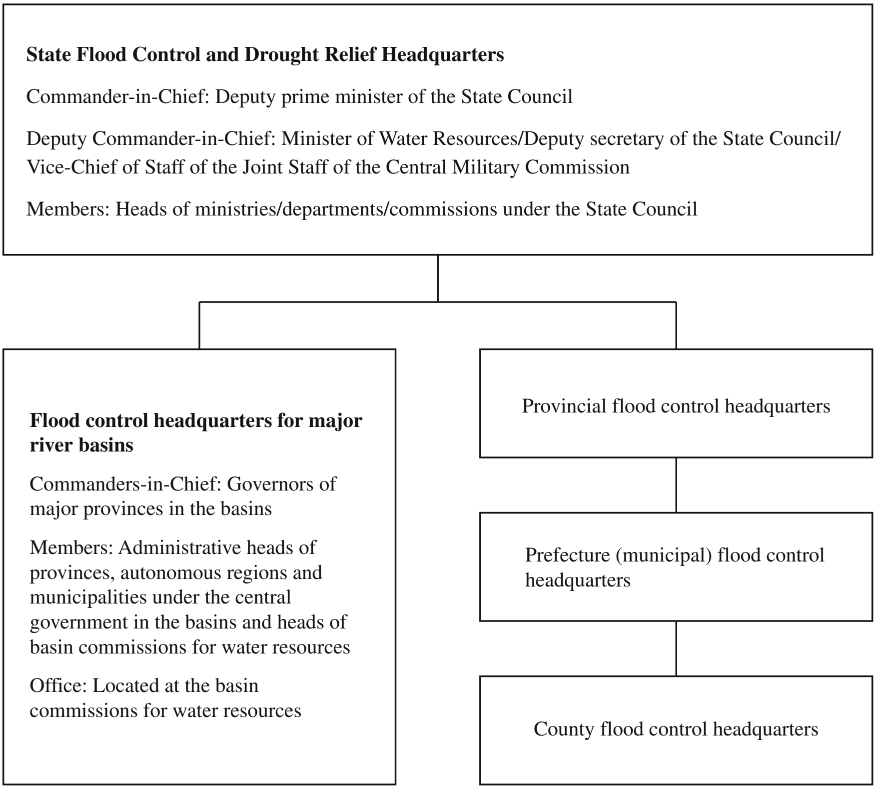

Fig. 3.1 Organization and command system for flood control and drought relief

Improving the System of Flood Control Works. To date, China has built and reinforced river, lake, and sea dikes of a combined length of 413,000 km, of which dikes that could withstand 10–20-year return period floods and 50–100-year return period floods extend 275,500 and 38,000 km, respectively. These dikes protect 46,831,000 hectares of arable land and 598 million people. China has also constructed 98,000 reservoirs, with a combined storage capacity of 932 billion m^3; developed 98 key flood detention and storage areas with an aggregate area of 33,700 km^2 and a total flood storage capacity of 107.4 billion m^3; and constructed 268,000 water sluices of all types. Key dikes such as those along the Yangtze River and Yellow River are compliant with relevant standards; and key multipurpose water projects such as the Three Gorges Project on the Yangtze River and the Xiaolangdi Project on the Yellow River have started operation in succession. The main sections of the major rivers are capable of defending against the largest floods since the foundation of new China in 1949; key cities are capable of standing against 100–200-year return period floods, while key sea dikes are up to the 50–100-year return period standard.

Strengthening Flood Monitoring, Forecasting, and Early Warning. The implementation of the national flood control and drought relief command system and other projects has given rise to the preliminary shape of a nationwide multilevel full-range system for monitoring rainfall and water regimes as well as forecasting and early warning of floods. China has built more than 100,000 stations across the country to monitor water and rainfall conditions. These radar-based monitoring systems basically cover all major cities and key areas in the country. All large and key medium-sized reservoirs have been equipped with systems for automatic monitoring, forecasting, and transmission of rainfall and water levels. After years of relentless modernisation efforts, 98% of this monitoring information across the country can reach the SFCDRH command centre within 15 min. China has also developed robust flood forecasting and early-warning systems, prepared flood forecasting programs for more than 2300 important sections of major rivers, lakes, and reservoirs, and built a preliminary system for flash flood and geological disaster prevention and control, monitoring, and early warning that covers 2058 counties nationwide. Modern remote sensing and telemetry technologies, big data and cloud technology, flood impact simulation, and early-warning technology are being used to improve the accuracy of forecasting and early warning, extend the forecast lead time, and boost preparedness and capacity to combat flood events.

Scientifically Scheduling Flood Control Works. China has revised and improved the flood defence programs and flood scheduling programs for major rivers, developed flood control emergency response plans and flood scheduling and utilisation plans for large and medium-sized reservoirs and hydropower stations, and formulated flood utilisation programs for all flood detention and storage areas. Pursuant to the principles of putting flood control ahead of benefit enhancement, river basins ahead of administrative regions, and water scheduling ahead of electricity scheduling, China is optimising joint scheduling of reservoir clusters and cascade reservoirs, and comprehensively arranging various measures that include ‘interception, diversion, storage, detention, and discharge’, which gives full play to the comprehensive scheduling and storage functions of water works and fully realises the benefits of flood control and disaster mitigation. Since its completion, the Three Gorges Reservoir has been used for flood control 23 times. It has successfully coped with flood peaks of more than 50,000 m^3/s ten times, cumulatively intercepted and stored 145 billion m^3 of floodwater, generated over 100 billion RMB in benefits from flood control and disaster mitigation, achieved the 175-m experimental storage target level for eight consecutive years, and realised multiple benefits in flood control, water supply, power generation, irrigation, navigation, and ecological restoration.

Organising Timely Evacuation for Risk Mitigation. Governments and flood control and drought relief headquarters at all levels uphold the philosophy of putting people first and always assign top priority to protecting people’s lives. In accordance with the principle of focusing on prevention and integrating prevention, escape, and rescue, they organise and guide localities in their jurisdictions to implement flood prevention and defence responsibilities, specify evacuation and escape programs, and define evacuation routes and escape locations. People under threat are evacuated in advance before disasters strike, and emphasis is placed on better organisation and protection of such vulnerable groups as the elderly, children, women, construction workers, and tourists. In the prevention of damage from typhoons, emphasis is placed on ensuring the return of sea vessels to harbour for shelter and the return of people engaged in offshore operations and aquaculture to the land to escape disaster. Cascade evacuation is carried out by group according to the development trend and impact scope of the typhoon, while low-lying areas, construction sites, urban-rural fringes and other weak points are carefully screened to avoid or minimise casualties.

Persevering in Scientific Flood Control According to Law. China has promulgated and implemented laws and regulations to guarantee the rule of law in flood prevention and control and in compensating for the use of flood detention and storage areas. These include the Water Law (NPCSC 2016b), the Flood Control Law, the Flood Control Regulations (State Council 2005), the Regulations on River Course Management (State Council 2017a), the Regulations on Management of Reservoir and Dam Safety (State Council 2011), the Hydrological Regulations (State Council 2017b), and the Interim Measures on Compensating for the Use of Flood Detention and Storage Areas (State Council 2000). In recent years, China has completed the preparation of State Flood Control and Drought Contingency Plans (General Office of the State Council 2006), formulated flood defence programs and flood scheduling programs for major rivers such as the Yangtze River and the Yellow River and their important tributaries, and made improvements in emergency response plans for urban flood control, flash flood prevention, use of flood detention and storage areas, and reservoir flood control and rescue work. All these have made the national flood control and drought relief planning system increasingly robust.

3.2.3 Main Achievements in Safeguarding Flood Control Security

Since the founding of the People's Republic of China, flood control has reduced arable-land inundation and grain losses by 192 million hectares and 781 million tons, respectively, generated RMB 4.94 trillion in economic benefits, and reduced the proportion of flood-induced losses in the GDP to 0.5% (Fig. 3.2). Important cities have raised their flood control capacity to the 100- or 200-year return level; and the annual death toll of floods and loggings has declined from an average of 3744 deaths in the 1990s to an average of 576 deaths since 2011.

Case 1: Flood Defence along the Yangtze River Basin in 2016
In July 2016, the middle and lower reaches of the Yangtze River were caught in the most catastrophic flood since 1998. The storms and floods exhibited four marked features (MWR 2017a):

Huge volume of precipitation and heavy intensity of rainstorms. The four strong precipitation events in the Yangtze River Basin (1.8 million km^2 basin area) dropped a cumulative quantity of 247 mm, 33% more than in the same period in normal years. The cumulative precipitation in the middle and lower reaches (800,000 km^2 basin area) reached 329 mm, 74% more than in the same period in normal years and the second-most since 1954.

Large inflows during intervals and dramatic rise of floodwater. The maximum combined flow of the four rivers feeding into Dongting Lake, the five rivers emptying into Poyang Lake, and the six rivers in east Hubei Province reached 27,100, 15,000, and 25,000 m^3/s, respectively. Mainstream water levels in the middle and lower reaches of the Yangtze River recorded a maximum daily increase of 0.53–1.31 m, an extremely rare phenomenon.

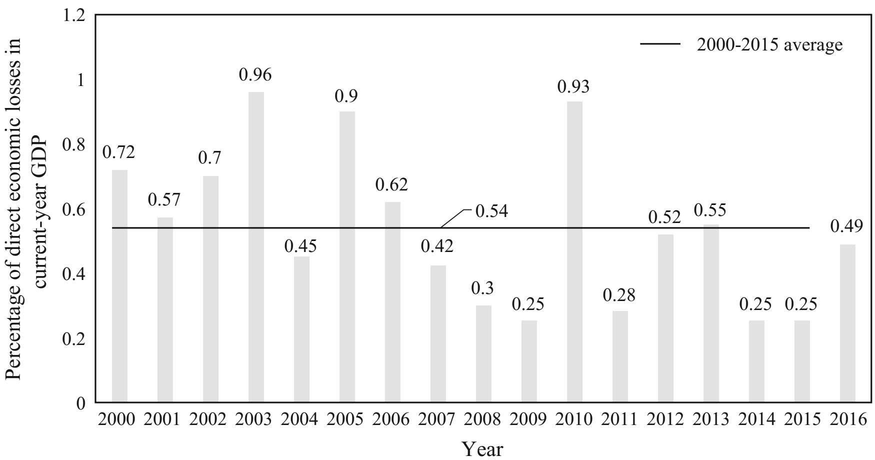

Fig. 3.2 Proportion of flood-induced losses in GDP, 2000–2016

High water levels during the flood peaks, with many rivers exceeding their alarm thresholds. Water levels in the main streams and Dongting and Poyang Lakes in the lower reach of Jianli exceeded their alarm thresholds by 0.76–1.97 m, with water levels at some hydrological stations and points recording new highs since 1999; 24 rivers broke old records for water level, 41 exceeded guaranteed water levels, and 123 rose above alarm thresholds.

Water levels exceeded alarm thresholds for long durations and on long sections of dikes. The mainstream in the middle and lower reaches of the Yangtze River and the two lakes exceeded their alarm thresholds for a cumulative total of 12–29 days, the longest since 1998; the middle and lower reaches recorded 3338 risky sites along the dikes; and 11,000 km of the dikes (of which 2950 km were mainstream dikes) exceeded their alarm thresholds during the flood peaks.

The central government and local governments at all levels rapidly pooled resources to respond to the Yangtze River flood in accordance with the Flood Control Law and other relevant provisions. (1) They reinforced uniform command. The SFCDRH timely initiated Level III flood control emergency response, whereby daily consultations were held to strengthen the rainfall and water regime analysis and flood scheduling. Local flood control and drought relief headquarters at all levels intensified their mobilisation efforts, timely started emergency responses, and fully engaged in flood control. (2) They intensified dike patrol and defence. The SFCDRH issued more than 20 notices to focus on arrangements for dike patrol and defence and handling of risky situations. During the flood peaks, the five provinces mobilised up to 870,000 people for flood control, of whom 32,000 were army officers and soldiers, and enlisted a cumulative manpower input of 17.49 million people-times for flood control and rescue work, of which the military contributed more than 700,000 people-times. (3) They practised joint scheduling and control of the reservoir clusters. In advance of the flood, 21 large reservoirs in the upper reaches of the Yangtze River released about 45 billion m^3 of flood control capacity. In the midst of the flood, the SFCDRH and the Yangtze River Flood Control and Drought Relief Headquarters jointly regulated the Three Gorges Dam and the reservoir cluster in its upper and middle reaches, intercepting 22.7 billion m^3 of water in total, which significantly reduced the water level in the lower reaches of the Three Gorges and avoided inundation of the cities. (4) They strengthened technical guidance and support. The SFCDRH sent 45 working groups, expert groups, and technical groups in succession to guide the local areas in carrying out dike patrol and defence, risky-situation analysis, and emergency response and make urgent arrangements for rescue funds, materials, and devices, rendering full support to the local areas in their control of and fight against the flood. (5) They enhanced coordination and cooperation for greater synergy. Member units of the NFCDR and its local counterparts coordinated and cooperated on such aspects as monitoring and forecasting, project scheduling, rescue and assistance, population relocation, health and epidemic prevention, information dissemination, and financial support in accordance with their division of duties. Thus, they fought the disaster in an orderly manner.

Thanks to this scientific scheduling and full-effort defence, the main streams in the middle and lower reaches of the Yangtze River, along with Dongting Lake and Poyang Lake, saw their water levels drop below the alarm thresholds on 31 July. The goals of protecting people's lives and ensuring the safety of critical dikes and vital facilities were attained.

Case 2: Overcoming Deficiencies in the Flood Control System
In 2016, due to the successive impacts of the super El Niño events and the La Niña phenomenon, the Yangtze River Basin was caught in the most catastrophic flood since 1998; Taihu Lake was hit by a basin-wide catastrophic flood and recorded the second-highest water level in history; the Hai River suffered rainstorms and floods very rarely seen for years; and the Huai River and the main stream of the West River experienced floods that exceeded their alarm thresholds. Floods in some basins and areas were especially serious; dikes along some small and medium-sized rivers were flooded or breached; small reservoirs were overtopped and became risky; many farmland and agricultural facilities were damaged; and some cities and polder areas suffered serious waterlogging. All these revealed the prominent weaknesses existing in the Chinese flood control and disaster mitigation system.

The Chinese government attached great importance to post-disaster reconstruction. In December 2016, the executive meeting of the State Council considered and adopted the Program of Action for Post-Disaster Efforts to Overcome Deficiencies of Water Conservancy and Defects in Urban Drainage and Prevention of Waterlogging (State Council 2016). The program required the pooling of resources to further enhance the capacity of river basins and administrative regions for flood control, drainage, and disaster reduction within 3–5 years, through acceleration of the development of projects for harnessing small and medium-sized rivers, risk removal and consolidation of small risky reservoirs, drainage capacity building in key areas, and flood control, forecasting, and early-warning systems in grass-roots rural areas, as well as construction of urban underground drainage pipelines and canals (pipe gallery), rainwater source discharge reduction devices, and drainage and risk removal facilities in cities that suffered severe waterlogging in recent years. The program made it clear that the national government would invest RMB 630 billion for such purposes, including RMB 320 billion planned for overcoming the deficiencies of water conservancy and RMB 310 billion for capacity building in drainage and waterlogging prevention in 60 cities prone to severe flooding and waterlogging.

In May 2017, the Chinese government issued the Program on Accelerating the Implementation of Post-Disaster Efforts to Overcome Deficiencies of Water Conservancy (MWR et al. 2017). The program put forward the following development targets: to pool resources to complete risk removal and consolidation of over 10,000 small risky reservoirs; to basically complete the harnessing of 244 medium-sized rivers with watershed area of more than 3000 km^2 each and small rivers with watershed area of 200–3000 km^2 each so that these rivers will comply with the planned flood control standards; to increase drainage capacity by 5700 m^3/s so as to raise the drainage standards of the severely waterlogged areas along the Yangtze River, and enhance the scheduling and storage functions of important lakes, to improve the flood control and drainage capacity of the entire region; to develop rural grass-roots flood prevention, forecasting, and early-warning systems in 562 counties not designated for prevention and control of flash floods, in order to effectively improve the capacity for collection and transmission of information about rainfall regimes, water regimes, and disaster situations; and to further enhance the capacity for flood control command and scheduling as well as emergency response. The overall goal is to speed up efforts to overcome deficiencies in small-scale water works, and comprehensively upgrade the capacity to prevent and fight floods and to prevent and mitigate disasters, by the end of the 13th Five-Year-Plan period.

3.3 Consolidating and Improving the Conditions of Urban and Rural Water Supply

3.3.1 Challenges to Water Supply Security in China

Supply security is an important basis for and at the same time one of the greatest challenges to safeguarding water security in China. Factors that influence water supply security include natural ones such as limited water resources per capita, uneven distribution of precipitation in time and space, and intensifying impacts of global climate change, as well as practical ones such as excessive growth of water demand and inadequate water supply infrastructure.

Insufficient Natural Endowment and Coexistence of Resource-Based Water Shortage, Water Quality-Related Water Shortage, and Structural Water Shortage. Due to limited precipitation, Beijing, Tianjin, Hebei, and other northern areas suffer serious resource-based water shortages. In some of the developed areas in south China, severe water pollution makes water quality-related water shortage an increasingly acute problem. The south-west is not short of water resources in the aggregate, but faces structural water shortages as a result of poor water supply infrastructure.

Growing Demand for Water as a Result of Accelerated Urbanisation and Industrialisation. At present, there are nearly 100 cities in China with more than one million inhabitants each. As urbanisation accelerates, domestic demand for water rises accordingly. Since 2000, continued promotion of industrialisation, especially the rapid development of heavy and chemical industries such as the energy sector, has increased annual industrial water use by nearly 20 billion m^3, accounting for one-third of total incremental water use.

Rural Drinking Water Security Is a Complex Issue, Rendering Security of Water Supply Very Difficult to Achieve. In 2016, China's rural population accounted for 43% of the national total, of whom a considerable proportion lived in the mountainous and hilly areas that make up 70% of the national territory. Some rural areas still have problems such as deficient water supply infrastructure and limited scale and low guarantee rate of water supply.

Increasingly Acute Threat and Extensive Impacts of Droughts. The growing trend of global climate change in recent years has led to more frequent droughts. While the northern water-scarce areas experienced frequent droughts, the water-rich south and south-west also recorded continuous severe droughts. Droughts affect not only agriculture and rural development, but also industrial production, urban development, and the ecological environment.

3.3.2 Main Measures to Safeguard Water Supply Security

Given the severe situation confronting water supply security, the Chinese government has implemented the Most Stringent Water Resources Management System. Among other policies, it has defined the Three Red Lines—control total water use, improve water use efficiency, and restrict water pollution in water functional zones—in order to practise systematic governance from the source, through the process, to the end of water development and utilisation. Meanwhile, China is applying measures to construct a modern water supply security system, such as protecting water sources, increasing infrastructure investment, reasonably arranging water transfer and diversion, developing and utilising unconventional water sources, and cultivating the market for trading of water rights.

Implementing the Most Stringent Water Resources Management System. In 2012, the Chinese government promulgated the Opinion on the Implementation of the Most Stringent Water Resources Management System (State Council 2012), defining the Three Red Lines as the red line pertaining to total quantity control in development and utilisation of water resources, the red line pertaining to improvement of water use efficiency, and the red line on restricting water pollution in water functional zones, and establishing supplementary management and performance evaluation systems (Fig. 3.3).

According to the Most Stringent Water Resources Management System, by 2030, total water use in China will be capped at 700 billion m^3; water use efficiency will reach or approach the most advanced levels in the world; water consumption per RMB 10,000 of industrial value added will be reduced to less than 40 m^3; the farmland irrigation water use coefficient will be improved to above 0.6; and the water quality compliance rate in water functional zones will reach 95% or higher. To achieve these targets, the Chinese government further clarified the periodic water resources management targets for 2015 and 2020, and broke them down by provincial, municipal, and county administrative levels. In addition, the water resource management responsibility system was established for performance evaluation in connection with their implementation. In 2016, actual total water use nationwide was recorded as 604 billion m^3, beating the 635 billion m^3 target and supporting the goal of healthy sustainable socioeconomic development with only a marginal increase in total water consumption.

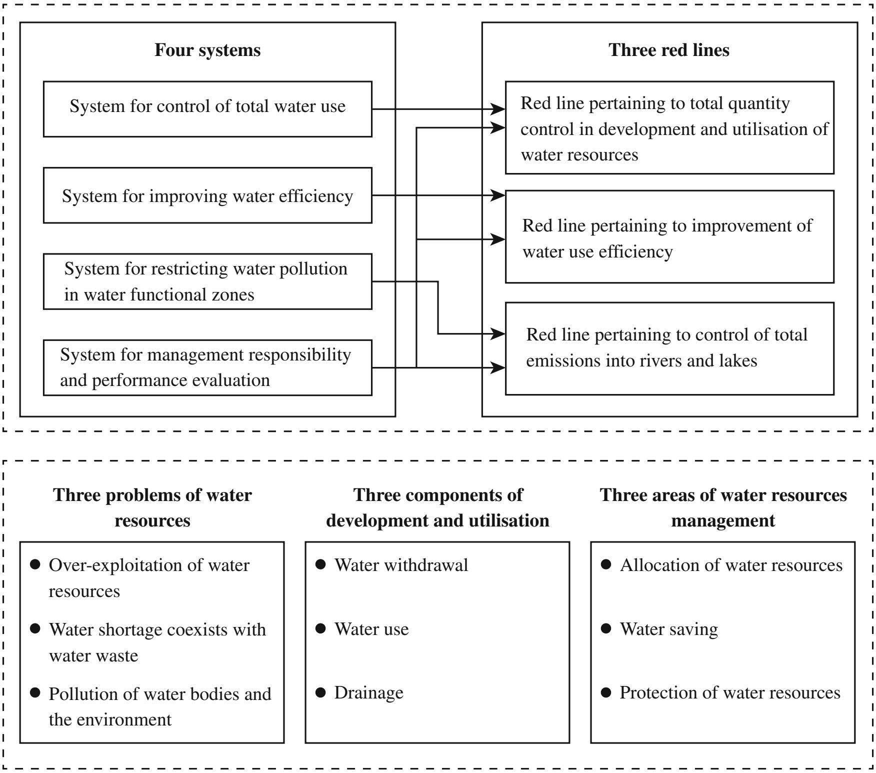

Fig. 3.3 Overall framework of the most stringent water resources management system

Strengthening the Protection of Drinking Water Source Areas. In 2006, the Chinese government prepared and implemented the National Plan on Safeguarding Security of Urban Drinking Water Source Areas (State Council 2007). The plan covered the following tasks: improving compliance of important drinking water source areas, cleaning up and rectifying pollution sources and discharge outlets in drinking water source areas, shutting down and relocating enterprises that seriously affect the safety of drinking water sources and are unable to control their pollution, and developing emergency response plans for unexpected environmental incidents in drinking water source areas. In 2015, the Guidance on Strengthening the Protection of Rural Drinking Water Sources (General Office of MEP and General Office of MWR 2015) defined the protection areas or scopes to strengthen standard development of rural drinking water sources and ensure their safety.

Optimising the Layout of Water Resources Allocation. On the basis of scientific demonstration, the Chinese government has built a group of water resources allocation works, which effectively alleviate the stress of water supply in Beijing, Tianjin, Hong Kong, and Macau. After more than ten years' construction and total investment of about RMB 300 billion, Phase I of the Eastern and Middle Routes of the South-to-North Water Diversion Project officially began to transfer water in 2013 and 2014, respectively. The two routes, with project lengths of 1432 and 1857 km and annual water transfer volumes of up to 8.77 and 9.5 billion m^3, respectively, play an important role in addressing water shortage in northern China. The Chinese government has constructed 172 major water saving and water supply works. In particular, a group of major water diversion and transfer works, large reservoirs, and networks of backbone irrigation and drainage channels and networks will be built in the central and western regions, to effectively alleviate regional water shortage.

Improving Infrastructure to Safeguard Urban and Rural Drinking Water Security. China is undertaking the following measures to safeguard urban drinking water security: constructing a group of urban water supply works, establishing a unified urban and rural water supply service system, and expanding the service scope of public water supply; accelerating the development of urban emergency backup water source projects, improving emergency response mechanisms, and refining emergency response plans, to better safeguard emergency water supply; upgrading water treatment processes; addressing problems in non-compliance of water supply quality; renovating pipeline networks; reducing pipeline leakage; increasing water supply efficiency and benefits; and constructing national and local networks to monitor the quality of urban water supply and strengthen control over water quality indicators such as microorganisms, heavy metals, and organic pollutants. With regard to security of rural drinking water, China is carrying out the following efforts: in-depth investigation and assessment of the condition of rural drinking water safety and formulation of national-level planning on rural drinking water safety projects; implementation of rural safe drinking water projects; and formulating and improving policies, regulations, and technical standards on rural drinking water safety to standardise project construction and management. At present, China has basically solved the rural drinking water problem, and started implementation of a new programme to consolidate and elevate rural drinking water safety.

Enhancing Development and Utilisation of Unconventional Water Sources. China is incorporating unconventional water resources into the unified allocation of water resources, and tailoring the development and utilisation of unconventional water resources to local conditions. Between 2005 and 2016, the use of unconventional water resources including recycled water and rainwater increased from 2.2 to 7.1 billion m^3. In 2016, the national use of recycled water was 5.9 billion m^3, and the production capacity of such water reached 10.1 billion m^3. In terms of overall scale, the national desalination project produces a yearly total of 430 million m^3 of desalinised water; and annual direct use of seawater amounts to 88.7 billion m^3, which is mainly used as cooling water in thermal and nuclear power generation.

Vigorously Cultivating the Market for Trading of Water Rights. The Chinese government has promulgated the Interim Measures for Management of Water Rights Trading (MWR 2016a) and organised pilot projects in several provinces for development of a national water rights trading system. The three pilot areas included registration of water use rights acquisition, trading and transfer of water rights, and development of the water rights system. Water allocation was carried out for 53 interprovincial rivers to create the conditions for clarification of water rights. In June 2016, the China Water Rights Exchange began operation, enabling normative trading of water rights.

3.3.3 Main Achievements in Safeguarding Water Supply Security

In terms of the capability to safeguard water supply, China has built more than 98,000 reservoirs, 800,000 water diversion works, and 300,000 pumping stations to date. With a combined annual water supply capacity of 700 billion m^3, these water structures basically meet economic, social, ecological, and environmental demand for water use, and have effectively responded to multiple severe droughts and minimised drought-induced losses.

In terms of safeguarding urban and rural water supply, China has addressed the drinking water security problem for 570 million rural residents cumulatively since 2005. Some 82% of China's rural population has access to centralised water supply. Tapwater penetration in rural areas is 76%. In 2016, urban water supply facilities nationwide attracted capital investment of RMB 52.4 billion; urban water supply registered a total volume of 58.1 billion m^3; daily production capacity of water supply in urban areas reached 300 million m^3; water supply pipelines extended 760,000 km; water coverage was 98.4%; and there were 2039 urban wastewater treatment plants nationwide, treating 44.9 billion m^3 of wastewater every year (a 93.4% treatment rate). All these have given a strong boost to the regulation, control, and safeguarding of water resources.

In terms of improving the efficiency of water resources utilisation, as of 2016, water consumption per RMB 10,000 of GDP and per RMB 10,000 of industrial value added had been reduced to 81 and 53 m^3, respectively, a marked improvement in water use efficiency and effectiveness.

Case 3: Implementation of the Project for Rural Drinking Water Safety in China

Constrained by natural, economic, and social conditions, rural water supply infrastructure in China has long remained very weak, making unsafe drinking water in rural areas an acute problem.

The Chinese government attaches great importance to addressing the rural drinking water problem and has put forward explicit requirements for efforts relating to rural drinking water security. The Ministry of Water Resources, together with other ministries, issued the Indicator System for Assessing Security and Healthiness of Rural Drinking Water (MWR and MOH 2004) in 2004, and compiles national plans for rural drinking water security projects on a regular basis. The ministry has released a series of rules and regulations, including the Administrative Measures for the Construction of Rural Drinking Water Security Projects (NDRC et al. 2013) and the Measures for Annual Performance Evaluation Regarding the Construction and Management of Rural Drinking Water Security Projects (MWR 2013). At the same time, the ministry has promulgated and implemented full sets of technical standards, such as the Design Code for Rural Water Supply Engineering (MWR 2014a), Acceptance Code for Construction Quality of Rural Water Supply Engineering (MWR 2014b), and Code of Practice for Operation and Maintenance of Rural Water Supply (MWR 2014c). All these have further standardised the construction and management of rural drinking water security projects. China offers rural drinking water security projects incentives in the three areas of electricity consumption, land use, and taxation, reducing project operating costs by 15% on average and thus promoting sustainable operation of the projects. Other measures, such as clarifying project ownership, determining the players responsible for project management and maintenance, making project funding available, establishing and improving grass-roots management and service systems, and setting up professional management and maintenance teams, ensure effective management and maintenance as well as long-term benefits of the rural drinking water security projects. Of the counties in China, 93% have established specialised county authorities for project management, and 68% have made funding for repair and maintenance available at the county level. More efforts are being made to reinforce water purification and disinfection and quality testing of source water, finished water, and peripheral water.

By 2009, the Chinese government had already halved the proportion of the population unable to access or afford safe drinking water, six years ahead of the deadline for the relevant UN Millennium Development Goal. Moreover, China went on to initiate implementation of the Project on Consolidating and Elevating Rural Drinking Water Security in 2016, focusing on addressing the low guaranteed rate of rural drinking water security in high-poverty areas. It is expected that by 2020 in rural China centralised water supply and tapwater penetration will exceed 85 and 80%, respectively, and the water supply guarantee rate and water quality compliance rate will both record a further increase.

Case 4: The China Water Rights Exchange Opens for Business

To give full play to the roles of the market and the government in allocation of water resources, China piloted trading of water rights from 2000 onward. Since 2014, pilot projects connected with water rights have been carried out in seven provinces and autonomous regions, including Inner Mongolia, Jiangxi, and Henan, centring on the registration of water use rights acquisition, trading and transfer of water rights, and development of the water rights system.

On the basis of extensive pilot practices, the Ministry of Water Resources issued the Interim Measures for Trading of Water Rights (MWR 2016b) in April 2016 and set up the China Water Rights Exchange jointly with the Beijing municipal government in June of the same year, officially putting the transfer of water rights on the track of rule of law.

The main business of the exchange is to trade regional water rights, water withdrawal rights, and water rights of irrigation water users across the country through an online cloud-based water rights trading system. Participants of water rights trading include local people's governments above the county level or their authorised departments or units, units or individuals that have acquired water withdrawal rights, and irrigation water users and other water use organisations that have defined water use rights. The three trading approaches are public trading, agreement transfer, and water rights trading for irrigation water users (Fig. 3.4). Between June 2016 and April 2017, the exchange brokered a total of 15 water rights transactions, trading a total water volume of 876 million m^3 at an aggregate transaction price of RMB 550 million.

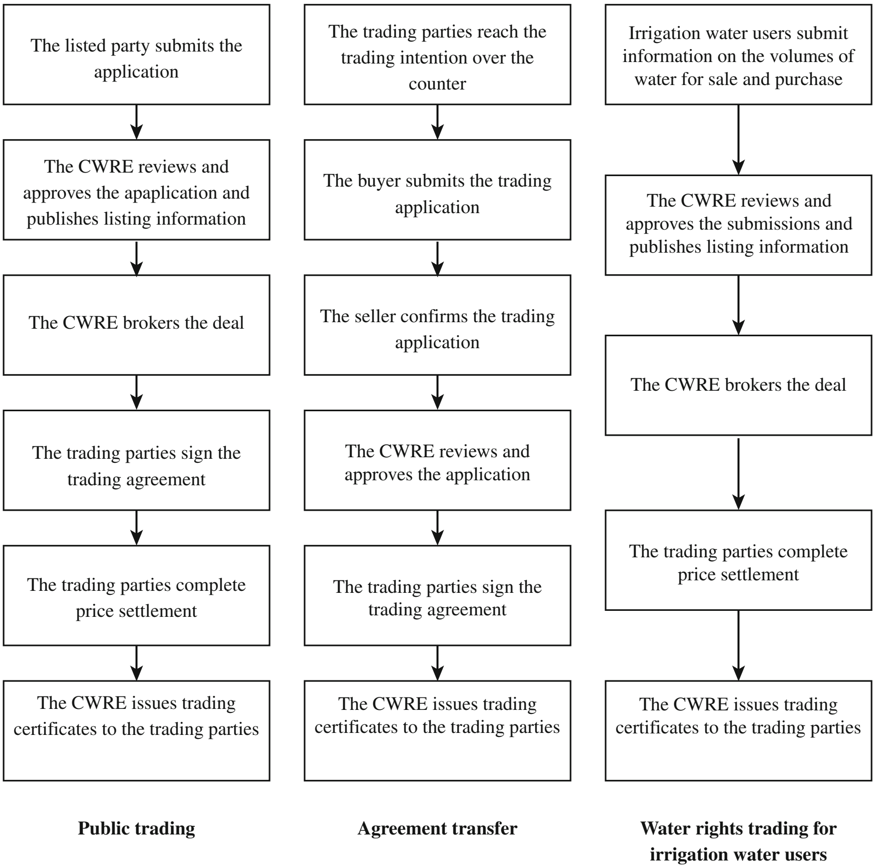

Fig. 3.4 Trading flowchart

3.4 Expanding and Renovating Agriculture Irrigation and Drainage Infrastructure

3.4.1 Challenges to Food Security in China

China is a populous country. To feed its 1.3 billion people is always a top priority for China in its attempt to achieve good governance and social stability. In safeguarding food security, China faces the following challenges.

Agricultural production in China relies heavily on irrigation. Since the founding of the Peoples' Republic of China, enormous achievements have been made in the development of farmland irrigation systems, with a large expansion of the irrigation area. However, nearly half of arable land is still rainfed, without irrigation-and-drainage conditions, especially in mountainous regions and pastoral areas. Given China's specific natural climate, land, and water resources conditions, ensuring stable and growing agriculture production entails not only the renovation of existing water works and facilities (which may be obsolete, of poor standards, and missing supplementary devices) but also the construction of a large number of new high-standard farmland water conservancy facilities.

Water use efficiency in agriculture needs to be improved. Along with the increasing water demand of industry and cities in China, agricultural development is exposed to the growing constraints of water resources and the water environment due to the limited total water supply. To safeguard national food security, it is imperative for China to greatly expand the effective irrigation area and constantly improve irrigation water use efficiency without increasing total agricultural water consumption. China has to step into the path of modernised agricultural development featuring water conservation and higher efficiency.

Systems and mechanisms for irrigation development are inadequate. Along with rapid urbanisation and modernisation, profound changes have taken place in China in the composition of the rural population and the structure of rural society. Accelerated reform and innovation in farmland conservancy is badly needed, because the conventional development mode is hard to sustain.

3.4.2 Main Measures to Safeguard Food Security

Safeguarding the sustainability of water resources for food production is the basic condition for food security. By actively expanding effective irrigation areas, promoting high-efficiency irrigation, and strengthening farmland water conservancy construction, China has ensured bumper grain harvests in consecutive years with no increase in agricultural water use.

Actively developing water-saving irrigation. China has taken positive steps to develop water-saving irrigation. Measures such as canal lining, pipeline water transmission, and sprinkler, drip, and micro-irrigation, as well as land levelling, are being adopted to improve water use efficiency. Large-scale, high-efficiency, water-saving irrigation has been implemented in various regions—to increase grain output in the north-east, raise water efficiency in the north-west, reduce groundwater use in the north, and improve water conservation and reduce pollution discharge in the south. Through scientific and proper scheduling, irrigation is being carried out with the right timing and quantity, so that available water resources can meet the needs of crop growth and increase yield per unit of water use. Gradual improvement has been seen in China's policy and legal frameworks, technical standard systems, and scientific research and development systems that support the development of water-saving irrigation. Moreover, enterprises engaged in the manufacturing of water-saving irrigation devices have seen booming growth, and the technical service system is constantly being improved.

Reinforcing development of farmland water conservancy. China has been developing irrigation systems for more than 2000 years. Facilities such as the Dujiang Weir (a UNESCO World Heritage Site) illustrate the important role farmland water conservancy has played throughout China's history of development. In recent years, the Chinese government has regarded farmland irrigation and drainage systems as a key measure for increasing grain output, responding to natural disasters, and improving the water environment. In addition, more efforts have been made to rehabilitate and renovate large and medium-size irrigation districts, move county-based small waterworks construction forward, carry out waterworks construction in the slack farming seasons of winter and spring, and overcome difficulties related to the last kilometre of terminal canal systems.

Speeding up modern water conservancy development in pastoral areas. China is the world's second-largest grassland country, with 400 million hectares of natural grassland of all types. As people's living standard improves, China's consumption of grains, milk, and beef products keeps growing. Adhering to the concept of 'building small oases to protect the large ecology', the Chinese government has stimulated the development of irrigation systems for forage land, developing 1 million hectares of irrigated forage land in pastoral areas, which could provide premium forage for about 14 million head of livestock and enables recuperation and rehabilitation of 33 million hectares of natural grassland.

Building a reasonable agricultural water pricing mechanism. The Chinese government is actively promoting a reasonable agricultural water pricing mechanism, that is, to reasonably determine agricultural water tariffs so that prices reflect the scarcity of water resources and thereby enable sound operation and maintenance of agricultural water-saving irrigation systems and waterworks. In 2016, the Chinese government released the Opinion on Promoting Comprehensive Reform of Agricultural Water Tariffs (General Office of the State Council 2016), aiming to establish and improve an agricultural water pricing mechanism that will reasonably reflect the cost of water supply, be conducive to water saving as well as institutional and mechanism innovations for farmland water conservancy, and adapt to the investment and financing systems, thereby promoting the transformation of agricultural water use from the extensive pattern to an intensive one in about a decade's time. Effective results have already been obtained in the reform of agricultural water pricing systems, which involves nearly half of the cities and counties in the country, covering about 5 million hectares of farmland.

Institutional and mechanism innovation for development of farmland water conservancy. China will vigorously promote the ownership reform of small water conservancy works, and encourage and guide social capital to invest in farmland water conservancy. At the same time, more efforts will be made to develop grass-roots water service systems, vigorously cultivate professional services teams for flood control and drought relief and irrigation and drainage, encourage participation of water users, and support the growth of farmers' water cooperatives.

3.4.3 Main Achievements in Safeguarding Food Security

By developing agricultural water conservancy facilities, China has safeguarded food security for 21% of the world's population, with only 6% of the world's freshwater resources and 9% of the world's arable land.

Developed a large number of irrigation systems composed of water sources, water transfer and distribution facilities, and field irrigation works. China has developed an irrigation area of 73.18 million hectares, of which 67.14 million hectares are farmland, and completed the construction of more than 7700 large and medium-sized irrigation districts and more than 20 million small-scale farmland water conservancy works. The irrigated land produces 75% of the national grains and more than 90% of the national cash crops.

Substantially increased agricultural water use efficiency. At present, China has a 0.542 farmland irrigation water use coefficient. It has achieved bumper grain harvests for 13 consecutive years since 2004 with zero growth in agricultural water consumption.

Significantly boosted agricultural production capacity. From 1978 to 2016, grain output in China increased from 305 to 616 million tons, and grain production capacity enjoyed an enormous improvement.

Case 5: The Initiative on Water Saving for Higher Grain Output in North-East China

The three provinces and one autonomous region in North-East China (Heilongjiang Province, Jilin Province, Liaoning Province, and Inner Mongolia Autonomous Region) have a combined arable land area of 28.67 million hectares, 23.5% of the national total. North-East China is one of the most important grain production bases in China and one of the regions with the greatest potential for higher grain yield, giving it an extremely important strategic position in safeguarding national food security.

To give full play to the advantages of land resources in North-East China and improve its comprehensive grain production capacity, since 2012 the Chinese government has focused on developing water-saving irrigation in the Songnen Plain and the Liao River Basin, with a total investment of RMB 38 billion. New water conservancy and agricultural technologies are being applied to improve the level of scientific farming and promote intensive standardised agricultural production with economy of scale, and thereby modernise agriculture in the region. Highly efficient water-saving irrigation systems have been installed on an area of 2.53 million hectares.

Due to large-scale input of capital, technology, and services, comprehensive integration of irrigation technology and measures relating to agronomy, agricultural machinery, and management has been realised, which focuses on matching water use to the carrying capacity of water resources. The construction of water-saving irrigation facilities, coupled with supplementary agricultural and agro-machinery measures and adoption of scientific irrigation practices, enables timely supply of moisture and nutrients for crop growth, and reduces water loss in the process of conveyance and ineffective supply in the farmland. This increases yield per unit of water consumption, or in other words, produces more food with less water. According to follow-up observations, after implementation of the initiative on water saving for higher grain output, the project areas have higher grain output, but also higher quality of agricultural products and better market competitiveness. By implementing the initiative, the four provinces/regions have increased their overall grain production capacity by more than 100 billion kg annually, enough to meet the grain needs of more than 13 million people.

Case 6: Participation of Farmers' Water Cooperatives in the Management of Irrigation Areas

In the mid- and late 1990s, the construction, operation, management and maintenance of farmland water conservancy facilities in China were confronted with new tasks and challenges. The provinces of Hunan and Hubei took the lead in developing farmers' water user associations, along with the implementation of a World Bank loan project, to address the absence of players in managing and maintaining small-scale farmland water conservancy works.

Over the past 20 years, the Chinese government has actively encouraged and guided the development of farmers' water cooperatives, favouring them with policy and investment incentives. At the same time, the internal operation of water cooperatives is being gradually standardised. First, their internal organisational structures are being improved. Democratic management approaches such as a farmers' water users' assembly or board system are adopted, while an executive committee is set up to take charge of daily operations, and a board of supervisors for oversight. Second, more robust management regulations are put in place. The farmers' water cooperatives have developed a series of management regulations such as those on irrigation and drainage management, water use management, calculation and collection of water tariffs, and repair and maintenance of water works.

At present, farmers' water cooperatives enjoy good momentum of development, producing diverse water user associations and cooperatives and a variety of organisational forms. In line with different types of irrigation and drainage works, a rich variety of development models have come into being, such as 'specialised authority in the irrigation area + associations + water users', 'specialised authority in the irrigation area + the confederation of associations + water users', 'associations + water users', and 'water use cooperatives + water users'. By the end of 2016, there were 83,400 water cooperatives across the country, which managed a total irrigation area of 20 million hectares and had over 60 million farmer participants. These organisations were distributed across 30 provinces, autonomous regions, and municipalities directly under the central government, except Shanghai. Among them, 32,800 water user associations were registered with the civil affairs authorities and over 3000 water cooperatives were registered with the industry and commerce administrations.

Over years of experience, farmers' water cooperatives have played an important role in the construction, operation, management, and maintenance of farmland water conservancy works, management of water use, and calculation and collection of water tariffs. In particular, the water cooperatives: (1) participate in the establishment and construction of farmland water conservancy projects, making the projects more open, transparent, scientific, and efficient; (2) address the absence of players responsible for management and maintenance of small-scale water conservancy projects, thereby enabling more professional management and maintenance of the projects and providing organisational guarantees for sound operation of the water works; (3) improve irrigation water use efficiency and save on agricultural water use; (4) use professional management that saves farmers both labour input and time for water keeping and water use, thus liberating rural labour productivity; (5) help improve crop yields and increase opportunities for farmers to participate in non-agricultural employment, increasing farmers' income; (6) reduce intermediate links of water tariffs and thus improve the transparency of water tariff collection; and (7) help reduce water use disputes and thereby improve the order of agricultural water use.

3.5 Promoting Water Ecological Civilisation Development and Water Environment Protection

3.5.1 Challenges to Water Ecological Security in China

With the rapid economic and social development and population growth in China, economic and social demand for water use is rising fast, and wastewater discharges keep increasing. New challenges are emerging with respect to water ecological security.

The water ecological environment is fragile. China is one of the countries in the world with the most extensive distribution of ecologically fragile areas, the greatest number of fragile ecological types, and the most obvious signs of ecological fragility. Areas with moderate ecological fragility account for 55% of the national land space.

Control of water pollution is very difficult. Currently and for some time into the future, wastewater discharges will be on the rise. In recent years, pollution discharges into some rivers and lakes have failed to comply with relevant water quality standards. The water quality of these bodies needs to be addressed promptly.

Soil erosion is severe. In China, a total area of 2.95 million km^2 nationwide suffers soil erosion (1.29 million km^2 from water and 1.66 million km^2 from wind). The average annual soil erosion is 4.5 billion tons, with 53% of the total eroded area suffering from moderate or severe soil erosion.

Water ecological functions are deteriorating. Chronic overdevelopment in some areas has exceeded the carrying capacity of water resources, resulting in partial shrinkage of river and lake systems as well as wetlands. The national total of groundwater overexploitation stands at 17 billion m^3 per year on average, with overexploited areas of about 300,000 km^2. The overexploitation of groundwater has resulted in a funnel area of 120,000 km^2 in North China.

3.5.2 Main Measures to Safeguard Water Ecological Security

The Chinese government attaches great importance to the construction of water ecological civilisation. It has strengthened top-level design, made institutional and mechanism innovations, vigorously promoted various governance and protection measures, and striven to build a system for safeguarding the security of water ecology.

Fully Implementing the Action Plan on Control of Water Pollution. In 2015, the Chinese government issued the Action Plan on Control of Water Pollution (State Council 2015), which put forward ten measures for prevention and control of water pollution: comprehensively control pollutant discharge/emission, promote the transformation and upgrading of economic structure, save and protect water resources, strengthen scientific and technological support, give full play to the role of market mechanisms, toughen environmental law enforcement and regulation, effectively reinforce management of the water environment, safeguard security of the water ecological environment with all possible efforts, define and implement the responsibilities of all stakeholders, and enhance public participation and social supervision.

Fully Implement the River Chief System. In November 2016, the Chinese government issued the Opinion on Full Implementation of the River Chief System (General Office of the CPC Central Committee and General Office of the State Council 2016). The opinion explicitly required full implementation of the ‘river chief’ system across the country, in which main Party and government leaders at all levels are appointed as river chiefs—that is, responsible for organising and leading the management and protection of relevant rivers and lakes, and building river/lake management and protection mechanisms that are clear in division of duties, coordinative and orderly in operation, strict in supervision, and effective in protection.

The main tasks of a river chief include protecting water resources, preventing and controlling water pollution, improving the water environment, restoring the water ecology, managing and protecting shorelines, and supervising law enforcement (Chen 2017).

Speeding Up Comprehensive Control of Soil Erosion. China has implemented soil and water conservation projects and ecological restoration projects in the upper and middle reaches of both the Yangtze River and the Yellow River, in the karst areas in the south-west, and in the black soil areas in the north-east; practised comprehensive control of soil erosion on sloping land; and actively promoted the construction of clean watersheds in important headwater areas, peripheral areas of cities and towns, and the eastern region. While boosting comprehensive control of soil erosion, China also practises enclosed protection and cultivation, with a ban on grasing and rotational grasing. The purpose is to fully rely on the self-recovery ability of Great Nature to speed up rehabilitation of vegetation, reduction of soil erosion, and improvement of the ecological environment.

Reinforcing Groundwater Monitoring and Protection. China has completed a national assessment of areas suffering groundwater overexploitation, and will complete a national groundwater monitoring project. Other measures include the approach of dual control of groundwater quantity and level, strict control of groundwater mining, and development of alternative water sources. More intensive efforts are underway to control groundwater overexploitation. For instance, such measures as underground reservoir construction, rainwater and floodwater utilisation, and groundwater recharge have been adopted to restore and replenish groundwater aquifers.

Connecting the Water Systems of Rivers, Lakes, and Reservoirs. China has scientifically planned and implemented a project to connect the water systems of rivers, lakes, and reservoirs under the premise of ecological protection and based on the natural water systems of rivers and lakes, plus water storage/scheduling works and water diversion/discharge projects. By dredging, breaking barriers, and connecting water networks, the project has helped shape healthy natural river-bank curves and build a modern water network system characterised by reasonable layout, sound ecological environment, proper diversion and drainage, smooth circulation, balance of storage and discharge, coordination between wet and dry seasons, mutual complementation of multiple sources, and easy regulation and control.

3.5.3 Main Achievements in Safeguarding Water Ecological Security

In terms of water pollution control, in 2016, the combined length of all rivers with Grade I–III water quality took up 76.9% of the national total, 12.7% points more than in 2011, while the combined length of all rivers with Grade V (inferior) water quality took up 9.8% of the national total, 7.9% points less than in 2011. In 2016, 73.4% of major river/lake water functional zones complied with relevant water quality standards, up 12.2% points from 2011.

In terms of controlling soil erosion, to date, more than 70,000 small watersheds have been brought under comprehensive governance, and an area of over 800,000 km^2 has been closed to cultivation. Soil and water conservation programs cover 1.16 million km^2 nationwide. The grass and forest coverage rate of key project areas has seen a remarkable increase.

In terms of ecological governance of rivers and lakes, comprehensive governance of the water environment in Taihu Lake has had early fruits, seen in the marked improvement of major water quality indicators. The short-term harnessing project of the Tarim River and key control projects of the Shiyang River have both achieved their major targets and milestones, bringing preliminary improvements in the ecological environments of the two basins.

In terms of groundwater governance and protection, overexploitation of groundwater is being effectively curbed nationwide, with the situation in excessively overexploited areas undergoing a preliminary reverse. In 2015, national groundwater utilisation was 4 billion m^3 less than in 2011. A remarkable achievement has been made in control of overexploitation of groundwater in the water diversion area of the Eastern and Middle Routes of the South-to-North Water Diversion Project, with a reduction of 0.82 billion m^3 by the end of 2016. The pilot project on comprehensive control of groundwater overexploitation in Hebei Province has registered periodic accomplishments. After three years' pilot governance, groundwater utilisation has fallen by 3.87 billion m^3; in the pilot areas, the continuous decline of groundwater level has been effectively curbed, and in some areas the groundwater level is rising again.

Case 7: Comprehensive Implementation of the River Chief System

In 2007, a blue algae outbreak in Taihu Lake triggered a water crisis in Wuxi City, in Jiangsu Province. To address the acute problems in the management and protection of rivers and lakes, Wuxi became the first city to practice the river chief system, which holds local administration heads accountable for water management and protection. The Party and government leaders at all levels in Wuxi served as the 'chiefs' of the 64 rivers in the city, effectively putting all pollution control measures in place. In June 2008, the Jiangsu provincial government decided to extend Wuxi's river chief system to the entire Taihu Lake Basin, requiring each and every river to have a provincial leader and a municipal leader as its co-chiefs so that the arduous task of harnessing the Taihu Lake and its river courses could be fulfilled in a coordinated manner. Implementation of the river chief system greatly improved the management and protection of the water systems of rivers and lakes. The eutrophication index of Taihu Lake changed from moderate to mild, indicating an enormous improvement in water quality. This Jiangsu practice attracted extensive attention. Other places including Zhejiang, Tianjin, and Jiangxi started exploring ways to implement the river chief system. All of them have achieved remarkable results.

On the basis of such practices, in November 2016, the Chinese government issued the Opinion on Full Implementation of the River Chief System, requiring comprehensive establishment of the system at four levels (provincial, municipal, county, and township). The river chief general of a province, autonomous region, or municipality directly under the central government is the provincial party/government leader who has overarching responsibility for management and protection of the rivers and lakes in the province. River chiefs at lower tiers of government are directly responsible for management and protection of the rivers and lakes or just river sections corresponding to their administrative geographic boundaries. Their main tasks are protection of water resources, shoreline management of water bodies, water pollution control, governance of the water environment, restoration of water ecology, and supervision of law enforcement. They take the lead to organise the rectification of prominent problems (such as intrusion into river courses, enclosure and reclamation of lakes, excessive discharge/emission of pollutants, and illegal sand mining), coordinate the solution to major issues, supervise and guide relevant departments and river chiefs at the next tier in their performance of duties, and evaluate the fulfilment of targets and tasks. Offices are set up for river chiefs at and above the county level to carry out specific work organised by the river chiefs and implement decisions made by them. All relevant departments and units coordinate to push forward various tasks in accordance with their division of duties. To date, China has designated nearly 270,000 river chiefs at provincial, municipal, county, and township levels nationwide, of whom 330 are provincial river chiefs.

In the river chief system, administrators' performance is judged by how well the main problems of the rivers and lakes they are responsible for have been addressed. River chiefs at and above the county level are responsible for evaluating the performance of the next-lower-level river chiefs with respect to corresponding rivers and lakes. The results on water are used as an important basis for overall evaluation of local government leaders at all levels. In addition, institutional arrangements such as the river chiefs' meeting system, the information sharing system, the supervision/guidance/examination system, the inspection and acceptance system, and the evaluation/accountability/incentive system are made to ensure all-round promotion and effective implementation of the river chief system.

Case 8: The Pilot Project for Water-Ecology-Oriented Urban Development
Since 2013, the Ministry of Water Resources has selected 105 typical and representative cities and counties (in two successive groups) with sound basic conditions in which to carry out a pilot project for ecology-oriented urban development. The project aims at exploring experiences and models for restoring and improving water ecology in cities of different levels of development, conditions of water resources, and status of water ecology, and consequently serves as a model for promoting ecological progress nationwide.

In 2015, twenty-five cities out of the first pilot group significantly reduced their total water use compared with their pre-pilot levels; the water quality compliance rate of the water functional zones in 30 pilot cities was higher than the national level; and in 38 pilot cities water consumption per RMB 10,000 of industrial value added was lower than the national level. At the same time, the security of domestic and production water use was effectively safeguarded. Thirty-eight pilot cities achieved 100% compliance in terms of safeguarding the security of centralised drinking water sources. In addition, marked improvements were recorded in ecosystem stability and the human-resident environment. The first group of pilot cities restored 10,268 km^2 of water bodies or wetlands and protected or restored 8021 km^2 of river courses. Eighteen pilot cities achieved a rate of ecological restoration along their rivers and lakes better than 80%; in 20 pilot cities the proportion of the combined length of rivers with Grade I–III water quality was higher than the national average; and black odorous water bodies in urban areas were brought under control.

Jinan was in the first group of cities to pilot ecology-oriented urban development. After three years of pilot efforts, in spite of an average annual GDP growth of 8.8%, the city reduced its total water withdrawal and water use from 1.68 billion m^3 in 2012 to 1.52 billion m^3 in 2015, reduced its water withdrawal per RMB 10,000 of industrial value added from 15.7 to 12.3 m^3, raised its agricultural irrigation water use coefficient to 0.65, and improved its water quality compliance rate in water functional zones from 42.6 to 78.6%. All these effectively improved the water ecological environment in Jinan, ensuring sustainable flow of historic springs. During the pilot period, Jinan, in close connection with the overall municipal situation and its water conditions, performed more than 400 construction tasks, such as connecting the water systems of rivers and lakes, restoration and protection of water ecology, construction of a water saving and discharge reduction system, and cultivation of a water culture in the Spring City. In this process, Jinan focused on restoration and protection. Among other things, it vigorously cultivated water sources and protected the water environment, practised systematic governance and ecological restoration of the agricultural water networks, carried out renewal and supplementary construction and water-saving renovation of existing irrigation areas, reinforced control of rural non-point pollution, and promoted water-system connection of rivers and lakes. These efforts enabled marked improvement of the quality of its water ecology, which is evidenced by the continuing flow of key springs, such as Baotu Spring for 13 years. Thus, Jinan has developed a pattern for constructing a city of water ecological civilisation that is characterised by 'government leadership, inter-agency cooperation, and public participation' (MWR 2016c).

Case 9: Comprehensive Control of Groundwater Overexploitation in Hebei Province

Hebei Province makes up a third of the national total in terms of both the volume and the area of groundwater overexploitation. In early 2014, the Chinese government decided to pilot comprehensive control of ground overexploitation in Hebei Province. It prepared the Plan on Comprehensive Control of Ground Overexploitation in Hebei Province People's Government of Hebei Province 2015) and annual programs on piloting comprehensive control in Hebei Province between 2014 and 2017. The pilot scope covers all major funnel areas in the province.

Comprehensive control of groundwater overexploitation in Hebei Province focuses on ‘saving, diversion, storage, scheduling, and management’ of water resources to implement control measures such as saving water and reducing exploitation. Specific efforts include: accelerating the construction of supplementary works for the South-to-North Water Transfer Project; implementing the Project for Diverting Water from the Yellow River to Supplement Water Flow of Baiyangdian Lake in Hebei Province; adjusting agricultural and industrial water use structures; developing highly efficient water-saving agricultural irrigation; practising shut down/monitoring and metering of wells; promoting comprehensive reform of water tariffs; developing and using unconventional water sources; deepening the reform of the water use rights system; and carrying out pilot projects for collecting a water resources tax. As a result, a comprehensive control system is already in place, which ranges from water sources to farmland, from water works to agronomy, and from construction to operation. In addition, a model for comprehensive control of groundwater overexploitation has taken preliminary shape, which acquires water rights and prices water resources, combines control and management, practises water saving internally and water diversion externally, and comprehensively implements policies and measures.

After three years of implementation, the reduction of groundwater exploitation reached 3.87 billion m^3. In the pilot areas, the dropping of groundwater level has slowed or even reversed in some parts. Fruitful results have been achieved in the pilot efforts to curtail overexploitation of groundwater in Hebei Province.

Case 10: The National Initiative for Education and Communication on Water Resources and Soil and Water Conservation

The Chinese government has always attached importance to communication and education regarding water resources. It has significantly enhanced the perception and awareness of water security in the whole society by cultivating public awareness of water saving and soil and water conservation.

In 2008, the Ministry of Water Resources launched a national communication and education initiative pertaining to the state policy on soil and water conservation. In 2012, it established the Water Education Centre, dedicated to dissemination of water knowledge and communication and education on water resources. In June 2015, the government promulgated the National Plan on Water Education 2015–2020 (MWR et al. 2015), setting the basic principles for scientific and effective water education nationwide. Using multiple approaches such as the construction of physical education platforms, organisation of public activities, and publication of science books, China has established a relatively sound public water education system, attracting growing community participation year by year.

For such annual events as World Water Day and Chinese Water Week, the Ministry of Water Resources carries out water education activities in all dimensions and various forms, as well as from multiple angles, echoing the current year’s themes. Water Saving—On the Way, a large-scale public water-saving advocacy initiative, has been going on for many consecutive years. Under this initiative, the ministry has used public transport facilities as a platform to broadcast and launch a group of outstanding TV programs, public advertisements, and works of literature that strongly promote and foster the healthy trend of understanding, saving, protecting, and cherishing water, as well as a social atmosphere of harmony between people and water. The initiative has attracted the participation of 90 million people to date.

China has established 24 soil and water conservation education and social practice bases (MWR 2017b), 127 national high-tech soil and water conservation demonstration parks, and 19 such parks for primary and secondary schools. A number of online displays have been developed at the same time to become important platforms for the public to participate in interaction and access education on soil and water conservation, as well as for the water sector to popularise the concept of ecological civilisation. Twenty national water education bases have been set up in such locations as the Dujiang Weir and Three Gorges. These water education platforms are models that provide premises for the public to participate in water education events and expand the social impacts of water education.

The Chinese government is actively promoting incorporation of education on soil and water conservation into school curriculums. The Ministry of Water Resources has compiled and published the *Soil and Water Conservation Reader (Elementary School Edition)* (CSSWC 2012) and circulated more than 300,000 copies of science books on soil and water conservation. All these efforts have markedly raised public awareness of soil and water conservation and ecological protection among adolescents. The Ministry of Water Resources has also developed a series of water education readers and produced water education leaflets for the public in general and for civil servants, primary students, and preschool children in particular, providing a variety of media for public education on water security.

3.6 Conclusion

The World Water Council plays an important role in creating the World Water Forum as a dialogue and exchange platform and in committing the world to addressing issues such as global water security. Thanks to the advocacy and influence of the World Water Council, the topic of water security has aroused close international attention at important international water events. The Ministerial Declaration of the Seventh World Water Forum (WWC 2015) called for the strengthening of good governance of water resources at all levels, encouragement of public participation, improvement of infrastructure, enhancement of management systems, and effective solutions to the challenges facing water security. The Political Declaration adopted at the 2016 Budapest Water Summit, co-organised by the Hungarian government and the World Water Council, proposed that water resources be included in the relevant policies of the 2030 Sustainable Development Agenda and that countries strengthen their political and technical cooperation, coordinate the development of water policies pertaining to economy, energy, climate change, health, food, and protection of biodiversity, and effectively ensure water investment and finance for better world water security.

Looking forward, the Chinese government will uphold the new development concept of 'innovation, coordination, green, open, and sharing' and build on the international cooperation opportunities presented by the Belt and Road Initiative to actively build a community of shared future for all humankind. China would like to conduct multi-layer, multi-area exchanges and cooperation in the field of water resources. Through high-level visits, policy dialogues, technical exchanges, personnel training, and mutually beneficial partnerships, China will join hands with other countries and the international community to jointly promote the attainment of the water-related targets on the 2030 Sustainable Development Agenda, build a system of global water governance that is green, safe, efficient, circular, and conservation-oriented, and thereby make new contributions to the well-being of all humankind.

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Chapter 4
Quest for Water Security in Singapore

Cecilia Tortajada and Cheryl Wong

Abstract For decades, the main goal of Singapore in terms of water resources has been to become water-secure. As a result, water availability, accessibility, and affordability have traditionally been decided at the highest political level. Singapore's overall development is linked to a great extent to 'blue development', the amount of water available in sufficient quantity and quality and at affordable prices for the growing number of uses and users in every sector. The city–state aims to be water-secure, self-sufficient, and resilient by 2060, when water consumption will be twice today's level. An important global city, Singapore will continue improving its economic and social conditions to match both local expectations and global prospects. Trends indicate that it will become more urban, more industrialised, and more competitive, which will result in higher water demand. Known for its key policies and innovations, Singapore will have to continue planning within a long-term framework to become water-secure and achieve its overall development goals.

4.1 Introduction

Singapore is a city-state of 719.2 km^2 in Southeast Asia. It has a total population of 5.6 million and a population density of 7797 persons per km^2 (Singapore Department of Statistics 2017a).

Singapore has to be considered within its own context: a small island, and thus area-constrained, that has grown continuously only through land reclamation. It has no natural resources and no hinterland to provide them, and a historical dependence on outside sources of water, energy, and food. These seemingly serious limitations have been overcome, however, with long-term comprehensive planning, key

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policies, and innovation in all the sectors, where the overall development of the city-state, rather than the individual sectors, has been the main priority.

Since independence, when planning for water resources, water security (availability, accessibility, and affordability) has been a main consideration. To become more water-secure, the city-state has developed forward-looking, comprehensive strategies that have ensured that Singapore can meet present and projected requirements (Tan et al. 2008). These strategies have included all aspects of water resources policy, planning, management, development, governance, finance, technology, and most recently, consideration of societal behaviour. This has included diversification of water supply sources within and outside of Singapore; cleaning-up of rivers and waterways; protection of water catchments; water conservation measures; development of infrastructure; wastewater treatment and disposal; production of high-grade reclaimed water for potable and non-potable purposes (known as NEWater); and desalination. The last two have been planned to supplement local catchment and imported water, and they have effectively enhanced water security (Parliament of Singapore 2016a). All this is within a regulatory and institutional framework that is modified and improved when and as required (Tortajada et al. 2013).

The constraints of land area and competing land uses have added complexity to water resources planning and implementation. The constant need to increase provision of water due to population growth and economic and social development forces numerous trade-offs between land use (housing, commerce, industry, defence, farming, fisheries, leisure activities, etc.) and water resources development. In fact, land availability has been the main consideration when deciding on the amount of land that can be converted into watersheds to collect water, and thus on the size of the watersheds; the places where water and wastewater treatment plants, as well as desalination plants, are built; which ones have to be built either underground or on top of existing facilities in the most innovative ways; etc. This balancing act continues until today (Ng 2018; Tortajada et al. 2013).

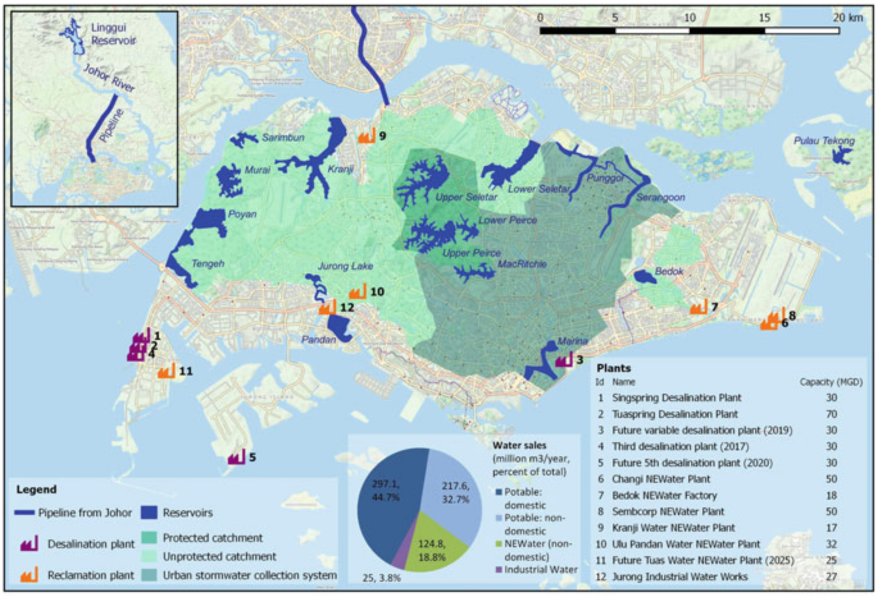
Water resources are strategic for Singapore. Johor, Malaysia, has historically been an important source of water for the city-state, and about 50% of its water is still imported from there. Several water agreements have been signed with this purpose: in 1927 (no longer in force), 1961, 1962, and 1990. This paper will not discuss the agreements or the related differences of opinion in different periods; they have been discussed extensively elsewhere (e.g., Kog 2001; Long 2001; Kog et al. 2002; Lee 2003, 2005, 2010; Ministry of Information, Communications and the Arts 2003; National Economic Action Council 2003; Chang et al. 2005; Saw and Kesavapany 2006; Sidhu 2006; Dhillon 2009; Shiraishi 2009; Luan 2010; Tortajada and Pobre 2011; Tortajada et al. 2013).

Total water demand in Singapore is projected to double by 2060. Long-term water security strategies towards this time horizon include continuing to augmenting supply from local sources and increasing the production capacities of NEWater and desalination. Already, two-thirds of Singapore can be considered water catchment areas where stormwater is collected.

There are plans to increase this proportion to 90%. Regarding NEWater and desalination, PUB (Singapore's National Water Agency) plans to double their production capacities by 2030. By 2060, the two sources are expected to supply up to 85% of Singapore's water requirements. This water portfolio will be decisive to ensure that water is available for all uses and also to reduce vulnerability to climate-related uncertainties (Parliament of Singapore 2016b). Figure 4.1 is a map of Singapore, its water resources and also the water sales figures in 2016.

Climate change is likely to add constraints in terms of water security, and Singapore is already planning for it. Extreme weather events, including heavy rainfall and prolonged dry periods, are projected to occur more frequently, not only in Singapore but across Southeast Asia (Chow 2017). This has been a concern for Singapore for several decades. To develop unconventional sources of water (recycled wastewater and desalination) that do not depend on climate, major investments were made in the 1970s in research and development to support technological developments such as membrane technology and reverse osmosis. The construction of the Marina Reservoir, the most urbanised reservoir on the island, for drinking purposes and flood control, was conceived in the same decade. Four decades on, all these initiatives have been realised (Parliament of Singapore 2010).

In 2014, Singapore experienced a two-month drought, the worst in many decades. February 2014 was the driest month since 1869, with near-zero rainfall. In



Notes: Locations and years of future plants are approximate. Data sources: OpenStreetMap, Google Earth, Singstat and various media articles. Water sales data are for 2015.

Fig. 4.1 Map of Singapore's water resources and water sales figures *Source* Buurman et al. (Forthcoming) neighbouring Malaysia, water rationing was implemented in Johor (from where Singapore imports water), Selangor, Negri Sembilan, Kuala Lumpur, and Putrajaya. In Thailand, 20 provinces were declared drought disaster areas. But in Singapore there was no rationing; in fact, water consumption increased by 5% (Parliament of Singapore 2017a). This has been taken as a sign that Singapore's strategies are on the correct path. But even so, there have been comments that this drought presented an opportunity to implement water conservation strategies (Salleh 2014) that was not realised (Tortajada 2016).

Therefore, within a framework of water security, planning and investment in water resources ahead of time have become even more relevant (Parliament of Singapore 2017c), as has the participation of the population and commercial and industrial sectors in using water more efficiently. The more involved the economic and social sectors are in water conservation, the more secure the city-state will be in the longer term.

Singapore has not followed any specific paradigm that has been prevalent internationally at any time. On the contrary, given its specific characteristics, it has searched for its own most appropriate alternatives, looking for solutions that will be cost-efficient in the long-term. Priorities have changed with time: from water availability to self-sufficiency, then to security and, finally, to resilience. This analysis presents a historical review of the decision-making, policies and practices that have contributed to Singapore's water security. It discusses some of the trade-offs that have been made at different times in terms of land use, energy, and food to develop water resources. In this land-constrained city-state, it has been essential to use land as efficiently as possible and for as high-value uses as possible. This explains many of the decisions taken.

The analysis extensively refers to discussions in the parliament. The objective is to show that water security, trade-offs, and related decisions have been a constant concern for the leadership.

4.2 Water Security: Development of Water, Energy, and Food Resources in Land-Constrained Singapore

The interlinkages and interdependencies among the water, food, and energy sectors in land-constrained Singapore are not intuitive. While in general water is needed for energy and food production, this is not the case in the city-state, which imports nearly 100% of its energy, 90% of its food, and 50% of its water resources. This means that water resources are not necessary to produce energy and that only a small percentage is used for local agriculture. On the other hand, energy is needed to pump, treat, recycle, desalinate, and distribute clean water, especially for production of NEWater and desalinated water. The development of the various sectors, and how they have affected each other when this has been the case, are presented in the following sections.

4.2.1 Development of Water and Energy Resources

The limited land in Singapore means that any land that is available has to be put to the best and most productive possible uses. To make sure that Singapore would have the necessary land for development, it introduced the Land Acquisition Act (Parliament of Singapore 1966b). The act gave the government the power to acquire land for public development. The impacts of this act have been much discussed. In terms of development, because the demand for land was high and escalating due to increasing and competing uses, control of land prices was necessary to ensure that the cost of public projects could be met, including those related to water resources.

At the time of independence in 1965, there were three reservoirs: MacRitchie (formerly Thomson Road Reservoir), Lower Seletar, and Lower Peirce. However, population growth in both urban and rural areas, along with industrialisation, resulted in higher demand for water and electricity.

To develop local capacity for water resources, several projects and reservoirs were built in the 1960s and 1970s. These include the Jurong Industrial waterworks, expansion of Upper Seletar Reservoir, Kranji-Pandan scheme, Chestnut Avenue waterworks, and Murai, Pandan, Poyan, Pulau Tekong, Sarimbun, and Tengeh Reservoirs (Tsang and Perera 2011). Regarding electricity, Phase I of the Pasir Panjang Power Station was completed in 1965, adding 120 megawatts of generating capacity (Parliament of Singapore 1965). The added energy also supported the government's ongoing Rural Electrification Scheme, which brought electricity to 155 *kampongs* (villages) (Parliament of Singapore 1965).

Two pump houses were built in Pontian and Tebrau, in Johor, Malaysia (Mohamad 2015). Approximately at the same time, a booster station was built to increase the pumping capacity of MacRitchie Reservoir (Parliament of Singapore 1965).

The average water consumption of 32 million gallons per day (MGD) in 1949 had increased to over 80 MGD by 1965 (Parliament of Singapore 1965). In August 1969, Seletar Reservoir opened (Parliament of Singapore 1970). It impounded water not only from its own catchment, a protected area where development has not been allowed historically, but also from eight neighbouring streams: the Sembawang, Sembawang Kechil, Simpang Kiri, Bukit Mandai, Mandai, Mandai Kechil, Pang Sua, and Peng Siang. Water from these streams had to be pumped into the reservoir because all eight were at lower elevations (Parliament of Singapore 1970).

Energy was increasingly needed for sewage pumping stations and treatment plants (Parliament of Singapore 1966a). This resulted in the construction of a sewage pumping house in Ulu Pandan (Parliament of Singapore 1967b). The government had the long-term objective to provide sewerage services to the entire island, including urban and rural areas, to prevent water resources being polluted with sewage. However, given the limited human and financial resources, the development of the sewerage scheme was carried out in phases and according to priorities. For example, the developed areas of Toa Payoh, Jurong, Kallang Basin, and other similar big new towns, where new projects were already taking place, were given highest priority so that facilities would be ready in time for population when they moved to the new housing (Parliament of Singapore 1967a).

The sewerage system was continuously expanded, and by 1969 it served over half the population, a significant increase from a quarter of the population in 1949 (Parliament of Singapore 1969).

To serve industrial development, more power stations were built. The power station in Jurong was built to provide electricity for the Jurong Industrial Complex, west of the island. Stage I of the Jurong Power Station was completed in March 1971, with a generating capacity of 120 megawatts. With the increasing demand for power for both housing and industry, construction of Stage II had to start immediately after (Parliament of Singapore 1971). In mid-1974, Stage II was completed, and three more 120 MW units were commissioned (Parliament of Singapore 1975). This was followed by the building of the Senoko Power Station, completed in 1976 (Senoko 1976).

As generating capacity expanded, substantial investments were made to extend the network for transmission and distribution, including to the rural areas (Parliament of Singapore 1966c). In the third quarter of 1974, PUB's 10-year rural electrification programme (Energy Market Authority 2017a) was completed. Through this programme, electricity was provided to rural areas and newly built public housing (Energy Market Authority 2017b). It included approximately 500 projects in 18 stages of implementation. Electricity was now available to all parts of the island, except remote rural sites earmarked for redevelopment (Parliament of Singapore 1975). A 230 kV underground transmission network was constructed to transmit power from Senoko Power Station to load centres on the island (Senoko 1976).

As industrialised and populated land area expanded, more energy was required for water treatment. Water from the Pandan Reservoir initially flowed through an industrialised and populated area and was prone to pollution. To make it safe for human consumption, the water had to undergo more advanced treatment (Parliament of Singapore 1976b). A wastewater treatment plant was also constructed to treat the liquid effluents of the petrochemical complex in Pulau Ayer Merbau.

In 1977, the Ministry of Environment conducted a survey to identify all sources of pollution affecting rivers and water catchments. The main sources of pollution were found to be pigs and ducks, trade and backyard industries, rundown urban areas, squatter pockets, street hawkers, and riverine activities. A programme was developed to coordinate the efforts of the ministries to eliminate such pollution. Together with a clean-up programme, premises would be connected to sewers, reducing the number of premises served by over-hanging latrines and nightsoil buckets. These were phased out by 1987 (Tan et al. 2008).

In rural areas where houses were not due for clearance within the next two years, population had to install their own onsite wastewater treatment systems to treat the wastewater (Parliament of Singapore 1982b). Street hawkers (food sellers) were relocated to proper markets and food centres with treatment facilities. All but one of the pig farms in the Kallang River catchment were relocated. Later, they were phased out or encouraged to change to a different activity. The overall objective was to prevent pollution of the reservoirs (Parliament of Singapore 1982b).

To this end, in 1981, a comprehensive plan was issued to clean up the Singapore River, Kallang Basin, and water catchments by 1987 (Tan et al. 2008; Tortajada et al. 2013; Joshi et al. 2012a, b). This enormous effort was carried out together with the redevelopment of Singapore.

Until the 1990s, Singapore's power stations relied entirely on imported oil to generate electricity (Parliament of Singapore 1981). In response to the oil crises of 1973 and 1979, which affected the world economy, the government came up with a policy to tap alternative sources of energy (Parliament of Singapore 1982a). Power stations were modified so that they could use different types and grades of fuel oil (Parliament of Singapore 1981). In addition, an 80 MW gas turbine was constructed at the Pasir Panjang Power Station to supplement the power supply during peak hours and emergencies (Parliament of Singapore 1981). PUB (then responsible for water, gas, and electricity; now the National Water Agency) converted five boilers at Senoko Power Station to burn gas rather than oil (Parliament of Singapore 1990a). Its 250 MW boilers were modified to use both natural gas and fuel oil (Senoko 2014).

Between 1982 and 1984, the demand for water rose at an increasing rate: in 1982, by 3.5%; in 1983, by 5.1%; and in 1984, by 7.2%. Discussions in the Parliament (Parliament of Singapore 1985b) noted that if Singapore continued consuming water at the current rate, in 15 years, it would need more water than was available in all the reservoirs in Singapore, in addition to the water imported from Johor.

The development of more reservoirs and projects followed. The Western Catchment scheme and Choa Chu Kong waterworks were completed in 1981, and Sungei Seletar, Bedok Scheme, and Bedok waterworks in 1986. Since at that time almost half of Singapore was a catchment area from where rainwater was collected (Parliament of Singapore 1985a), PUB started looking to develop further water resources outside the island. It developed three schemes in Johor to draw the water resources Singapore was entitled to: the extension to the Scudai waterworks, the extension to the Johor waterworks, and the Johor River pipeline (Parliament of Singapore 1985a). Singapore recognised that the scope for further development of surface water resources was seriously constrained. If the rapid growth in consumption continued, more expensive solutions, such as desalination, would be necessary. Desalinated water was calculated to be more than 10 times as expensive as water from the local catchments (Parliament of Singapore 1985a, 1986).

In 1990, Singapore and Malaysia signed a new water agreement as a supplement to the 1962 Johor River agreement. The new agreement allowed Singapore to build a dam across Sungei Linggiu (a tributary of the Johor River) to facilitate the extraction of water from the Johor River (Parliament of Singapore 1989, 1990b). During negotiations between the two countries, it was also agreed that Malaysia would supply Singapore with gas on a long-term basis (Parliament of Singapore 1989).

Also in 1990, to further diversify water sources, Singapore signed a water agreement with Indonesia on ‘economic cooperation in the framework of the development of the Riau Province’. Under this agreement, Singapore and Indonesia agreed to cooperate on the sourcing, supply, and distribution of water to Singapore. The agreement also included cooperation over trade, tourism, investment, infrastructural and spatial development, industry, capital, and banking (Government Gazette 1990). The water agreement provided for the supply of 1000 MGD for 100 years from sources in the Province of Riau. The sources would be harnessed at the appropriate time after evaluating various options, including desalination (Parliament of Singapore 1998b). This water agreement was not implemented. It is now only of historical interest.

In 1995, the power industry was restructured to increase efficiency and competition in both electricity generation and supply, starting with the corporatisation of the Electricity and Gas Departments of PUB to form Singapore Power Ltd. To facilitate competition, Singapore Power was structured as a holding company with five separate subsidiaries: two generation companies (PowerSenoko and PowerSeraya), a transmission and distribution company (PowerGrid), a supply company (Power Supply), and a piped-gas company (PowerGas). Another power station being built in Tuas was put under a separate company, Tuas Power Ltd, owned directly by Temasek Holdings, so that it could compete against the Singapore Power generation companies. To facilitate competition in the generation and supply sectors, the Singapore Electricity Pool was established as an exchange for trading electricity. In March 1999, the government decided that the next step in restructuring the electricity industry was for Singapore Power to fully divest its generating companies to Temasek Holdings in 2001. This separated ownership of the generators from the transmission and distribution network. In 2001, there were several competing generation companies: PowerSenoko, PowerSeraya, Tuas Power, and SembCorp Cogen.

The government continued looking for additional local water sources. With experts’ support, PUB carried out geophysical and hydrogeological investigations of groundwater resources. None were found, even at relatively great depths. Therefore, PUB focused on unconventional sources of water: desalination, and sources of non-potable water to supplement mainly non-potable uses (Parliament of Singapore 1998a). In 2002, after years of investment in research and development, NEWater was introduced with the first plant in Bedok. It was used for industries which required large quantities of high-grade water, such as wafer fabrication plants (Parliament of Singapore 2001a). In September 2005, PUB also introduced desalinated water, as its cost had reached an affordable level (Parliament of Singapore 2003a); the first plant was established in Tuas.

NEWater and desalination are energy-intensive processes, raising energy demand (Parliament of Singapore 2003a). Energy is necessary to treat and produce freshwater, to pump it to the reservoirs, and later on to distribute it. NEWater is very clean, and blending it with reservoir water is not necessary. It also requires more energy. However, Singapore has implemented this practice following the recommendations of an international panel of experts (Parliament of Singapore 2003a, b). NEWater is less energy-intensive and cheaper to produce than desalinated water. Therefore, it has been produced in larger amounts. Each of the NEWater plants has a separate reticulation system to distribute the water to the industrial estates and commercial areas where it is used (Parliament of Singapore 2003a, b). NEWater has become one of the main sources of water for the city-state (PUB n.d.).

Information on the energy used for all water-related activities is not publicly available. However, we have compiled data from several sources on the amount of electricity supplied in the system between 1963 and 2016. It is presented in Table 4.1. According to Singapore Power (SP) between 1995 and 2002 this includes energy generated from power stations and waste-to-energy incineration plants from the then Ministry of Environment (ENV) now Ministry of the Environment and Water Resources (MEWR). From 1995 to March 1998, the electricity generated data was made up of generation from power stations plus purchase from ENV (energy sent out to grid). Due to the formation of Singapore Electricity Pool (SEP) in Apr 1998, the purchase from ENV data has since changed to generation from ENV. With the introduction of autoproducers in 2000, the generation data also includes generation from autoproducers (personal correspondence with Singapore Power, November 2017). According to Energy Market Authority (EMA), 2003 onwards, the data includes electricity from power station and waste-to-energy plants (WEP) (personal correspondence with EMA, November 2017).

In terms of fuel, according to the Energy Market Authority (2016), oil used to be the predominant fuel. From 2001, it changed to natural gas with which approximately 95% of electricity in Singapore used to be generated, most of it via pipelines from Indonesia and Malaysia. A Liquefied Natural Gas terminal was opened in May 2013 allowing the city-state to import from markets globally. In 2016, natural gas accounted for 95.2% of fuel mix, same percentage since 2014. Main Power Producers represented 93.2% of total electricity generated, with the remaining 6.8% generated by autoproducers (Energy Market Authority 2017c).

4.2.2 Development of Water Resources and Food Production

Efforts to keep the reservoirs clean have had an impact on Singapore's food production. Farming and pig-raising activities have been relocated in some cases and phased out in others. In 1965, family farming was considered an essential element of food security (Chou 2015; Kai 2012/2013). There were 20,000 farms, using approximately 25% of the land (145 km^2), and producing 60% of the vegetables that were consumed on the island.

Table 4.1 Total units of electricity supplied in the system in Singapore, 1963–2016 (based primarily on PUB annual reports)

Year	Total units of electricity supplied in the system	Sources
1963	822,922,790 kWh	Public Utilities Board Annual Report 1964 (p. 29)
1964	914,232,150 kWh	1. Public Utilities Board Annual Report 1964 (p. 29) 2. Public Utilities Board Annual Report 1965 (p. 31)
1965	1,047,583,900 kWh	1. Public Utilities Board Annual Report 1965 (p. 31) 2. Public Utilities Board Annual Report 1966 (p. 50)
1966	1,236,471,850 kWh	1. Public Utilities Board Annual Report 1966 (p. 50) 2. Public Utilities Board Annual Report 1967 (p. 32)
1967[a]	1,424,434,000 kWh (reference 1) 1,424,534,000 kWh (reference 2)	1. Public Utilities Board Annual Report 1967 (p. 32) 2. Public Utilities Board Annual Report 1968 (p. 24)
1968	1,639,449,100 kWh (reference 1) 1,639 million kWh (reference 2)	1. Public Utilities Board Annual Report 1968 (p. 24) 2. Public Utilities Board Annual Report 1969 (p. 18)
1969	1876 million kWh (reference 1) 1,876.1 million kWh (reference 2)	1. Public Utilities Board Annual Report 1969 (p. 18) 2. Public Utilities Board Annual Report 1970 (p. 17)
1970	2,205.2 million kWh (reference 1) 2,205,207,100 kWh (reference 2)	1. Public Utilities Board Annual Report 1970 (p. 17) 2. Public Utilities Board Annual Report 1971 (p. 16)
1971	2,585,272,000 kWh	1. Public Utilities Board Annual Report 1971 (p. 16) 2. Public Utilities Board Annual Report 1972 (p. 18)
1972	3,143,560,910 kWh	1. Public Utilities Board Annual Report 1972 (p. 18) 2. Public Utilities Board Annual Report 1973 (p. 19)
1973	3,719,368,250 kWh	1. Public Utilities Board Annual Report 1973 (p. 19) 2. Public Utilities Board Annual Report 1974 (p. 16)
1974	3,864,322,500 kWh	1. Public Utilities Board Annual Report 1974 (p. 16) 2. Public Utilities Board Annual Report 1975 (p. 22)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1975	4,175,980,480 kWh (references 1 and 2) 4,175.7 GWh (reference 3)	1. Public Utilities Board Annual Report 1975 (p. 22) 2. Public Utilities Board Annual Report 1976 (p. 24) 3. Department of Statistics Singapore 2017[b]
1976	4,604,920,600 kWh (references 1 and 2) 4,604.9 GWh (reference 3)	1. Public Utilities Board Annual Report 1976 (p. 24) 2. Public Utilities Board Annual Report 1977 (p. 20) 3. Department of Statistics Singapore 2017
1977	5,114,681,650 kWh (reference 1) 5,114.68 million kWh(reference 2) 5,114.7 GWh (reference 3)	1. Public Utilities Board Annual Report 1977 (p. 20) 2. Public Utilities Board Annual Report 1978 (p. 30) 3. Department of Statistics Singapore 2017
1978	5,897.99 million kWh (reference 1) 5,897.9 GWh (reference 2)	1. Public Utilities Board Annual Report 1978 (p. 30) 2. Department of Statistics Singapore 2017
1979[c]	6483 million kWh (reference 1) 6483 million kWh(Adding the values from references 2 and 3)	1. Public Utilities Board Annual Report 1979 (p. 22) 2. Public Utilities Board Annual Report 1979 (p. 23): 35.2 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017[d] *Electricity generated from power stations:* 6,447.8 GWh
1980	6,967.2 million kWh (Adding values from references 1 and 2) 6,967.7 million kWh (Adding the values from references 2 and 3)	1. Public Utilities Board Annual Report 1980 (p. 29): 6940 million kWh *generated from power stations* 2. Public Utilities Board Annual Report 1980 (p. 29): 27.2 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 6,940.5 GWh
1981	7,462 million kWh (Adding the values from references 1 and 2) 7,461.9 million kWh (Adding the values from references 2 and 3)	1. Public Utilities Board Annual Report 1981 (p. 22): 7442 million kWh *generated from power stations* 2. Public Utilities Board Annual Report 1981 (p. 22): 20 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 7,441.9 GWh

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1982	7884 million kWh (Adding values from references 1 and 2) 7,883.5 million kWh (Adding values from references 2 and 3)	1. Public Utilities Board Annual Report 1982 (p. 21): 7860 million kWh *generated from power stations* 2. Public Utilities Board Annual Report 198 (p. 21): 24 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 7,859.5 GWh
1983	8665 million kWh (Adding values from references 1 and 2) 8,664.9 million kWh (Adding values from references 2 and 3)	1. PUB Annual Report 1983 (p. 21): 8626 million kWh *generated from power stations* 2. PUB Annual Report 1983 (p. 21): 39 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 8,625.9 GWh
1984	9452 million kWh (Adding values from references 1 and 2) 9,451.7 million kWh (Adding values from references 2 and 3)	1. PUB Annual Report 1984 (p. 21): 9421 million kWh *generated from power stations* 2. PUB Annual Report 1984 (p. 21): 31 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 9,420.7 GWh
1985	9917 million kWh (Adding values from references 1 and 2) 9,917.3 million kWh (Adding values from references 2 and 3)	1. PUB Annual Report 1985 (p. 17): 9876 million kWh *generated from power stations* 2. PUB Annual Report 1985 (p. 17): 41 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 9,876.3 GWh
1986	10,576 million kWh (Adding values from references 1 and 2) 10,576.5 GWh (reference 3)	1. PUB Annual Report 1986 (p. 17): 10,466 million kWh *generated from power stations* 2. PUB Annual Report 1986 (p. 17): 110 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017[e] *Electricity generated:* 10,576.5 GWh
1987	11,814 million kWh (Adding values from references 1 and 2) 11,813.8 GWh (reference 3)	1. PUB Annual Report 1987 (p. 18): 11,625 million kWh *generated from power stations* 2. PUB Annual Report 1987 (p. 18): 189 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 11,813.8 GWh
1988	13,017 million kWh (Adding values from references 1 and 2) 13,017.5 GWh (reference 3)	1. PUB Annual Report 1988 (p. 18): 12,821 million kWh *generated from power stations* 2. PUB Annual Report 1988 (p. 18): 196 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 13,017.5 GWh

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1989	14,039 million kWh (Adding values from references 1 and 2) 14,038.9 GWh (reference 3)	1. PUB Annual Report 1989 (p. 19): 13,847 million kWh *generated from power stations* 2. PUB Annual Report 1989 (p. 19): 192 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generate:* 14,038.9 GWh
1990	15,618 million kWh(Adding values from references 1 and 2) 15,617.6 GWh (reference 3)	1. PUB Annual Report 1990 (p. 29): 15,398 million kWh *generated from power stations* 2. PUB Annual Report 1990 (p. 29): 220 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 15,617.6 GWh
1991	16,597 million kWh (Adding values from references 1 and 2) 16,596.6 GWh (reference 3)	1. PUB Annual Report 1991 (p. 16): 16,374 million kWh *generated from power stations* 2. PUB Annual Report 1991 (p. 16): 223 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 16,596.6 GWh
1992	17,543 million kWh (Adding values from references 1 and 2) 17,543.1 GWh (reference 3)	1. PUB Annual Report 1992 (p. 17): 17,283 million kWh *generated from power stations* 2. PUB Annual Report 1992 (p. 17): 260 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 17,543.1 GWh
1993	18,962 million kWh (Adding values from references 1 and 2) 18,962.4 GWh (reference 3)	1. PUB Annual Report 1993 (p. 19): 18,508 million kWh *generated from power stations* 2. PUB Annual Report 1993 (p. 19): 454 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 18,962.4 GWh
1994	20,675 million kWh (references 1 and 2) 20,675.4 GWh (reference 3)	1. PUB Annual Report 1994 (p. 19): 20,234 million kWh *generated from power stations* 2. PUB Annual Report 1994 (p. 19): 441 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated:* 20,675.4 GWh
1995	16,447 million kWh (references 1 and 2)[f] 22,057.4 GWh (reference 3)	1. PUB Annual Report 1995 (p. 33): 16,156 million kWh *generated from power stations* 2. PUB Annual Report 1995 (p. 33): 291 million kWh *purchased from Ministry of ENV* 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 22,057.4 GWh
1996	24,101 GWh (reference 1) 23,909.4 GWh (reference 2)[g]	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 23,909.4 GWh

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Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
1997	26,898 GWh(reference 1) 26,709.4 GWh (reference 2)[h]	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 26,709.4 GWh
1998	28,424 GWh(reference 1) 28,374.8 GWh (references 2 and 3)[i]	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 28,374.8 GWh 3. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
1999	29,520 GWh (reference 1) 29,520.1 GWh (references 2 and 3)	1. PUB Annual Report 1999 (p. 17) 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 29,520.1 GWh[j] 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305)
2000	31,665 GWh (reference 1)	1. Department of Statistics Singapore 2017[k] *Electricity generated from power stations:* 31,665 GWh
2001	33,061.0 GWh (references 1 and 2)	1. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 33,061 GWh 2. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309)
2002	34,664.6 GWh (reference 1)	1. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 34,664.6 GWh
2003	35,281.5 GWh (references 1 and 2)	1. Department of Statistics Singapore 2017[l] *Electricity generated from power stations:* 35,281.5 GWh 2. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2004	36,809.6 GWh (references 1 and 3) 36,809.5 (reference 2)	1. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 36,809.6 GWh 2. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305)

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Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		3. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2005	38,212.7 GWh (references 1–4)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 38,212.7 GWh 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 4. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2006	39,480.4 GWh (references 1 and 2) 39,442.0 GWh (reference 3) 39,480.1 GWh (reference 4) 39,442.1 (reference 5)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 39,480.4 GWh 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 4. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327) 5. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2007	41,134.1 GWh (references 1 and 2) 41,134.2 GWh (references 3, 4 and 5) 41,137.7 GWh (reference 6)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 41,134.1 GWh 3. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		4. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 5. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327) 6. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2008	41,669.1 GWh (reference 1) 41,669.6 GWh (reference 2) 41,716.7 GWh (reference 3) 41,716.8 GWh (references 4, 5 and 7) 41,669.7 GWh (reference 6)	1. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 2. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 41,669.6 GWh 3. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 4. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 5. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 6. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327) 7. 2009, Yearbook of Statistics Singapore, Electricity generation and sales
2009	41,800.6 GWh (references 1–6) 41,816.7 GWh (reference 7)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 41,800.6 GWh

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Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		4. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 5. 2010, Yearbook of Statistics Singapore, Electricity generation and sales (1999, 2004–2009), http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=BE7056BA1A86D1FAF2BB809EBE273448?doi=10.1.1.186.7755&rep=rep1&type=pdf (p. 305) 6. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 7. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006-2012) (p. 327)
2010	45,366.5 GWh (references 1–5) 45,367.8 GWh (reference 6) 45,366.4 GWh (reference 7)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 45,366.5 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 6. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 7. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327)

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Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
2011	45,999.4 GWh (references 1–5) 45,999.3 GWh (reference 6) 45,998.4 GWh (reference 7)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 45,999.4 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330) 6. 2012, Yearbook of Statistics Singapore, Electricity generation and sales (2001, 2006–2011), http://staging.ilo.org/public/libdoc/igo/P/70490/70490(2012)319.pdf (p. 309) 7. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006-2012) (p. 327)
2012	46,936.2 GWh (references 1–5) 46,936.0 GWh (reference 6)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 46,936.2 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
		6. 2013, Yearbook of Statistics Singapore, Electricity generation and sales (year 2006–2012) (p. 327)
2013	47,963.5 GWh (references 1–4) 47,948.4 GWh (reference 5)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 47,963.5 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330)
2014	49,309.65 GWh(references 1 and 2) 49,309.7 GWh (references 3 and 4) 49,304.5 GWh (reference 5)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 49,309.7 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343) 5. 2015, Yearbook of Statistics Singapore, Electricity generation and consumption (2008–2014), http://istmat.info/files/uploads/50355/yearbook_of_statistics_singapore_2015.pdf (p. 330)

(continued)

Table 4.1 (continued)

Year	Total units of electricity supplied in the system	Sources
2015	50,271.6 GWh (references 1–4)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 50,271.6 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 343)
2016[m]	51,586.6 GWh (references 1–4)	1. 2017, Energy Market Authority, Total electricity generated (monthly and yearly) https://www.ema.gov.sg/statistic.aspx?sta_sid=20140802apItNJRIa9Pa 2. 2017, Energy Market Authority, Electricity Balance Table, 2005–2016, https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Statistics/15RSU.pdf 3. Department of Statistics Singapore 2017 *Electricity generated from power stations:* 51,586.6 GWh 4. Yearbook of Statistics Singapore 2017, http://www.singstat.gov.sg/docs/default-source/default-document-library/publications/publications_and_papers/reference/yearbook_2017/yos2017.pdf (p. 339, p. 343)

[a]There is an inconsistency in reported amounts of total units of electricity supplied in the system in certain years. For example, in 1967 in the 1967 and 1968 PUB annual reports. This is indicated in all the cases

[b]Department of Statistics Singapore (Singstat), M890841—Electricity Generation and Consumption, Annual, http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=3726

[c]According to the 1979 PUB Annual Report, PUB started purchasing electricity from the Ministry of the Environment's (ENV) waste-to-energy (WTE) incineration plant in 1979. Hence, the value for the total units of electricity supplied in the system from 1979 onwards includes electricity generated from the power stations and electricity bought from ENV's WTE plants

[d]Data from Singstat for years 1979–1985 only reflects the amount of electricity generated from power stations and does not include the amount of electricity bought from ENV's WTE plants

[e]Singstat data started accounting for electricity bought from ENV's WTE plants, in addition to electricity generated by power stations, for years 1986–1994. This is in contrast to footnote d whereby the same Singstat dataset did not account for electricity bought from ENV's WTE plants for years 1979–1985

[f]There may be an error in the electricity generation values from the 1995 PUB report as it had mentioned that there was a 7.0% increase in electricity generated in 1995 compared to the year

1994 (p. 33). This would mean that the total electricity supplied in 1995 should be 22,122.3 GWh. Yet, this value does not correspond with the Singstat value. However, Singapore Power (the data source for the Singstat electricity generation data for years 1995–2002) has confirmed that the Singstat data for the year 1995 includes electricity generated from the power stations and electricity bought from ENV's WTE plants (SP, personal correspondence, November 2017)

[g]From years 1996 to 1998, electricity generation values reported by Singstat are lower than the electricity generation values reported by the PUB annual reports. However, Singapore Power (the data source for the electricity generation data for Singstat from 1995 to 2002) has confirmed that the Singstat data for years 1996–1998 includes electricity generated from the power stations and ENV's WTE plants (SP, personal correspondence, November 2017)

[h]Refer to footnote g

[i]Refer to footnote g. Up till March 1998, the Singstat electricity generation data consisted of electricity generated from power stations plus electricity purchased from the ENV's WTE plants. However, due to the formation of Singapore Electricity Pool (SEP) in Apr 1998, "purchase from ENV" data has since changed to "generation from ENV" (SP, personal correspondence, November 2017)

[j]Same Singstat source as the data obtained for years 1995–1998 where the values differ from that reported in the PUB annual report (footnotes f and g), but the value for year 1999 corresponds with the 1999 PUB annual report value

[k]With the introduction of Autoproducers in year 2000, the generation data from year 2000 onwards also includes generation from Autoproducers (SP, personal correspondence, November 2017). Autoproducers are "enterprises that produce electricity but for whom the production is not their principal activity". Source: https://www.ema.gov.sg/cmsmedia/Publications_and_Statistics/Publications/SES%202016/Publication_Singapore_Energy_Statistics_2016.pdf (pg 22)

[l]The Energy Market Authority (the data source for the electricity generation data for Singstat from 2003 onwards) has confirmed that the Singstat data for electricity generation from 2003 onwards includes both energy generated from power stations and ENV's WTE plants (EMA, personal correspondence, November 2017)

[m]From Jan. 2016, the data incorporates output from solar generation: http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=3726

As Singapore developed, farming changed from traditional to more intensive and high-tech. Farms became fewer in number and smaller in size. Between 1960 and 1967, in spite of the shrinking farmland, the value of production of vegetables, pigs, fowl, ducks, cattle, goats, and eggs was SGD 285 million. Between 1964 and 1990, family farms achieved near self-sufficiency in pigs, poultry, and eggs. They also produced leafy vegetables throughout the year for the local markets (Chou 2015).

However, farming and animal raising were increasingly associated with pollution of water resources. For example, the catchment area of one of the reservoirs, Seletar Reservoir, was inhabited mainly by squatters and vegetable, pig, and poultry farmers (Parliament of Singapore 1968). Additionally, the catchment area of the eight streams that carried water to the reservoir, approximately 8000 acres, was unprotected (Parliament of Singapore 1970) and thus exposed to pollution sources. In 1968, when Seletar Reservoir was built, it was not possible to resettle the farmers and their activities to keep the waters clean. Instead, latrines, cess-pits, and pigsties were constructed. The cost was divided between the government and the farmers (Parliament of Singapore 1968, 1970).

In 1970, a total of 361 pigsties were relocated and 692 demolished in the eight catchment areas (Parliament of Singapore 1970). Five years later, due to pollution from pig waste in Kranji Reservoir, the government decided to acquire certain parts of Punggol, in the northeast of Singapore, for the pig-farming industry. Numerous families were relocated there (Parliament of Singapore 1976a). Farmers who were not deemed *bona fide* were not allowed to retain their plots of farmland, and some were given compensation in the form of three-room apartments, as an *ex gratia* payment (Parliament of Singapore 1976a). Over a period of six years, 547,000 pigs were relocated to Punggol (Tortajada et al. 2013). Fishing was also affected by development activities. With the construction of Changi Airport, 25 *kelongs* (fish farms) had to move because of land reclamation. This affected the livelihood of 60 fishermen and their families (Parliament of Singapore 1976a).

In 1980, the government decided that farming would not be subsidised but that it would become fully commercial. In 1984, in its most important policy on food security, the government decided not to pursue food self-sufficiency. Since land had been always limited, Singapore would not use it for traditional agriculture to achieve self-sufficiency but instead would import food from the global markets and focus on producing goods and services in which it would have a competitive advantage (Goh 1984).

Farmers who decided to retire received a one-time compensation grant. Those who were not using land required for development and who wanted to keep their farms could keep them, as long as they were able to control pollution within specific standards (Parliament of Singapore 1984b). Following the reduction in agricultural land and employment, overall production declined irreversibly, with pig farms disappearing in 1989–1990 (De Koninck et al. 2008).

Measures put in place to protect water resources included not only reducing farming and animal-raising activities, but also limiting development. Between 1983 and 1999, overall urbanisation was capped at 34.1%, and a population-density limit of 198 dwelling units per hectare was imposed on anticipated developments up to 2005 (Tan 2015; Tortajada et al. 2013).

Table 4.2 presents an overview of the 1983 Water Catchment Policy. The timeframe for the policy dates back to 1971, with the establishment of the Pollution Survey Unit, enactment of legislation such as the Water Pollution Control and Drainage Bill and Environment Pollution Bill, pollution control measures, caps on urbanisation and population density, and so on.

The 1983 Water Catchment Policy ended in 1999, when the urbanisation and population-density limits were lifted, subject to strict water pollution control measures. Less intensive development and more stringent pollution control measures enabled Singapore to ensure the good quality of the water collected even from unprotected sources.

In terms of farming, the Primary Production Department, responsible for developing and regulating the local farming industry, was also given the responsibility to open investment opportunities for the development of agro-technology projects and services in aquaculture, horticulture, livestock, and other services. Farmland was transformed into agro-technological parks for high-technology

Table 4.2 1983 Water catchment policy

Timeframe	Historical development/milestone
1971	Pollution Survey Unit is set up. Initially meant to serve the Kranji/Pandan Reservoir Scheme, it eventually oversaw all anti-pollution work in connection with the water supply
1972	The Ministry of National Development announces that farms would be planned to reduce the pollution of water by pig waste in the catchment areas of the Kranji and Pandan Reservoirs
1974	Cabinet discussion on high-rise pig farming
1975	Relocation of pig farms
1975	Introduction of the Water Pollution Control and Drainage Bill for more effective protection of water resources and prevention of water pollution. Population growth and rapid industrial and economic development in the past 10 years had led to a corresponding increase in the demand for water and, with rising affluence, a demand for a healthier and cleaner environment In the Kranji and Pandan catchment areas, pig farms and some polluting industries have to move to non-catchment areas. In the catchment areas, only non-polluting industries and activities are allowed. All wastewater from premises, including trade effluent, has to be discharged into the sewers to minimise the pollution of water in streams and canals, some of which feed into reservoirs Authority for sewage, drainage and water pollution control is vested in the Director of Water Pollution Control and Drainage, who also has the powers to control the quality, extraction, storage, and use of water in Singapore
1977	Further discussion of the resettlement of farmers. Sembawang Pig Farm, under the Primary Production Department, is eliminated. Protecting the supply of water is deemed more important than the rearing of pigs. An alternative pig farming area is developed in Punggol
1982	Decision to phase out all nightsoil buckets by 1984, because their use increased the risk of infectious diseases and the workforce of nightsoil workmen was dwindling Installation of R2 wastewater treatment system
1983	Introduction of the 1983 Catchment Policy. Key provisions: • Housing Development Board is allowed to develop to its normal density of 198 dwelling units/ha • Developed land is restricted to 34.1% of unprotected water catchment area, excluding the water surface • A list of pollution control measures is agreed between the Ministry of Environment and the Ministry of National Development
1983	New section 14A of the Water Pollution Control and Drainage Act prohibits the discharge of toxic substances into any inland water. Penalties include fines and imprisonment. This came about due to the threat of water contamination of one reservoir through indiscriminate dumping of toxic waste
1984	Pig farms are phased out
1989	PUB accommodates recreational activities in the reservoirs and catchment areas that do not pollute the waters, such as fishing and paddle boating

(continued)

Table 4.2 (continued)

Timeframe	Historical development/milestone
1999	The Water Pollution Control and Drainage Act is consolidated with the Clean Air Act and the Drainage Act under the new Environment Pollution Bill. Part V of the new bill deals with water pollution control. Some key points: • Under Clause 15, any person who intends to discharge trade effluent, oil, chemical, sewage or other polluting substances into any drain or land must obtain a licence • Clause 16 requires any occupier to treat such trade effluent before it is discharged • Clause 17 prohibits the discharge of any toxic or hazardous substance into any inland water • Clause 18 empowers the Ministry of Environment to require any person who has discharged any polluting matter onto any land or into any drain or sea to remove and clean up that substance or matter within a specified time • Clause 19 empowers the Ministry of Environment to require any person to take measures to prevent water pollution due to the storage or transportation of toxic substances or other polluting matters
1999	Pollution control measures for golf courses within water catchments: • Water quality of runoff closely and regularly monitored • Use of pesticides and chemical fertilisers in golf courses regulated to prevent pollution
1999	A review of the Water Catchment Policy concludes that water pollution control measures have been largely successful, and therefore land in unprotected catchments could be opened up for other uses beyond housing • Urbanisation cap and population-density limit are also removed • Water treatment plants are upgraded to cater to water from developed areas • Stringent pollution control measures continue to be enforced to prevent water pollution from community-based activities

Source Centre for Liveable Cities and PUB National Water Agency (2012) WATER: From Scarce Resource to National Asset. Singapore's Urban Systems Studies Booklet Series. Ministry of National Development and Ministry of Environment and Water Resources. Singapore: Cengage Learning Asia

farming (Ministry of National Development 1989). In April 2000, the Primary Production Department was restructured into a statutory board, the Agri-Food & Veterinary Authority with broader responsibilities. These include diversification of food resources globally and simultaneously developing the city-state into a regional centre for agrotechnology and agri-business (Agri-Food & Veterinary Authority of Singapore n.d.)

By 2000, local farm production supplied only 1.5% of the poultry, 10% of the fish, 30% of the eggs, and 6% of the vegetables consumed in Singapore. Most of the primary food requirements have been met for years from overseas sources. This heavy dependence on food imports may make Singapore vulnerable to disruptions of primary food supplies due to unforeseen circumstances at the source. Therefore, the Agri-Food & Veterinary Authority's strategy is to continually diversify sources of food (Tortajada and Zhang 2016) and increase trade of agricultural and food products through Singapore (Parliament of Singapore 2000).

Singapore has just launched a Farm Transformation Plan, trying to implement next-generation farming concepts where more local produce is obtained with less resources: less land, less labour, and less water. More vertical spaces, roof-tops and under-utilised spaces would be used more efficiently and more productively (Urban Redevelopment Authority 2017). This plan is part of the Three National Food Baskets: imports from around the world, internationalisation (which includes opening new markets), and local production. Farming will continue to be a fundamental part of Singapore's future, but it will have to be different: more modern, more efficient, more productive, and more innovative (Parliament of Singapore 2017b).

Water security has been a concern for Singapore for decades, but so have food and energy security. Singapore has learnt that the only way to progress is to plan for the long-term, and the future will not be different.

4.3 Lessons Learnt and Looking to the Future

In Singapore, water security has been understood in its broadest sense, going well beyond the traditional definitions. It has meant an overarching strategy using policies, laws, and regulations that are updated as required; systems of governance; a national water agency that is responsible for the entire water cycle (water supply, sanitation, desalination, and wastewater that is recycled and supplied for potable and non-potable uses); business plans to make commercial use of recycled water; educational and awareness strategies that contemplate every sector of society; research and development; and technology.

One of the characteristics of Singapore in its search for water security has been innovation. Its limited natural resources, small size, and historical dependence on outside sources of water, energy, and food, instead of holding back its development, have triggered numerous innovations in planning, management, development, governance, research, and technology adoption. These innovations have been the result of numerous discussions at the policy and political levels. They have been thoroughly discussed because they have been meant to be implemented in the most pragmatic manner. Even after implementation, there has been room for experimentation, and even then, there is still room for improvement.

PUB has made major investments to build up water supply sources, including development of local catchments and imported water from Johor, protection of water resources, and production of freshwater through NEWater and desalination. All the investments have borne fruit. The water portfolio has contributed to water security and is expected to continue contributing more in an uncertain future where change will be the only certitude.

Singapore cannot be compared to many cities due to its unique position as an island. Addressing and resolving most difficulties has proven even more critical due to the lack of hinterland to rely on for natural resources and the state of dependence in drawing part of its water, food, and energy resources from outside sources. This has meant that the small island has always absorbed the adverse impacts of growth on the environment. But it has also meant that all development-related decisions have traditionally been dealt with at the highest political level (Ng 2018).

The broad vision of Singapore for water resources has relied on holistic planning that has gone well beyond the boundaries of the water sector to focus on its overall development. As discussed by Neo and Chen (2007), policymaking has followed a 'think ahead, think again and think across' philosophy that proposes a comprehensive, holistic vision including for the management of water resources. Within this philosophy, decision-making considers possible future events (think ahead), re-evaluates and modifies decisions in the light of different scenarios (think again), and looks for experience and know-how worldwide to enrich its pool of knowledge (think across).

To augment its water resources to provide clean water to all users and for all uses, under uncertain conditions, the city-state will have to develop an even more comprehensive strategy that focuses much more on water demand and that leverages pricing, more public engagement, and the understanding of human behaviour. Behavioural economics, a new field of knowledge, has the potential to provide new ways of reducing water use, which, in turn, could provide a much-needed new 'water source'.

Given its goal of water security, Singapore's plans for future overall development will have to pay more attention to societal responses. Unless society becomes part of the water security and resilience processes, difficult times lie ahead for the city-state.

Singapore has excelled in the past, but the future is uncertain. Its water supply systems may still not be robust enough to cope with prolonged droughts, and energy availability and prices do not depend on the city-state. Planning will have to consider more innovations to face the uncertain future. This will require not only all that has been learnt in the past, but also much more of the highly structured and forward-looking policy innovation and implementation that has guided the city-state so far.

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Chapter 5
Current and Future Challenges of Water Security in Central Asia

Stefanos Xenarios, Ronan Shenhav, Iskandar Abdullaev and Alberto Mastellari

Abstract The notion of water security in Central Asia has evolved throughout the years in an attempt to control an extensive transboundary river network which divides the region between upstream (Kyrgyzstan, Tajikistan) and downstream (Uzbekistan, Kazakhstan, Turkmenistan) countries. In Soviet times, the belief in engineering and technical supremacy over nature was applied in the installation of numerous hydraulic facilities and mechanical interventions. Water for energy was provided by a series of hydropower stations upstream, while downstream, extended supply and drainage networks and large pumping stations served mainly cotton monoculture. After independence in 1991, water security in the newly established downstream states became synonymous with sufficient irrigation volume for agricultural production, while upstream, water security was interpreted as increased hydropower capacity. Still, however, the transboundary nature of water resources in Central Asia determines to a large extent the need for coordinated national policies and compromises between the Central Asian countries for the attainment of water security in the region. The current study indicates the geophysical, institutional, and historical challenges to be met for the mutual understanding of water security among these five countries. The newly introduced river basin management approach is presented as a crucial reform that may improve common initiatives in water resources management between the riparian countries. Attention is given to the increased effort to be made by interstate and regional organisations in the implementation of feasible and effective solutions for better allocation of transboundary water resources in Central Asia.

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5.1 Introduction

Central Asia (CA) is one the few regions in the world where water security is inextricably linked with energy, food, and the environment. The geophysical diversity of CA encompasses great mountain ranges and abundant freshwater sources but also steppes and arid landscapes, which fosters diverse notions of water security in the region.

The countries of Tajikistan and Kyrgyzstan host the mountains of Karakoram, Pamir, and Tien Shan, called the 'water towers' of CA and hosting some of the largest glaciers in the world outside of the polar regions (Davies 2017). A vast river network is formed in these two countries which crosses the entire region before flowing into the Aral Sea. The downstream countries of Turkmenistan, Uzbekistan, and Kazakhstan are situated on large plains along these rivers, which have been mainly converted to extensive irrigated lands; they are also endowed with abundant hydrocarbon (coal, oil, and gas) resources (Sehring and Diebold 2012).

All CA countries have undergone a Soviet Union past in which water security was clearly understood as a multidimensional factor dependent on energy, agricultural, and environmental aspects (Freedman and Neuzil 2015). In the Soviet era, the water-rich upstream countries provided water for irrigation to downstream countries in spring and summer. In exchange, they were supplied with coal, oil, and gas for heating and electricity in the winter months. Upstream countries also received staple crops and other agricultural and industrial products.

However, major intensification of agricultural production, focusing mostly on cotton production, and over-abstraction of surface water in all of CA, came at a high price for the environment, of which the best-known example is the degradation and shrinking of the Aral Sea. The degradation of the natural environment and mainly water resources in CA had major repercussions for water, energy, and food which are still apparent today (Malsy et al. 2012).

National aspirations and the struggle for state-building following independence in 1991 shifted the concept of water security from a regional approach to country-focused policies, in which geopolitical interdependence seemed to be of secondary importance (Zakhirova 2013). In the upstream countries, water security is mainly interpreted as energy independence, reduction of disasters stemming from water, and sufficient agricultural water for irrigation and pastoralism. For downstream countries, water security mostly means intensified agriculture, fisheries, and pastoralism, and reduction of water scarcity incidents. However, the transboundary water resources in CA are of paramount significance for the development of the energy, water, and agriculture of the entire region and still imply the need for a regional conception of water security (Rasul and Sharma 2014). National water security for each CA country will be difficult to achieve without consent and compromises between upstream and downstream neighbours.

This study initially addresses the regional context of water security by considering the Aral Sea Basin, which is the drainage area of the major Central Asian rivers and encompasses a population of around 60 million people (Food and

Agricultural Organization 2013). The notion of water security and regional interdependence created by the region's common Soviet past is presented to better illustrate the current situation in CA countries. The geophysical and socio-economic differences, as well as the objectives, priorities, and strong interdependencies between upstream and downstream countries, are further depicted. In turn, the current shift from an administrative to a basin management approach in the region is addressed, and the pertinent institutional and technical parameters arising from this transition are mentioned. Finally, policy recommendations to curb the future challenges to water security in CA are presented.

5.2 Soviet Legacy and Regional Interdependence

The Central Asian countries are among the most water-intensive economies in the world, with mean water withdrawals of 2200 m^3/y per capita and nearly 90% of water diverted for irrigation purposes (Sehring and Diebold 2012). As early as the 1930s, a cotton monoculture known as the 'dictatorship of the white gold' (Kulchik et al. 1996) was established in Turkmenistan, Uzbekistan, and to a lesser extent Tajikistan. CA was transformed into the main cotton-producing centre for the entire Soviet Union. In the early 1960s, agricultural mechanisation took place in the entire region, which intensified irrigation systems. Irrigated farming was strongly prioritised in Soviet times to cover the needs of the highly water-demanding cotton crops through the construction of numerous reservoirs, extensive water supply and drainage networks, and large pumping stations.

Irrigation management was partly supervised by the individual Soviet republics, but the entire process was centralised in Moscow, in the Ministry of Land Reclamation and Water Resources (Horsman 2003). Moscow was the final arbiter that directed the procedure and settled disputes between the states (Weinthal 2002). In the Soviet period, water was not considered a source of dispute between the five separate Soviet republics of CA, and internal borders were disregarded. As Weinthal (2002) asserts, 'During the Soviet period, the Central Asian republics did not worry about who had clear legal rights to the use of fresh-water resources in the Aral basin, because the water system was considered a purely domestic resource within the territorial borders of the Soviet Union.' However, in some cases Soviet republics did contest decisions of the central administration on water allocation issues (Wegerich et al. 2016).

The intensified irrigation which started in Soviet times has put much strain on the surface and groundwater sources of the Amu Darya and Syr Darya basins, the two largest rivers in CA. As more water was diverted than the region's renewable water resources could resupply, major shrinking of the Aral Sea ensued. It also resulted in other massive environmental problems, such as progressive evaporation and salinisation, which were often associated with pollution and over-irrigation (Oren et al. 2010).

By the early twenty-first century, more than 90% of the Aral Sea had been drained, with dramatic impacts on the entire region, now considered one of the worst man-made environmental disasters in history. Only a decade ago did Kazakhstan begin efforts to mitigate the effects, reviving about 20% of the initial lake size (Kazakhstan Green Energy 2017). As shown in Fig. 5.1, the Aral Sea originally occupied an extensive area of 68,000 km^2. The current size, the zones of irrigation development, and the basins of major rivers are also delineated.

Water management in the Soviet period was organised according to 'water-use regions' or 'irrigation districts' depending on the different type and use of water supply systems. Some districts were fed only with groundwater from deep drillings, and others from large pumping stations which diverted river discharge to irrigation canals, while in other cases a conjunctive use of surface and groundwater was applied (Thurman 2001). In many cases, the irrigation zones (districts) crossed republican boundaries (Wegerich et al. 2012; Pak and Wegerich 2014). In the Syr Darya basin in the Ferghana Valley, for instance, there were six irrigation districts, of which three were transboundary. The transboundary districts incorporated irrigated areas from nearly all the CA countries (Fig. 5.2). For example, the Chakir District incorporated irrigated areas in Kazakhstan, Kyrgyzstan, and Uzbekistan, while the Mid-stream District incorporated irrigated areas in Kazakhstan, Tajikistan, and Uzbekistan (Wegerich 2015).

As noted above, each irrigation district had a different focus in utilisation of and access to water resources. The different water management approaches reflected

Fig. 5.1 Aral Sea basin. *Source* Food and Agricultural Organization (2013)

Fig. 5.2 Irrigation districts in the Syr Darya basin. *Source* Wegerich (2015)

different understandings of water security in each district. Some districts, for instance, believed that groundwater sources and large drillings could provide better water security than irrigation canals. Consequently, after the Soviet dissolution, the impacts on water security in the Syr Darya basin varied according to the facilities that existed in each district. Nevertheless, concerns about water security arose in the entire region when the increasing desiccation and salinisation of the Aral Sea led the Gorbachev government to publicly admit to the 'Aral problem' and seek solutions (Micklin 1991). At that time, some conflicts over water and land were already arising at the local level in the form of sporadic clashes between communities (Tishkov 1997).

The transboundary irrigation districts ceased their existence after the collapse of the Soviet Union in 1991. New administrative boundaries for water resources management were drawn, making water management a matter of competence of national authorities. Intensified irrigation practices have continued until today, although at a slower pace due to the lack of funding of maintenance and operational services.

Similar issues arose related to the region's production of energy, mainly from hydropower plants (HPPs) in the water-rich upstream countries of Kyrgyzstan and Tajikistan, and from hydrocarbon resources in downstream Uzbekistan, Turkmenistan, and Kazakhstan. In the Soviet era, the seasonal fluctuations associated with hydropower were compensated for by a Central Asian regional energy system. The Central Asia Power System was established in the 1970s and included all five Central Asian Soviet republics. As in irrigation, internal borders were disregarded, and the Central Asia Power System could meet the needs of the whole region. In summer months, the upstream countries were responsible for releasing water and generating electricity for the whole region. In return, they received fossil fuels and surplus electricity in winter from the hydrocarbon-rich downstream countries. The high regional demand for irrigation was met throughout the summer, while winter energy shortages in the upstream countries were similarly compensated. For instance, during this period, 60% of Tajikistan's electricity needs were covered by imports from other Soviet Republics (World Bank 2013a). Through this system, the region was provided with sufficient power generation at low costs, transforming CA into a 'breadbasket' and a main cotton production centre.

After independence in 1991, the centrally planned water and energy management systems from the Soviet period had to be reconfigured to work in a regional economic complex. Energy allocation between the countries became a source of conflict due to the price differences between upstream hydro energy and downstream fuel-produced energy. A reconfiguration of the energy interdependence among the Central Asian countries was attempted in the 1990s through multiple bilateral agreements. In February 1992, the five new republics signed the Almaty Agreement, which recognised their equal rights and responsibilities in ensuring rational use of water resources and agreed that only joint management actions can solve the region's water problems. The agreement in essence was a continuation of the Soviet system of water allocation. With the agreement, the Interstate Commission for Water Coordination of Central Asia was established to set quotas and to facilitate implementation, with decisions on key issues to be made by consensus among the five states. The Central Asian republics also agreed (in a declaration in 1995) that they would continue to recognise all signed agreements and quotas that regulated the allocation of water. However, these declarations were not legally binding, and the agreed water allocation has been violated multiple times (Petrov 2015).

In the late 1990s, the system failed to deal with growing tensions over resources. International frictions emerged around the implementation phase, which hampered electricity trading in the region. Today, a situation has emerged in which regional optimisation is no longer a goal, and energy production seems to be more a subject of national interest.

The national ministries still retain many of their Soviet-administration features, but with much less resources available (Bichsel 2009). The states tackle the problem as a zero-sum game, each state trying to gain the most at the expense of the others. As a result, cooperation between the five Central Asian states to create a stable regional water management system has so far been very limited. Instead, the CA countries have chosen to address issues related to water management through short-lived, bilateral barter agreements. Such agreements seem to only partly and temporarily solve the core issues of water management, as in the case of water pricing, where disagreements occur frequently (Horsman 2003). Moreover, national water management policies tend to focus on routine administrative burdens, with limited focus on long-term objectives (Abdullaev and Rakhmatullaev 2016b).

It can be said that the transition to national sovereignty in CA has shown evidence of 'hydropolitical vulnerability' (Møller 2004) and a lack of institutional capacity to manage a smooth transformation from centralised to nation-based water management (Petersen-Perlman et al. 2012).

5.3 The Present Situation of Water Security in Central Asia

5.3.1 Overview of Water Security Status

Since independence in 1991, the five Central Asian states have had to deal with the Soviet legacies of cotton monoculture, large but ageing infrastructure, and environmental degradation, as well as economic challenges and increasing international disputes over resources. The desire of each country to unilaterally exploit its natural resources has further aggravated regional frictions. There are large imbalances in the region when it comes to the spread of water and energy resources and arable land. Upstream Tajikistan and Kyrgyzstan are rich in surface waters, and 81% of the overall water resources in the region are controlled by these two countries. But they are poor in hydrocarbon resources, which the downstream countries of Uzbekistan, Turkmenistan, and Kazakhstan have in abundance. Uzbekistan and Turkmenistan have 23 and 44%, respectively, of the region's natural gas deposits, while Kazakhstan is one of the world's top 20 oil producers. But all three downstream countries face water scarcity, with Turkmenistan the worst-off at only 300 m^3/y per capita available (Alford et al. 2015).

Kyrgyzstan and Tajikistan have used their weight in water resources to become forerunners in hydropower generation. Hydropower accounts for over 90% in these two countries. The downstream countries have mainly used their water inflow for irrigation. Agriculture is a key component of the CA economies and accounts for 90% of total water withdrawal in the region (Rahaman 2012). Agriculture is dominant in the downstream areas: of the 7.4 million hectares of irrigated land in CA, 4.3 million are in Uzbekistan and 1.6 million in Turkmenistan (Alford et al. 2015).

The two main rivers of the region, the Amu Darya and Syr Darya, are the most important water sources for the livelihoods of 60 million inhabitants in CA. Both rivers originate in the mountain ranges of the upstream countries. The Amu Darya, the larger in water volume, is formed by the Panj River on the Tajik–Afghan border and the Vakhsh River in Tajikistan and continues into Uzbekistan and Turkmenistan before emptying into the Aral Sea. The Syr Darya, which is longer, has its source in the Tien Shan Mountains in Kyrgyzstan, flows through the Ferghana Valley into Tajikistan and Uzbekistan, and also ultimately empties into the Aral Sea (Fig. 5.3).

About 75% of the Syr Darya runoff originates in Kyrgyzstan, while 74% of the main flow of the Amu Darya originates in the territory of Tajikistan (CA Water Info 2017). In total, the upstream countries contribute 77% of the inflow to the Aral Sea basin, while Afghanistan contributes around 10% (Table 5.1).

As a result, the downstream countries are dependent on transboundary rivers that originate outside their territories. This has been the basis of many international tensions over access to water. The disputes are associated with both water apportioning and regulation of water usage (Petrov 2015). A further complication is the seasonal nature of water release and irrigational demand. Both rivers have high

Fig. 5.3 Water resources in the Aral Sea basin. *Source* CA Water Info (2017)

Table 5.1 Surface water resources in the Aral Sea basin (mean annual runoff, km3/y)

Country	River basin		Total, Aral Sea basin	
	Syr Darya	Amu Darya	km^3	%
Kazakhstan	2.516	–	2.516	2.2
Kyrgyzstan	27.542	1.654	29.196	25.2
Tajikistan	1.005	58.732	59.737	51.5
Turkmenistan	–	1.405	1.405	1.2
Uzbekistan	5.562	6.791	12.353	10.6
Afghanistan	–	10.814	10.814	9.3
Total, Aral Sea basin	36.625	79.396	116.021	100

Source CA Water Info (2017)

water levels in spring and summer due to melting snow, which is used for hydropower generation upstream and irrigation in downstream countries. In winter, the water levels are low, resulting in hydropower production levels as low as 60–70% of the spring and summer periods (World Bank 2013a). To combat this, the upstream countries have been lately engaged in the construction of large-scale water reservoirs, which has sparked fears, mainly in Uzbekistan, of disruption of the seasonal outflow of water.

5.3.2 Tajikistan and Kyrgyzstan: Water for Energy

Tajikistan and Kyrgyzstan have little arable land; only 6.1 and 6.6% of their total area, respectively, is suitable for agricultural production (Kocak 2015). Water-rich but land-poor Tajikistan has emerged as the most impoverished country in the region. Severe food insecurity has threatened the livelihoods of the mostly rural population of Tajikistan. Without hydrocarbon resources, Tajikistan and Kyrgyzstan have therefore resorted to strengthening their precious hydropower potential to increase economic development.

Facing energy isolation, Kyrgyzstan and Tajikistan have suffered from increasing energy shortages in winter months. But their hydropower potential is high. Tajikistan ranks top in the world in hydropower potential per unit of area (World Bank 2013b). But it currently only uses 5% of this potential; Kyrgyzstan, about 10% (Kocak 2015). Both countries have therefore further strengthened their focus on exploiting their full hydropower capacity. They have set hydropower investment and rehabilitation as a national priority. The government of Tajikistan has stated that one of its main goals is to achieve full energy independence by increasing hydropower production and making energy imports redundant (Government of Tajikistan 2011). It allocates more than USD 300 million annually (15% of the state budget) to hydropower rehabilitation (Government of Tajikistan 2014).

Tajikistan and Kyrgyzstan's energy isolation has driven them to reinvent themselves as forerunners in the hydropower sector. Tajikistan already has numerous HPPs, the largest being Nurek, Kairakkum, Baipazin, and Sangtuda I and II (Barqi Tojik 2016). Over 75% of the country's electricity supply is generated by the Nurek HPP on the Vakhsh River—currently the largest dam in CA, at a height of 300 m—with a capacity of 3000 MW and a reservoir of 10.5 km^3 (World Bank 2013b).

Nevertheless, Tajikistan has thus far not surpassed its 1990 hydropower production level of 18 billion kWh; current hydropower production stands at 17.2 billion kWh (Government of Tajikistan 2007). Furthermore, due to low river volumes in winter months and the high electricity demand, the country's energy system cannot adequately respond to the seasonal needs. The HPPs in Tajikistan and Kyrgyzstan cannot sustain energy supply in winter, when heating demands are highest and river flows the lowest, due to smaller releases of snow melt and glacial water. Most of the HPPs are run-of-the-river plants, without reservoirs, and vulnerable to variations in precipitation, climate change, and the whims of river flows. With worsening conditions of the ageing facilities, this shortage is predicted to further increase in the coming years. Continued deterioration of power facilities will further worsen shortages throughout the year. Most HPPs have been in operation for an average of 45–50 years without major upgrading or maintenance investments. Many are now producing well below their potential output. The ageing electricity network similarly often fails to transfer power to large parts of the country throughout the year. Insufficient energy supply nowadays has a great impact on Tajikistan's economic development, forcing the closure of around 850 small and medium-size enterprises annually, and costing an estimated 3% of GDP (Government of Tajikistan 2014). Winter shortages were estimated at 2700 MW in 2012, but if current trends continue, these deficits could increase to over 6800 MW by 2020 (World Bank 2013b).

To combat these issues, both upstream countries are trying to increase their hydropower capacity. Tajikistan has started the construction of its largest hydropower project yet. In October 2016, filling of the Roghun Reservoir was initiated in the upstream area of the Vakhsh River in eastern Tajikistan. The Roghun Dam is an ambitious, USD 3.9 billion dam which, once completed, will be the tallest dam in the world, at 335 m. It will provide another 3600 MW of generation capacity, doubling Tajikistan's electricity production.

In Kyrgyzstan, the largest HPP (capacity 1200 MW), at Toktogul on the Naryn river, a tributary of the Syr Darya (Granit et al. 2012), provides the country with over 90% of its energy. However, the large Toktogul Reservoir, which holds the door of the Syr Darya River, has been a source of disputes with Uzbekistan, Tajikistan, and Kazakhstan. In recent years, low water levels have led Kyrgyzstan to release less water into downstream countries. In the summers of 2008 and 2009, mismanagement of the Toktogul Dam led to water shortages in Uzbekistan and Kazakhstan, as well as lengthy power cuts in Kyrgyzstan.

Kyrgyzstan is planning to construct the Kambarata I HPP on the Naryn River, which, with a height of 275 m and a capacity of 2000 MW, will also be one of the largest dams in the world. Like the Roghun, the project is strongly opposed by Uzbekistan, which argues that the filling of the reservoir would reduce the flow of the Syr Darya (Rickleton 2013). In the past, Uzbekistan has made bellicose statements against Kyrgyzstan and Tajikistan over the construction of new reservoirs (Nurshayeva 2012).

Although these projects could significantly reduce energy shortages in the upstream countries, and are a matter of great national pride, they have been source of major tensions with downstream countries, mainly Uzbekistan. This is because the impacts on agricultural water supply have not yet been well defined. However, tensions in the region have abated somewhat, through an effort to mitigate the impacts downstream, as mentioned in feasibility studies (SNC-Lavalin n.d.) and strategic environmental assessments (World Bank 2014) for large dams in Kyrgyzstan and Tajikistan. More importantly, the recent (2016) change of government in Uzbekistan seems hopeful for reconciliation on water sharing and management between the upstream and downstream countries.

Their greater hydropower potential may enable Kyrgyzstan and Tajikistan to become leading regional exporters of electricity, potentially supplying growing economies in Afghanistan, Pakistan, and Iran. The inauguration of the first phase of the Central Asia–South Asia electricity network (CASA-1000) in May 2016 marks the future opportunity for Tajikistan and Kyrgyzstan to export their summer electricity surpluses at lucrative prices. The USD 1.16 billion transmission lines will connect Kyrgyzstan, Tajikistan, Afghanistan, and Pakistan, enabling large power flows from north to south (Fig. 5.4). Tajikistan and Kyrgyzstan are expected to supply up to 5 billion kWh of summer electricity annually to Afghanistan and

Fig. 5.4 The Central Asia–South Asia power transmission project (CASA-1000). *Source* Ministry of Energy and Water Resources (2017)

Pakistan via this power transmission line (SNC-Lavalin 2011; Barqi Tojik 2016). However, difficulties in the construction phase suggest that completion of CASA-1000 may take several years (Michel 2017).

According to the recently signed agreements, Tajikistan and Kyrgyzstan will be able to sell electricity for up to USD 0.05 per kWh through CASA-1000. Large revenues can be brought in from transferring water to hydropower, which in turn can be reinvested in further HPP projects. But this prospect creates further international rivalry with Uzbekistan, which also wants to position itself as a regional exporter of electricity. Also, the lucrative pricing of electricity exports could have significant impacts on domestic electricity usage and irrigation pumping. These export prices are significantly higher than what the upstream countries are charging for irrigation water. In Tajikistan, for example, water abstraction from pumping stations cost only USD 0.0030 per kWh in 2016. Electricity subsidies to keep prices low come at a high cost to the national budget. And low energy efficiency wastes large amounts of potentially exportable electricity (World Bank 2013a).

The new incentives to allocate hydropower production to export, combined with the low efficiency, could put pressure on domestic food and energy security and thus should be contemplated cautiously. However, regional energy trade could enhance cooperation on water issues. A recent agreement between Kyrgyzstan and Uzbekistan on energy trade could be a good illustration of such cooperation (Anadolu Agency 2017).

5.3.3 Uzbekistan, Kazakhstan, and Turkmenistan: Water for Food

The downstream countries of Uzbekistan, Kazakhstan, and Turkmenistan are poor in water resources but rich in hydrocarbon reserves. Coal, oil, and natural gas make up more than 90% of energy consumption in Kazakhstan, Turkmenistan, and Uzbekistan (Granit et al. 2012). The share of agriculture in the economy of Kazakhstan is low, at only 4.7% of GDP in 2012, whereas in upstream Tajikistan and Kyrgyzstan it accounts for 26.6 and 20% of GDP, respectively. Also relatively high is the GDP contribution of agriculture in downstream Uzbekistan and Turkmenistan, at 20 and 14.5%, respectively (Kocak 2015). Agriculture in all CA countries demands vast amounts of water (Fig. 5.5). Agriculture accounts for 87.2% of all water withdrawals across the region. Uzbekistan consumes almost 45% of that, twice as much as the second-biggest consumer, Turkmenistan. The total water consumption of the upstream countries, Kyrgyzstan and Tajikistan, amounts to only 15.6%.

For the expansion of cotton monoculture, numerous dams, canals, and artificial lakes were built in Soviet times between 1950 and 1990 which are still operating today. For instance, in Uzbekistan the North and Grand Ferghana Canals transport water from the Syr Darya to the Ferghana Valley; the Amu-Bukhara Canal irrigates land in the Bukhara Region in Uzbekistan from the Amu Darya; Kirov Canal irrigates the Golodnaya ('Hungry') Steppe from the Syr Darya; and the Karshi Canal provides water to 1.2 million ha in Uzbekistan's Karshi Steppe. However, the condition of these irrigation assets is poor, with many canals ageing and

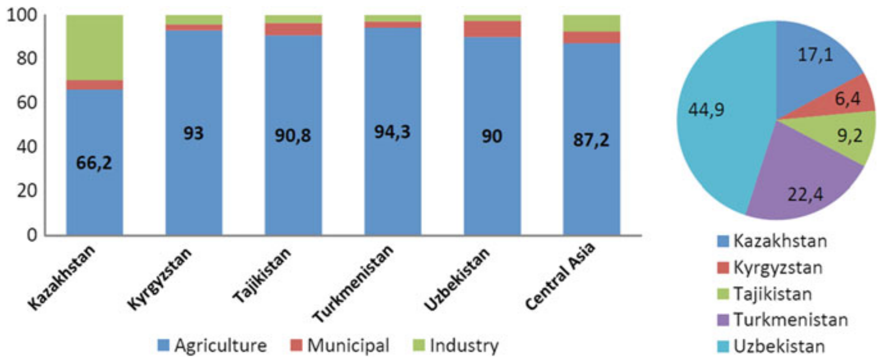

Fig. 5.5 Sector and country shares of water consumption (in percent). *Source* Kocak (2015)

deteriorated. In Turkmenistan the huge Karakum Canal (see Fig. 5.3) was completed in 1988, transferring 12.9 km^3 of water—almost 15% of the flow of the Amu Darya River—to irrigate parts of the Karakum Desert (Kraak 2012). It is still the largest irrigation canal in the world and the most significant for Turkmenistan.

After the Soviet Union's dissolution, agricultural policies in the downstream countries changed to meet the new conditions. Uzbekistan enforced a reduction in cotton production and focused on wheat. Cotton's share of irrigated agriculture fell from 45 to 25% between 1990 and 1998, while the area under cereals increased from 12 to 50%. Uzbekistan accounted for 20% of globally traded cotton in the early 1990s, but only 10% nowadays (2017). Also, the irrigated area under cotton in Uzbekistan has been reduced from 2.8 million ha in the early 1990s to 1.1 million ha. But cotton still makes up more than 20% of all exports from Uzbekistan.

Kazakhstan also shifted to cereal production and currently is among the world's top eight grain-producing countries; 60% of Kazakhstan's agricultural exports are grains, and it ranks sixth in the globe in wheat exports (Granit et al. 2012; Ray et al. 2013). The main reason for this, next to assuring food security, was to reduce irrigation needs: wheat requires less than half as much water as cotton. However, producing more wheat instead of cotton did not reduce the importance of water as much as anticipated.

In Turkmenistan, which is the most sparsely populated state in CA (10.5 people per km^2), cotton still has the lion's share of agricultural production, as Turkmenistan is among the top ten cotton producers in the world, and its high-quality cotton is in great demand. Despite being traversed by the largest waterway in the region, the Amu Darya River, the country is very much at risk for drought and water scarcity (Collado 2015). The large quantity of water used to irrigate cotton fields certainly plays a big part in increasing the per capita water consumption, but there are other factors at stake: the inefficient household and industrial usage, the high rate of water waste, and the poor conditions of water infrastructure, including the main water infrastructure of the country, the Karakum Canal (International Crisis Group 2014; Collado 2015).

All the reasons listed above show that water security is a paramount issue for the downstream countries, and it might become a more pressing concern in the years to come, in view of the predicted effects of global warming for the region.

5.3.4 Climate Change and Water Security in Central Asia

A further threat to water security is the rising global temperatures and climate change. Studies strongly indicate that global warming will affect water security in CA (Gan et al. 2015). The region's glaciers have been melting more quickly in recent decades: 20% of the ice cover of the glaciers in the Aral Sea basin was lost between 1957 and 1980; it decreased 10% in the last 50 years (Eurasian Development Bank 2008, 2009). However, the exact effects of these developments for the region's water resources continue to be debated. Some studies suggest that runoff will be decreased significantly in the long term, resulting in lower river flows. Some estimates suggest that the water flow will be reduced 10–15% in the Amu Darya and 2–5% in the Syr Darya by 2050 (Eurasian Development Bank 2008). However, other studies give significantly smaller percentages, as the shrinking of glacier area seems to be counterbalanced by faster melting during the largest part of the year. Even so, they project an important seasonal shift of water resources from summer to spring, resulting in a runoff reduction of 25% in July and August, especially in the Amu Darya. This could hurt agriculture and irrigation in the lowlands, which reaches peak demand in summer. Evapotranspiration losses in the downstream regions also seem to further limit water availability in summer (Hagg et al. 2013).

The changes in seasonal precipitation patterns are also expected to impact river flows. A recent study (Hijioka et al. 2014) published by the Intergovernmental Panel on Climate Change indicates an increase in Central Asian precipitation by analyzing long-term time series and seasonal patterns. Others conclude that changes in seasonal precipitation, rather than temperature, dominated the decline in levels of the Amy Darya in 1951–2007. It is claimed that the flow of Amu Darya fell by 15.5% during this period because of lower precipitation, and increased by only 0.2% as a result of higher temperatures (Wang et al. 2016). Another study agrees that changes in the seasonality of precipitation are likely to have the most significant impact on water availability, with runoff likely to continue to decrease by 10–20% in CA (White et al. 2014). The study concludes that in periods of extended drought there is a high possibility that the available water resources will satisfy only 50% of the regional demand.

Another study considered the heterogeneous impacts of precipitation patterns in CA countries (Nelson et al. 2010). In Kazakhstan, for instance, water availability is projected to increase, while in Uzbekistan and Turkmenistan the average annual runoff of water is expected to moderately decrease. This, in turn, is argued to be a possible source of further international disputes. Together with growing populations and increasing demands for food and energy, it could result in domestic unrest and international discord (Swinnen and Van Herck 2013). However, some policy analysts argue that there is enough time for CA's riparian countries to set up an effective international framework for water allocation and mitigate the effects of climate change, thereby making conflict over reduced water resources water unlikely (Bernauer and Siegfried 2012).

5.4 Discussion

5.4.1 Water Security and Coordination of National Policies

There are major efforts to transform the water sector in CA after the collapse of the Soviet regime. Although strong global influences and the experiences of other regions with similar features have been 'exported' to the water sector of Central Asian countries, the water sector reforms in the region have mainly been endogenous. For example, the strongly promoted concepts of irrigation management transfer and joint management have been not taken up by Central Asian countries. The water infrastructure almost in all the countries is still in the hands of the state. Although irrigation management transfer and participatory irrigation management have been at the core of water sector reforms supported by international funding, there is still little acceptance in Central Asian countries (Abdullaev and Rakhmatullaev 2016a).

The water-energy-food nexus concept has recently appeared in CA as a paradigm to address the major challenges of water security and management in the region. But it is feared that the outdated infrastructure in all sectors (irrigation, energy, and food processing) may create greater problems rather than bringing benefits from intersectoral cooperation.

Water resources governance and management in a transboundary context are key elements of regional stability and security for CA. Over the 25 years of the post-Soviet period, water issues have been transformed from a techno-economic perspective to a socio-political approach. Institutional structures for joint allocation of common water resources were established as early as 1992, as mentioned above, including the Interstate Commission for Water Coordination, the Interstate Council for the Aral Sea Basin, and the International Fund to Save the Aral Sea, but without meeting expectations. The current state of affairs of water in the region seems to be leaning more towards the coordination of five water national policies and less towards regional cooperation over water governance and management (Fig. 5.6). Efforts to promote more regional transboundary cooperation through creating a single water policy for CA may not be that fruitful. The core idea of regional cooperation in CA should probably shift to strong efforts towards coordination of the different water policies of the five countries.

Changes at the local level should initially focus on the water and land rights systems. In the Soviet period, water rights were determined through complicated

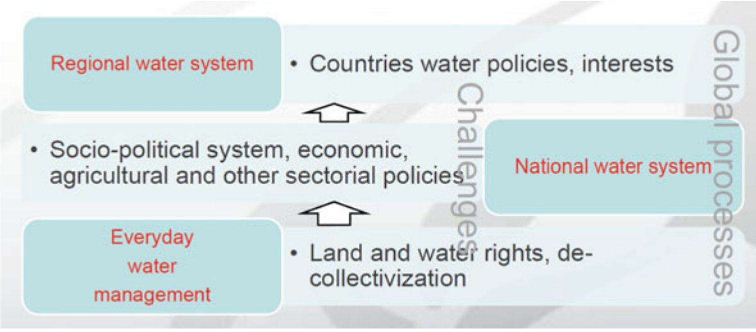

Fig. 5.6 Interlinkages of different water systems and processes in Central Asia. *Source* Abdullaev and Rakhmatullaev (2016b)

criteria based on cropping structure, biophysical conditions of the irrigated area, and availability of water resources. In theory, the irrigated areas were classified in different categories and the water rights were determined before each irrigation season. However, in practice water rights were dependent on water availability, and priority was given to cotton cultivation. Since the breakup of the Soviet Union, the water rights systems have been changed, and de facto water distribution now depends fully on water availability in particular basins, sub-basins, and irrigation networks, but still without providing efficient distribution mechanisms.

Further, in Soviet times, planners and managers considered water an essential input for economic growth and prosperity. The nature of water institutions was technical: focused on water provision and allocation, mostly in agriculture. The water institutions were centralised in their planning, management, and financing aspects and therefore independent of local and national peculiarities. Water was perceived as a sectoral component in the entire Central Asian region. With the collapse of the Soviet system, the water sector lost both its significance and its funding sources.

The example of the Ferghana Province Irrigation Department in Uzbekistan can showcase the situations in the pre- and post-Soviet periods. Until 1985, expenditures on operation and maintenance appear to have been nearly constant; then there were distinctive increases between 1986 and 1990 (Fig. 5.7). There was initially much emphasis on water supply security and control of water supply, which was representative of the overall situation in the Soviet period. During the economic crisis which followed independence, expenditures on operation and maintenance, as well as rehabilitation, declined to insignificance. Although from 1996 onwards the Uzbek GDP started to increase again (Taube and Zettelmeyer 1998), this increase has not triggered reinvestment in the Ferghana Province Irrigation Department.

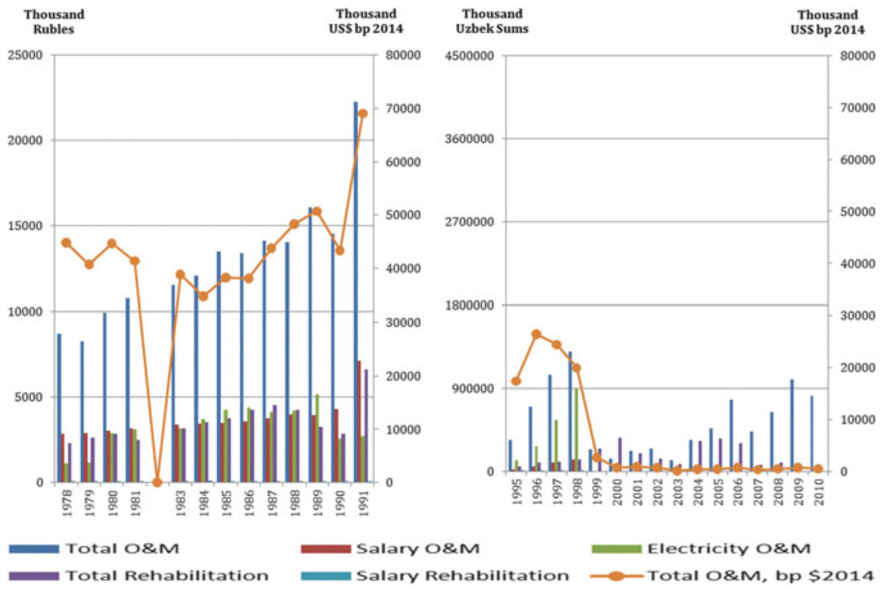

Fig. 5.7 Operation and maintenance costs for Ferghana Province Irrigation Department, Uzbekistan, 1978–2010. The primary axis in left and right tables present the expenditure in 1000 Soviet Union Rubles for the period 1978–1991 and 1000 Uzbek Sums for the period 1995–2010, respectively. The secondary axis is in both tables presents the expenditures in 1000 USD purchasing power (bp) as of the year 2014. *Source* Wegerich et al. (2015)

5.4.2 Current Status Quo and Challenges of Water Security in Central Asia

The water sector in Central Asian countries has undergone serious transformations, and major reforms are still taking place. Many researchers have considered the water sector changes in CA through the prism of standard international processes such as irrigation management transfer and participatory irrigation management (Abdullaev et al. 2010). But most of these assumptions were short-lived, and the trajectory of water sector transformations in CA has been more about strengthening the role of the state in day-to-day water management.

In other regions, South Asia for instance, irrigation management transfer and participatory irrigation management were implemented more successfully, because the farmers had relative autonomy in operation and maintenance of irrigation infrastructure (Qureshi 2005). But in CA the governments have not transferred the actual operation and management of irrigation infrastructure to farmer organisations (e.g. water user associations). Also, declines in funding and human capacity have severely affected the performance of water institutions. And the low functioning of water institutions has resulted in alternative water governance schemes (informal, business-like, etc.), with as yet unknown results.

On a regional level, water issues became political and interstate on the collapse of Soviet Union. The newly emerged Central Asian states have started to shape their national policies and systems on all aspects of development, including security, economy, and resources. During the transition period and until now, water disputes in the Aral Sea basin have never led to military incidents but remained at the level of political tension. There have been some incidents, limited to local disputes over access to water, which, however, exacerbate inter-ethnic tensions (International Crisis Group 2014). Nevertheless, in CA, the national governments have tended to 'securitise' water-related issues, with water being 'used as a tool for intra-state posturing' (Cummings 2012). This was the case especially between Uzbekistan (under the former government) and its neighbours. The tension, especially with Kyrgyzstan and Tajikistan, increased on several occasions. In 1997, for instance, 130,000 Uzbek troops carrying out military exercises, practising for the seizure of a strategic object, were deployed near the Toktogul Reservoir (the largest in the Syr Darya basin), on the Kyrgyz border (Dinar et al. 2007).

However, it is at the sub-national level, where communities often have to rely on alternative networks to secure access to water—which is threatened by both poor infrastructure and the absence of border demarcation—that disputes over water usage often originate (International Crisis Group 2014; Horsman 2003). A number of local conflicts have taken place in the Ferghana Valley, which is shared between all CA countries except Turkmenistan. There are frequent cases of such conflicts especially in the Kyrgyz town of Batken, on the Tajik border, and the Tajik exclave of Isfhara inside Kyrgyzstan, where the Tajik population is often accused of 'creeping migration'. The Kyrgyz people maintain that the Tajiks are gradually stealing a portion of their land and water resources by taking advantage of the undefined borders (Bichsel 2009).

In 2012–13 there were 38 security incidents on the Kyrgyz–Uzbek border (with four resulting deaths) and 37 on the Kyrgyz–Tajik border (International Crisis Group 2014). Clashes in Uzbekistan's exclave of Sokh and Tajikistan's exclave of Vorukh in 2013–14 involved several thousand people, serious injuries, arson, hostage-taking, and extensive property damage. The tensions are caused by unresolved borders and disputes over access to water and land. On 11 January 2014, Tajik forces fired grenades and mortars into Kyrgyz territory. A senior Kyrgyz defence official said they were aimed at a Toktogul Reservoir pumping station (International Crisis Group 2014). In 2014, unrest broke out between Tajik and Kyrgyz villagers over access to water resources. In 2015, a crowd of nearly 500 Tajik and Kyrgyz villagers threw stones at each other, injuring several people on both sides of the border. Uzbekistan and Kyrgyzstan have also had increased tensions along their border in the Ferghana Valley, with both sides placing strategic troops to protect water assets.

Despite the local frictions, all CA states have agreed on setting up regional organisations (e.g., the Interstate Commission for Water Coordination, see above) for the adoption of water management decisions through a consensus approach. Thus, regional-level water relations have gradually became an outcome of negotiations between the five independent countries. The Soviet-period water paradigm—hydraulic mission with centralised control system—appears inadequate for the new water security and management concept. But agreement on a paradigm for water resources management and security is still difficult to reach due to the differing water visions of the riparian states. As shown in Fig. 5.8, a technical notion of water management was maintained after the Soviet period and until early 2000 by most of the CA countries.

But after that and up to today, a shift to pursuing new regional water agreements through a political-economic perspective is noticeable. Moreover, the notion of water security emphasised by all these countries since 2015 has been one in which effective and pragmatic solutions are sought (Abdullaev and Rakhmatullaev 2016a).

5.4.3 *The Way Forward to Water Security Through a Hydrographic Basin Approach*

In the last decade, a river basin management approach was gradually introduced in each of the CA countries in an attempt to improve national water use and allocation plans on the principles of the EU Water Framework Directive (WFD 2000/60/EC). The EU Water Initiative was established in 2002 as a transnational, multi-actor partnership to support water governance reforms around the globe (Fritsch et al. 2017). For the region of Eastern Europe, Caucasus, and CA, one partnership was established with 10 countries (Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russia, Tajikistan, Turkmenistan, Ukraine) for the improvement of legal and regulatory water-related frameworks in alignment with the Water Framework Directive, development of River Basin Management

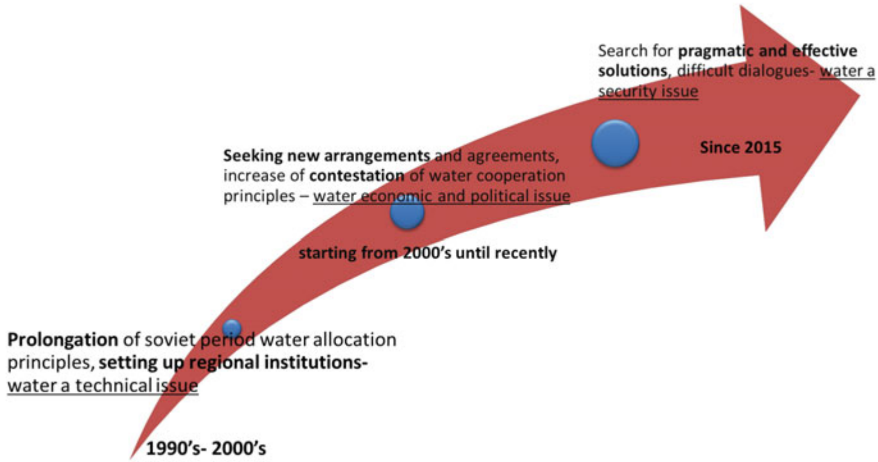

Fig. 5.8 State of interstate water cooperation in Central Asia. *Source* Abdullaev and Rakhmatullaev (2016b)

Plans (RBMPs), and engagement of stakeholders through National Policy Dialogues and River Basin Councils.

For the implementation of the RBMPs, River Basin Organisations (RBOs) have to be established to monitor all activities related to water management on a basin level. The RBMPs have to gather information from local institutions (e.g. WUAs) and centralised institutions (e.g. ministries), and reduce the currently unregulated water withdrawals from rivers, canals, and newly built groundwater wells which are still common practice in rural areas. All CA countries have set up the legal basis for introducing the basin approach, while RBMPs have gradually been developed in Kazakhstan, Kyrgyzstan, and Uzbekistan over the last three years (2014–17). The legislative documents, mostly called 'water codes', emphasise the water-energy-food nexus of each country and the need to harmonise each national document with those of the neighbouring countries.

The RBMPs in the upstream countries will be obliged to monitor the construction of big controversial dams for hydropower production, such as the Roghun in eastern Tajikistan and Karambata I in north Kyrgyzstan. These large-scale interventions have until recently created conflicts between the upstream countries and Uzbekistan as the most vocal downstream country. But, as mentioned in Sect. 5.3.2 new feasibility studies and strategic environmental assessments are aiming to mitigate the impact downstream, while the change of government in Uzbekistan has raised hopes for reconciliation between CA countries. The current and future hydropower developments are presented in Fig. 5.9.

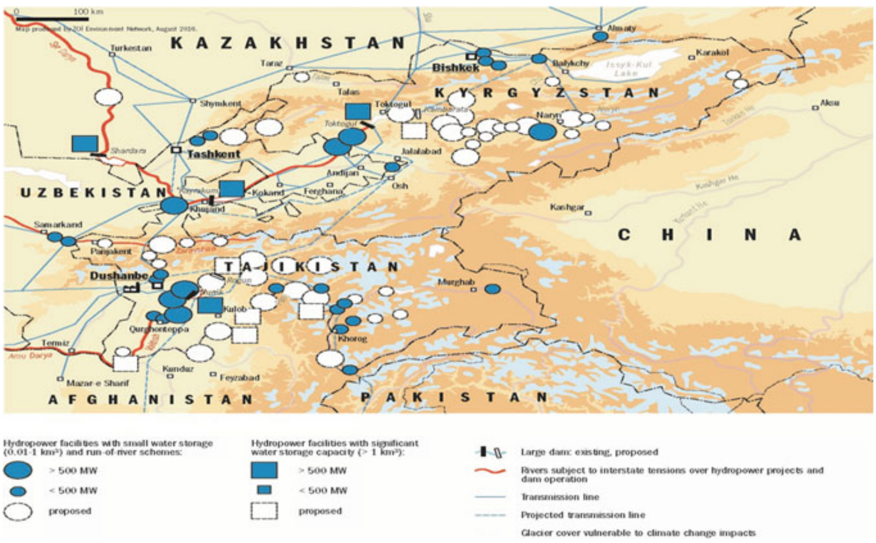

Fig. 5.9 Hydropower developments in Central Asia, with focus on the upstream countries of Kyrgyzstan and Tajikistan, *Sources* CASA-1000 project (http://casa-1000.org); Electric power sector of Tajikistan, Barqi Tojik, 2011; Afghan Energy Information Centre (http://aeic.af/)

Most importantly, the RBMPs have to address the major challenge of extremely inefficient water supply provided through mechanised pumping. The 30–40% efficiency in many CA farming areas signals the need to restructure irrigation practices at large. Major initiatives have been taken towards shifting to less water-demanding crops in Tajikistan and Uzbekistan, rehabilitation and modernisation of pumping systems all over CA, redesign of tariff policies, and provision of more authority to local agencies like water user associations (UNECE 2017).

Also, in the drinking water supply sector there are major efforts to improve the technical efficiency of the network and carry out economic and institutional reforms (e.g. European Bank for Reconstruction and Development 2015, 2016). International organisations and donors are investing in the rehabilitation of irrigation networks and drinking water supply, mainly in rural areas of Tajikistan, Kyrgyzstan, and Uzbekistan. Moreover, investments in technological interventions in oil, gas, coal, and uranium mining in the region are slowly increasing in volume (Kazakhstan Green Energy 2017). These interventions are anticipated to reduce water input and also to mitigate the water pollution induced by these activities.

However, there is a notable lack of coordination, monitoring, and assessment of these interventions, which is mainly due to overlaps between too many governmental authorities and the differences between governments in prioritising water resources management. For instance, Kazakhstan sets a high priority on water management for food production and holds the Ministry of Agriculture responsible for the development and implementation of agricultural policy and water management. Groundwater use remains under the supervision of the Ministry for Investment and Development and the Committee of Geology and Subsoil Use (UNECE 2017). A similar situation presents itself in Uzbekistan, where the Ministry of Agriculture and Water Resources is responsible for surface water resources and the State Committee on Geology and Mineral Resources for groundwater. Agriculture also plays a dominant role in downstream Turkmenistan, where the Ministry of Agriculture and Water Resources is mainly accountable for efficient agricultural water management.

Kyrgyzstan in 2005 tried to assign greater importance to the water sector by establishing the National Water Council to coordinate all the state and private agencies involved with water resources management. But the council has been inactive for many years, and the newly introduced basin approach is in substance being implemented by the Department of Water Economy and Melioration under the Ministry of Agriculture and Melioration. The clear priority of water for energy use in Tajikistan found expression in the creation of the Ministry of Energy and Water Resources in 2013. While hydropower development is the primary mandate of the ministry, water for agricultural use is supervised by the Agency of Land Reclamation and Irrigation, which is of inferior importance to the ministry.

Coordination of the activities of these authorities by the national RBOs and communication of these RBOs within the framework of a river basin (e.g. the Syr Darya) remains a major challenge to be confronted in the CA region.

5.5 Concluding Remarks

The transition to state sovereignty in CA has involved a shift from regional to national policy on natural resources, with major effects for water security. The five countries were initially bound together 'by history, by culture and geography, but also because of decisions made during the Soviet period' (Olcott 2001). The change of the regime signalled the need to securitise water sources on the national level, mainly in connection with the need to securitise the economy of the new states.

National concerns have echoed the need to securitise water resources since the last days of the Soviet area (the *glasnost* period—Weinthal 2002). For instance, on multiple occasions the governments of Central Asian countries have blamed the Soviets for the deterioration of natural resources (Wegerich 2001, cited in MacKay 2009). Yet, the solutions proposed for such environmental problems sometimes resemble the Soviet mega-projects in being based on the engineering of water sources. For instance, representatives of Central Asian states have revived a Soviet-era plan to divert Siberian rivers to refill the Aral Sea (EurasiaNet 2002; The Telegraph 2010).

The latest reforms in water management through a hydrographic approach are expected to bring a new era in water planning and administration by slowly decentralising authorisation from the ministries to RBOs. The River Basin Councils, although they may initially have a limited role, are expected to eventually engage major actors in each region by also informally auditing the activities in each basin. There are major challenges to be met in the communication between RBOs, both within each country and between neighbouring countries. It is questionable for instance whether RBOs will effectively become the main coordinating agency on a basin level or become another intermediary actor in the governmental structure.

Regional organisations and commissions like the Interstate Commission for Water Coordination of Central Asia and the International Fund for Saving the Aral Sea are currently the main outlets of regional cooperation on water resources management and planning in CA. But small steps have been taken in the post-Soviet period to promote a common understanding of water security.

International organisations and donors like the Swiss Development Agency, World Bank, Asian Development Bank, and German Federal Foreign Ministry have attempted to securitise water resources by heavily investing in 'hard' (rehabilitations of HPPs, pumping systems, dredging, etc.) and 'soft' (institutions, legislation, etc.) water management components (Mogilevskii et al. 2017). Improved water services and planning is considered by many donors and agencies a major element of regional stability in CA. But more vigilance is needed with respect to engagement of local communities, as well as endorsement by the central government in each country. More than a few initiatives in the water sector in CA have been gradually abandoned due to lack of attention by local stakeholders and national authorities (Varis 2014).

In CA water security is undeniably a multidimensional concept—perceived differently by each country. Diverse priorities and objectives for water use management at the national level may torpedo water security in CA through excessive demands and unilateral initiatives. The current (2017) new government in Uzbekistan has brought a new policy dialogue with all its neighbours on water resources management, offering hope for a compromise between upstream energy needs and downstream agricultural and food demands.

There have also been attempts to enhance the regionalisation of infrastructure, trade, and services among the five countries and promote cohesive economic development. For example, interstate train itineraries between the major cities of Uzbekistan and Kazakhstan have been launched (Trend News Agency 2017), while the inclusion of Kazakhstan and Kyrgyzstan in the Eurasian Economic Union (RT 2015) has brought closer economic ties between the two countries.[1]

The political-economic approach that is currently being followed for water management and security in CA as described in this study is greatly affected by the surrounding economic developments in the region. It is anticipated that the common desire of all five countries to promote economic welfare and growth on the national level will also benefit water security and planning on the regional level.

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[1]The Eurasian Economic Union is an international organisation for regional economic integration. The member states are the Republic of Armenia, the Republic of Belarus, the Republic of Kazakhstan, the Kyrgyz Republic, and the Russian Federation.

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Chapter 6
Integrated Water Resources Management in Morocco

Mohamed Ait Kadi and Abdeslam Ziyad

Abstract In Morocco security of water supply has always been an important consideration in the economic and social development of the country. The consequence of population and economic growth, accentuated by an increased variability and scarcity of water resources, is the growth of requirements for the quantity and quality of water, their more intensive and comprehensive use. The emphasis in Moroccan development planning has been for the last five decades on maximizing the capture of the country's surface water resources and providing for their optimal use in irrigated agriculture, potable water supplies, industrialisation and energy generation on a sustainable basis. Enormous capital resources have been invested in the essential infrastructure to control surface water flows. To meet the challenges posed by the growing water scarcity, the rising costs of supplying additional water and more direct and intense competition among different kind of water users and uses, emphasis has shifted to the more sophisticated and difficult task of ensuring socially and technically efficient allocation of the existing water resources among competing consumer groups on a sustainable basis. An integrated approach to water resources management is adopted through mutually reinforcing policy and institutional reforms as well as the development of a long term investment program mobilizing innovative financing mechanisms including public-private-partnerships.

6.1 Introduction

Morocco is a water-scarce country, and securing an uninterrupted supply of water for the nation's sustainable socio-economic development has been a constant concern. The success of Moroccan water policy can be associated with a number of

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achievements. These include a long-term planning policy launched in the early 1960s, and a 'state-of-the-art' institutional framework and legal arsenal, most prominently Law 10–95, enacted in 1995 (and updated in 2016), which consolidated integrated, participatory, and decentralised water resources management through, in particular, the creation of river basin agencies. These policies endowed the country with 140 large dams, an area equipped for irrigation of approximately 1.5 million hectares, the satisfaction of domestic, industrial, and tourism water needs, the development of hydropower production, and the improvement of drought alleviation and flood protection.

In spite of these achievements, Morocco's water sector is facing growing challenges. Indeed, water scarcity is becoming a serious challenge and affecting development in the country. A changing climate, decreasing precipitation and higher frequency of droughts, population growth, and urbanisation are increasing the pressure on the resources. The present water use patterns and withdrawals are not sustainable (CESE 2014).

Driven by these challenges, Morocco has embarked on reforming its water sector. A change in thinking and action in water management has taken place through embracing a holistic water sector approach that is economically, socially, and environmentally sustainable.

The National Water Plan (NWP) was launched in 2010 as the vehicle of the National Water Strategy, combined with the regional water master plans. It is based on an optimal mix of both a vigorous demand management strategy, involving comprehensive reforms and actions to make better use of existing supplies, and a supply management strategy, involving highly selective development and exploitation of new water supplies (conventional or non-conventional such as desalination and reuse of sewerage water). Moreover, the NWP pays more attention than in the past to the protection of water resources and the natural environment, as well as adaptation to climate change.

6.2 The Geographic and Hydro-Climatic Contexts

Located on the extreme north-west of the African continent, Morocco's territory covers an area of over 700,000 km^2. Its coastline on the Atlantic Ocean and the Mediterranean totals 3500 km.

Four rugged mountain chains dominate Morocco's topography and divide the country into three geographic regions: the mountainous interior, including plateaus and fertile valleys; the Atlantic coastal lowlands; and the semi-arid and arid area of eastern and southern Morocco, where the mountains descend gradually into the Sahara Desert. In the north, the Rif mountain range runs parallel to the Mediterranean. South of the Rif range, a series of three Atlas ranges somewhat overlap one another as they slant across the country on a generally north-east/south-west axis.

The Rif and Atlas ranges divide Morocco into two climatic zones: one that receives westerly winds from the Atlantic and one that is influenced by the proximity of the Sahara Desert. Western and northern Morocco have a Mediterranean (subtropical) climate, with mild winters and hot, dry summers. The pre-Saharan and Saharan south have semi-arid and arid climates. Rainfall varies from moderate in the north-west to scanty in the south and east (Fig. 6.1). Morocco has the most extensive river system in North Africa. It is managed by ten river basin agencies (Fig. 6.2). The country is also endowed with groundwater resources. Some 32 deep aquifers and more than 46 shallow ones scattered all over the country have been inventoried (Fig. 6.3).

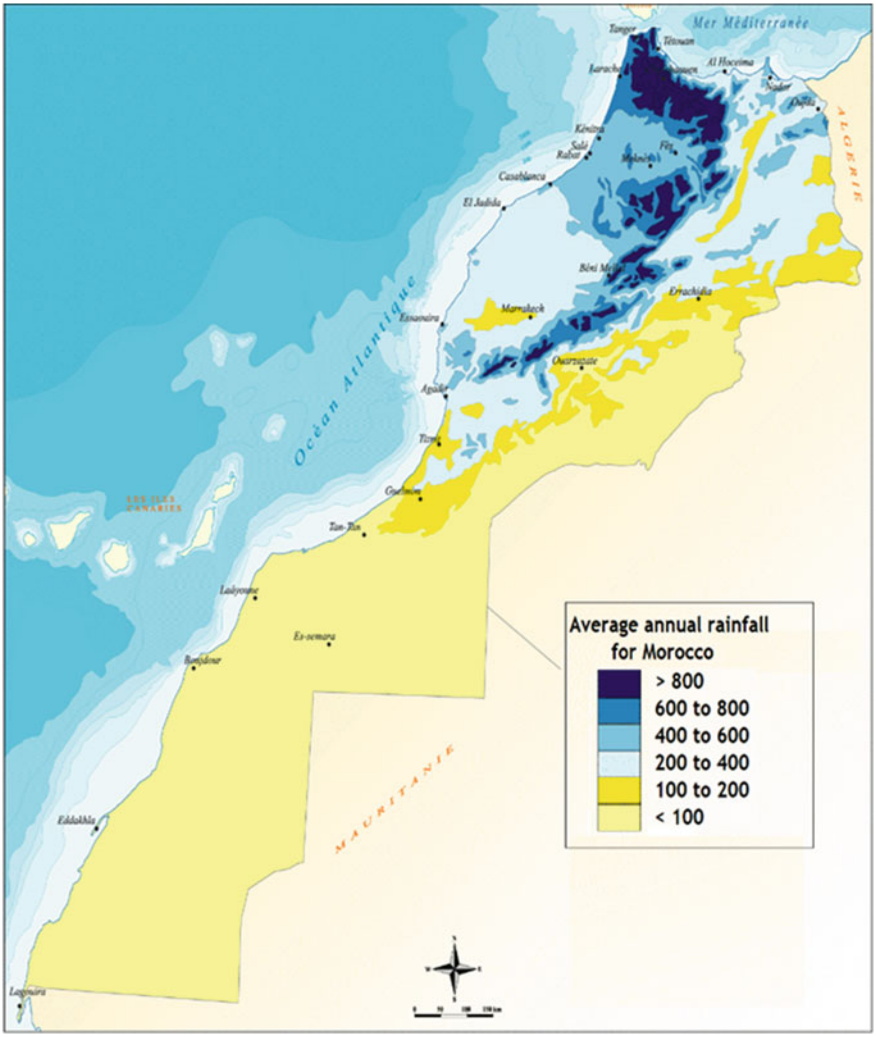


Fig. 6.1 Spatial distribution of precipitation

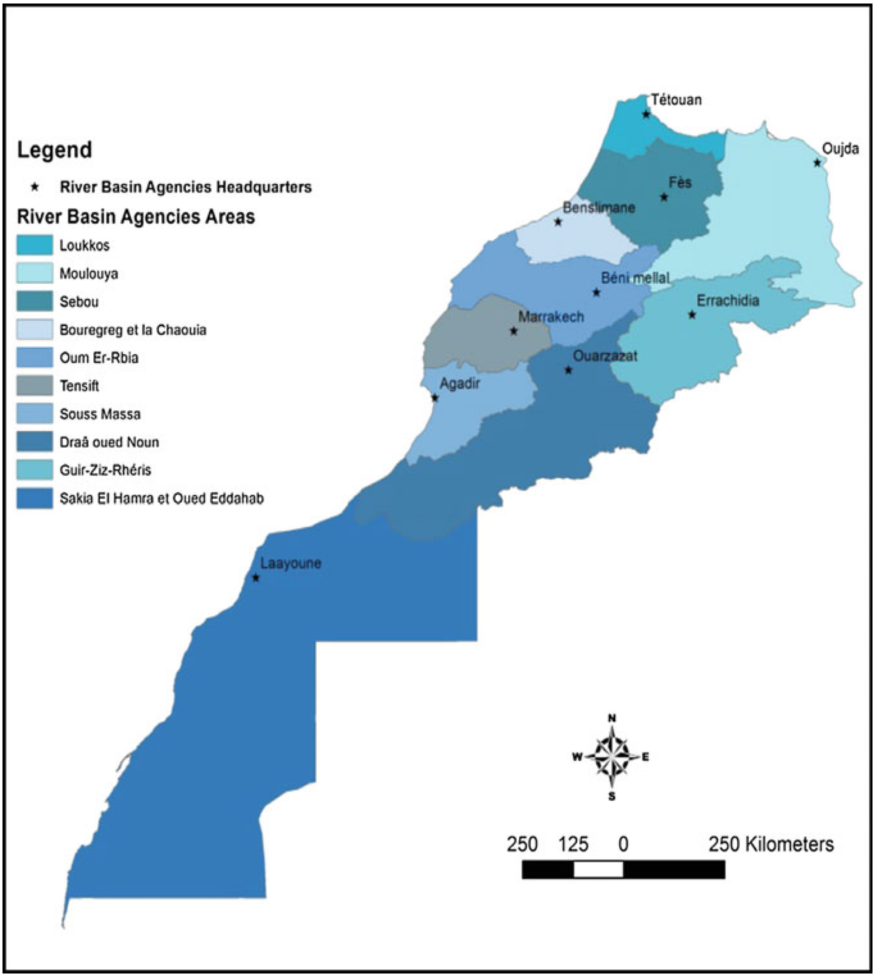


Fig. 6.2 River basin agencies in Morocco

The mean annual rainfall throughout Morocco under average seasonal conditions is estimated at 140 billion cubic metres (BCM). However, the renewable water resources do not exceed 22 BCM: 18 BCM from surface water and 4 BCM from groundwater. More than half of these resources are concentrated in the northern basins and the Sebou Basin, which together cover a mere 7% of the country's surface area (Fig. 6.2). Moreover, water supply is very irregular over time: the ratio between the wettest and the driest year can vary from 1 to 9. The spatial variability is also very high: the water supply per capita can vary in the proportion of 1 to 8 between the different drainage areas. Because of its inconsistent rainfall, Morocco is subject to periodic droughts, which take a considerable toll on agriculture and the economy.

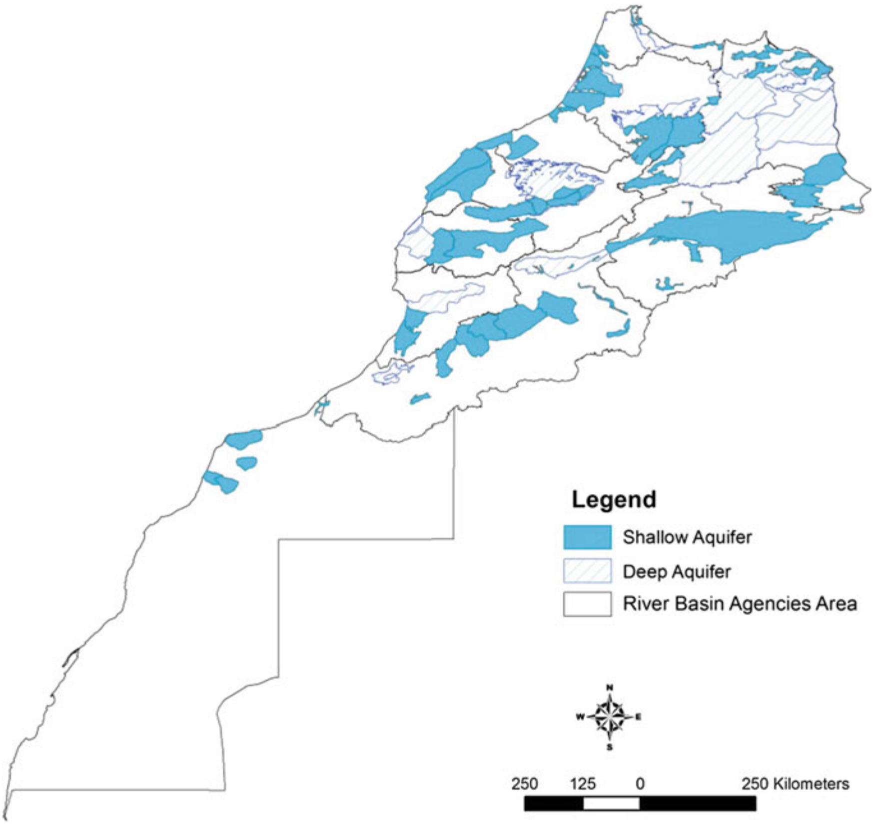


Fig. 6.3 Groundwater in Morocco

The population has more than tripled since 1956, rising from 10.5 million in that year to 33.8 million according to the 2014 census (Fig. 6.4). Morocco has seen rapid urbanisation in recent decades, with its urban population rising from 29% in 1956 to 60% today. The consequence of a rapidly growing population, accentuated by a progressive shift from rural to urban living, is the growth of requirements for the quantity and quality of water resources, as well as their more intensive and comprehensive use.

Morocco's economy is well diversified. The economy is dominated by the service sector, with a 56% share of GDP in 2016, against 24% for industry and 20% for agriculture and agro-industry. On the other hand, agriculture employs 40% of the active population of the country. Morocco is proceeding with a core economic growth path with critical development activities in industry (Plan Emergence), agriculture (Plan Maroc Vert), tourism (Plan Azure), and energy. The demands of these sectors will have to be met against the backdrop of shrinking water resources and amidst rapidly growing competition for water use.

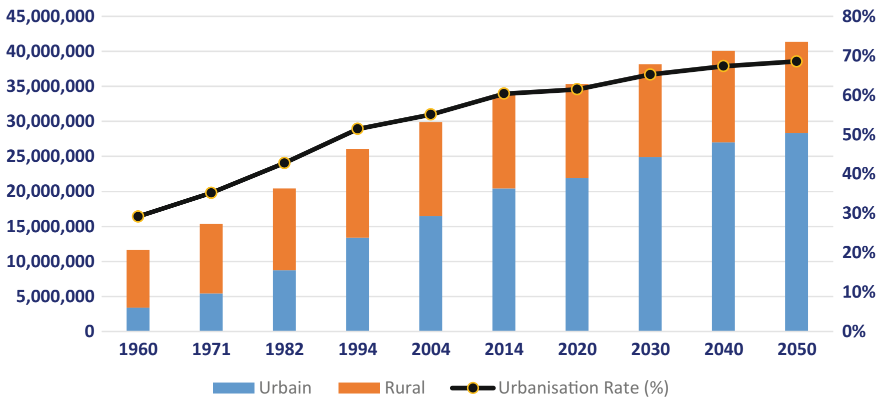


Fig. 6.4 Moroccan population, 1960–2050

6.3 Water Resources Development and Uses

For the last five decades, the emphasis in Moroccan development planning has been on maximising the capture of the country's surface water resources and providing for their optimal use in irrigated agriculture, potable water supplies, industrialisation, and energy generation on a sustainable basis.

Enormous capital resources have been invested in the essential infrastructure to control surface water flows. The number of large dams increased from 16 in 1967 to 140 in 2016, and led to a nine-fold increase in water storage capacity (Fig. 6.5) to 17.6 BCM, equivalent to 530 m^3 per capita (Ziyad 2017b). In addition, Morocco has 13 inter-basin water transfer systems. A number of major infrastructure projects are in advanced stages of planning and/or construction to capture most of the remaining surface runoff by the year 2020. Most of the major hydraulic infrastructure is multipurpose, integrating in its design and operation the water-agriculture-energy nexus.

Groundwater mobilisation efforts have resulted in an extensive development of wells and boreholes. This strategic resource contributes about one-third of drinking water production across the country, but up to 90% in rural areas. In addition, 40% of the currently irrigated area, mostly growing high-value export crops, depends on groundwater. Groundwater also plays the role of a strategic water reservoir in drought years.

The bulk of Morocco's water resources is used by agriculture. Irrigation accounts for 85% of the water use, compared to 10% for domestic use and 5% for industry. Irrigated agriculture has a high priority in Morocco, to meet the needs of its rapidly growing population and to expand export of both commodities and processed agricultural products. In 1967 the government committed itself to the provision of irrigation to a million hectares of land by the year 2000. Thanks to considerable investments over the period, this goal was achieved by 1997, and as of

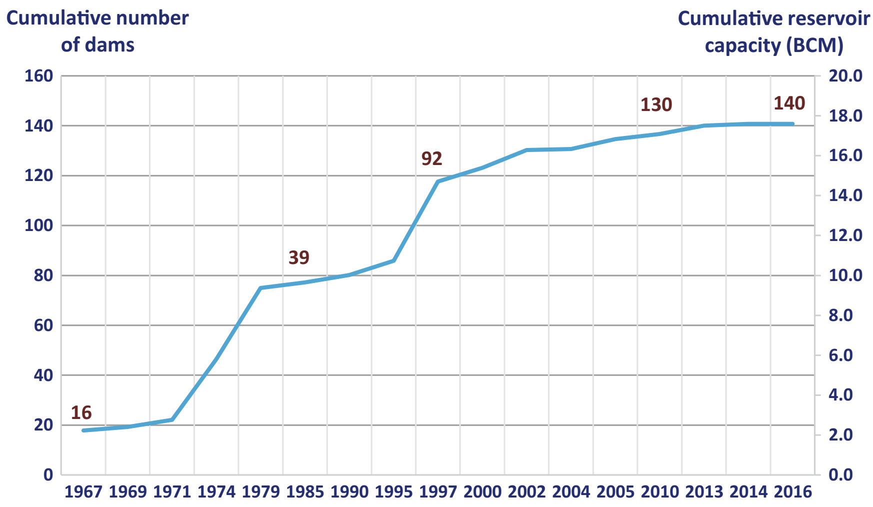


Fig. 6.5 Reservoir number and capacity since 1967

2016 the area was 1.5 million hectares. Morocco has made modern, large-scale irrigation projects the centrepiece of its irrigated agricultural development. They represent new investments in major civil works for water regulation, conveyance, and distribution systems (including on farm) using modern technologies. Nine irrigation perimeters have been developed in the major river basins of the country. Each one is developed and managed by a regional irrigation and agricultural development agency, or ORMVA (*office régional de mise en valeur agricole*). The ORMVAs are responsible for the design, construction, operation, and maintenance of the irrigation networks. They integrate all the productive services required by farmers under one management structure. They provide assistance to rainfed farmers, and those dependent on traditional irrigation, in their jurisdictions. ORMVAs are semi-autonomous organisations overseen by the Ministry of Agriculture, Fishery, Rural Development and Forestry.

The whole irrigation subsector currently contributes 45% of the agricultural value added and 75% of agricultural-export earnings. In addition to boosting food production, irrigation development has also increased rural employment, promoted agroindustry, and helped stabilise domestic production. It has also raised productivity and incomes significantly by bringing modern agriculture to small farm families, and in several areas it has reversed the flow of people from rural to urban areas, while contributing to natural resources conservation by relieving the pressure on areas with fragile ecology.

Concerning the drinking water sector, production has been multiplied by 5 in the last three decades, reaching more than 1.2 BCM in 2015. Currently, 100% of the urban population and 94% of the rural population (against 14% only in 1994) have access to an improved water supply.

Morocco lacks the large oil or gas reserves that some other North African countries boast; it is a net energy importer. Thus, hydropower production plays an important role in meeting the country's energy needs and reducing the energy imports bill. The current installed capacity is 1770 MW. In a typical hydrological year, hydropower provides 10% of the energy produced.

6.4 Issues and Constraints

Despite all its efforts and remarkable achievements, Morocco faces a growing challenge and many constraints in the water sector, which if not properly managed may hinder the growth of the country. These constraints can be summarised as follows (Ait Kadi 1998b).

6.4.1 Decline in Available Water Resources and Increase of Extreme Events

Morocco is highly exposed to climate change, resulting in hotter and drier climate. The warming trend of climate in Morocco is clearly shown by observations. An increase of the total annual number of warm days was seen in 1961–2016 at both national and local levels, along with a decrease in the number of cold days. Heat waves are following the same kind of evolution towards more high-temperature events. Moreover, this warming is accompanied by a decrease in total rainfall and a positive trend in the maximum number of consecutive dry days (slightly more persistent drought). These changes are illustrated in Figs. 6.6, 6.7, 6.8, 6.9, 6.10 and 6.11.

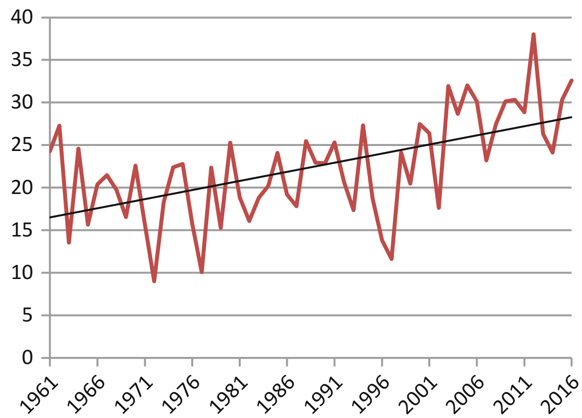


Fig. 6.6 Annual number of warm days, 1961–2016

Fig. 6.7 Annual number of cold days, 1961–2016

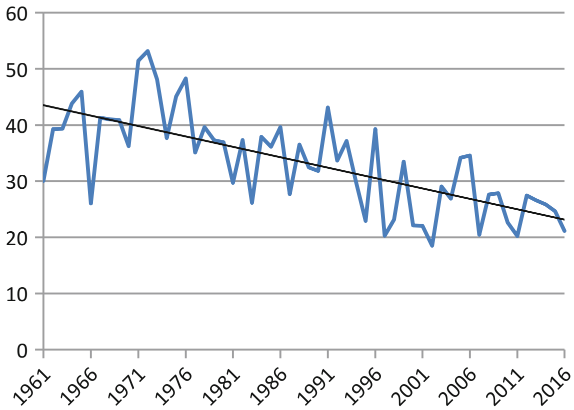


Fig. 6.8 Cold spell duration index, 1961–2016

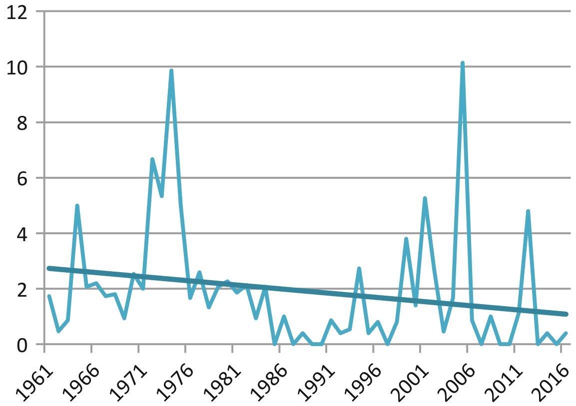
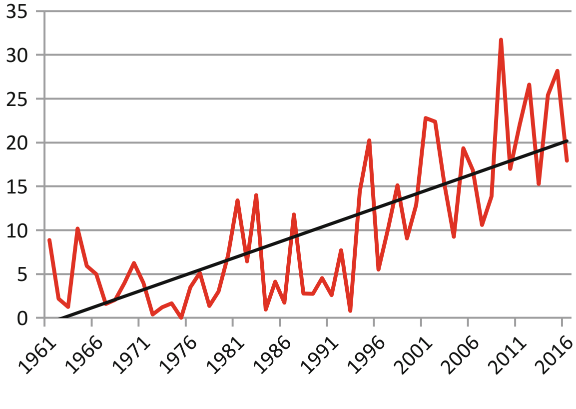


Fig. 6.9 Warm spell duration index, 1961–2016



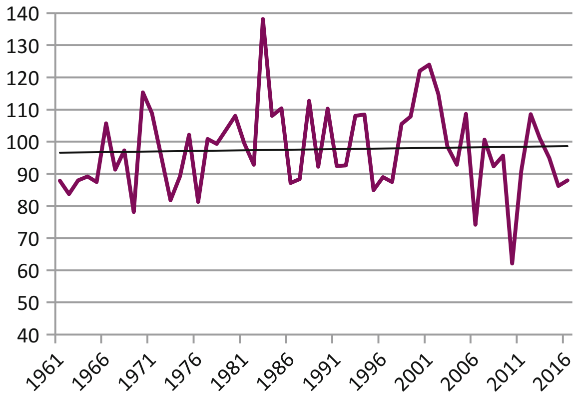


Fig. 6.10 Maximum number of consecutive dry days, 1961–2016

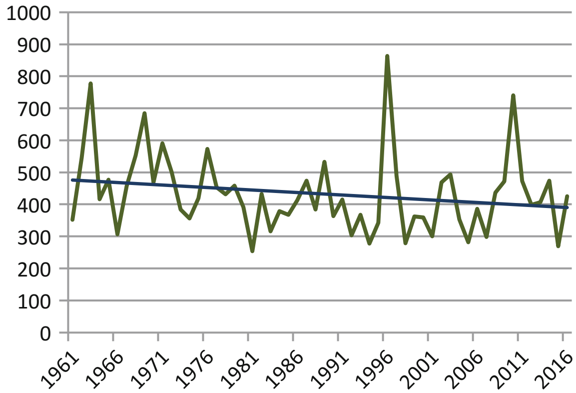


Fig. 6.11 Annual rainfall (mm), 1961–2016

A change in hydrological regimes is already observed, with lower average runoff and low flows, and higher frequency and intensity of flash floods. These changes add a layer of complexity to the operation of dams and flood control. Hydroelectric generation has also been affected, sometimes falling by more than 50% due to low water reserves in the dams. As an example, Fig. 6.12 illustrates the deviation from the normal and the temporal variability of flows at the Allal El Fassi Dam.

Drought is a recurrent natural phenomenon of Morocco's climate, and experience over the years has allowed the gradual establishment of an integrated drought management system (Box 6.1). However, current climate change projections suggest an increase in the frequency, intensity, and duration of droughts, with substantial impacts in the food, water, energy, and health sectors.

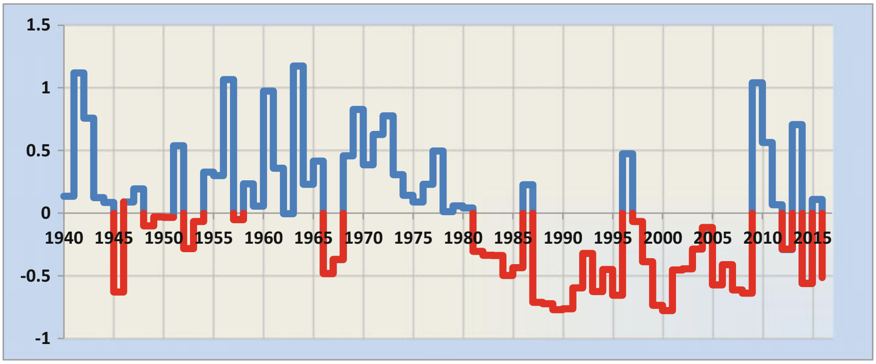


Fig. 6.12 Deviation from the average of the inflow at the Allal El Fassi Dam, 1940–2015

Box 6.1 Integrated drought management in Morocco

Drought is a recurrent natural phenomenon of Morocco's climate. A dendrochronological study undertaken in the early 1980s helped reconstruct the history of drought in the last millennium (1000–1984). It showed over 89 droughts of one to six years' duration, at an average interval of about 11 years. The average duration of a drought is around 1.6 years. The twentieth century was one of the driest in the last nine centuries (Fig. 6.13).

Morocco's experience over the years has allowed it to gradually establish an integrated drought management system structured around three essential elements:

A monitoring and early warning system. Morocco has developed national institutional and technical capacities, particularly in the areas of climate modelling, remote sensing, and crop forecasting. A national Drought Observatory was established in 2000 to improve forecasting, assess impacts, and develop strategies and tools for decision support and drought preparedness.

Emergency operational plans to alleviate the impacts of drought. Morocco has much experience in the development and implementation of programmes to alleviate the impacts of drought. These programmes are based on interventions aimed at (1) securing safe drinking water for rural populations in particular, (2) preserving livestock through feed distribution, (3) implementing income- and job-creating activities (maintenance of rural roads and irrigation infrastructure), and (4) conserving forests and natural resources.

A long-term strategy to reduce vulnerability to drought. This strategy is based on a risk management approach that reduces the vulnerability to drought of the national economy as a whole and of agriculture and the rural economy in particular. It involves a diverse and multidimensional array of policies that takes drought risk into account in its geographical diversity and economic and social implications, as well as in its long-term recurrence.

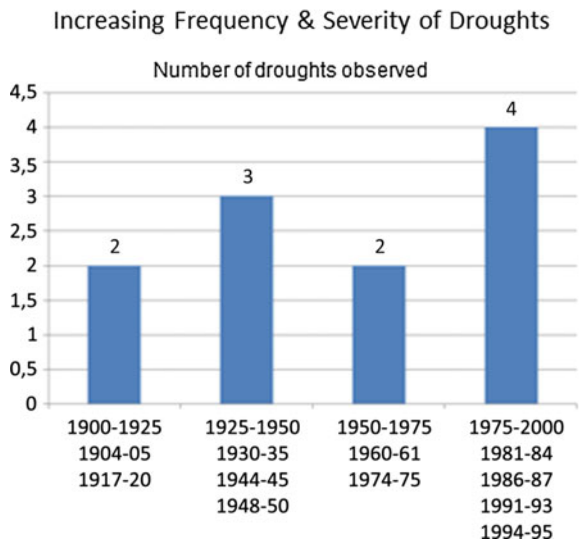


Fig. 6.13 Increasing frequency and severity of droughts in the twentieth century

Morocco is also facing more pronounced hydrometeorological extremes, with locally more intense rainfall and higher frequency of intense floods, causing significant economic losses and asset damage. A National Flood Protection Plan was developed in 2002 and updated in 2011. The aim of the plan is to treat flooding in a comprehensive and integrated way. The plan includes structural and non-structural measures. The structural measures cover all kinds of methods for controlling and preventing floods with tangible facilities. The non-structural measures include the establishment of a flood monitoring system and flood information and vulnerability maps, as well as improving legislation and institutional frameworks.

6.4.2 Overexploitation of Groundwater Resources

Depletion of groundwater resources is of particular concern. According to estimates, about 5 BCM of water are abstracted annually, against a renewable potential of 4 BCM.

This overexploitation has resulted in falling piezometric levels, reduced flows (or even drying up) of sources, and degradation of the quality of groundwater in some coastal areas due to salt intrusion. Monitoring of the evolution of water levels in almost all of the country's aquifers shows a continuous decline, sometimes reaching alarming values that may exceed two metres per year. The examples presented in Fig. 6.14 showcase the difficulties of a command-and-control approach based solely on the enforcement of the 1995 law. A more holistic approach is being used to reverse groundwater depletion trends in the Souss Aquifer. The aim is to reduce

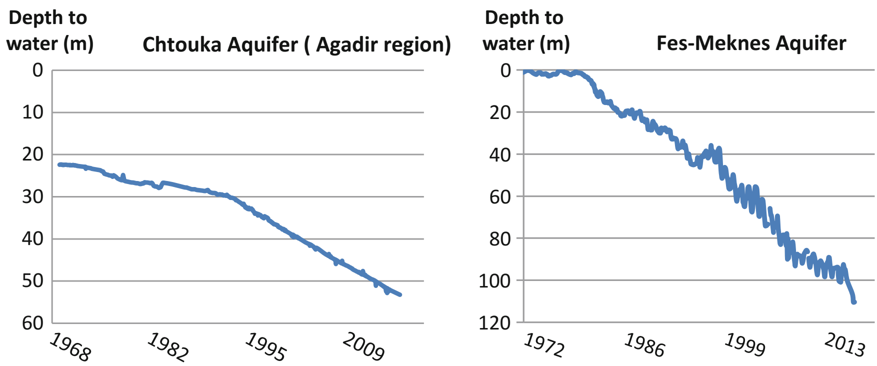


Fig. 6.14 Evolution of piezometric level in the Chtouka and Fes-Meknes Aquifers

abstractions while ensuring the socio-economic viability of agriculture, which is heavily dependent on groundwater in the region (Box 6.2).

Box 6.2 A holistic approach to groundwater management in agriculture: The Souss Aquifer contract in Morocco

The unsustainable abstraction of groundwater and the depletion of groundwater aquifers is a major problem. Rapid declines of groundwater levels reached alarming values, mainly in the Souss region (Fig. 6.15).

The Souss region, in the south-west of Morocco, has a semi-arid climate, with average annual rainfall not exceeding 250 mm. The region ranks first in production and export of citrus fruits and fresh vegetables. Irrigated agriculture covers nearly 120,000 ha, relying mostly on groundwater (72%). Because of a succession of droughts the region has been experiencing since 1985, the annual recharge of the aquifer does not exceed 40 million m^3, compared to 650 million m^3 withdrawn annually. The decline of the water table has consequently been dramatic: two to three metres per year. This situation has forced many farmers to uproot their citrus orchards, especially in the Elguerdane area (3750 ha, representing 38% of the total citrus area). The imposition of more restrictive legislation did not correct this tragic situation, and so the state and the regional authorities have developed a comprehensive programme for the development and management of water resources in the Souss region. This programme is based on two major pillars.

Conjunctive use of groundwater and surface water. This is made possible by the development of the Elguerdane large-scale collective irrigation project. It is a pioneering public–private partnership for irrigation development and management in Morocco in the form of a 30-year build-operate-transfer contract. Its main objective is to supply an additional 45 million m^3 of surface water to preserve citrus orchards threatened by rapidly sinking groundwater

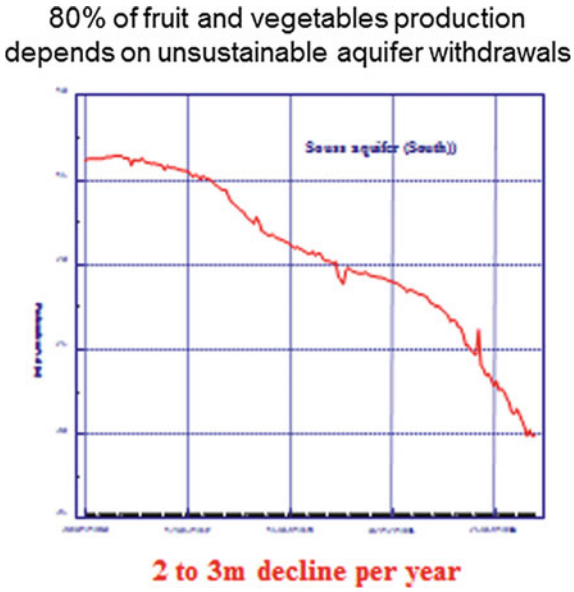


Fig. 6.15 Eighty percent of fruit and vegetable production depends on unsustainable aquifer withdrawals

levels in the Elguerdane area (10,000 ha). It consists of a reservoir and piped conveyance and distribution systems supplying a portion (50–70%) of the irrigation water requirements to farms, to be used conjunctively with groundwater. Citrus farmers have subscribed to the project on the basis of their agreement to use exclusively drip irrigation, contribute 40% of the investment cost, and pay a volumetric water fee, as defined in the public–private partnership contract.

An ambitious action plan to improve governance and water productivity. A convention for the preservation and development of water resources in the Souss region was established in the form of an 'aquifer management contract'. It was the result of a process of intensive consultations with all the stakeholders: government and local authorities, water users' associations, farmers' organisations, and credit institutions. The action plan under this contract covers control on the digging of wells and boreholes, control on the expansion of orchards and irrigated areas, adopting water-saving technologies (drip irrigation coupled with irrigation scheduling services), and awareness-raising of farmers and the general public in the region on issues of saving water and preventing pollution. A commission was formed by representatives of all the stakeholders to enforce the implementation of the aquifer contract.

To date, more than 50 water users' associations in agriculture, covering an area of 12,300 ha, have benefited from the programme. The commission has played a key role in the development and adoption of legislative amendments to adjust the fees paid by farmers for the use of irrigation water.

The originality of the approach stems from:

- Coupling aquifer governance to the development of a surface water project for conjunctive use as well as the introduction of more virtuous practices in the use of water resources;
- Shifting from a system of policing that was purely authoritarian but ineffective, to a system of voluntary commitments by users;
- Offering a comprehensive agricultural and water management package through the combination of many regional initiatives inspired by a collective action to solve the many water challenges the region faces.

6.4.3 Degradation of Water Quality

Water resources are increasingly threatened by pollution. The main pollution sources are agriculture, industry, and households. Water quality is deteriorating further as a consequence of the variability of the hydrological regimes, with lower flows during the summer dry season. Sanitation and wastewater treatment infrastructure has not kept pace with drinking water supply, and urban effluent is currently the major contributor to pollution of surface, coastal, and groundwater. Therefore, if the Moroccan economy proceeds along its growth path, water quality requirements will grow faster than quantity requirements. Hence, a National Plan for Water Quality Improvements has been formulated. The plan calls for (1) diagnosis of the quality of water resources, (2) analysis of the sources of pollution and their impact on water quality, and (3) preparation of a water quality protection plan for the major rivers (Sebou and Oum er Rbia) and the country in general, including the formulation of remedial measures against pollution.

6.4.4 Soil Erosion and Dam Siltation

Soil erosion affects all parts of the country, with various intensities. The annual cumulative land erosion contributes to the loss of nearly 75 million m^3 of available storage capacity per year, plus eutrophication and degradation of water quality. Moreover, it sharply increases the cost of operation and maintenance of downstream infrastructure and the cost of production of drinking water (Fig. 6.16).

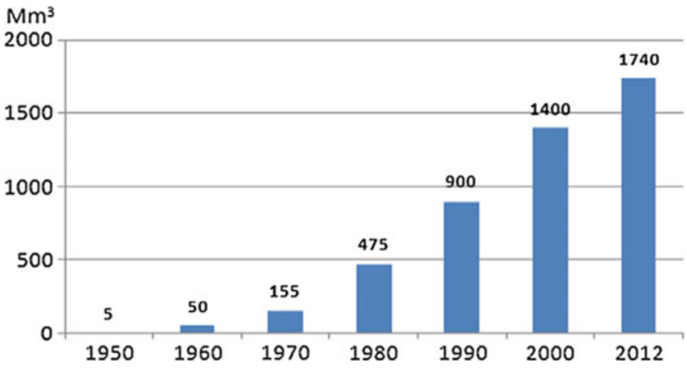


Fig. 6.16 Evolution of cumulative annual losses of dam reservoirs due to siltation

6.4.5 Low Water-use Efficiency

Morocco's water economy is now characterised by sharply rising costs to supply additional water and more direct and intense competition among different kinds of water users and uses. This has fostered a substantial change in attitudes to water conservation. Water shortages in general, and problems of groundwater overexploitation in particular, have spurred calls for improved efficiency in all sectors.

6.5 Holistic Water-sector Reform

The successive droughts of the 1990s, coupled with the challenges posed by the growing water scarcity, moved the management of water resources, already high on the national development agenda, even further up. Morocco opted to face up to these thorny problems (which were constraining the benefits of its prolonged efforts to secure its water supply) by adopting an integrated approach to water resources management through mutually reinforcing policy, legal, and institutional reforms, and developing a long-term investment programme (Ait Kadi 2014a, b).

6.5.1 The Strategic Framework

The major policy reforms are:

- Adopting a long-term strategy for integrated water resources management. The NWP is the vehicle for strategy implementation and serves as the framework for investment programmes until the year 2030;
- Developing a new legal and institutional framework to promote decentralised management and increase stakeholder participation;

- Introducing economic incentives in water allocation decisions through rational tariffs and cost recovery;
- Taking capacity-enhancing measures to meet institutional challenges for the management of water resources; and
- Establishing effective monitoring and control of water quality to reduce environmental degradation.

6.5.2 The Legal and Institutional Frameworks

The Water Law 10–95 was enacted in 1995 and updated in 2016 to consolidate integrated, participatory, and decentralised water resources management (SGG 2016). Its major features are:

- Stipulates that water resources are public property;
- Provides for the establishment of river basin agencies in individual or grouped river catchments. It clarifies the mandates, functions, and responsibilities of the institutions involved in water management. In particular, the status and the role of the High Water and Climate Council has been enhanced as the higher advisory body and a forum on national water policies and programmes. All the stakeholders from the public and private sectors, including water users' associations, sit on this council;
- Provides for the elaboration of the NWP and river basin master plans;
- Establishes a mechanism for the recovery of costs through charges for water abstraction and the introduction of a water pollution tax based on the principles of 'user pays' and 'polluter pays';
- Reinforces water quality protection by defining environmental mandates, sanctions, and penalties.

Concerning the institutional set-up, the major change was the establishment of river basin agencies empowered to manage individual or grouped river basins. The three principal responsibilities of these agencies are development of water resources, allocation of water as defined by the master plan, and control of water quality. The agencies reinforce the network of existing institutions in charge of the different water management functions (World Bank 1995).

6.5.3 The National Water Plan

To consolidate past successes and overcome the aforementioned challenges, a new impetus for the reinforcement of the water policy was triggered and exposed through the NWP based on the National Water Strategy and regional water master plans. This plan, which defines the priority actions to be engaged by 2030, aims to provide sufficient water resources to support the economic and social development of the country, ensure integrated and sustainable water resources management, and reinforce convergence and integration with other sectorial plans and strategies (Interministerial Commission 2015).

The main guidelines of this plan consist of consolidating past successes through additional water supply, facing new challenges relating to climate change, and proposing funding mechanisms adapted to the needs of the various projects and water uses (public–private partnership, Ziyad 2017a). The NWP is structured around three pillars:

6.5.3.1 Water Demand Management

Managing water demand and water valorisation through new technical, regulatory, and financial tools are priorities of the NWP. In the field of drinking water, in addition to the supply security objectives, the plan aims to improve the efficiency of distribution networks to reach a national average efficiency of 80% by 2025. It invites the tourism and industry sectors to adopt water-saving practices including reducing water use and maximising water reuse and recycling. In agriculture, a national irrigation-water-saving programme has been developed. It is based on a massive conversion of surface irrigation to drip irrigation over an area of 500,000 ha by 2020.

The NWP also envisages the development of hydroelectric power production, which is a clean and renewable form of energy. In effect, the expectations of the water and energy sectors are that development of hydropower will accelerate in the future. The energy strategy aims to increase the contribution of renewable energies to electricity production in the kingdom to 42% in 2020 and to 52% in 2030, of which a third is to be hydroelectric power.

6.5.3.2 Supply Management and Development

Morocco has invested great efforts in water resource mobilisation, and these efforts must be continued in two ways:

- The pursuit of surface water mobilisation by large, medium, and small dams, through the construction of three dams per year, to expand storage capacity from 17.6 BCM at present to 25 BCM by 2030. There is also the possibility of transferring water from water-surplus basins in the north-west to the central-west basins experiencing deficit.
- Non-conventional water resources mobilisation, through seawater desalination and treated wastewater reuse, mainly in agriculture and green-space watering. Desalination contributes about 1% of drinking water production today. By 2030, through the realisation of large-scale projects, desalination will cover nearly 16% of drinking, industry, and tourism demand.

6.5.3.3 Water Resources Preservation, Natural Environment Protection, and Climate Change Adaptation

As part of sustainable development promotion, the NWP offers a battery of activities:

- Preservation of water resources quality, fighting pollution by strengthening water quality monitoring, acceleration of the implementation of a National Programme of Sanitation and Wastewater Treatment, development of a National Sanitation Programme in Rural Environment, and the fight against water pollution, especially domestic and industrial pollution;
- Preservation of groundwater through the implementation of a new governance mode for sustainable and participatory management of this strategic resource, within a contractual framework (groundwater contracts), artificial recharge of deficit aquifers, and preserving groundwater quality;
- Watershed management and protection against water erosion;
- Safeguarding and preservation of sensitive areas through the implementation of specific action plans for wetlands and oasis areas; and
- Proposed measures to protect against flooding and drought effects (see above).

6.5.4 Financing

There are various sources of funding for water in Morocco. The national budget is currently the major funder of investment. Cash flow from water revenues covers recurrent costs (operation and maintenance) but only rarely contributes to investment funding, though Morocco has a well-established cost recovery system in both the irrigation sector and the water supply and sanitation sector.

In irrigation, the Agricultural Investment Code provides a legal and institutional framework for the significant recovery of both investment and operating costs. It calls for the full recovery of operations and maintenance costs and up to 40% of the initial investment costs (Ait Kadi 1998a). Similar principles apply to potable water pricing. In this sector the tariffs are differentiated between production and distribution, between cities, and between different categories of users in a progressive pricing structure. A solidarity tax paid by urban users has been established to support investment in improving access to potable water in the rural areas.

Morocco has granted a series of concessions to private international companies for the development and management of the water supply and sanitation systems in some major cities (Casablanca, Rabat, Tangier-Tetouan). A public–private partnership in the form of a BOT (build, operate, transfer) agreement has been pioneered for the development and management of the Elguerdane Irrigation Perimeter (Box 6.2). Other public–private partnerships are being launched in the field of irrigation and drinking water production through the mobilisation of surface water and the use of desalinated seawater. Two examples are (1) a project to save and develop irrigation in the areas of Bir Jdid, Saiss (Fes Meknes), Loukkos (linked to Dar Khrofa Dam), and Guir (associated with Kadoussa Dam); and (2) a project to strengthen the drinking water supply of Agadir City and safeguard irrigation in the Chtouka region through seawater desalination.

6.6 Conclusion

Morocco is continuing its efforts towards the completion of integrated water resources reforms. A holistic approach is being adopted based on:

- Developing an enabling environment in terms of adequate policies and institutions (including regulations and organisations);
- Mobilising the necessary financial resources both for selective development and exploitation of new water supplies and more vigorous demand management, with comprehensive reforms and actions to make better use of existing supplies; and
- Fostering greater cooperation between the various water subsectors.

Morocco's water reform experience offers a range of useful features, covering mainly the new institutional arrangements governing the water sector, with the reinforced role of the High Water and Climate Council as an apex body for national water policy and programmes, and the creation of river basin agencies. At the sub-sectorial level, the Moroccan irrigation agencies are unique, as they integrate the provision of production services to farmers with water supply, an approach that is crucial for enhancing water productivity and farm output.

This experience emphasises the need for major shifts in conceptual approaches to water governance to reach a more desirable future and limit calamities that can otherwise be foreseen. This is particularly relevant as many societies are currently facing socio-economic transformations which need to be reflected in changes in the respective governance systems (Ait Kadi and Arriens 2012; Ait Kadi 2015b). But putting effective water governance into practice is a very large and complex agenda (Ait Kadi 2015a). Tackling this agenda must start with new institutional mindsets and mechanisms that can develop a more coordinated approach to the challenge of water resources development and management, reflecting stronger interconnectedness among water systems. It calls for the creation of an enabling environment based on an adequate set of mutually supportive policies and a comprehensive legal framework, with a coherent set of incentives and regulatory measures to support these policies. Yet, policies and regulations, though necessary, are not sufficient. Putting effective water governance into practice also means strengthening and/or creating institutions and mechanisms that can transcend the boundaries between sectors.

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Chapter 7
Water Security in a Southern African Context

Mike Muller

Abstract The approaches taken to water security by the countries of the Southern African region reflect their particular contexts. There are two overarching challenges that are common to all these countries. The first is the ongoing requirement to ensure that all citizens have access to safe and reliable water supplies, particularly in rural areas. The second is to ensure greater resilience to climate variability, since drought regularly disrupts subsistence agricultural production, on which a substantial population still depends. While floods have a significant local impact, they are a second-order challenge affecting a relatively small proportion of the regional population. In this context, the principal barriers to achieving water security are economic status and institutional capacity. The variability and relative scarcity of the water resource is, in itself, not the dominant determinant of water security, since there is evidence that the natural resource challenges have been overcome where there are competent institutions, able to access adequate financial resources. There are also opportunities to mitigate some of the impacts of drought at a regional scale, but political barriers make it difficult to implement cooperative approaches for this purpose.

7.1 Introduction

7.1.1 Water Security is a Contextual Concept

Southern Africa shows that water security is defined and determined by context. In some regions, the primary problem is too much water—floods can be among the most immediately destructive impacts of the hydrological cycle. In other places, the challenge is one of drought, the unpredictability of rainfall that can devastate the economies of agrarian societies. And in regions with substantial industrial activity

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and dense human settlements, the quality of water may become so poor as a result of pollution that it is not suitable for use without extensive and expensive treatment.

Southern Africa has examples of all these dimensions. Its experience also shows that the ability of societies to cope with the challenges that water brings depends fundamentally on their economies and institutions. If there are enough financial resources, it is possible to build infrastructure that can mitigate the problems, whether by storing water against drought, protecting communities from floods, or treating polluted water. However, effective use of financial resources requires institutions capable of diagnosing the problems and then designing, implementing, and sustaining appropriate solutions. So a further challenge for Southern Africa is that many of its countries depend on external financial and institutional support which is not always adapted to local challenges. As a result, there is a rapid cycle of adoption of new management paradigms, of which water security is one more example.

This review of water security in Southern Africa thus necessarily begins with an outline of the physical, social, economic, and institutional context.[1]

7.1.2 The Physical and Hydrological Context

The climate of Southern Africa varies greatly across the region. The extreme southern part has a temperate Mediterranean climate with winter rainfall. Much of the rest is a summer-rainfall region, with temperatures ranging from temperate in the high areas of South Africa to tropical along the north-east coast.

Rainfall varies from under 200 mm/y in desert areas along the west coast to 2000 mm/y in the mountainous areas of Malawi in the east, with substantial intra- and inter-seasonal variability. Many parts of the region are arid, with evaporation substantially exceeding rainfall, and there are large regions of desert and semi-desert, notably in the southwest. Runoff from rainfall is generally low, around 5% in South Africa, a consequence of aridity.

There are few large perennial rivers, and the flows in those show significant seasonal variability. This constrains their large-scale utilisation without the development of storage and transmission infrastructure. The east coast is subject to regular tropical storms, which result in serious flooding but also account for a substantial proportion of rainfall in the wider region. The whole region also experiences regular cycles of drought, often associated with El Niño events,

[1]For the purposes of this review, "Southern Africa" is the member countries of the Southern African Development Community minus Tanzania and the Democratic Republic of the Congo, which have overlapping membership in other regional organisations, and the island states of Mauritius, Madagascar, Seychelles, and Comoros. Some organisations, notably the UN Department of Economic and Social Affairs, use other groupings, and there is considerable overlap between the countries of Eastern and Southern Africa.

although these impacts are not correlated between the northern and southern parts of the region.

Finally, groundwater resources that are adequate to support the domestic needs of many rural communities are widely distributed. However, there are few equivalents of the large and productive alluvial formations common in South and East Asia, Europe, and North America. The aquifers in the hard rock geology that characterises much of the region do not generally yield sufficient water to underpin irrigation on a significant scale or to support large urban and industrial supplies.

The Southern African Development Community (SADC 2006) characterises the region's water resources as highly variable and unevenly distributed, with their management and use challenged by pervasive poverty and the fact that much of the water is found in shared watercourses.

7.1.3 The Social and Economic Context

Southern Africa is a region larger in area than the European Union (almost 6 million km^2 vs. 4.4 million km^2), but its population is currently less than a quarter of the EU's (around 155 million compared to 730 million).

Unlike Europe's, however, Southern Africa's population is growing rapidly, expected to reach 300 million by 2050 and to continue on that trend to 2100. Still predominantly rural, like much of sub-Saharan Africa, the region is also expected to experience rapid urbanisation, with 56% (169 million people) living in cities by 2050, up from 44% (69 million) in 2014 (UN Department of Economic and Social Affairs 2014).

In economic terms, the countries of the region range from those characterised as low-income (Malawi, Mozambique, and Zimbabwe) to others in the upper-middle-income range (Botswana, Namibia, and South Africa). Angola, Lesotho, and Zambia, while classified as lower-middle-income, are included in the UNDP's list of 'least developed countries' by virtue of their poor social indicators, the result of war, economic dependency on volatile commodity markets, and other factors (World Bank 2017).

While there are pockets of prosperity, the majority of the region's population is still poor. Almost half live in a formally defined state of poverty, with incomes below USD 1.90/day, supported by rural subsistence activities or informal activities in urban areas. The region is also characterised by high levels of inequality, notably in South Africa, which has one of the highest Gini coefficients in the world, but also in many of its neighbours. This poses particular problems for water security, since institutions and infrastructure have to cater to a variety of economic circumstances and respond to the social and political challenges and pressures that are generated by different service standards and the qualities of service that are available to different communities.

Many poor communities in the region have very limited access to safe and reliable water and are vulnerable to water-related disasters such as droughts and, to a lesser extent, floods. Meanwhile, smaller affluent communities have high levels of service but also high expectations about the quality of the aquatic environment and thus in the effective provision and functioning of expensive services such as wastewater treatment, even where the majority of people have no access to any form of safe sanitation.

7.1.4 The Institutional Context

The achievement of many dimensions of water security is dependent on the quality of institutions, formal or informal, that determine how water is managed and used.

Domestic water supply is often the responsibility of local or municipal authorities, particularly in urban areas. The quality of water-related services thus depends on both the competence of the organisations and the resources available to them. This institutional capacity is extremely variable across the region.

Some of the smaller, better developed countries, such as Namibia and Botswana, where urban communities depend on organised collective supplies, have relatively effective municipal organisations. In Zambia, where urban supplies are provided by private utilities, these have proven to be relatively effective. South Africa, the best-resourced country in the region from a financial perspective, achieved high levels of coverage during the first decade of democratic governance. However, limited skills and poor political oversight have seen municipal capacity decline in many areas. As a result, there has been a failure to sustain existing supplies, particularly in poorer, more rural areas, and access to safe, reliable water has recently begun to fall. In Angola, urban water supply has been weak, with many communities dependent on informal channels such as private water tankers, even in Luanda, the national capital, where supply is the responsibility of a dedicated city utility.

In poorer countries, less formal community-based institutional arrangements have, in some cases, managed local supplies effectively, particularly in rural areas, although coverage of safe and reliable supplies remains low. In these countries, responsibility for urban water supply is sometimes the responsibility of regional utilities (Malawi) or a national utility (Mozambique). Such institutions tend to be constrained by financial resources which limit their capacity.

With respect to management of water resources, the challenge is somewhat different. Institutional requirements in this context are to monitor water resources and to develop them to make water available for productive use and then to manage competition and conflicts between users, as and when they occur. Overall responsibility for this function is invariably at the national level throughout the region. However, operational responsibility is often delegated to regional or catchment-based organisations, with individual supply schemes sometimes managed by user-based organisations.

Finally, since most of Southern Africa's major rivers are shared between more than one country, institutional arrangements are required to manage cooperation and conflict between countries. In Southern Africa, these issues are formally dealt with in the 1995 Protocol on Shared Watercourses of the SADC, the regional cooperation organisation. In terms of the protocol, countries must cooperate on the use of shared rivers through appropriate institutional arrangements.

This is an area in which external drivers have had significant impact, with much emphasis on the establishment of formal river basin organisations (notably ZAMCO, ORASECOM, and OKACOM, on the Zambezi, Orange, and Okavango Rivers, respectively). However, substantive cooperation on shared rivers where joint development action or regulation was required has occurred principally through ad hoc or bilateral organisations. So a trilateral task team of the riparians manages issues on the Komati River; a bilateral treaty organisation between South Africa and Lesotho, two of the four riparians on the Orange River, promotes their joint water supply project; and there are bilateral arrangements between Zambia and Zimbabwe to develop hydropower and between Malawi and Tanzania to promote power and agriculture on the Zambezi, which is shared by eight riparians.

7.1.5 Water Security

What does 'water security' mean in this context? For politicians and communities, the focus is often on access to basic water supply and sanitation services. However, it is recognised that water security is a more complex construct. A definition commonly used in the region is that of Grey and Sadoff (2007), 'the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks'.

This usefully distinguishes between

- the water requirements of human communities to meet their basic requirements for health and well-being
- the water required for economic activities that support the communities
- specifically, because it inevitably represents such a large proportion of 'consumptive use', the water requirements of agriculture, both for subsistence food security and as an economic sector in its own right
- the wider requirements of urban areas for water to support social and political institutions as well as commercial activities.

Importantly, it also encapsulates two other important dimensions of water security:

- the protection of human communities and their assets from the destructive power of water (or its absence); and
- the state and functioning of the aquatic environment and the impact of environmental conditions on other dimensions of water security.

These are all factors that are more or less important to the countries of the region and contribute to the recognition of the broad definition of water security rather than one that is limited specifically to service provision.

7.2 Some Dimensions of Water Security in Southern Africa

7.2.1 A Composite, Regional Perspective

Rather than attempt to catalogue each dimension for each country, this review presents some examples of these different dimensions of water security from across the region. From this composite picture, some conclusions are then drawn about the state of water security across the region but also about the factors that contribute to greater or lesser water security.

Although sanitation provision and the associated use of water to support hygienic practices essential for health are often dealt with together, a different approach is taken in this review. Since the focus is specifically on water security, sanitation is considered primarily as a potential demand for water or as the source of harmful impacts on water quality and the aquatic environment. This is not to minimise sanitation's importance but to recognise that there may be alternatives to the extensive use of water to provide for household sanitation and domestic wastewater disposal. To the extent that sanitation provision impacts negatively on water security, this may in turn offer motivations for an intensification of efforts to better manage the interface between them.

7.2.2 Water for Basic Human Needs

In general, Southern Africa demonstrates that even in a region with relatively limited water resources, water scarcity is not a constraint on meeting the basic human needs of water for health, comfort, and dignity. Access to safe water is rather correlated with national incomes at the level of countries and household incomes at the level of communities. This does not mean that all people have access to adequate quantities of safe water, but rather that the constraints are more usually financial and institutional and not the physical availability of the resource itself.

In a rural context, most households depend on resources in their surrounding landscape for water. Many still rely on water from open watercourses or shallow wells which are unsafe because they are vulnerable to pollution, and often unreliable, not least because they may be affected by drought. To ensure that the water used by rural communities is safe and reliable, national governments, often in partnership with NGOs, have for many decades promoted programmes to provide and support low-cost, low-tech supply systems, including handpumps and 'improved' wells and, in some instances, small treatment and reticulation systems.

The initial provision of this kind of supply infrastructure often requires site-specific investigation to guide the selection of the appropriate intervention, which can be costly. Sustaining the reliable operation of such systems after construction has also proved to be a major challenge. While considerable effort is devoted to working with communities to enable them to undertake basic operation and maintenance, the failure rate of these schemes remains high and slows the expansion of coverage.

Thus, while all countries in the region have public programmes to promote water supply in such circumstances, effective coverage of safe and reliable water supplies to rural communities remains relatively low in many countries—ranging from 23% in Angola and 32% in Mozambique to 63% in Namibia and South Africa and 66% in Lesotho (Joint Monitoring Programme 2017). This low coverage reflects the limited institutional and financial capacity to provide and support operation of rural systems.

That income is a limiting factor is shown by the experience of South Africa. The initial programme to provide safe water supplies to all citizens was backed by a constitutional provision establishing access to enough water as a human right and a 'free basic water policy' designed to ensure that affordability did not constrain access in the poorest communities (Muller 2008). However, political pressure rapidly expanded the interpretation of the basic supply, specifically who was allowed to receive free water and the amount of water that was provided free. In communities where de facto free access was allowed, coverage of reliable supplies is now declining as consumption exceeds the design capacity of the systems (Statistics South Africa 2016). This is aggravated by the fact that municipalities with a large proportion of poor households rarely have the financial resources to increase supply capacity beyond the basic minimum provision which is subsidised by the central government.

7.2.3 Water for Urban Communities

The growth of large urban areas presents challenges of a different nature and scale as the water demand for urban communities sooner rather than later outstrips the availability from local sources. In such cases, water supplies have to be drawn from a wider area, which requires greater economic and more sophisticated institutional resources than are required for relatively small and scattered settlements.

A further constraint is that, in most cases, the bulk of the water is still required for domestic rather than economic activity. There are thus limits to the extent to which cross-subsidy from commercial users can support domestic supplies (unlike the case of electricity, where commercial use is often dominant). And domestic users in most of Southern Africa's urban areas do not have the financial capacity to fund investments in such bulk water supply systems.

This situation is aggravated by the fact that the volumetric use of water per capita for domestic purposes is usually greater than in poor rural communities, often by an order of magnitude. In the region, per capita consumption can exceed 200 litres per person per day in some high-income urban communities, particularly those that enjoy a suburban lifestyle with gardens, even in water-scarce cities such as Namibia's capital, Windhoek (Remmert 2017). Even in these communities, there is often a reluctance to pay the full costs of supply, often associated with weak institutions which also have to cater to large poor urban communities.

Maintaining water security for large urban areas in terms of a reliable supply becomes a significant challenge in such contexts. It requires long-range planning and development to identify and promote the implementation of bulk water schemes as well as the ability to mobilise significant financial resources for the capital works required. The importance of political commitment to long-term programmes is illustrated by South Africa. While the country had a long track record of effective planning and implementation of large-scale regional projects, political interference in the technical processes has more recently weakened its institutions. As a consequence, major cities such as Cape Town have suffered severe water shortages, while other centres are at risk, as system capacity is no longer adequate to provide protection from a 50-year drought event (Muller 2017).

The development of the urban interior of South Africa illustrates how such challenges have been addressed in the past (Muller 2016). However, many urban areas in the SADC suffer from greater or lesser supply deficits. Often, these deficits reflect limited financial resources more than simply institutional incapacity. In general, as urban areas grow, the sources they draw on are more expensive than those used initially. If population growth is largely of poorer people, they can rarely afford water charges that reflect the full marginal cost of future schemes (even if that were an equitable approach). Urban utilities are thus cash-constrained, and their customer base cannot be presented to potential financiers as offering a bankable tariff-based cash flow. As a consequence, supply invariably lags demand.

Notwithstanding these constraints, because urban dwellers often have limited alternative sources of supply, access to formal water supply in the region's urban areas is substantially higher than in rural areas. South Africa and Namibia are reported to have 97% coverage, Zimbabwe 94%, Lesotho and Malawi 87%, Zambia 86%, Mozambique 79%, and Angola 63%. However, when the reliability of supply is taken into account, these figures reduce significantly: South Africa to 85%, Zambia to 90%, and Zimbabwe to only 60%. Consideration of water safety (absence of contamination) sees a further reduction in the minority of countries where data are available (Joint Monitoring Programme 2017).

The water supply and wastewater disposal requirements of commerce and industry, as well as of public institutions such as schools, health facilities, and public offices, are generally met through municipal supplies. However, some water-intensive industries, mining in particular but also paper and pulp production, have to develop their own supplies or contribute financially to larger regional supply schemes.

7.2.4 Environmental Quality: Wastewater and Other Impacts

Water quality is an inherent element of water security which has both objective and socially determined, subjective dimensions. These are often (but not always) related to the natural aquatic environment. In terms of direct human impact, poor water quality imposes a burden on water users, who must either incur additional expenditure for water treatment or accept the use of poorer-quality water. This effectively reduces their water security.

The maintenance of water quality is a significant local challenge around many urban settlements in the region, particularly in inland areas where water sources are located close to developed zones. In the inland areas of South Africa where a concentration of mining, industrial, and urban development has occurred, water quality is now a systemic challenge that affects agriculture as well as downstream settlements.

While it has proven to be possible to regulate the quality of discharges from large, isolated, urban activities such as mines, pollution from urban sources is more difficult to manage. In part this is because there is always a higher priority placed on investment in water supply rather than effective wastewater treatment and disposal. But it is also due to the impact of diffuse pollution from low-income settlements and small-scale economic activities.

The provision of effective sanitation systems to remove, treat, and dispose of human wastes is thus a significant indicator of broader water security. Here again, performance varies across the region. According to the Joint Monitoring Programme (2017), the highest levels of coverage in urban areas were in Botswana and South Africa, with 77 and 76%, respectively. The lowest levels, between 46 and 49%, were in Lesotho, Malawi, Mozambique, and Zambia. It is thus clear that, in all urban areas, there will be significant pollution from human waste and wastewater. Coverage in rural areas is lower and much more variable, from 12% in Mozambique to 69% in South Africa, reflecting income levels as well as population density, since, where households are closer together, the impact of poor sanitation on water quality and health is more immediate and obvious.

Southern African countries have significant mining industries, and the post-closure impact of mining on water quality is a specific problem. South Africa's old gold mines, which have often been closed without adequate provision for remediation, contribute a small (15%) but significant proportion of the total dissolved solids load in the Vaal River system, which supplies the heartland of the country. The treatment of these wastewaters is attractive as a system-wide quality management intervention because they are easily accessible as a point source, but this has proven costly (Council for Geoscience 2010).

New mining operations are now regulated to ensure that adequate measures are in place to prevent post-closure pollution. These require supervision to ensure that the mandated measures are effectively applied. In other parts of the region where mining operations are more isolated, the situation is less acute at a regional and systemic level, but there are still often severe local impacts. In addition, widespread artisanal mining in Zimbabwe and Zambia is associated with extensive downstream pollution.

While protection from the impact of pollution is an obvious environmental focus, abstractive water use can also cause significant damage to the aquatic environment. In systems with highly seasonal flows, abstraction of even relatively small proportions of the annual flow can, if concentrated during dry, low-flow periods, effectively destroy aquatic ecosystems. The development of storage reservoirs to mitigate low flows may also have negative environmental impacts. While these are addressed in many countries through the development of operating rules that include provision for environmental flows, this may only occur where environmental and social impact assessments are undertaken in larger, formal development projects, for which these procedures are increasingly required in the region.

7.2.5 Water for Food, Agriculture, and Rural Subsistence

The degree of water security for food (and other agricultural) production varies considerably across the region as well as with the nature of the agriculture considered.

A substantial proportion of the SADC's population still relies to a significant extent on subsistence agriculture for both income and food security. Since this type of agriculture is characterised by low levels of input and investment, only limited irrigation is practised, and it is vulnerable to the droughts which regularly visit the region. As a consequence, large proportions of the population are food-insecure.

On the other hand, there are significant areas of commercial farming which are supported by extensive storage and transmission infrastructure. The bulk of this is in South Africa, but there are also extensive plantations of, notably, sugar as well as other crops in Mozambique, Malawi, Zimbabwe, and Zambia. Once established, such relatively high-value horticultural and industrial crops can often support the ongoing operation, maintenance, and even expansion of their supply systems, although in most cases they were initially dependent on public subsidies.

As already indicated, the Southern African region is subject to climatic extremes and drought, which often compounds the impact of aridity and limited rainfall. There are significant areas in which rainfed agriculture is practised. However, in many parts of the region, rainfall is not sufficient or sufficiently reliable to support viable agriculture without at least some irrigation.

But another important factor is the availability of land and the farming systems adopted in different communities. So it is notable that, while South Africa has significant areas under rainfed production in areas that are vulnerable to drought, its commercial agricultural sector is relatively successful. However, demand for water from other sectors is growing rapidly, and water use (as a proportion of total available water) is already high (estimated at 35% in 2005) and is approaching the economically feasible limits of development at around 40%. In these circumstances, it is likely that competition with other uses will result in less water available for agriculture, a situation that was foreseen as long ago as 1970 (South Africa 1970).

In the other countries of the region, the situation is not so acute. According to the FAO's Aquastat data set (FAO 2017a), the proportion of available water used in other countries is lower, and much more is thus available for agriculture. Swaziland uses an estimated 23% of its available water, 95% for agriculture; Zimbabwe (18 and 82%) and Malawi (6 and 80%) follow closely. Namibia, widely considered water-scarce, uses only 2% of its available water, 45% for irrigation and 26% for livestock; Botswana similarly uses less than 2% of its available water; Zambia, less than 2%, with 76% going to agriculture.

A cautionary note is that many of these data are relatively old, often dating to 2002–04. This reflects a general problem in the region of a paucity of information about national water resources and, in particular, about their use. It also provides a national picture, while there is often a substantial disjuncture between the distribution of people and of water.

However, the data do indicate that, if regional cooperation and integration were to advance and allow agricultural production to shift towards areas where water resources are available, water for agriculture need not be a major constraint on agricultural development. Political considerations will however constrain the migration required from relatively water-stressed and land-stressed countries such as Malawi to water-rich and land-rich countries such as Zambia (Muller et al. 2015).

7.2.6 Water for Energy

In this region water is both a source of energy, through the production of hydropower, and a constraint, where cooling water is required for thermal electricity generation. Outside South Africa, the majority of countries in the region derive a significant proportion of their energy from hydropower.

Africa's primary hydropower resource is the Congo River, whose potential (770 TWh) is of a similar order of magnitude to that of South America's Amazon. However, it is almost unexploited. Plans have long been mooted to develop the next phase of one identified project (Inga), which has a potential of perhaps 50,000 MW. These have not proceeded, and the site currently produces less than 3000 MW. One result has been a renewed focus on the region's smaller-scale resources. Aside from the Congo, Southern Africa is not considered water-rich, but it does have significant hydropower resources, of which only 11% is currently exploited (UNEP 2017).

Mozambique has identified and sought to promote four projects with a total capacity of over 4000 MW on the Zambezi, with the power destined initially for export. Zimbabwe and Zambia are also promoting a 1500 MW project in the Batoka Gorge on their shared portion of the Zambezi, intended to meet their internal needs, while Zambia is expanding the capacity of its scheme on the Kafue tributary of the Zambezi from 2000 to 2750 MW. Angola has mobilised receipts from its oil resources to fund the recently completed 2000 MW Lauca project, which will significantly reduce the power deficit in the country.

Hydropower is sometimes considered unreliable, since its production is curtailed in times of drought. However, such shortages usually reflect limited investment in additional generation. Where extreme restrictions have been introduced, this is often because hydropower projects have been operated beyond their rated capacity and outside their operating rules, often in response to political pressures. One exception is Malawi, where the relatively small amounts of hydropower generated on the Shire River are dependent on outflows from Lake Malawi, which are particularly vulnerable to climate variability and change (Kumambala 2010).

Where energy is produced from thermal sources, a reliable supply of water is required for cooling. Any failure of water supply rapidly leads to a reduction or cessation of power generation. This is particularly important in South Africa, whose energy-intensive economy is largely dependent on coal-fired power. Since most of the economic activity and power generation occurs inland, in the centre of the country where water is relatively scarce, considerable water resource investment has been required to support power production. Since 1970, dry cooling has been encouraged, and, as a matter of policy, nuclear power is considered only in coastal areas (South Africa 1970). Current energy planning explicitly considers water requirements, and water impacts are now an integral dimension of statutory energy planning (Department of Energy 2013).

7.2.7 Floods and Droughts

Current understanding of water security recognises that the concept includes the negative impacts of the hydrological cycle on peoples' lives and economies. In this respect, large parts of Southern Africa are water-insecure because of floods and droughts.

The primary challenges for the region are drought-related. El Niño–influenced droughts occur regularly. Since much of the rainfed agriculture is relatively marginal, this has severe impacts on the livelihoods of subsistence farmers as well as production more generally. The absence of infrastructure limits greater access to reliable supplies of water for irrigation.

These impacts could be mitigated by the fact that the northern and southern parts of the region are differentially affected. The south suffers drought during El Niño events and higher-than-average rainfall during La Niñas; in the north the effect is the opposite. This means that the region as a whole would be more food-secure if agricultural production could be coordinated and infrastructure existed to enable food crops to be transported from surplus to deficit areas, a situation which is being enabled through trade cooperation and infrastructure investments.

Parts of Southern Africa are vulnerable to floods, although these do not pose as general a threat as drought. Floods in the region are often the result of tropical storms from the Indian Ocean, which have a significant influence on the rainfall in the eastern and central parts of the region. Countries on the Atlantic margin, notably Angola and northern Namibia, are affected by poorly understood weather processes that also regularly cause flooding events, albeit of a lesser magnitude.

While the production of electricity may not seem to be directly related to water security, hydropower dams often provide flood protection as well. This was demonstrated in Mozambique, where the operation of the Cahora Bassa Dam, targeting maximum generation, was considered to have contributed to serious flooding downstream in 1976. Under revised operating rules, similar flows in 2001 caused much less damage and loss of life (Beilfuss and Brown 2010).

However, while intervention by water management institutions can help mitigate the impact of floods, they can also aggravate it if their interventions fail to function properly. This was a factor in floods in the Limpopo and other smaller river basins in southern Mozambique in 2000, in which 700 people died and two million lost property or were affected in other ways (Hellmuth et al. 2007; Christie and Hanlon 2001).

7.3 Discussion

7.3.1 Historical Perspectives on Approaches to Water Security

From the outset of formal regional cooperation, Southern African countries recognised that there was significant potential for benefits from cooperation between them in water management. Their focus was on the development of the energy resources of the shared rivers, notably the Zambezi. While the potential was emphasised, the need for careful and phased planning and implementation was highlighted (Nsekela 1981). This approach was seen as a strategy for achieving energy security at a time when fluctuations in global energy markets were causing considerable economic turmoil.

South Africa, as one of the most water-scarce countries in the region (in terms of both water availability per capita and intensity of water resource use), had also long realised the strategic importance of sound water resource management. The framework proposed by the 1970 Commission of Enquiry into Water (South Africa 1970) was put in place to manage water resources on the basis of integrated systems to assure macro water security to all users. As already noted, a particular focus was to ensure coordination in energy and water planning. Future constraints on the availability of water for agriculture were also identified.

At independence in 1975, Mozambique's new government realised that the country was vulnerable to drought and particularly to flood. They intervened quickly in the management of the Cahora Bassa, the country's largest hydropower dam, to ensure that it mitigated rather than aggravated the flood impacts. And much of the country's subsequent development policy has been guided by the need to mitigate climate risk, with a national Disaster Management Institute formally mandated to coordinate risk reduction programmes as well as maintaining permanent surveillance (Hellmuth et al. 2007).

In other countries, strategic approaches to critical water-related issues have been limited. In terms of availability of water per capita at the national level, both Botswana and Namibia are very well watered. Between them, they are riparian to five of the largest rivers in the SADC. However, these rivers are not close to main population centres; as a result, both countries are regarded as water-scarce. In both cases, there has been little effort to focus development in areas that are not water-constrained, not least because the colonial settlement patterns were driven by other factors. Thus, in Namibia, where a substantial proportion of the population live near large rivers, it is only relatively recently that serious efforts have been proposed to develop the potential of the region for irrigated agriculture (Namibia 2008).

For its part, Botswana has opposed efforts by its Namibian neighbour to promote large-scale agricultural projects on their shared rivers, for environmental reasons. Some Green Scheme projects would divert water from the Okavango River (Southern Africa's third-largest, by flow), which feeds the Okavango Delta, a large RAMSAR wetland. Internally, there is growing conflict between eco-tourism-related environmental protection and agricultural development (Kolawole et al. 2017).

Two countries in the region that have used their water resources quite deliberately are the small former British 'protectorates' of Lesotho and Swaziland. The former has cooperated with South Africa to divert the water shared in the Orange River to areas of economic activity in South Africa; the latter has used its water resources to support the development of large-scale sugar production, although it has begun to diversify this into other crops as well. In both cases, these water-based developments did not directly address household-level water security but concentrated on ways in which economic development could be promoted. In both cases, it has been pertinent to ask whether such approaches enhanced water security at the household, community, or national level.

7.3.2 Institutions for Water Security

At a macro or resource level, the institutional requirements required to underpin water security change markedly as societies develop. Where water is relatively abundant, the requirement is usually for the operational capability to develop variable local water resources to provide reliable supplies. This is the situation in the poorer countries, where resource development is constrained primarily by limited financial resources and water use as a proportion of the 'total renewable water resource' (FAO 2017b) is typically below 5%. In countries such as Zimbabwe where central government is weak, local catchment councils have taken on an important role. Mozambique has also delegated most water resource management functions to regional (rather than river) organisations.

These institutional requirements tend to evolve as water becomes more intensively used. South Africa has developed its resource sufficiently to be able to use around 35% of the total renewable water resource; Swaziland, 23%; Zimbabwe, 16%. In these cases, resource development and use which was initially supported through public funding is now funded by users, although development and management continues to be undertaken by public institutions.

This has brought new challenges. As water becomes more intensively used, institutional arrangements to manage cooperation and contestation between users become necessary. This requires legislation to establish criteria and procedures for potential users to access the resource as well as institutions to support and regulate the process. While most countries have established water law, their ability to support and enforce it is limited, with limited hydrological information available and even less information about actual resource use.

This is even the case in South Africa, whose institutional capacities were by far the most advanced in the region. In 1998, pioneering legislation was introduced allowing operational water resource functions to be delegated to regional catchment management agencies. However, this has yet to be implemented on a significant scale, even as the national government's capacities weakened. One consequence has been a growing number of supply shortages in major systems due to weak planning and implementation.

7.3.3 *The Barriers to Water Security in Southern Africa*

Given this context, it becomes possible to identify the barriers to greater water security in Southern Africa. The region shares some generic challenges that are common around the world.

7.3.3.1 Economic Challenges

The first challenge is economic. The region has substantial untapped water resources. But to make beneficial use of the resource at an economy-wide level, investment in storage and transmission infrastructure is often required to address its variability and spatially unequal distribution. Such infrastructure has demonstrably enabled substantial, sustainable economic development in South Africa. However, much of it was developed during a mining boom, when greater financial resources were available. Meanwhile, the economic capacity of the rest of the region is much more constrained. The translation of water resource availability into reliable household services also requires financial capacity for both infrastructure investment and operation.

7.3.3.2 Social Inequality and the Rural/Urban Divide

The high level of inequality in many Southern African countries has already been noted. This inequality is reflected in household access to water supply but also in urban/rural disparities. Thus, in Angola, 63% of urban households but only 23% of rural households were reported to have access to a basic water supply. A similar picture emerges for Botswana (95% vs. 58%), Mozambique (79% vs. 32%), Namibia (97% vs. 63%), South Africa (97% vs. 63%), and Zambia (86% vs. 44%). As telling was the fact that none of the countries in the region were able to report the extent to which rural water supplies were 'free from contamination'.

It may be that these results simply show that supply coverage is greatest in the urban areas, where there are fewer alternatives. But economic disparities are also found between regions and wealth quintiles within countries. The latest Joint Monitoring Programme (2017) data do not cover all the countries of the region, but they do show that Angola's best-served region has 76% coverage of water supply, compared to 25% in the worst-served region; 80% in the richest wealth quintile have access, but only 15% in the poorest. A similar picture emerges in Mozambique (99:19; 91:22) and Zambia (83:15; 89:13).

7.3.3.3 Institutional Challenges

Another challenge is institutional. Even where investments have been made, these have often not delivered the expected returns, not least because of failure to manage them effectively. And countries with adequate financial resources have often failed to deploy them effectively. Despite its oil wealth, Angola has only recently begun to develop its abundant water resources to adequately supply major urban centres and to produce hydropower. Botswana, after a decade-long diamond-driven economic boom, failed to complete the infrastructure required to transfer water from its copious shared rivers to population centres and suffered serious water shortages in its capital and surrounding urban areas as a result.

In part, these failures reflect technical weaknesses; the region's challenges often require relatively complex analysis and response, and the relevant institutions may find it difficult to develop and retain the necessary competences, even in relatively prosperous South Africa. As a consequence, there is often limited reliable information on the nature and state of the local resource. Governance weaknesses also undermine technical responses. South Africa has again recently provided examples of the challenges when, according to well-documented reports, decisions on resource development were delayed at a political level to benefit special interests (City Press 2016).

It has been suggested that some of these weaknesses may be addressed through greater involvement of the private sector. Yet, after some decades of experience, it is clear that the complexity and cost of water management is compounded by intersecting social and environmental values. These place additional demands (and costs) on water management, since water supply is a high priority in urban areas and water users are a large, politically vocal group. As a result, risks for private enterprise are high, and the financial rewards available are limited and not sufficiently attractive to mobilise significant private involvement. However, where specific relatively wealthy communities or organisations are involved, it has proved possible to mobilise private-sector funding for major public-sector-led developments, as in the different phases of the Lesotho Highlands Water Project.

7.3.3.4 Regional Opportunities and Constraints

The Lesotho Highlands project also highlights the contribution that greater regional integration could make to the achievement of water security, as well as the limits to this contribution. While investment in the project assured water supply to rich urban communities in urban South Africa, it did not automatically improve water security for people in Lesotho, except to the extent that the benefits of economic growth spilled over into the wider community.

A specific opportunity has been identified for the impact of water insecurity on food production to be mitigated by regional cooperation in food production and marketing (Muller et al. 2015). Southern Africa has a number of climatic zones which do not share the same propensity for water-related disasters and are indeed often out of phase with each other. Thus, South Africa and its neighbours are usually self-sufficient in staple grains but need to import some produce in drought years. In those years, there are normally good rains (and harvests) in northern Zambia and Mozambique as well as Angola. The implication is that greater cooperation could enable the region to maintain an adequate supply of staple foods, despite climatic variability.

A related issue is the differential levels of water scarcity (using the crude metric of available water per capita). Malawi, though it has one of the largest (and deepest) lakes in the world, is not, as commonly believed, water-rich. With just 1400 m^3 per capita of available water, it is, with South Africa (1110 m^3 per capita), the most water-scarce country in the region. This is largely due to a large population in a relatively small land area. Meanwhile, northern Zambia is relatively thinly populated and well-watered. Were it not for national borders, the rational response to water scarcity would be to encourage migration. There are however substantial barriers to this, although there is nonetheless significant semi-legal migration from Malawi to employment markets in the region.

These examples highlight areas in which dimensions of water security will only be effectively addressed if there are supportive, high-level political arrangements. While this was the original intent of the SADC structure, it has proven difficult to make progress on issues that involve sensitive matters of trade, migration, and finances even where there are, potentially, win-win outcomes for the parties concerned.

7.4 Conclusions: Barriers and Opportunities to Water Security

In Southern Africa, water security at a household and community level is highly dependent in the first instance on economic status. Urban communities are far more likely to have safe and accessible domestic water supplies than communities in rural areas. Access to water in support of economic activities is also skewed in favour of urban centres or users with the financial resources to enable self-provision. Similarly, with the exception of large-scale commercial farmers, the farming activities of the majority of rural communities are vulnerable to drought due to their inability to fund water resource infrastructure that could mitigate drought impacts.

Institutional capacity is a second important determinant of water security. While this is partially dependent on the economic circumstances of the community or country concerned, Southern Africa provides a number of examples where poor communities have organised to improve their water security while institutions in richer communities have failed to do so. The deterioration in service standards in South Africa associated with a period in which short-term politics has taken priority over sound administrative and technical management offers a significant example of the dangers.

It is thus clear that the variability and relative scarcity of the water resource is, in itself, not the dominant determinant of water security. Climatic variability imposes costs on users that are higher in Southern Africa than in regions with a less variable climate and more predictable hydrology. But these challenges can be overcome if there are competent institutions, able to access adequate financial resources. Similarly, at a regional scale, water scarcity and climatic variability need not lead to food scarcity, although the political, economic, and social difficulty of implementing cooperative approaches to mitigate their impacts should not be underestimated.

The Southern African experience also shows how water insecurity may itself block the achievement of water security and growth and development more broadly. There is a vicious cycle in which the economic costs of water *in*security prevent societies from achieving the economic development that greater water security could support. Farming is less productive and profitable than it might be if water were better managed. Industrial development and urban economic activity are constrained in the absence of reliable, safe water supplies. And the absence of economic development in turn limits the ability of communities to invest and support the interventions needed to achieve greater water security, particularly in the domestic context. The resulting financial constraint also reduces the capacity of the institutions required to identify cost-effective approaches to meeting water needs and implement and operate them efficiently.

In this sense, the trite conclusion from this review of water security in the Southern African region is that it derives primarily from the economic capacities of the households, communities, and countries concerned. But it is also evident that competent, focused institutions at all levels can make a significant difference in the levels of water security achieved and thus in their ability to break out of the vicious cycle of underdevelopment, which is driven in some measure by water insecurity.

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Chapter 8
Global Water Security: Lessons Learnt and Long-Term Implications in France

Eric Tardieu

Abstract Although France has never used and still does not use the phrase 'water security', water security policies have indeed been designed and implemented in France since the 1960s, focusing on governance issues. The national level is largely in charge of flood risk management, local authorities are responsible for drinking water supply and sanitation security, and the basin scale has been chosen as the core level for integrated water resources management. A comprehensive set of decision-making, planning, and financing tools regulate the balance and constant adaptation of water management in each of the six basins. The 'water user pays' and 'water pays for water' principles have been providing a secured investment capacity for water management and infrastructure improvement.

Many examples illustrate how this collective investment in governance and stakeholders' commitment has proven its effectiveness in terms of quantitative and qualitative water security, including ecological recovery capacity for rivers and aquifers. French organisation is currently evolving towards the broader approach of 'ecological security': ecosystem and biodiversity preservation and restoration have to be put at the centre of water security. This evolution, together with the new and increasing effects of climate change in France, will test the robustness of French organisation, particularly for agricultural water uses.

8.1 Setting the Scene: The Main Water Security Issues in France

France does not use the phrase 'water security'. Public policies talk about water management and development, risk management related to climate change, flood risk management, and pollution control, but not water security.

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The first reason is most likely the relatively privileged situation of France in terms of availability of water resources. France has a moderate population density (65 million inhabitants in 551,000 km^2, without the overseas territories) and generally abundant water resources. Since almost all of the catchment areas of the major French rivers are in its national territory, France depends little on other countries for water resource management. Within the country itself, few interbasin transfers have been developed.

Another reason is probably the general feeling that the French water problems have been solved. France has invested heavily in the governance of water resources, with the historic choice made in 1964 to consider the river basin as the relevant management scale, and to focus on shared governance and dialogue among stakeholders, as the prime security factor.

8.1.1 Water Is a Relatively Abundant Resource in France, but Uncertainties Are Growing

Water bodies in France represent around 230,000 km of rivers, 2000 km^2 of lakes and 574 aquifers.

The water balance on the French mainland totals 168 billion m^3/year, most of which comes from precipitation (486 billion m^3), slightly reduced by the transboundary runoff balance (11 billion m^3 entering from neighbouring countries, compared to 18 billion m^3 running out of France), and in particular by evapotranspiration amounting to 311 billion m^3. This balance is divided between 100 billion m^3 of groundwater and 75 billion m^3 in rivers and streams. Per capita share of renewable water resources is about 3100 m^3. Annual precipitation ranges from 700 to 1200 mm, with the majority in autumn and winter (Figs. 8.1 and 8.2).

8.1.2 French Organisation Framed by European Laws

French law on water management is aligned with the European legal framework, the lynchpin of which is the Water Framework Directive (WFD), in place since 2000. This directive centres on a general objective of reaching good ecological status for water bodies. Water security per se is not listed as an objective.

The WFD establishes goals, a timetable, and a working method for EU member states based on a key principle: 'Water is not a commercial product like any other but, rather, a heritage which must be defended, protected and treated as such.' This requires in particular improving the chemical quality of water and reducing discharges of dangerous substances such as pesticides, heavy metals, and hydrocarbons. These requirements contribute to water security in terms of water quality.

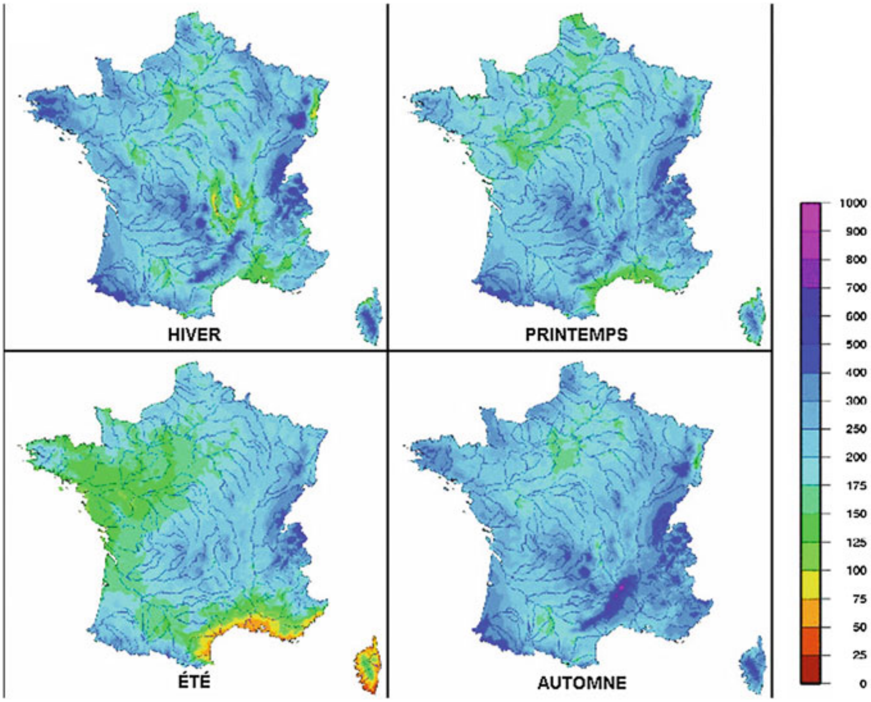

Fig. 8.1 Annual precipitations in France 1981–2010 (*Source* Météo-France, *Artwork Source* Météo-France)

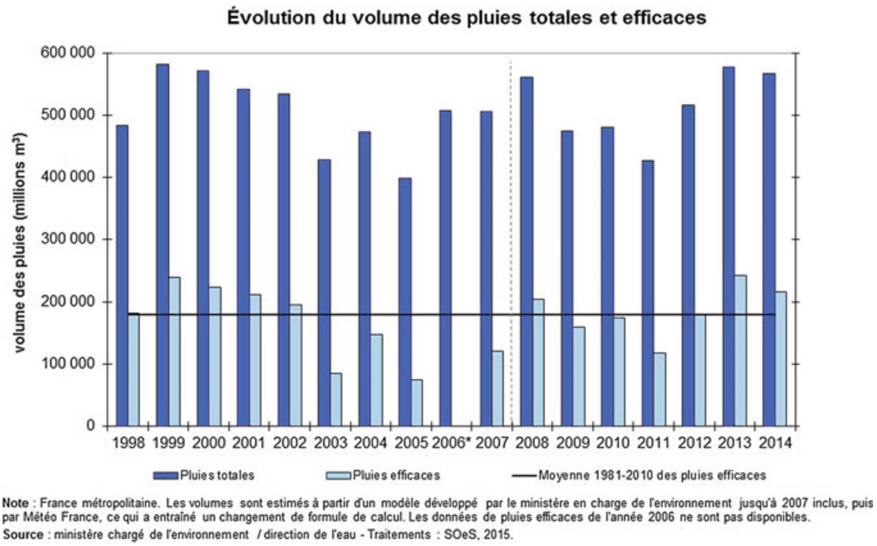

Fig. 8.2 Evolution of the volume of total and effective rainfall (*Source* Ministry in charge of the environment—Météo-France, Treatment: SOeS 2015, *Artwork Source* Ministry in charge of the environment)

The WFD also establishes the creation of river basin districts managed by a competent authority, including at an international level when necessary; the identification of basic units called water bodies; and the setting of targets and establishment of action plans. For each district, a plan comprises six-year cycles involving three steps: characterisation of water bodies, preparation of a management plan that defines the targets, and implementation of a programme of measures that determines the actions to undertake to reach the targets. The characterisation lists information on the status of the resource, water uses, and specific protection zones (drinking water abstraction, ecosystem protection, etc.). Water bodies are defined as hydrographic (surface water) or hydrogeological (groundwater) units. In France, 11,500 water bodies have been defined.

The European framework therefore involves performance targets, reporting, and an overall approach to economic and environmental assessment that impact the organisation of stakeholders and the national conduct of the water policy. This focus on methodology, governance, reporting, and stakeholders' organisation is the key WFD contribution and message in terms of water security.

8.1.3 Current Main Water Management Issues in France

Water security depends on specific conditions for each use, and many different public policies are involved, still very often with insufficient coordination. The main challenges for water management in France are as follows.

Adaptation to climate change: establishing a different way of sharing water resources to anticipate climate change, and to face increasing complexity and volatility. Flood management remains a priority for French water policy, especially in the context of increasing urbanisation. In this regard, renaturation of rivers and recovery of aquatic environments have gained new attention. Restoring aquatic ecosystems and implementing ecological continuity and wetlands contribute not only to water quality but also to flood management. Since the 1990s attention has also been put on the other aspect of the problem: scarcity management. Specific challenges will need to be addressed, especially with new impacts and uncertainties related to climate change.

Combating diffuse pollution, in particular agricultural pollution (crop protection products and nitrates), together with improvement of large-scale agriculture through improved environmental engineering. In terms of water quality in rivers and lakes, advances have been made on major rivers (see the example of the Seine, below), but progress on diffuse pollution has been slower; it is important to consider the long time needed to return a polluted watercourse to good ecological status. Stakeholders' awareness of the bad impacts of their activities on the environment is slowly increasing. Figures 8.3 and 8.4 describe the chemical status of water bodies in France, as reported to the European Commission. A good or moderate chemical status was reported for more than 78% of river water bodies and more than 69% of groundwater bodies.

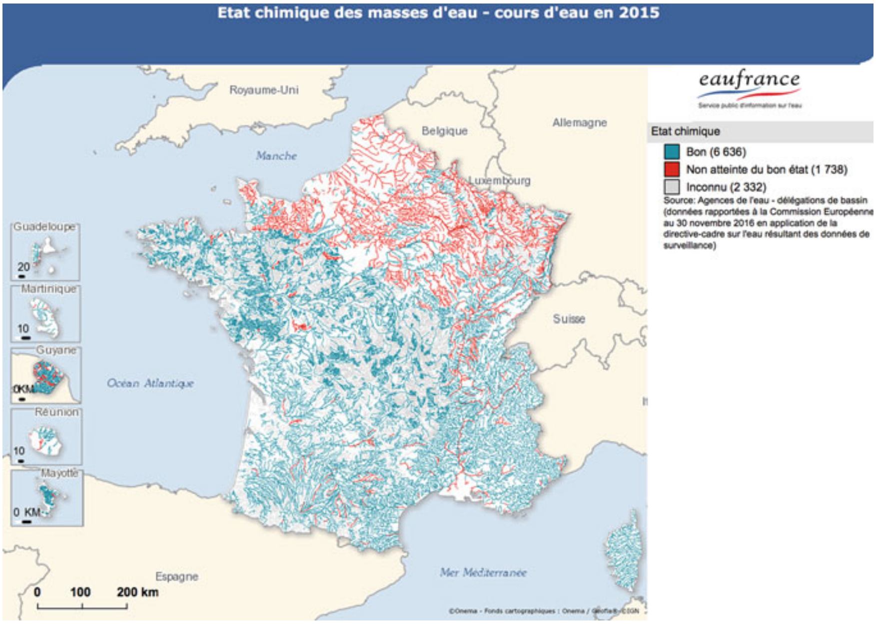

Fig. 8.3 Chemical status of surface water in 2015 (*Source* Eaufrance, *Artwork Source* Eaufrance)

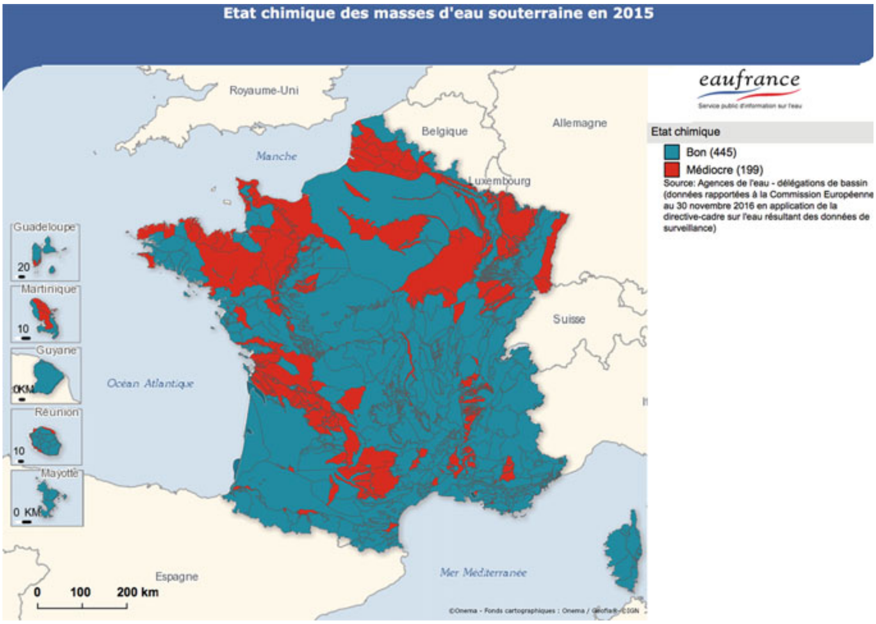

Fig. 8.4 Chemical status of groundwater in 2015 (*Source* Eaufrance, *Artwork Source* Eaufrance)

8.2 French Organisation of Water Security: Focus on Basin Governance

According to Article L. 210-1 of the French Environment Code, ‘Water is part of the common heritage of the nation. Its protection, enhancement and development as a usable resource, with due respect to natural equilibriums, are of general interest. The use of water belongs to all within the framework of laws and regulations as well as that of previously established rights. The costs relating to the use of water, including the costs to the environment and the resources themselves, are borne by the users, taking into account the social, environmental and economic consequences and geographical and climatic conditions.’

This legal water status in France is perceived as an important factor in water security. In particular, it does not allow private water rights and therefore related economic speculation. The notion of water as a common good preserves the freedom of public authorities such as basin committees (see below) to set strategy for the use and preservation of water resources.

8.2.1 Water Management in France Goes Beyond Standard Administrative Organisation

Water management is an example, rare in France, of going beyond the traditional administrative organisation. This exception reflects the awareness gained, which goes back more than 60 years, that water security requires a specific approach, freed from the complexity of the usual political-administrative divisions (Richard et al. 2013).

Mainland and overseas France is organised into almost 36,000 towns, 101 departments, and 18 regions, with no hierarchical link between these different levels. Municipalities or towns (*communes*) are the smallest (and oldest) administrative subdivision. Each is managed by a municipal council elected by direct universal suffrage every six years. The municipal councillors elect a mayor who exercises the town’s executive authority. In the water domain, towns have long been responsible for managing water and sanitation utilities, and from 2018 will also be in charge of managing aquatic environments and flood protection.

In practice, municipal competences are often regrouped into intermunicipal cooperation bodies. Since 2014, with the aim of improving performance and efficiency, several laws have accelerated this trend by making it obligatory to regroup into larger bodies. These new municipal competences and their pooled organisations constitute a considerable change currently under way in French water management practices, the consequences of which are examined in Sect. 8.5.

The departments and regions are managed by a departmental or regional council, elected for six years by universal suffrage and featuring an elected president who embodies the executive authority of the department or region. Departments and regions have no direct obligatory authority in terms of water management. Nevertheless, the departments are frequently involved in either providing financial support for drinking water and sanitation or aquatic environment projects, or in providing technical assistance to municipalities.

The regions can also finance projects, and mostly play a planning role. They are thus in charge of several strategic management plans connected to water resource management and biodiversity issues, which include establishing regional sustainable and spatial planning strategies. They sit on the board of institutions responsible for managing water, such as basin committees, water agency boards of directors, and Local Water Commissions (see below).

The State produces laws through the parliament and organises the water policy through the government; and it negotiates EU directives, which determine the core of the French legal water framework (see below). The Ministry of the Environment coordinates the action of the different ministries involved, including via a Water Directorate created in 2002. The State also has representatives at the regional and departmental level who locally exercise the authority of the State in conjunction with local authorities. State interministerial representatives called prefects (*préfets*) are responsible for coordinating State services at departmental or regional level.

8.2.2 The Heart of the French System in Terms of Water Security: Basin-Level Organisation, with More Than a 50-Year History

The above description still corresponds to the classic French administrative organisation. However, in terms of water management, the French strategy has a specific governance level, the river basin.

Since the Act of 16 December 1964 (loi du 16 décembre 1964 relative au régime et à la répartition des eaux et à la lutte contre leur pollution), water resource management is determined at the natural level of each major river basin, independent of the standard administrative boundaries. In mainland France, seven major river basins have been defined (Fig. 8.5), and each is subject to an integrated approach to risks connected with the water resource, taking into account all water uses, ecosystem requirements, and risk prevention. In terms of the WFD, France comprises 13 river basin districts, five of which are in its overseas territories. France also shares Lake Geneva and the Rhine, Meuse, Scheldt, and Moselle Rivers with its neighbouring countries.

The same 1964 act (which was extended and revised in 1984, 1992, and 2006) established the foundations and institutions that to this day still govern water management in France, including the basin committees and water agencies.

France is articulating its approach to water security around three key tools: shared governance at the basin level, planning for the conservation and use of water resources and aquatic environments, and the mobilisation of a dedicated financial resource.

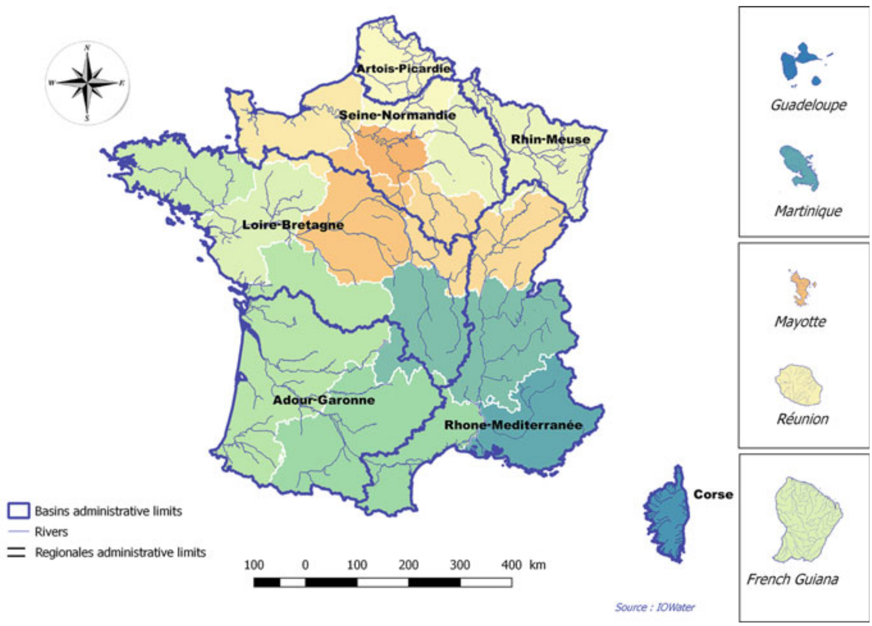

Fig. 8.5 France division using river basins (*Source* IOWater, *Artwork Source* IOWater)

8.2.3 Basin Committees: Local Water Parliaments for Shared Governance

Basin committees are consultative bodies that gather representatives from different economic sectors that use water; they constitute 'shared' governance for cooperating on and coordinating actions (Fig. 8.6). All users are represented: municipalities, farmers, industrialists, land planners, hydroelectricity producers, fishermen, environmental protection associations, the tourism industry, water supply companies, and so on. Each basin committee is chaired by an elected representative from one of the local authorities of the basin and comprises 40% local community representatives, 40% user and association representatives, and 20% State representatives. Its 'water parliament' role is crucial for joining vision, sharing commitment, planning action, and distributing financial support between different types of water usage.

In this regard, basin committees are a key tool for water security, since they are in charge of establishing early dialogue between stakeholders in order to share information, to prevent conflicts, to promote changes and adaptations, and hence to avoid any water security crisis (Akhmouch and Clavreul 2017).

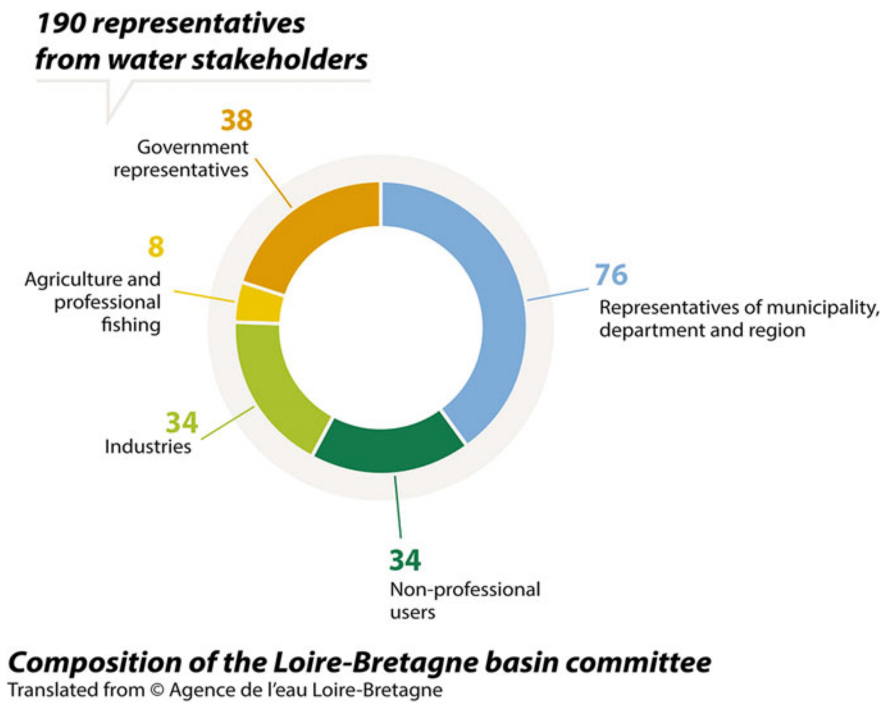

Fig. 8.6 Example of composition of a basin committee for Loire-Bretagne basin (*Source* Loire-Bretagne water agency, *Artwork Source* IOWater)

8.2.4 Planning with an SDAGE

Each basin committee draws up a river basin development and management master plan (RBMP; in French, *schéma directeur d'aménagement et de gestion des eaux,* SDAGE), which is submitted for State approval. The RBMP is a planning tool that provides general guidelines for water policy in the basin, and targets. It thus constitutes a legal framework to be complied with in all administrative decisions concerning water (urban planning, local regulations, financial aid, etc.). French RBMPs are river basin management plans in the sense of the WFD, and now include a programme of measures that sets out the means and actions for attaining good water status objectives.

A multiannual action and investment programme (or 'plan of measures' in the sense of WFD) is established to reach these objectives. The programme determines both the amount of charges to be collected from water users ('water fees', see below) and the priority actions resulting from the objectives of the RBMP. Each RBMP also includes a specific part on dealing with climate change, through climate change adaptation plans (Agence de l'eau Loire-Bretagne 2017).

Since the WFD, the planning and implementation of action plans has been organised in six-year cycles. Each cycle considers the revision of the RBMP and its

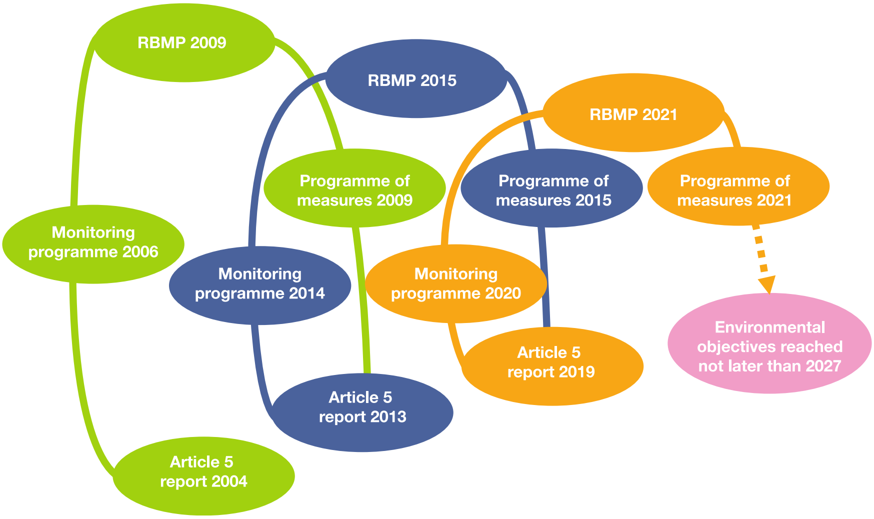

Fig. 8.7 WFD implementation cycles (*Source* IOWater, *Artwork Source* IOWater)

associated action plan, and monitors the progress made. At present, the European ambition is to achieve good ecological status of all water bodies no later than 2027 (Fig. 8.7).

8.2.5 Water Agencies: Implementing Bodies

Six water agencies (*agences de l'eau*) were created in 1964 on a basin scale. Water agencies are public executive bodies. They feature a board of directors whose chairperson is appointed by State decree. They are entrusted with technical and financial missions related to the preparation and the implementation of the RBMP. Water agencies are not State agencies: they have no sovereign power to enforce water regulations, authorise water use (see below), or punish violations of the law. Neither are they in charge of operational water management or project owners. They concentrate on designing strategy and implementing actions necessary to improve integrated water resources management in their basin, and to reach good ecological status of water bodies, following the decisions of the basin committee and the provisions of the RBMP. In the overseas territories, the agencies' responsibility is taken by water offices (*offices de l'eau*), created in 2000.

Water agencies can collect specific charges or fees (*redevances*) from water users, generally according to either the volume of water used or the pollution generated. These specific fees play the role of an ecological compensation mechanism. They are a tool for 'water solidarity' at the basin level, as they are levied on users (drinking water consumers and economic activities) in application of the prevention principle and the principle of repairing damage to the environment. With these fees, water agencies can provide financial support (subsidies and loans) to public and private bodies that carry out river basin actions or projects, with the goal of achieving sustainable water resources management. Of these fees, 90% is reallocated, while 10% is used to finance internal technical and scientific expertise. Water agencies therefore support assessment of present status and pressures, but also prospective models and studies.

This direct financing model of collecting fees from water users at the basin level to fund water projects in the basin is the core of the economic security of the French water resources management system, since it provides a dedicated and sustainable financial resource for the improvement of water management and infrastructure. It is based on the two principles of 'polluter pays' (or 'user pays') and 'water pays for water'. The original name of water agencies was indeed 'basin financial agencies', expressing the priority need of that time for the establishment of sustainable funding sources for water management infrastructure. Water agencies progressively expanded to their current comprehensive role.

Water fees collected by the agencies are divided into seven types according to the nature of the impact on the water resource: water pollution, modernising sewage collection systems, diffuse agricultural pollution, water withdrawals, water storage for low-water periods, obstacles in waterways, and protection of the aquatic environment. The fee system obliges users to integrate environmental costs into their water use, giving them an incentive to save water, or make better use of it (Fig. 8.8).

Fee rates and amounts, which are determined by the basin committee within a national framework, are adjusted according to the intensity of use and the sensitivity of the environment. The pollution charge thus depends on the level of pollution discharged annually according to various pollution parameters (COD, BOD_5, suspended solids, etc.). The modulation of water fees between different uses is thus a powerful tool for water security at the level of each basin. The financed actions can either correct management imbalances or support the changes needed to improve the resource's status and guarantee its long-term availability.

8.2.6 Sub-basins' Management Plans and Local Water Commissions

Given the large size of the six river basins covered by the RBMPs, more local variations have been set up at the level of tributaries, sub-basins and aquifers. The sub-basin approach takes the form of a water development and management plan (*schéma d'aménagement et de gestion des eaux,* SAGE), which is a planning document that also has administrative and legal value. With the requirement of full compliance with RBMPs, SAGEs set the targets for their area and anticipate the action required to protect water, combat pollution, restore wetlands and aquatic

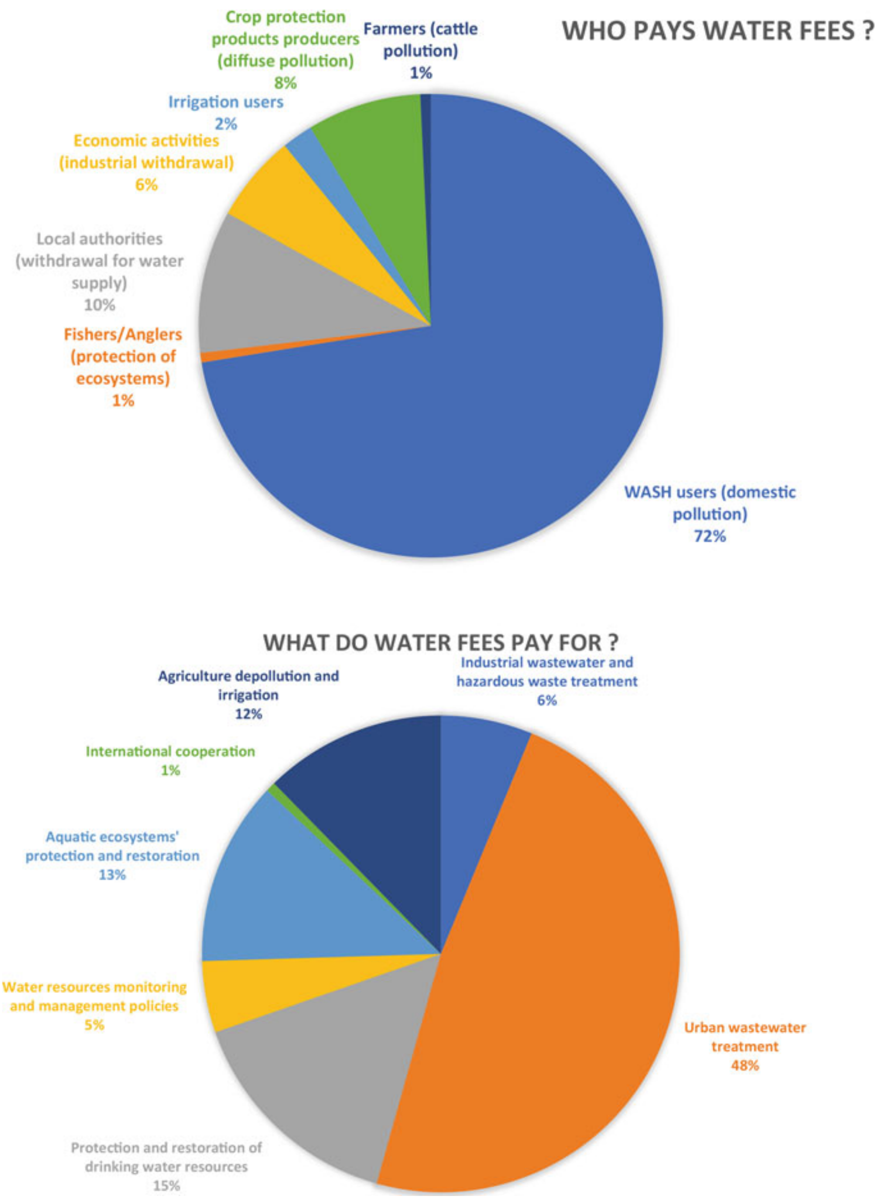

Fig. 8.8 Fee repartition for Loire-Bretagne water agency (*Source* Agence de l'eau Loire-Bretagne, *Artwork Source* IOWater)

ecosystems, maintain and develop rivers, and prevent and prepare for floods. SAGEs are drawn up by a Local Water Commission (*Commission Locale de l'Eau)* composed of 50% representatives from local communities, 25% user

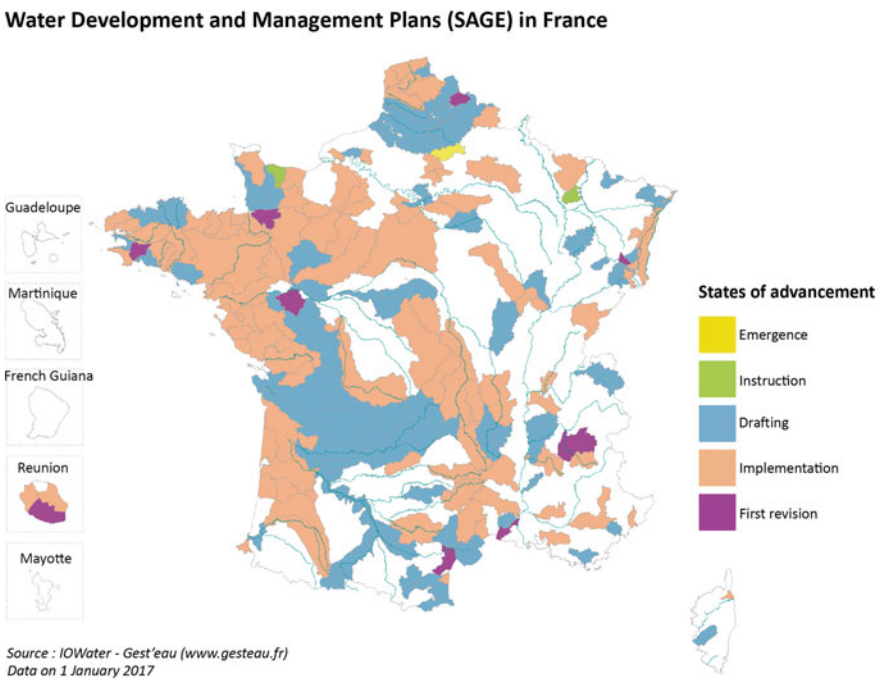

Fig. 8.9 Map of current WDMPs in France (*Source* IOWater-Gest'eau, *Artwork Source* IOWater)

representatives, and 25% State representatives. The French territory is now well covered by these SAGEs (Fig. 8.9), which are an essential step, as close as possible to the territory, in the implementation of actions to preserve water resources.

8.2.7 Water Authorisations and Policing

It is important to remember that the overall effectiveness of the water security system is also based on a set of authorisations and controls. Water is a common good of the nation, but its use is regulated, and controls are established to check users' compliance with rules.

The State is responsible for this regulatory role. Since the 1992 act, a unified system of 'authorisations' has been in place to regulate water uses based on a framework and national classification, which sets out an administrative system for declaring any installation, facility, work, or activity that has an impact on water, whatever the nature of the resource. Depending on the project's characteristics, and in line with the thresholds set at the national level, the department prefects are (usually) responsible for deciding whether or not to authorise projects. When authorisation is required, a public enquiry is organised to consult residents on the project's impacts. The authorisation, which covers a limited period, can be modified or cancelled in the case of risk, either to residents (public health or safety, e.g. in the case of flood risk) or to aquatic systems and the environment.

The authorisation must conform to the provisions of the SDAGE (and the SAGE if there is one), and also generally includes specific measures taking into account the availability of the water resource (the minimum flow to maintain in a river, for example) and compatibility with other water uses, to guarantee the effective accomplishment and maintenance of facilities and monitor the flow rate or the pollution generated. This prior administrative authorisation is crucial for securing water resource management. Not only does it provide for individual conditions specific to projects that affect water, it also brings the possibility of a global vision of a given territory.

The State also has the authority to enforce compliance with regulations. In 2009, some 30,000 violations were cited by water police services (Eaufrance, http://www.eaufrance.fr). Of course the national administration also can mobilise legal procedures (fines or courts) to apply the law. In the case of a polluting event, for example, certain officers have the authority to report the legal offense.

8.2.8 The French Water Information System

To monitor water quality and to understand water ecosystems, since the early 1970s France has been developing monitoring networks for chemical, biological, and hydromorphological parameters. These efforts have been expanded since WFD implementation, because the objective of good ecological status of water bodies reinforced the necessity of monitoring. Indeed, integrated water resources management requires collecting, interpreting, and comparing many data. Since these data are produced by numerous sources, in the early 1990s France started setting up systems to harmonise, exchange, and interoperate data. Today, the French Water Information System gathers all useful data—on quantity, quality, ecosystems, regulation and uses, and so on. This includes data from all data producers and disseminators, public and private, national and local, such as water agencies (generally in charge of water quality data management), ministries and their establishments (local State services are in charge of water quantity data management), local authorities, environmental protection associations, user associations, industrialists, scientific and technical centres, and engineering firms. The surveillance and monitoring networks represent around 16,000 measurement points for surface water and around 8000 for groundwater, which is on average one checkpoint for every 25 km^2. Thus, the French Water Information System can meet three main requirements: knowledge and monitoring of water resources and aquatic environments; evaluation of pressure on aquatic environments; and orientation of public policies and their evaluation, in particular for the protection and restoration of aquatic systems. Data (if not private) are available to every citizen through a national web portal, Eaufrance (http://www.eaufrance.fr).

The French Water Information System meets the reporting requirements of not only the WFD but also other water-related directives; it is also compliant with the Water Information System for Europe.

8.3 Flood Management

In France, the need for security with regard to floods remains serious, with an average of €650–800 million in damage annually over the last 30 years (DGPR 2014). In 2012, a survey estimated that flood risk threatens one in four people in France, and one in three jobs. In the Paris region, where a large part of the population and the country's wealth is concentrated, floods are the greatest natural hazard. Climate change is a potentially aggravating factor, especially in coastal areas.

8.3.1 Flood Risk Mostly Managed by the State

Besides the specific situations of coastal flooding, in France flood risk generally takes the form of slow, gradual floods caused by significant precipitation on the scale of major river basins; or localised but very violent flash floods, in which intense rainfall rapidly transforms some streams into dangerous torrents, mainly (but not only) in the French Mediterranean region, generally in late summer (due to hot air rising from the Mediterranean). The last dramatic flood occurred in the coastal area near Nice in October 2015, causing 20 deaths and €1.2 billion of damage, following an intense storm that caused strong runoff in urban areas (Morel et al. 2017).

The State has overall responsibility for preventing and combating flooding through:

(1) The adoption (in 2014) of a national flood risk management strategy, including mapping of the areas most at risk on a major basin scale; 122 high-risk flood zones have thus been identified (in line with the provisions of the EU Floods Directive). The national strategy is based on basin-wide solidarity: actions are undertaken upstream to protect some urbanised areas from excessive damage. The natural flood storage areas are preserved as much as possible, including on agricultural land, in conjunction with the activity concerned (see the Oise–Aisne example below). This solidarity is conceived with the aim of global damage reduction, and requires consultation prior to transferring the impact of floods from one territory to another. Basin solidarity requires the fair distribution of responsibilities and efforts to reduce the negative consequences of floods across all the territories and stakeholders concerned.

(2) The coordination of measures to anticipate floods and manage crises: 22,000 km of rivers and streams are thus monitored in real time by services of the Ministry for the Environment.
(3) The gradual establishment of flood risk prevention plans, mapping the extent and severity of flood risk over the whole French territory. Some 9000 municipalities have already been covered. At the beginning of 2017, 133 local prevention plans were formulated. Since 1 January 2016, regroupings of municipalities have been the relevant level for both flood prevention and the management of aquatic environments, in line with their responsibilities in urban planning and land-use planning (Mortureux 2017).
(4) The organisation of systematic feedback following crises, in order to constantly improve national organisation. This national process, carried out by the Ministry for the Environment, plans for feedback not only on crisis management during floods, but also on flood risk prevention and on better resilience of the territories (Guillet 2017; Gorget 2017; Faytre 2017). This exercise relies on the systematic collection of information during each flood (rainfall, hydrometeorology, high-water levels, etc.) (CGEDD 2017).

8.3.2 Local Authorities Are Now also Responsible for Managing Aquatic Environments and Flood Protection

Local authorities (regroupings of municipalities) now concentrate responsibilities for aquatic environment management and flood protection. They are therefore fully responsible for effectively integrating flood protection in urban planning, without forgetting the possibility of more integrated management of water and sanitation services in connection with the protection of aquatic environments. They establish, within a framework defined by the State, action programmes for protection against flooding, which are generally co-funded by the State. They also draw up local contingency plans, devised to organise crisis management, in line with plans established by the State at higher territorial levels (CEPRI 2017).

This significant reform of French governance to prevent and combat flooding fits in with a twofold principle that is set to increase in the future, that is, underlining a prevention and risk approach at the level of municipalities and inhabitants, and planning land use differently following a flood—in particular, seeking new balances between grey and green infrastructure.

8.3.2.1 Case Study 1: The Oise–Aisne Alliance (*Entente Oise–Aisne*)

Oise and Aisne are two important tributaries of the Seine River. The Oise–Aisne Alliance is a group of communities established in 1968 to control floods in the catchment area of the Oise River, northeast of the Paris metropolitan area. The river basin is predominantly rural upstream, but has many flood-prone urbanised areas in its downstream part. It represents 17,000 km^2 and 9000 km of water streams, with 2 million inhabitants.

The choice has been made to manage flood risk through a basin-wide approach. The alliance has thus built dynamic and static structures (over-storage spaces, rustic works on tributaries, etc.) in some upstream areas, on farmlands, with the occasional compensation for crop damage, to the benefit of the downstream urban populations.

In the event of floods, the flooding of upstream agricultural areas is preferred, to protect downstream urbanised zones. The damage in flooded areas upstream is more than counterbalanced by the cost of the damage avoided downstream. Dynamic flood retarding is thus carried out upstream of the basin, both to reduce peak flow and to delay flooding. Each 1 cm of flood reduction upstream of the basin saves an estimated €6 million in damage. It is considered that for just one of the upstream structures, savings of €78 million is provided by delaying the flood of the main upstream tributary by 13 h.

8.3.2.2 Case Study 2: Loire River Conservancy Plans

The *Plan Loire grandeur nature* is an integrated action plan for reducing the Loire Basin's vulnerability to flooding, together with conservancy of the Loire ecosystem. This programme was established by the French government in 1994, after fierce ecological conflicts over the construction of dams in the 1980s. The plan has now become a shared and peaceful framework for integrated management of the Loire River Basin, with strong involvement of stakeholders. Since 1994, successive action plans have been contracted between the State, water agencies, local authorities, and the EU, with a global investment of more than €1 billion, for prevention and management of flood risks, reinforcement of dikes, levees, and spillways, global management of water resources, and enhancement of the Loire Valley's natural and cultural heritage. The plans' governance is based on a conference of the parties, involving all types of stakeholders in shared decision-making and monitoring of the results. Project funding is decided through basin-level or regional committees.

8.4 Scarcity Management

About 38 billion m^3 of French water resources are withdrawn annually for different uses (Fig. 8.10): 5.5 billion m^3 for drinking water supply, 2.8 billion m^3 for agricultural irrigation, 3 billion m^3 for industry, 5.5 billion m^3 to supply canals, and 21 m^3 to produce energy (putting aside hydroelectric reservoirs).

Net consumption is obviously different, depending on how much water is restored to rivers or other water bodies after each use. Following restitution, final

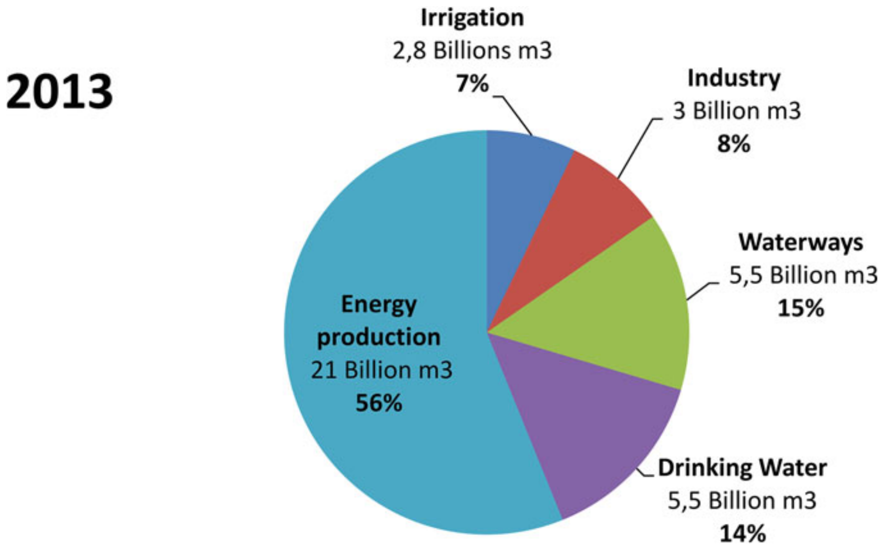

Fig. 8.10 Water abstractions in 2013 (*Source* BNPE, *Artwork Source* IOWater)

consumption is divided into 48% for irrigation, 24% for domestic use, 22% for energy, and 6% for industry.

Ultimately, the general abundance of water does not rule out local and seasonal difficulties, in particular during dry summers, and regional disparities have been growing in recent years. Water conflicts exist, and climate change has started to increase impacts on environmental balances and tensions, especially in southwest France and around Paris (Milano 2013). For the 2050 horizon, the French water deficit is estimated at 2 billion m^3/year based on current use. The Explore 2070 forecast carried out in 2012 by the French Ministry for the Environment (Carroget et al. 2017) predicted an average 20% reduction in river flows, and an average 30% drop in groundwater recharge, whereas in 2015 the quantitative status of groundwater was reported as good for almost 90% of the aquifers (Fig. 8.11).

It is widely accepted that there is now an increasing context of drought in France, more specifically during summer and in the southern part of France, when rainfall volumes are falling below historical average. From 2012 to 2016, the drying up of small sensitive streams was observed in an increasing number of monitoring stations (Fig. 8.12).

This situation has cascading effects, including lower river levels and smaller water flows, but also lower groundwater levels. Economic consequences are also felt, particularly by the agricultural sector, which is seeing a decline in harvest and production. Several measures have been adopted by the State to improve the management of water resources during drought and promote water savings through awareness campaigns on the good use of water, implementation of flow-control systems, and better monitoring and control of irrigation activities (Caude 2015).

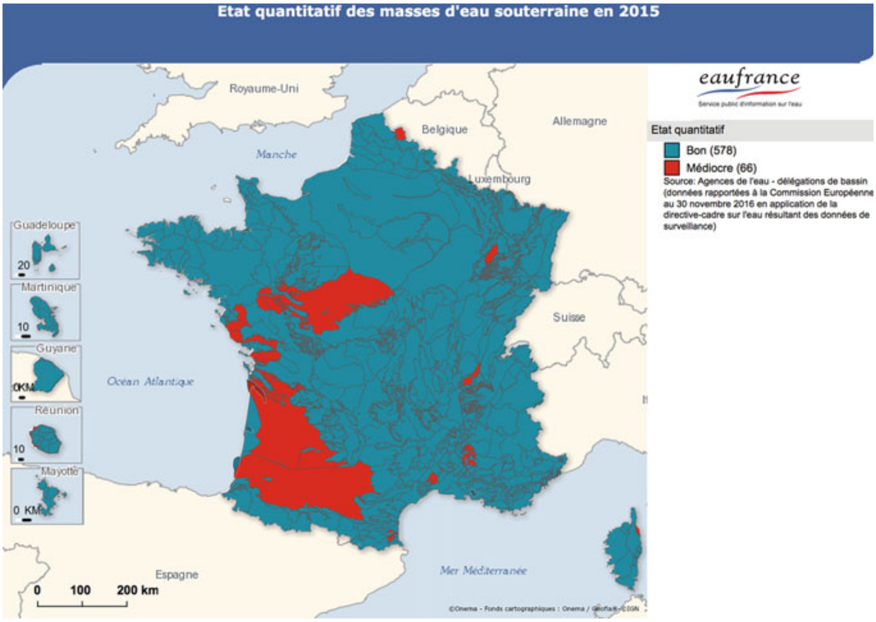

Fig. 8.11 Quantitative status of groundwater bodies in 2015 (*Source* Eaufrance, *Artwork Source* Eaufrance)

In situations of water stress, more drastic measures, such as restriction of water, are decided if the alert threshold is reached in rivers or aquifers (DRIEE 2017).

8.4.1 Case Study 1: Garonne 2050 Plan

A prospective study of the future needs and water resources on the scale of the Garonne Basin (southwestern France, see Fig. 8.5) by 2050 was initiated by the Adour-Garonne Water Agency with the aim of anticipating future issues and imbalances (Agence de l'eau Adour-Garonne 2014). This study integrates possible changes in climate, demography, energy, and agriculture. It starts from the premise that global warming will have consequences in terms of worse drought episodes and greater evaporative demand, and thus greater water needs during dry periods, especially for agriculture. Modelling tools and methods were used, and predicted a water deficit by 2050 in this basin. To prepare for this water deficit, an adaptive strategy has to be devised.

Three scenarios were submitted to the basin committee. They are all based on the assumption of a 15% reduction in irrigated farmland and of water savings by drinking water supply networks (users and managers) to counterbalance the increase in demand due to demographic growth. This prospective exercise,

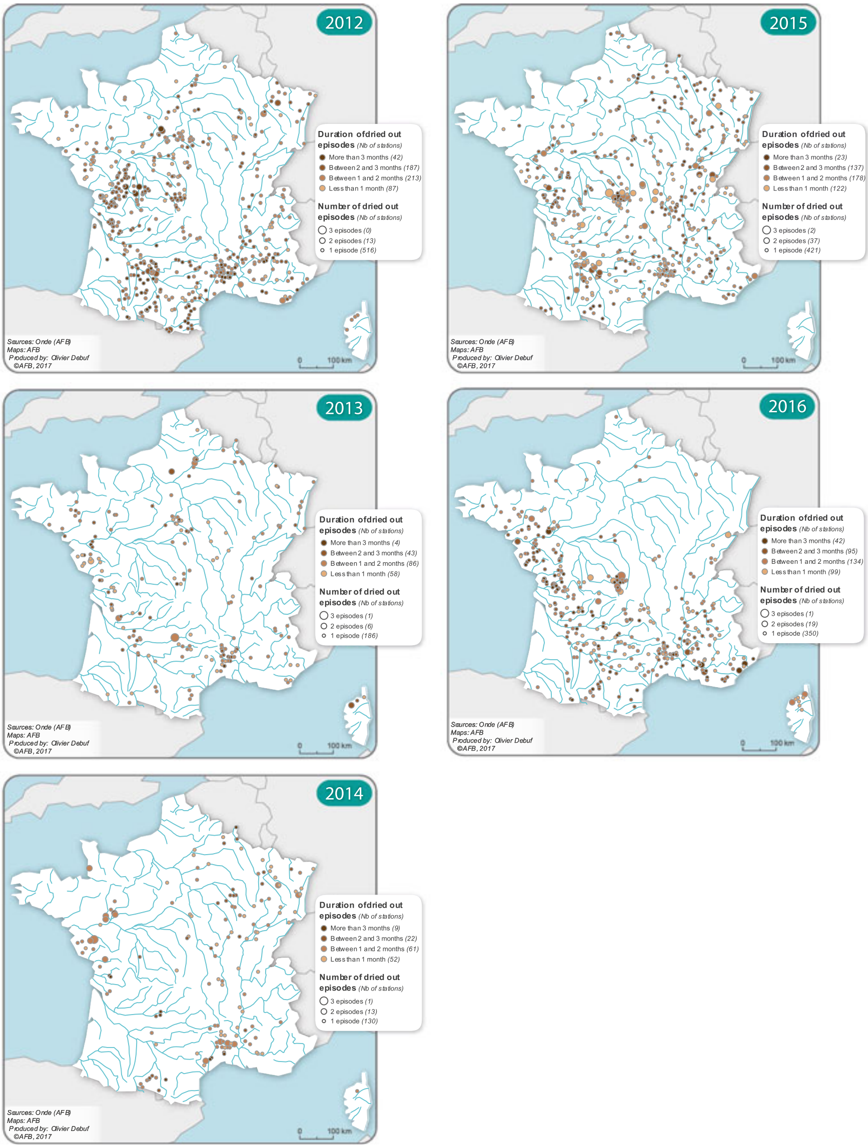

Fig. 8.12 Division and duration of dried out episodes from 2012 to 2016 (*Source* AFB, *Artwork Source* AFB)

conducted by mobilising all economic stakeholders and water users, makes it possible to anticipate not only the effects of climate change but also the necessary adaptation measures (water savings, low-water flow replenishment, new methods for the management of hydropower structures, etc.) and the corresponding investments. Shared knowledge and governance are the keys to preserving water security.

8.4.2 Case Study 2: Sustainable Use of the Beauce Aquifer for Irrigated Agriculture

The Beauce limestone aquifer complex is one of the biggest groundwater reservoirs in France. It covers around 10,000 km^2 to the south of the Paris metropolis, between the Seine and Loire Rivers, and has an estimated storage capacity of 20 billion m^3. Located in a low-rainfall area, this water source is regularly tapped for agriculture, industrial activities, and water supply: 3300 farmers withdraw from 100 to 300 million m^3 annually to irrigate mostly cereal crops; industrial activities use around 10 million m^3; and the drinking water supply for about a million inhabitants requires around 80 million m^3.

In the early 1990s, the high volume of withdrawals and a succession of dry winters led to both a considerable drop in the water table, and perturbations in the rivers it feeds. A vast participative campaign was thus undertaken, involving farming representatives, State departments, and the water agencies, to define a suitable management method for groundwater.

Water meters were installed for irrigators (1994), and regulation of withdrawals was set up (1995) according to thresholds connected to the level of the water table, along with a programme to model the water table (1998), and creation of a Local Water Commission (2000). Following a transition period for week-by-week management of irrigation bans, the general installation of metering led to the establishment in 1999 of collective management of withdrawals, which has improved over time to take into account the water supply from groundwater into rivers during low-precipitation periods.

The basic rules are: definition of an annual maximum volume to be withdrawn for irrigation (420 million m^3/y at the highest water table level; 200 million m^3 in an average year); and division into four management sectors to take into account local hydrogeographic features. In March each year, the farmers are individually attributed a water volume for withdrawal that reflects the water table level at the end of the winter. During the irrigation period, temporary bans (from 24 to 48 h a week) may be imposed depending on the low-water flow of the rivers, according to predetermined thresholds.

In 2013, following two decades of participative cooperation, these management measures were incorporated into the State-approved SAGE of the Beauce water table. Between 1999 and 2013, the average annual consumption of water for irrigation declined to 190 million m^3, which, according to the model, will provide water balance.

Improvements are still being discussed, including adjusting (downwards) the authorised volumes to the real requirements of crops for individual irrigators. At the same time, the total attributed volume should be re-evaluated to correspond to more balanced management. At the end of the day, the approach shows how to put an end to the overexploitation of groundwater.

8.5 Drinking Water Security

The last section examined the issues involved in the quantitative management of water resources in France, including the priority use of drinking water supply. This part focuses more on quality issues.

Drinking water supply can be divided into the management of two main risks: water resources management and quality preservation on the one hand; and the presence and good operation of drinking water treatment plants and networks, including wastewater treatment systems, on the other.

As described in the introduction and Figs. 8.3 and 8.4, France has reported good chemical status for 62% of its surface water bodies, and more than 69% of its groundwater bodies. This generally good quality of surface and groundwater resources is an asset for the production of drinking water, and results especially from the significant efforts made in wastewater treatment since the 1970s. Most of the pollutants remaining to be treated result from diffuse pollution of agricultural origin, including nitrates and pesticides. But in the future, the security of the drinking water supply will very likely be improved through better control of all the molecules now regrouped under the term ‘micropollutants’.

8.5.1 Protection of Drinking Water Sources

The security of the drinking water supply especially depends on a specific policy of localised protection of drinking water abstractions, in ‘drinking water safeguard zones’. There, specific monitoring of water quality and quantity is performed, together with restrictions, prohibitions, and control of some human and economic activities. The policy is based on the idea that it is better to preserve water resource quality than to have to develop and apply expensive treatments to produce drinking water. Of the 34,000 abstraction points used for drinking water supply, 3000 are now threatened by diffuse pollution, and about 3000 abstraction points were abandoned between 1994 and 2013. A protection approach is initiated for the most vulnerable catchment areas: it involves the establishment of various protection perimeters, within which human activities are more or less restricted. Various measures for protection and management of human activities are taken, and negotiations are generally conducted with farmers on these perimeters, to change their practices in the direction of better protection of the resource. At the end of the day, a set of measures is decided and applied upstream of the catchment area to avoid water contamination (Agence Régionale de Santé 2017a, b).

On a wider scale, the basin scale approach described in Sect. 8.2 is the tool most commonly used for preserving the availability and quality of the water resource used for drinking water supply.

8.5.1.1 Case Study: A SAGE for Deep Aquifers in the Bordeaux Region

The Bordeaux agglomeration has for a very long time been in a delicate situation regarding water availability. The use of groundwater developed from the end of the nineteenth century, but it was only in the second half of the twentieth century that Bordeaux's drinking water supply came from deep aquifers—surface waters (rivers and lakes) and shallow groundwater being very vulnerable, difficult to protect, and requiring more treatment. The volume of groundwater abstracted from deep aquifers, which was 35 million m^3 in 1955, reached its peak in 2003 with 160 million m^3, before the drafting of a water development and management plan (SAGE).

As early as the 1950s, some researchers wondered about the risks linked to the continuous increase in abstractions from the Eocene aquifer in the Gironde. As early as 1955, there was a drop in the hydrostatic pressure of the confined aquifer in the Lower and Middle Eocene sands, increasing the risk of brackish and saline water infiltration, as the aquifer is at a depth of only a few dozen metres in the northern part of the estuary of the Gironde.

For its part, the BRGM (Bureau de Recherches Géologiques et Minières—French Geological Survey) began piezometric monitoring of groundwater in 1958, first for the Eocene and then progressively extended to the five other local aquifer systems (Jurassic, Upper Cretaceous, Oligocene, Miocene, and Plio-Quaternary), and supplemented in 1990 by monitoring of groundwater quality to check for degradation of resources.

It was not until 1996 that studies evidenced the overexploitation of some deep aquifers. Given the complexity of the issue and the stakes involved, local stakeholders—the departmental council and the Bordeaux Urban Community—decided to set up a Joint Organisation for the Study and Management of Water Resources in the Department of the Gironde (Syndicat mixte d'étude et de gestion de la ressource en eau du département de la Gironde, SMEGREG), entrusted with the study of resources that could be alternatives to deep aquifers.

A first result of this study is the distribution of uses according to the type of resource, for example by using the deep aquifers to supply drinking water, and reserving the surface waters of some ponds for industrial activities (Fig. 8.13).

It was also decided to initiate the drafting of a SAGE dedicated to these deep aquifers, with the establishment of a Local Water Commission in 1999 to develop it. The SAGE for deep aquifers was adopted in 2003 and revised in 2013. At the same time, several other SAGEs were developed in the area for surface water: the SAGE for the Medoc Lakes, the SAGE for the Leyre, for the estuary of the Gironde, for the Garonne River, and so on. All these SAGEs are implemented with a real concern for consistency and take into account the specificities of each resource.

The SAGE aims to restore the 'good status' of the overexploited aquifers (the Eocene one being a priority) and to preserve the water quality of the other aquifers. The preservation of the 'good quantitative status' of these aquifers requires fixing and complying with a maximal volume of possible abstraction, which corresponds

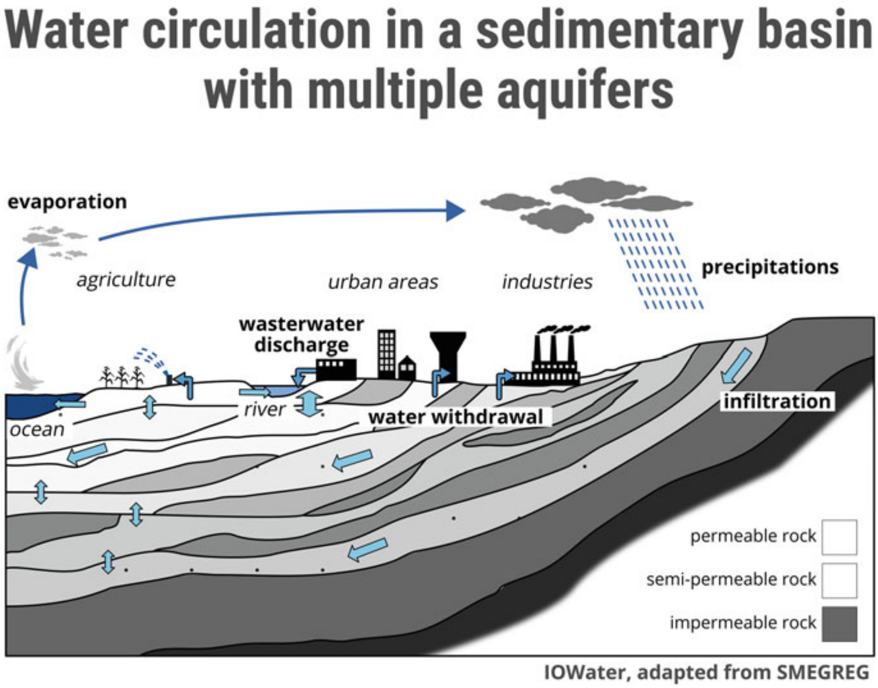

Fig. 8.13 Schematic organisation of multiple aquifer system (*Source* IOWater, *Artwork Source* IOWater)

to the recharge capacity of these aquifers. This limit was fixed and has not been exceeded for several years.

Moreover, on a local scale, it is necessary to constantly check that the abstractions do not reduce the pressure in the aquifers, which could lead to a degradation of the resource (change in physicochemical properties, saltwater intrusion, and vulnerability to pollution). The SAGE is therefore monitoring these pressures. The action developed by the Local Water Commission focuses on reducing losses in drinking water supply systems, optimising domestic use by the entire population, and putting new resources, known as substitutes, into service.

A control system, updated annually and validated by the Local Water Commission, monitors the implementation of the SAGE, and its impact on water use and the status of the resource, and evaluates its effectiveness. It also serves as a 'common reference' for resource sharing and management. The control system is fed by all the acquired knowledge and established databases and gives an update on the progress made in the studies likely to have implications for the SAGE.

These days, 97% of the drinking water consumed in the Gironde Department is abstracted from deep aquifers, several hundred metres deep, which are now monitored, and their quantity and quality controlled, and whose use (at an acceptable volume) is strictly reserved for drinking water supply.

The actions taken to reduce losses in the supply system reduced leaks from 25 to 20% of abstracted volume over ten years. Many actions were also undertaken to raise awareness: advice for users, programmes for schoolchildren, and so on. The substitution of groundwater for uses other than drinking water supply is underway and is expected to be completed by 2021: the Garonne River, Dordogne River, and other surface water resources for industry and to a lesser extent for irrigation, and the reorientation of drilling towards drinking water supply.

Since the establishment of the SAGE for deep aquifers in 2003, abstractions from deep aquifers have decreased, though the population of the area has increased by almost 10%. This proves the effectiveness of the measures and actions taken.

8.5.2 Drinking Water Supply and Sanitation Services

Water supply and sanitation infrastructure development in France can be considered complete. Quality, quantity, continuous availability, and wastewater treatment have been achieved in metropolitan France (some final progress is still needed in some overseas territories). Almost the entire French population (99%) is connected to a drinking water supply system through about 1,200,000 km of pipelines. Domestic wastewater is 95% treated, 81% in collective sanitation systems (20,271 wastewater treatment plants listed in 2013) and 19% in on-site sanitation systems. The average performance of water supply networks is about 80%.

8.5.2.1 Drinking Water and Sanitation Security Under the Responsibility of Local Authorities with a Large Range of Options for Service Management

Water and sanitation services are a decentralised public service that has been under the responsibility of municipalities since the French Revolution, including drinking water supply, collective and on-site sanitation, and rainwater treatment. For a long time, this resulted in a fragmentation of services. In 2014, France had 13,339 public drinking water services, 16,715 for collective sanitation, and 3800 for on-site sanitation.

Over the last 15 years, and especially since 2014, a series of reforms have simplified and streamlined this organisation, which now almost always comes under groups of municipalities. By 2020, the number of water and sanitation services is expected to have dropped below 4000, leading to facilitated development with more efficient, integrated, long-term strategic visions.

To set up water supply and sanitation services, French local authorities are generally free to choose direct management (using their own human, technical, and financial resources) or to delegate the management to a private organisation. In the case of delegation, the respective responsibilities of the two partners are defined in a contract signed by both parties and regulated by precise provisions, in particular since the Sapin Act of 1993 (and the Barnier Act of 1995), on the principle of a tendering procedure to procure the contract.

Three main options are open to a local authority, depending on whether it wants to be involved in financing the investments and operating the service, or prefers a public–private partnership (in all cases, the municipality remains the owner of the infrastructure):

- Direct management (*régie*). The municipality (from now on the regrouping of municipalities) is entirely responsible for investments and operations of the water services, and for relations with users. The employees are thus local civil servants and have a public status. This system usually concerns either towns with highly structured technical services or small rural communities.
- Delegated management. The municipality delegates management of all or part of the water service to a public or private industrial company under a public service delegation convention limited to 20 years (on average 18 years in the 1990s, currently around 13 years, with renewed contracts on average less than 11 years). Tariff increases are established in the delegation contract. Two types of contract are generally used, depending on whether (1) the local authority makes and finances the investments directly and only hands over the operation of the facilities to the operator, which remunerates itself from the water tariff; or (2) the operator builds the facilities and operates them at its own cost, paying itself back entirely from the water tariff. In both cases, the risk of deficit at the end of the contract is assumed by the operator.
- Mixed management. Direct management and delegated management can be combined, for example when the delegation concerns only part of the operating facilities or some of the services (customer management, billing, etc.).

In 2014 in France, 69% of public drinking water services (representing 39% of the population), 77% of public collective sanitation services (representing 59% of the connected population), and 91% of public on-site sanitation services were directly managed by the competent local authority. Around two-thirds of French inhabitants therefore benefit from water services managed by private companies, and over 40% come under sanitation services managed by private companies. In the end, the flexibility of the French system allows an effective combination of public initiative and private expertise, supporting overall robustness.

8.5.3 Water Pays for Water

The water fee system is applied at the level of the basin for water resource management. Likewise, the pricing of the service is calculated at the level of each local water and sanitation service so as to cover the costs.

Indeed, in France, water is mostly paid for by the user rather than the taxpayer. Over time, this approach has led to water pricing acceptable to users. The price of drinking water in France is low compared to the European average. The water budget of a French household generally corresponds to 1.25% of its average available income. Paying for water and sanitation services is therefore well accepted in France, and the price does not pose a major problem (except in cases of high precariousness, where it is regulated by specific social mechanisms).

Therefore, the twofold principle of 'polluter pays/water pays for water' is largely accepted among the national community, whatever water management problems may exist elsewhere. In particular, this principle consolidates the robustness of the system while respecting financial balances.

8.5.3.1 Case Study: The Recovery of the Seine River from 1970 Onwards

From the mid-nineteenth century to 1970, the quality of the water in the Seine deteriorated almost continuously, to the point that it was almost biologically dead. The collection and treatment of wastewater did not keep pace with the demographic and economic growth of the Paris region. The metropolis successively launched the construction of major wastewater collection systems (1895), increasingly extensive agricultural spreading (west of the city), an objective from 1900 of 'everything down the sewers, nothing in the river, everything on the land', and the progressive construction of biological treatment plants starting in 1940. However, these investments were not enough to deal with the increased volumes that needed treatment. The percentage of treated water dropped from 90% in 1900 to under 30% in 1950. In 1970, half of Parisian wastewater was still discharged into the river due to the increasing population.

The Greater Paris Sanitation Authority (Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne) recently published a book showing how the actions that were then taken on sanitation resulted in a spectacular improvement in the Seine's quality, on a stretch of around 500 km of river upstream and downstream from Paris (*Evolution de la qualité de la seine en lien avec les progrès de l'assainissement – De 1970 à 2015*, ouvrage collectif, coordination V. Rocher et S. Azimi, Editions Johanet, 2017).

The authority was created in 1970 (after a reorganisation of the Parisian departments in 1968). At the same time, a new sanitation master plan for the Paris region was created, which marked a turning point. It currently represents about 9 million inhabitants over an area of 1800 km^2, and treats 2.5 million m^3 of wastewater daily.

From 1970 to 1990, the capacity of the upstream Seine treatment plant increased by 1.5 million m^3. Almost 70% of pollution was thus treated (in BOD_5); the quality of the upstream water on the Seine improved distinctly, with a halving of BOD_5 concentration. However, at the time, the absence of specific treatment for nitrogen and phosphorus led to an increase in this type of pollution in the river. The situation was therefore still critical in terms of the river's oxygenation, in particular during the summer.

Starting in the 1990s, in particular thanks to increased credits from the water agency and developments in EU regulations (Urban Waste Water Treatment Directive 91/271/EEC, 1991), investments were made in more sophisticated treatment, including generalisation of nitrogen and phosphorus treatment. By 2013, 95% of organic pollution (BOD_5) had been eliminated, the ammonium concentrations observed upstream from Paris had been quartered, and phosphate concentration had been cut by nine-tenths. In parallel, and in particular since 2007, the bacteriological quality of the Seine's waters has significantly improved, partly due to this more advanced treatment and partly due to rainwater treatment, which has considerably limited the discharge of faecal bacteria into the river (Fig. 8.14).

The recovery of the Seine has also been spectacular in terms of biodiversity. Fish had practically disappeared from the river by the end of the 1960s. With the improved sanitation, the number of fish species observed in the river went from 12 in the early 1990s to about 20 currently, with almost double the number of individual fish recorded, although populations vary greatly from one year to the next. Better still, the distribution of species indicates the reconstitution of a normal food chain, featuring the reappearance of carnivorous species, which are more sensitive to the quality of the environment, and predators of omnivore species.

The Seine River case study clearly illustrates how improving wastewater treatment can aid the progressive recovery of the quality of an aquatic ecosystem. Two success factors in this recovery are worth noting. First, governance on the pertinent natural scale: the existence of the Greater Paris Sanitation Authority at the level of the Paris metropolis was crucial to bring together sufficient capacities for investment and innovation, ensure the overall coherence of the treatment measures implemented, and overcome standard administrative limitations. Second, long-term planning: the first general sanitation programme for the Paris region dates from the 1930s, and the new sanitation master plan of 1997 marked a major turning point in strategic vision and investments.

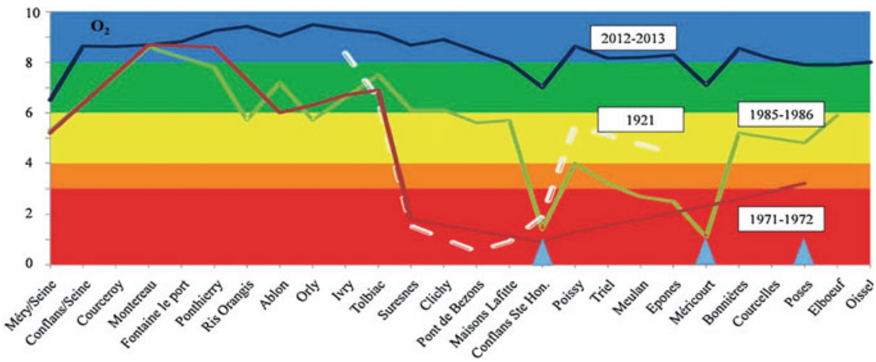

Fig. 8.14 Evolution of dissolved oxygen in the Seine river central zone (i.e.: from Paris upstream to Paris downstream) in 1921, 1971–1972, 1985–1986 and 2012–2013 (*Source* Rocher et Azimi 2017, *Artwork Source* Rocher et Azimi 2017)

8.6 Conclusions and Perspectives

At the moment, water security is not perceived as a critical issue in France. The relative abundance of the country's resources, as well as its demography and its agricultural and economic structure, have not led to regularly critical situations, as can happen in other parts of the world. The general feeling is therefore that water security is ensured in good conditions.

However, the situation is not yet satisfactory, particularly with regard to the objective of achieving good ecological status of water bodies as required by the WFD. Figure 8.15 describes the reported biological status of water bodies in France: 36% have good status, 39% moderate, 12% poor, and 4% bad. The improvements in quality still needed will include new adaptations of agricultural practices, made necessary in any case by the effects of climate change. Moreover, the quality of the forthcoming French thinking on agricultural development and water management will be an essential factor in preserving and strengthening French water security.

At the moment, these still incomplete results in terms of securing aquatic environments, this trust in water security, and the very good meeting of priority water needs are currently leading French public policy to focus its efforts more on the preservation of aquatic ecosystems, and more generally on the protection and restoration of biodiversity (not only aquatic but also terrestrial, coastal, and marine).

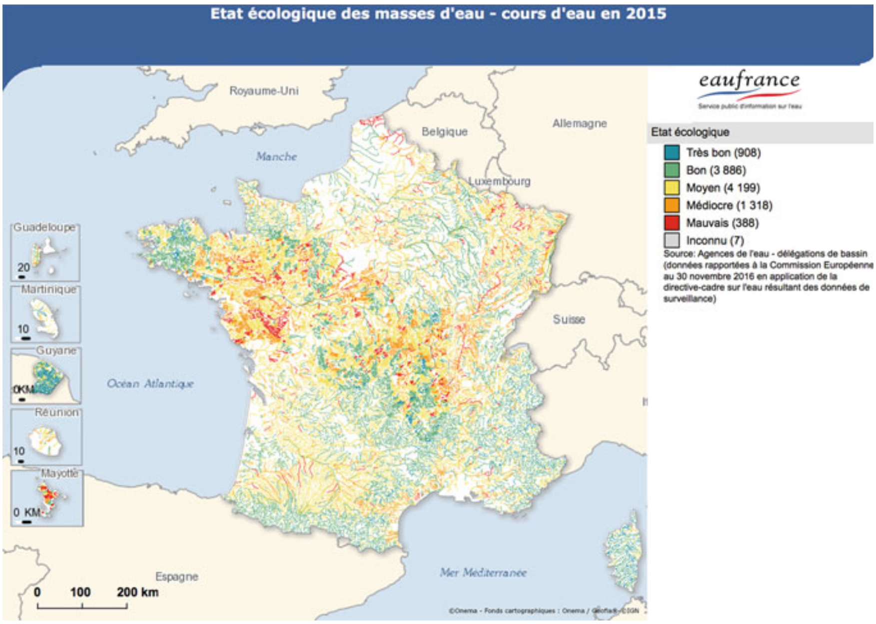

Fig. 8.15 Ecological status of surface water in 2015 (*Source* Eaufrance, *Artwork Source* Eaufrance)

A new French Agency for Biodiversity (Agence Française pour la Biodiversité) was established in January 2017; it is now the main national public actor in biodiversity protection and restoration, including water management. The agency focuses on the connection between climate change and biodiversity, through its impact on the integrity of all ecosystems, terrestrial and aquatic alike. It promotes biodiversity as a solution for limiting the damage from climate change. The agency provides scientific, technical, and financial support to the drafting, implementation, and assessment of the policies concerned, but also to knowledge dissemination, to the promotion of ecosystem services, and to projects for biodiversity preservation or restoration. The agency is also in charge of a national balanced and sustainable water management.

This new inclusion of water policy in a larger political approach focused on biodiversity preservation is currently affecting French organisation, reinforcing the focus on 'ecological security' for global management of water resources. The coming years will probably lead to noticeable developments in this regard.

This sharp reorientation is indeed the result of the realisation that the preservation of aquatic ecosystems is probably the best defence and the least costly solution to future uncertainties. This is especially the case for flood risk reduction: maintenance of wetlands or of natural flood storage areas, control of rainwater and runoff at the origin, and combating soil erosion are all approaches now being systematised.

This evolution represents a new challenge for the French organisation and for its two main assets: participative governance and dedicated funding. It will be necessary to follow what priority will continue to be given in the future to the specific security of water resources, organised at the basin level, and how long it will be ensured by the healthy self-financing of the system via dedicated fees at the basin level.

Increasing uncertainty regarding the future availability of water will necessitate a stronger basin-focused approach, and greater association of water users in defining priorities for action. With growing disparities in local and regional water quality and scarcity, a local approach and dialogue are increasingly necessary to define robust solutions.

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Chapter 9
Water Security in Latin America: The Urban Dimension. Empirical Evidence and Policy Implications from 26 Cities

Jose Carrera, Victor Arroyo, Franz Rojas and Abel Mejia

Abstract This chapter is about water security issues in urban areas of Latin America. It argues that development of water infrastructure has been impressive, but insufficient to consolidate water security in the region. It discusses why this region of plenty is still water-insecure. It reviews key issues in the nexus between cities and water, before discussing the findings and implications of recent analytical work by CAF (Development Bank of Latin America) on water security in 26 medium-size cities of the region. Finally, it claims that it would be possible to close the water infrastructure gap by 2030, and make substantial progress towards urban water security in Latin America, with investments that are equivalent to 0.3% of GDP over a period of 20 years, in parallel with substantial improvements in the governance of the services provided by water infrastructure.

9.1 Understanding the Water Security Paradigm

Water is essential to reducing poverty, improving health and nutrition, and ameliorating housing conditions. Water is also intrinsic to food and energy security. Managing floods and droughts reduces loss of life and negative impacts on the economy by strengthening the resiliency and sustainability of the urban and rural environments. Therefore, there is a growing consensus that water is at the centre of sustainable development.

The centrality of water to reaching the Sustainable Development Goals presents an even greater challenge because of the spatial and temporal asymmetries between the growing water demand and the availability of water, exacerbated by unabated water pollution, and climate variability and change, which intensify the interactions within the hydrological cycle.

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For these reasons, the concept of water security has gained traction in the last decade, by expanding the understanding of water scarcity and water stress for policy formulation and implementation (UNU 2013). While there are different approaches to water security, a common denominator found in the literature refers to the physical availability of and access to water. In this perspective, water security involves securing people's access to water of adequate quantity and quality, the availability of sufficient water to ensure a sustainable productive development, the conservation of water bodies (both surface and groundwater), and the reduction of risks associated with extreme hydrologic events.

Thus, water security is dependent on both water availability and water infrastructure, but also on institutions and governance arrangements. In sum, water security involves not only the public sector, represented by its institutions, but also the society at large which generates the demand for water, while being the beneficiary of water as a public good.

The urban dimension of water security requires a solid understanding of the infrastructure and the management capacity (and constraints) of the institutions in charge, as well as of the availability of water, to draw policy recommendations for decision-makers who are responsible for water management and development in urban areas.

9.2 Water Infrastructure Development: An Overview

Water infrastructure development in Latin America has been impressive. Since the 1950s, most countries have witnessed a significant expansion of water and sanitation infrastructure, in tandem with rapid population growth and urbanisation. The contribution of hydropower generation has grown to about 65% of the electricity generation market; and water use in agriculture has increased, including irrigation, as measured by the growing importance of Latin America to the global commodity markets of agricultural and meat products (Garrido and Shechter 2014).

Coverage of piped water supply services in urban areas increased from about 40% in 1950 to more than 90% in 2010, corresponding to an incremental population of about 400 million during this same period of time. However, in spite of the broad network coverage of water supply and sanitation services, the quality of such services is still low, and for two-thirds of the population, they do not meet international standards, including those living in rural areas, in small towns, and in slum areas of large and medium-size cities. Continuity of water supply services 24 h and seven days a week, adequate pressure in the pipes, and meeting the Pan American Health Organization's drinking water standards at the point of use, are still challenging for many cities in Latin America (Mejia 2012).

The high level of non-revenue water, over 35% for most utilities, illustrates the regional paradox of water abundance, strong coverage of network infrastructure, and low quality of water services. It is well known that reducing non-revenue water is not only about repairing leaking pipes, replacing water meters, and reducing waste, but more importantly it is related to the effective implementation of governance policies to enhance institutional accountability, economic improvements (including water tariffs that are reflective of costs), and implementation of transparent policies to address affordability issues.

Most urban rivers in the region are severely contaminated, because pollution continues unabated as a consequence of infrastructure and governance deficits in the water sector. Less than 30% of wastewater collected in Latin America receives some treatment, though there is infrastructure in place to treat about 40%. There have been large investments in wastewater treatment in cities like Buenos Aires, Mexico City, Bogotá, Lima, and São Paulo, as part of ambitious watershed restoration programmes. Wastewater treatment facilities have been built in thousands of small and medium-size cities to comply with environment regulations (Mestre 2017). But construction and operation are generally deficient, because of the lack of strong institutions and policy frameworks, including tariffs to account for operational costs, which hinders effective actions and sustainable solutions.

São Paulo, Rio de Janeiro, and Buenos Aires have suffered devastating floods, with both human casualties and large economic losses. Urban flooding is linked to a more intense hydrologic cycle, but it is also related to the uncontrolled expansion of imperviousness in land use, which in turn increases peak runoff flows (Tucci and Bertoni 2003). It is also the result of fragmented decision-making of metropolitan authorities in addressing water issues that require cross-sectorial and multilevel jurisdictional coordination. Current institutional and policy arrangements lead to inadequate planning of infrastructure investments to manage floods in urban watersheds, which is exacerbated by perverse incentives and insufficient enforcement to avert settlement in flood-prone areas.

In rural areas, floods are typically related to recurrent climatic events in large alluvial plains and in foothill areas. In Argentina, a significant portion of the population and the economic activity is located in the floodplain of the Paraná River system, which has suffered major flood events with a recurrence of about once every ten years. Since the early 1990s, the Argentinean federal government has undertaken a major effort to build infrastructure and implement non-structural measures to protect urban and rural areas. However, it needs strong coordination between national and provincial authorities, and substantial budgetary allocations to operate and maintain the extensive flood management infrastructure in place.

Latin America is the world's leader in hydropower generation as a proportion of total electricity generation capacity. In most countries of South America, hydropower represents more than 50% of the installed capacity. The potential for hydropower development in Latin America is estimated to be in excess of 200 GW, and governments are eagerly interested in new projects (Millan 2015). Expansion of hydropower capacity is taking place in sensitive ecosystems: the Amazon (Madeira, Tocantins, Tapajos, and Xingu), the eastern slope of the Andes (Peru), the Caroni River in Venezuela, and in southern Argentina and Chile. And all these new developments are facing formidable opposition because of their social impacts, issues linked to indigenous rights, and multiple environmental concerns, like environmental flows, protection of biodiversity hotspots, and RAMSAR sites.

Irrigated agriculture uses more than 75% of the water abstracted from surface bodies and aquifers. At the same time, the potential to expand the agriculture frontier is large, about 719 million ha, or about 35% of the total available land. According to the FAO (Food and Agriculture Organization of the United Nations (FAO) 2016), the irrigation potential is estimated at 77.8 million ha, of which 65% is in Brazil, Argentina, Mexico, Bolivia, and Peru. Though Latin America's share of the global irrigated area is less than 7%, the region has become a large world exporter of rainfed and irrigated agriculture products. However, irrigated agriculture faces significant problems in operation, maintenance, and rehabilitation of the infrastructure systems, as well as soil degradation due to salinity and waterlogging (CAF 2015).

9.3 A Region of Plenty, but Still Water-Insecure

Considering its landmass of 20.5 million km^2, or 15.2% of the world's total, Latin America enjoys a disproportionate share of the world's water resources: 30% of rainfall and 33% of runoff. However, while water is relatively abundant when measured by its availability—about 28,000 m^3 per inhabitant per year (ECLAC 2017) this endowment is highly skewed within and between years, and unevenly distributed in geographic space. Within each country, water availability is frequently subject to significant imbalances between the locations of water resources and the population and economic growth which are demanding water. In most countries, water is abundant in the less populated areas, while urbanisation and land development have taken place in less humid areas with milder climatic conditions that were more suitable for human settlement.

Since colonial times, the cities of the New World and the enclaves of economic activity have been concentrated either near the coast, to facilitate exports to Spain and Portugal, or in the hinterland, on top of the main cities of the Aztec and Inca empires, to take advantage of organised social structures and low-cost labor. In areas with less organised indigenous cultures, like in Brazil, Venezuela, and Colombia, labor acquired through slavery was at the core of the economic model of the colonial empires, which was based on maximizing exports and profits from coastal plantations.

Within this stylised historical context, Mexico is a textbook case because 77% of the population, 84% of the economic activity, and 82% of the irrigated area are in the north and centre, on the Mexican Plateau, above 1000 m in elevation. In contrast, 72% of the water availability is in the south and below that altitude. The situation in Peru is similar. It is a country with some of the highest per capita water availability (58,000 m^3 per year), but only 1% of this endowment is on the Pacific coast, where 70% of the country's population of 29 million resides and 90% of the economic output is generated. This asymmetry makes the most economically dynamic region of Peru severely water-stressed.

In Venezuela, 90% of the population and the economic activity is located in the north of the country, along the Caribbean coast, and in cities in the northern branches of the Andes range, with less than 10% of the country's water availability. Unfortunately, 90% of the water is found south of the Orinoco River, hundreds of kilometres from the main cities and economic activities.

Furthermore, the seasonal distribution of rainfall is quite uneven during the year. Mexico is at one extreme, since 68% of the rainfall takes place in the four months from June to September, and only 16% in the six months from November to April. In South America, the ratio between the wettest and driest three months of an average year is less skewed: 34.6% of streamflow occurs between May and July, and only 17% between November and January (SEMARNAT, CONAGUA, 2015).

Commonly used water scarcity indexes are based on annual averages, and they are not designed to capture the geographical and seasonal distribution of freshwater at the country level. For instance, the Falkenmark (1992) indicator proposes a threshold of 1700 m^3 of renewable water resources per capita per year to characterise 'water stress'. This threshold is based on estimates of water requirements in the residential, agricultural, and energy sectors, as well as environmental needs. Countries that fall below 1000 m^3 are under 'water scarcity', and below 500 m^3, 'absolute water scarcity'. In the region, only a few small island-countries in the Caribbean are below the 1700 m^3 threshold: Haiti, Barbados, and Antigua. The rest of the countries are well above this limit, with the exception of El Salvador, the Dominican Republic, and Trinidad and Tobago, which are near the 1700 m^3 threshold.

The water vulnerability index proposed by Shiklomanov (2003) is used to interpret water usage. It considers the balance of water supply and demand by estimating total annual withdrawals as a percentage of available water resource for each country, based on the aggregation of information on 26 economic regions of the world. The index suggests that a country is 'water vulnerable' if annual withdrawals are between 20 and 40% of annual supply, and 'severely water scarce' if this figure exceeds 40%. In Latin America, only Cuba (with an index of 21%) barely falls in the range of water vulnerable. Mexico (19.1%), the Dominican Republic (16.1%), and Argentina (10.1%) have a significant withdrawal of water, but in the rest of the countries, the vulnerability ratio is negligible.

While these types of indexes have been suitable for global discussions to identify issues and trends, they are less helpful in understanding water security issues at the country level. They can be even misleading to the general public and politicians, who are frequently convinced that water in Latin America's countries is plenty and free, and therefore water should be made available for all needs as an obligation of the government. Sadly, this general perception persists in spite of the acute needs of poor people in rural and urban areas, who are suffering from lack of water to satisfy their most basic needs of water supply and sanitation.

With these issues in mind, the International Water Management Institute has proposed a different approach to estimate water demand by calculating the share of renewable water resources which is available for human needs, accounting for existing water infrastructure (IWMI 2000). Its analysis of water demand is based on consumptive use (evapotranspiration), and the remainder of water withdrawn is accounted for as return flows. The institute made a projection of water demand in 2025, including an assessment of potential infrastructure development and higher efficiency in irrigation through improved water management policies (IWMI 2007). According to the institute, countries are ‘physically water scarce’ when they will not be able to meet the projected water demand of 2025, even after accounting for future adaptive capacity. On the other hand, countries that have sufficient renewable water resources, but not infrastructure to make these resources available to satisfy demand, are ‘economically water-scarce’, or ‘insecure’. By this metric, all of the countries in Latin America will be suffering from economic water insecurity by 2025, with the exception of Panama, Costa Rica, Ecuador, Surinam, and Uruguay.

The concept of economic water scarcity proposed by the International Water Management Institute is consistent with water security as described on this chapter, and it is particularly useful for Latin America because it facilitates a deeper understanding of scarcity, beyond the simple allocation of water that is available from the hydrology of each country every year. Therefore, an approach that considers the intrinsic nature of water supply and demand is needed. For water and sanitation services, water supply should satisfy the instantaneous demand, at all times and within the boundaries of the service area, at a standardised pressure and in compliance with sanitary norms.

To gain additional insights about water security, this chapter discuses water supply and demand in 26 urban areas of Latin America, from the base year of 2015, and with projections of water demand for 2030, 2040, and 2050. To better understand the security of a water supply system, it separates the capacity of the hydrology from the infrastructure to regulate, store, and transport water to the city gate. It also considers the network system from the city gate to the point of demand of the final consumer (at the household), and finally the management system in place to operate the entire physical system.

9.4 Urbanisation Trends and Water Security Issues

With 80% of its population living in cities, Latin America is the most urbanised region of the world. The region is characterised by emerging economies, albeit with high levels of inequality and environmental degradation. The most rapid urbanisation growth took place after the Second World War, with annual rates that exceeded 4% in peak years, but it has since slowed significantly, to only 1.3% in 2010 (ECLAC 2017).

When examining the spatial transformation and urban growth from a historic perspective, it is found that it has generally been messy. Latin American cities have grown on top of the informal occupation of urban areas, because of the incapacity of structured land markets to accommodate the demand for housing and infrastructure services. In part, this is due to the explosive urban growth that characterised the region for almost three decades, from 1950 to 1980. In just a few years, the informal land markets surpassed the ability of local governments, the private sector, and society at large to meet the housing and infrastructure demand with the existing levels of investments, institutional capacity, and social governance (The World Bank 2009).

Over the past 25 years, Latin America has reduced poverty from 48% to 28%, which is indeed a formidable achievement. However, inequality is large and growing, making Latin America the most unequal region in the world. In many countries, inequality has a strong racial dimension associated with the indigenous and African-descended populations. Inequality is worse in cities than in rural areas, because it is characterised by a territorial segregation of the people living in shantytowns, favelas, or slums, where they lack security and adequate public services, including water and sanitation, which are frequently in risky areas, such as hillsides, ravines, riverbanks and unstable land, and vulnerable to extreme events such as landslides and floods.

Behind these demographic and urbanisation processes, there are powerful social and economic incentives that draw people to cities in pursuit of economic opportunities, in spite of the high cost of living, the degraded environment, and the threat of violence. Attempts to control rapid urban growth through explicit government policy have generally failed. Some of these policies have been presented as an idealised concept of rural life, but whatever their basis, they have not worked, and cities continue to grow.

Empirical research based on data from thousands of cities has uncovered mathematical laws to explain the benefits of concentrating people in one place: economic activity is enhanced, returns on investment in infrastructure are higher, and there is a general progress of social vitality. More importantly, the findings on productivity and decreasing costs are fairly consistent across countries with different levels of economic development, technology, and wealth. There is evidence from around the world that the somewhat haphazard consequences of urban growth are unavoidable. As in the rest of the world, urbanisation trends in Latin America are already in motion and cannot be halted. Therefore, a primary test for those in charge of public policy is related to planning and implementing processes to formalise urban land use, build decent housing, and provide critical household services like electricity, water, and sanitation.

The urban population of Latin America is projected to reach 585 million by 2030. But in 2014, about 21% of Latin American city dwellers still lived in substandard conditions, with inadequate urban services (ECLAC 2017). How, then, will it be possible for Latin American cities to house another 200 million people while closing the infrastructure gap for those living in substandard conditions now, especially in regard to water services and sanitation, but also in housing and other urban services like solid waste disposal and collection? The real development challenge for Latin America involves formulating and implementing policies that make these processes rapid and effective, at the lowest possible cost, and with minimal human suffering. It is about providing water services to the populations, as they reach levels of economic growth and production, for which Latin American countries must create sustainable and transparent institutional governance for water, and use their financial resources wisely as they invest in water. Thus, water security in Latin American cities should be understood within an urbanisation process of widespread informality (and insecurity) in the occupation of land and the construction of shelter; with generally weak management of urban services, particularly water and sanitation; with severe degradation of the urban environment because of pollution and poor management of solid waste; and with the increasing frequency of devastating floods and distressing droughts.

In addition, the geographical imbalances between water supply and demand in Latin America are worsening as a consequence of climate change, whose impact is changing the historical trends of the hydrological cycle, including sea-level rise, which affects coastal lowlands, larger peak floods, and more prolonged droughts. Faced with this unfavorable hydrology and the asymmetry between water availability and demand, countries must strengthen water governance and water infrastructure. Resilient water infrastructure is an essential precondition to mitigate the loss of life and several points of GDP caused by a cycle (El Niño) which intensifies the hydrological cycle every 7–10 years, leading to devastating floods and more prolonged droughts. Therefore, discussing the link between cities and water in Latin America becomes a necessity for policymaking, but also for prioritizing public investments in infrastructure, considering the high urbanisation rate of the region, and the fact that a few cities are the true engines of growth of the region.

Urban water management is complex, and it is generally handled in a rather segmented way, which separates three distinct (and linear) components: water, sanitation, and drainage. However, the natural hydrological system is closed (circular), and of course does not have these artificial (and linear) distinctions. The natural water cycle is intimately connected to the forests, mountains, and aquifers that regulate and release water to the land and soil, where runoff takes place and water percolates. It is connected to urban processes, and to sediments and waste generated by both human activity and natural processes.

This chapter argues that in spite of the disorganised urban growth, it would be possible to close the infrastructure gap and improve management efficiency to achieve water security in Latin American cities by 2030. This assessment is based on projections of economic growth, macroeconomic stability, and deeply rooted and successful democratic processes. The Latin American region also enjoys a prominent proportion of population of working age that will peak around 2025. All in all, Latin America has a historic opportunity to reach higher levels of economic development, while reducing unacceptable levels of inequality and closing existing infrastructure gaps by 2030.

9.5 Urban Water Security: Empirical Evidence

The Global Water Partnership proposes that a ‘water-safe’ society is one that has a management system and infrastructure capable of maintaining the current risks at an acceptable level, as well as adapting to the risks of the future (Peña 2014). It also highlights that water security should include the means to access water. Situations of lack of access to water can occur through inadequate management, or lack of financing or infrastructure, not only through the physical absence of the resource. Intuitively, it is about the final consumers having sufficient and sanitary safe water in their homes.

With these conceptual approaches in mind, CAF (Development Bank of Latin America) conducted an investigation to better understand water security in urban areas of Latin America (Mejia 2015). The results of the study have been useful in informing decision-makers, and in providing guidance on the evaluation of credit applications aimed at the development of new sources of water, the strengthening of core infrastructure for water supply systems, increasing coverage of distribution networks, and management measures to improve the efficiency of supply and demand.

Twenty-six medium-size cities in 17 countries were identified as representative of the geographic diversity and management models of drinking water supply (Table 9.1). (Large cities such as São Paulo, Mexico City, Buenos Aires, Bogotá, and Lima were not included because of their size and complexity.) The population of the urban area was calculated based on the territory that is hydraulically connected to water sources and by pipes.

Watersheds supplying the cities were also delimited to identify the main infrastructure components and to analyse the hydrology. The 26 cities had a total population of 43 million at the end of 2015, an aggregate urban area of about 8000 km^2, and watersheds with a combined area of 1.7 million km^2. On average, density is relatively low, 68 inhabitants per hectare; only the cities of Medellín and Panamá exceed 200 per ha.

Urban water supply systems were broken down into four segments: hydrology, trunk infrastructure, network, and household.

The first segment is water security at the source of supply, which translates into the hydrological guarantee that there is sufficient water in the natural environment 95% of the time. It is related to the availability of water resources that are governed by the hydrological processes in the watershed; or to sources of groundwater, which is theoretically determined by sustainable abstraction from the aquifer.

The second segment comprises the different trunk elements of a water supply system (using as baseline the facilities existing in 2015). It consists of the intake systems, storage and regulation facilities, conveyance systems, and water treatment facilities up to the city gate, where the trunk infrastructure connects to the distribution system within the city, generally a large reservoir of potable water, downstream of the water treatment plant. In the case of groundwater, it was estimated by the pumping capacity, in the absence of data about aquifer recharge. The capacity of the trunk infrastructure was obtained from the web pages of the corresponding service providers, but many systems had master plans for drinking water, which allowed a more detailed analysis of the nominal capacity of the infrastructure. Aging was considered by reducing nominal capacity by 20%.

The third segment is the water security of the network within the city limits. It comprises elements like feeding pipes, reservoirs, pumping stations, and

Table 9.1 The results of the study for twenty-six medium-size cities in 17 countries (*Source* Mejia 2015)

City	Population	Urban area (km^2)	Population density (inhabitants per ha)	Area of watershed for water supply (km^2)	Capacity of trunk infrastructure (LPPD)	Non-revenue water (%)
Arequipa	989,332	99	100	3880.0	399	29.16
Arica	198,386	47	42	0.0	250	35.3
Asuncion	1,467,819	469	31	353,752.0	276	46.5
Barquisimeto	1,438,124	384	37	910.0	353	42
Barranquilla	2,427,061	478	51	2,574,438.0	247	66.6
Campo Grande	845,693	353	24	458.5	771	36.5
Guatemala	1,111,668	195	57	204.0	350	58
Cochabamba	785,756	107	73	623.0	152	42.93
Cordoba	1,367,188	592	23	2728.0	361	34.15
Cuzco	399,824	385	10	96.0	124	41.71
Guayaquil	2,672,786	392	68	4200.0	380	61.92
Managua	1,533,996	254	60	1216.9	263	45
Medellin	3,871,387	186	208	10,455.0	391	40.1
Monterrey	4,295,706	895	48	10,632.0	251	30.28
Montevideo	1,891,338	760	25	2385.0	343	49.39
Panama	1,662,008	60	279	1026.0	633	42.27
Porto Alegre	1,458,180	226	65	84,763.0	1164	24.74
Posadas	300,381	73	41	933,600.0	370	49.6
Queretaro	1,161,655	360	32	918.0	296	43
Quito	2,456,938	208	118	5420.0	272	27.75
San Jose	1,541,216	311	50	100.0	355	49
Santa Cruz	1,910,386	290	66	0.0	483	22
San Salvador	1,671,645	238	70	10,215.0	186	37.26
Tegucigalpa	1,239,417	155	80	470.0	124	45
Valencia	3,548,031	522	68	3960.0	395	46.8
Valparaiso	953,470	183	52	7640.0	438	40.4

distribution networks that should deliver sufficient potable water at a certain pressure to each individual connection, and it is measured before reaching the final consumer. To ensure the ability of the network to meet demand at all times, the sizing of the different physical components of the network should be designed to absorb the peaks of demand that occur at certain hours during the week, and seasonally, in places with a large variation of temperature and population depending on the time of the year. Ideally, water networks are divided into districts of operation that can be isolated and connected to SCADA systems for supervision and control of the operation in real time.

The fourth segment is the water security associated with the quantity and quality of water that is delivered and used by the final consumer. This segment of water security is related to health and quality of life, that is, the quantity and quality of water available inside the household, and how water is used, stored, and manipulated. In short, it is heavily dependent on habits of hygiene, including the disposal of excreta and wastewater evacuation. In this last stretch of water security, if the water supply is intermittent, it is necessary to provide storage for several days' consumption, and even to complement the treatment of drinking water with devices and disinfection at the point of use.

Water security of the source of supply was analysed for nine cities that have a strong dependence on hydrology and have sizeable watersheds: Medellín, Panamá, Monterrey, Arequipa, Córdoba, Valparaiso, Montevideo, Valencia, and Porto Alegre. For these cities, a simulation exercise of the monthly available volumes was conducted with a projection to 2050.

The projection of rainfall was made with a global circulation model (ECHAMS) under the A2 scenario of the Intergovernmental Panel on Climate Change. This scenario corresponds to a conservative projection of greenhouse gas emissions that assumes continuous population growth and low convergence of economic growth between the regions of the world. The rainfall data generated by ECHAMS were then used in a rainfall/runoff model (WaterGap) with geographic cells of 50×50 km. Despite the large scale of the model, the results were considered reasonable for the purposes of the study. The assumed scenario of climate change had a positive effect on the monthly volumes of water in the basins, with the exception of slight negative impact for Monterrey and Valencia.

The analysis showed that the hydrology projected for 2050 in these cities would be sufficient to satisfy an efficient demand for that year, and the volume of water available at the source would not be the greatest constraint on urban water security in seven of the nine cities that were analysed. Of course, this statement refers to monthly averages, and does not reflect interannual variations, which can be very pronounced and impose severe limitations on filling reservoirs of regulation and direct diversions from rivers.

Another important finding is the significance of groundwater. For more than 60% of the 26 cities, at least 40% of the water supply comes from groundwater. The real ratio could be even higher, considering the lack of regulations limiting the extraction of underground water and the construction of wells. Usually, there are many wells (for industrial or domestic use) that are not registered and that become important in times of drought.

According to the study, for 22 of the 26 cities, the trunk water infrastructure that was in place in 2015 will be sufficient to meet a per capita water demand of 200 litres per person per day in 2050 (Fig. 9.1). The four cities falling short were Tegucigalpa, San Salvador, Cuzco, and Cochabamba. When the existing capacity is compared with the projected demand in 2030, 73% of the cities could be supplied with 2015s trunk capacity. Only Managua, Monterrey, and Quito would have constraints, in addition to those that already had problems in 2015. Similarly, when you compare the capacity of the infrastructure with the projected water demand for

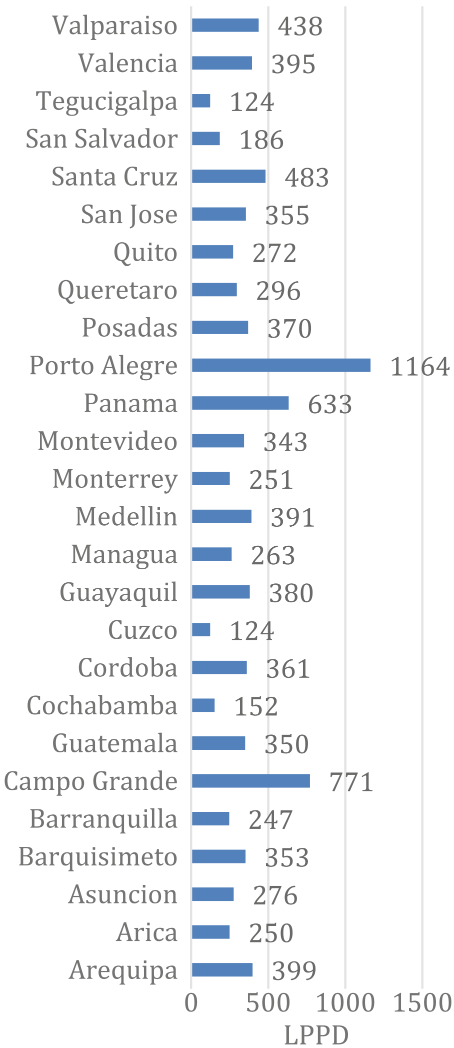

Fig. 9.1 Capacity of trunk infrastructure (*Source* Mejia 2015)

2040 and 2050, 61% of the cities can still meet an efficient demand with 2015s trunk infrastructure.

The water security of the network comprises the capacity of the feeding and distribution pipes, and of the entire network within the urban perimeter. The analysis considered three main indicators: water supply coverage gap, non-revenue water, and metering. The information was gathered from service providers and national statistics, assuming for the purposes of the study that it represented the existing infrastructure as of the end of 2015. Altogether, non-revenue water for the 26 cities exceeds 40% (Fig. 9.2). Of this group, the city of Santa Cruz is the lowest, at 22%, which reflects efficient management—but with the caveat that the provider

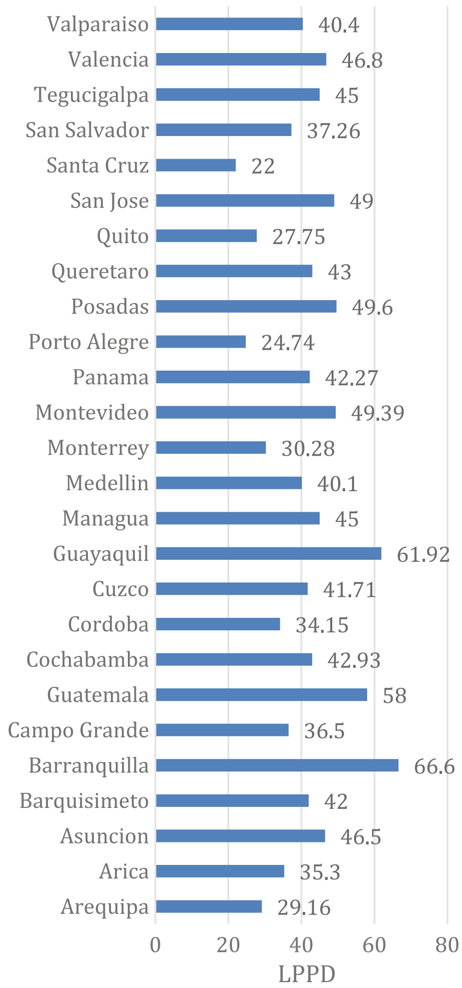

Fig. 9.2 Non revenue water (*Source* Mejia 2015)

there serves only 50% of the population, in the higher-income part of the city, where the service is under operational control.

Non-revenue water over 30% could be associated with low efficiency in managing the network of a water supply system, and ultimately it could be correlated with a lack of water security. The study finds that non-revenue water is very high for all providers included in the study, including those under private management, which should be driven by strong efficiency incentives to reduce costs and increase profits. This observation reflects that economic incentives to reduce non-revenue water in these cities are rather weak, while at the same time, it seems that incentives to increase the capacity of water supply at the source, and in trunk infrastructure facilities, are strong. This is the case in cities such as Barranquilla, Guayaquil, and Valparaiso, which have among the best-run utilities in the region and enjoy a generous hydrology.

Surprisingly, cities run by private operators that rely on groundwater (Arica and Campo Grande) also have very high rates of non-revenue water. One plausible explanation is that leak reduction is considered an operational cost for regulatory purposes, while expansion of sources of water and trunk infrastructure is treated differently by the regulator (that is, as an investment) at the time of setting the tariff base. If so, this might reflect a regulatory failure that could be corrected.

Managing the network is essential for urban water security. Based on this study some generalisations can be made. First, management of the network is a crucial and decisive element to ensure the water security of the cities. This statement is confirmed by recent crises attributed exclusively to the hydrology in the sources of surface water in São Paulo in 2014 and La Paz in 2016. In these cities, the lack of resilient infrastructure in the interior of the network was an important factor in the difficulties in responding to a sudden crisis. In both cases, when part of the city had large deficits and rationing of consumption, other parts had a surplus, which could not be used to help the areas in deficit because of the lack of interconnection of sources and lack of infrastructure for the redistribution of water within the city limits. In retrospect, these cases reveal a limited understanding of the water supply vulnerabilities and risks of the city, which were therefore not taken into account in planning and engineering; nor was the portfolio of risks associated with the various sources of water, corresponding to different basins with different hydrologic processes.

The economics associated with inadequate water and sanitation services has been studied by the World Health Organization and the World Bank in various countries of Latin America (Sanchez-Triana 2007; Hutton 2016). These studies concluded that these costs could exceed 1% of GDP for countries such as Colombia, Peru, and Ecuador. In less developed countries of the region, like Nicaragua, Honduras, and Bolivia, the cost could be much higher—some studies estimated 5% of GDP. The methodology followed in the studies used standardised indicators and metadata to assign costs to mortality and morbidity. The studies also observed that the impact of morbidity in Latin America is disproportionately high—comparable with countries in Africa with substantially weaker economic development and coverage of access.

Lack of drinking water and hygiene is a crisis for public health. Gastrointestinal diseases are devastating, in particular for children's health, through direct effects and indirectly through nutrient loss, which may have long-lasting negative effects, including cognitive and developmental problems. This situation is stark but seemingly inconspicuous for decision-makers, who usually focus on building infrastructure for access, without ensuring operation and maintenance. In Peru, for example, 50% of the population does not receive chlorinated water, which is needed to eliminate bacterial contamination.

9.6 Closing the Urban Water Infrastructure Gap by 2030

Despite the problems just reviewed, closing the water infrastructure gap by 2030 and at the same time improving urban water security is a realistic goal for Latin America's cities. An evaluation by CAF in 2011 showed that annual investments equivalent to 0.31% of 2010 GDP would suffice to close the gap of water and sewerage services, make significant advances in providing and improving these services for people who live in slums, expand water source and drainage infrastructure, and process almost two-thirds of collected sewage. These investments would total USD 250 billion (in 2010 dollars) over the period 2010–2030. Operational costs of water and sanitation services would be about 0.5% of regional GDP, equivalent to about USD 20 billion per year. This estimate is based on statistical information from the countries with the best sectorial data in Latin America: Brazil, Chile, Peru, and Colombia. Of the total envelope, the investments in water supply, sewerage, and wastewater treatment represented 65%, including rehabilitation, renovation, and expansion of existing facilities. Annual investments in urban drainage alone, aiming to reach 80% of urban built-up areas, and expansion of water supply sources to nearly 100 million additional urban dwellers, were estimated at 0.07% of GDP. Finally, remedying substandard water and sewerage connections in slums was estimated at 0.05% of GDP per year through 2030, with the aim of reducing the deficit in such services by 50% by that year. During the same period, investment in affordable housing for low-income populations requires an estimated investment of USD 200 billion, above and beyond that needed to provide water services to these populations. This highlights again the interconnectedness of urban and water sectorial planning and investments.

A large and predictable flow of investment in Latin American urban water systems is necessary to close the infrastructure gap and achieve universal-service goals by 2030. But even this will not be sufficient unless countries improve their weak water governance institutions and make substantive policy reforms to improve the administration and efficiency of water services. As a rough estimate, the hidden cost of inefficiencies in water and sanitation services in Latin America amounted to USD 5.8 billion in 2010 (Mejia 2012).

Finally, increasing investment requires a favourable environment based on the political will of decision-makers to lead reforms, access to financial resources both public and private, legal security, and adequate incentives for institutional reforms which are accountable, transparent, and efficient, to meet the growing societal demands and support the stewardship of citizens in achieving water security.

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Chapter 10
From Drought to Water Security: Brazilian Experiences and Challenges

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Abstract Water security is a relevant concept for public well-being and sustainable development. The word 'security' often refers to the idea of predictability, control, and assurance. These are relevant concepts in our changing world. Change involves social and natural processes on a planetary scale that shape and transform local realities. In this framework, the concept of water security must be understood as dialectically related to the concept of risk. In the past few years, the concept of water security has been increasingly disseminated in Brazil, owing to severe droughts that have struck several of the country's regions. Between 2013 and 2015, South-East Brazil experienced the worst drought ever recorded there. In North-East Brazil, a similar episode began in 2011 and still persists in 2017. The impacts of these events, which are associated with climate risk and societal adaptation, have placed the issue of water security on the Brazilian political agenda, but decision makers' conceptual approach is still fragile. This chapter describes the Brazilian experience with water security that emerged from the water crises in two large metropolitan regions: São Paulo, in São Paulo State, the economic power of the wet South-East Region; and Fortaleza, in Ceará State, a semi-arid part of the North-East Region that has dealt with the impacts of drought throughout its history. The respective droughts are described, as well as the water security strategies that were

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adopted during each of those crises, the lessons learned, and challenges for the future.

10.1 Introduction

Over the last few years, the concept of water security has been increasingly disseminated in Brazil owing to severe droughts that have struck several of the country's regions. From 2013 to 2015, South-East Brazil experienced the worst drought ever recorded there. Empty water reservoirs and water rationing were observed in major cities across the region during this event. The São Paulo Metropolitan Region, Brazil's largest economic power, and its population of 21 million were the hardest hit by the drought conditions. Rainfall was reduced far enough to raise serious water scarcity conditions.

The drought in the South-East Region also hit the hydroelectric sector, which operated near its lowest water supply levels in 2000–15. The Brazilian electricity sector has an installed capacity of 150.4 GW in operation, and hydropower currently accounts for more than 70% of electricity generation in the country. Furthermore, Brazil's economic growth requires ever-increasing production of electricity at a reasonable cost.

North-East Brazil is a semi-arid region with a population of 22 million that has historically dealt with drought. In that region, the latest drought began in 2011 and still persists in 2017. Initially, values of precipitation dropped below the historical average, directly affecting the stores of reservoirs destined for multiple uses, including water supply for the region's large urban areas, such as the capital of the state of Ceará, Fortaleza.

The impacts of these events, which are associated with climate risk and societal adaptation, have placed water security on the Brazilian political agenda. Yet, decision-makers' conceptual approach to water security is still incipient. Nevertheless, the central elements required to operationalise this concept have emerged with respect to the extreme circumstances of droughts. Long-term plans have been objectively devised with the aim of reducing vulnerability to droughts. They include constructing infrastructure for storage and interbasin water transfers, as well as demand management strategies. Moreover, reactive drought management plans have been developed to mitigate the impacts of drought.

The long-term planning process does not coordinate significantly with the short-term one. The long-term plans in question could be improved by designing them as water security plans that explicitly encompass climate risk management strategies, given the context of climate change and societal transformation. In the same spirit, Proactive Drought Plans, as proposed by de Souza Filho et al. (2016), could also be developed.

Brazil is known as the country with the greatest availability of water on the planet, yet the unequal distribution of water across its territory is also well known. Three distinct situations coexist in the country. There is one of abundance, represented by the north, where 65% of Brazilian water is found but only 5% of the population. Water scarcity marks the semi-arid North-East, which has only 4% of the water resources but 30% of the population. In this region, owing to the intermittence of its rivers, which dry up during the dry season, a continuous supply of water can only be guaranteed through the use of reservoirs. The third situation is represented by the South-East Region, which possesses the country's greatest financial wealth (60% of the national GDP), and 40% of the population, but only 6% of water availability. Large reservoirs are used to ensure that this region's increasing water demands will be met, mainly for hydropower generation and urban and industrial water supply. Anthropogenic pressures, together with these characteristics, strongly affect the region's water quality.

The case studies presented in this chapter describe two scenarios of water security under severe drought conditions in Brazil: one in the semi-arid North-East Region, represented by the Fortaleza Metropolitan Region and the state of Ceará; and the economic power of the wet South-East Region, represented by the São Paulo Metropolitan Region (Fig. 10.1). Both were particularly affected by the recent droughts in Brazil and have in common that they were the first states to approve their respective water policies, in the early 1990s, before a national policy was enacted in 1997.

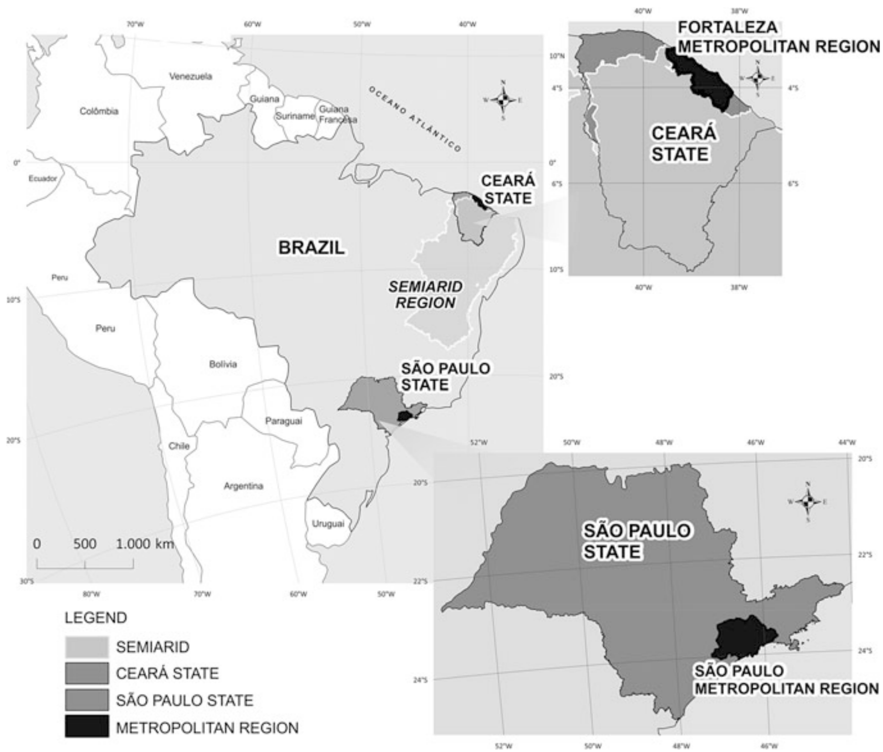

Fig. 10.1 Location of the study areas in Brazil

10.2 The Brazilian Context

Until the early 1990s, water policy in Brazil was essentially fragmented. Each user sector—hydropower, water supply and sanitation, agriculture, and others—developed its own sectoral policy without any integration among them. Since then, pressure on water resources has increased significantly as urban, industrial, and agricultural growth have required greater quantities of water while simultaneously contributing to increased degradation of rivers, aquifers, and lagoons.

In an attempt to solve this problem, the Union and the states of the federation established water resources management policies in the 1990s. In Brazil, all waters are public, be they in the domain of the Union or of the states. All rivers shared by more than one state of the federation or with other countries are of Union domain; all other water bodies are of state domain, including groundwater. Currently, each state has its own water laws. In 1997, policy was implemented at the federal level, and between 1991 and 2007 policies were enacted at the state level. Much progress has been made; however, those policies still struggle to achieve more effective results in terms of water protection and water security. And although management principles and instruments are practically the same in federal and state legislation, their combination with different organisational elements may result in management systems that are quite different in their political and operational structure (Formiga-Johnsson and Kemper 2005).

The water resources management system of the state of São Paulo (São Paulo 1991) was inspired by the French experience of basin committees and water agencies. This model strongly influenced the federal law (Brasil 1997) by defining the river basin as the unit of planning and management, establishing decentralised and participatory management through river basin committees and their executive secretariats (river basin agencies), and adopting management tools: water resources plans, water use rights, water body classification according to the predominant uses of water (*enquadramento*), water resources information systems, and bulk water charges. Command-and-control instruments continued to be exercised by the traditional state water management agencies, the Department of Water and Electric Power (*Departamento de Águas e Energia Elétrica*—DAEE) and the São Paulo Environmental Sanitation Technology Company (*Companhia Ambiental do Estado de São Paulo*—CETESB). DAEE is mainly responsible for quantity management (control and regulation of the use of state waters), and CETESB for water quality management and pollution control.

The state of Ceará adopted a management structure that differs substantially from São Paulo model. The creation of Ceará's Water Resources Management Company (*Companhia de Gestão dos Recursos Hídricos*—COGERH) in 1993, almost two years after the passage of that state's water law, made the differences between the Ceará model and other states' systems even more striking. While most states relied on existing environmental or water agencies funded through the general state budget, COGERH, the agency created to carry out management, monitoring, and enforcement functions in Ceará, was strong, independent, and eventually self-financed. Since COGERH was created, the predominant logic has been to centralise the technical aspects of water management as well as the collection of water charges in that agency, with the objective of financing both its administrative expenses and the operation and maintenance of the water infrastructure for which it is responsible. One of the reasons behind centralising water charging, rather than operating on a basin-by-basin basis, as the federal framework proposes, was the need to redistribute financial resources among basins in the state. With the exception of the Metropolitan basin, no other basin could be expected to cover its own operating and maintenance expenses.

At the federal level, the National Water Agency (*Agência Nacional de Águas*—ANA) is an authority that was created in 2001 and is responsible for implementing the National Water Resources Management Policy. ANA substantially changed the context of water management at the federal level as it became a robust institution with several major initiatives in the water resources sector. ANA is funded by revenues from charges levied in the hydroelectric sector. The amounts levied are variable each year; in 2016, a total of BRL 208 million (USD 65 million; USD 1 = BRL 3.2). Nationwide, ANA plays a leading role in Brazil's integrated water resources management. Its main activities involve water resources planning, water use regulation, dam safety, hydrological information, water resources training, structural programmes and monitoring, and management of critical events—the focus of the present study.

Several planning tools involving water security concerns have been developed by ANA:

- 'Atlas Brazil: Urban Water Supply' (ANA 2010) consolidates a large diagnostic and planning initiative on Brazil's water resources and sanitation sectors. Its focus is on guaranteeing water supply for urban centres throughout the country, of which there were 5560 at the time of the study. According to the atlas, 46% of those urban centres require expanded urban supply systems, and another 9% need new sources.
- The 'Brazilian Atlas of Sanitation' (ANA 2017) aims to assess the situation regarding urban sewage collection and treatment in Brazil's 5565 municipalities. It also proposes options for the expansion of those services, considering different needs in alternative planning scenarios, the costs of implementing different technical options, and possible financial sources in the public and private sectors.
- Another important instrument is the National Water Security Plan, which is scheduled to be completed in 2018. It will define the main structural and strategic projects for the whole country, region by region, to guarantee water supply for human and productive activities and to reduce risks associated with droughts and floods. The document will present a portfolio of strategic infrastructure to be undertaken to ensure water security in the country.
- ANA has also been developing (and supporting the development of) tools to monitor extreme events (droughts and floods). For example, the Situation Room (Sala de Situação) was created to monitor hydrological trends across the

country. It also analyzes the evolution of precipitation, river discharge, water levels of reservoirs, and weather and climate forecasts. It performs mathematical simulations to assist in preventing extreme events. It acts as a critical management centre and contributes to ANA's decision-making processes, especially for the short-term operation of reservoirs. Its main function in this sphere is to monitor the hydrological conditions of the main national water resources systems to identify possible critical events. It can thereby allow early mitigation measures to be established to minimise the effects of droughts and floods.
- Another important and innovative tool to monitor drought conditions is the North-East Drought Monitor. Under the technical and operational coordination of ANA, the Drought Monitor integrates technical and scientific knowledge of various institutions at the state and federal level: the Meteorology and Water Resources Foundation of Ceará (*Fundação Cearense de Meteorologia e Recursos Hídricos*—FUNCEME), the Pernambuco State Agency for Water and Climate (*Agência Pernambucana de Águas e Clima*—APAC), and the Bahia State Institute of Environment and Water Resources (*Instituto do Meio Ambiente e Recursos Hídricos*—INEMA). Its main objective is to monitor and understand drought conditions (their severity and their spatial and temporal evolution) and their impacts. The Drought Monitor conducts regular and periodic monitoring of the drought situation in the North-East, with consolidated results that are disseminated through the Drought Monitoring Map. Updated information on the drought situation is available every month. Using indicators that reflect the recent short-term (last 3, 4, and 6 months) and long-term conditions (last 12, 18, and 24 months), the evolution of droughts in the region can be assessed.

10.3 Drought and Water Security in the São Paulo Metropolitan Region

Located in South-East Brazil, the São Paulo Metropolitan Region[1] (SPMR) is one of the largest urban agglomerations on the planet, with an estimated population of almost 22 million occupying an area of 8051 km^2. Because the metropolis is in the upstream reaches of the Tietê River, its water demand largely surpasses local water availability. Sanitation services are not yet universal, and strategic water reservoirs are under great urban pressure. There is a need to improve governance related to water demand management, to encourage the rational use of water, to optimise conflict management, and above all to prepare for extreme events (Porto 2003; Formiga-Johnsson and Kemper 2005; SSRH-SP 2017).

[1]In Brazil, a 'metropolitan region' is an area established by state legislation that is composed of groups of neighbouring municipalities. Its purpose is to integrate the organisation, planning, and execution of public services of common interest.

Water supply in the SPMR is provided by the Integrated Metropolitan System and operated by the Water and Sanitation Company of São Paulo State (*Companhia de Saneamento Básico do Estado de São Paulo*—SABESP). It is a complex system of reservoirs, tunnels, channels, pumping stations, and one interbasin transfer, containing eight potable water systems (Table 10.1). The entire system's joint maximum production capacity is almost 74 m^3/s (ANA-DAEE 2016).

10.3.1 The Importance of the Cantareira System for Metropolitan Region Supply

The Cantareira System is located in the neighbouring basin of the Piracicaba River and supplies about 9 million inhabitants of the SPMR (IBGE 2014). Water travels 80 km to the treatment plant through an extremely complex system. First, the water is transferred by gravity along the Jaguari-Jacarí, Cacheira, Atibainha, and Paiva Castro reservoirs (Fig. 10.2). It is then lifted through the Santa Inês pumping station, through the Cantareira mountain range, to the Águas Claras reservoir. After the Águas Claras reservoir, water continues by gravity to the Guaraú Water Treatment Station, whose production capacity of 33 m^3/s supplies half of the SPMR's population.

The operational water management rules of this system remain under the jurisdiction of either federal or state government, since the rivers are federal or state owned.[2] Thus, the Cantareira System is managed by ANA for federal rivers and DAAE for state rivers. The water released downstream of the Cantareira System contributes to regulating the Jaguari, Cachoeira, and Atibainha Rivers of the Piracicaba River basin, where there are many urban and industrial users. Some very large ones, such as the city of Campinas, supply more than a million people.

10.3.2 The Attempt to Reduce Dependence on the Waters of the Cantareira System: The São Paulo Megalopolis Plan

With the aim of increasing water security and reducing dependence in the SPMR on the Cantareira System, the state government decided to promote broader studies

[2]Under the Brazilian Constitution of 1988, waters that cross state or international boundaries are in federal jurisdiction, while those located entirely within the territory of a single state, including groundwater resources, are in the state domain. One major exception is also established in the 1988 constitution: state waters collected in or regulated by federal structures are under federal jurisdiction. This provision is especially relevant in the semi-arid North-East, where the majority of reservoirs were built by federal agencies in charge of drought prevention policies and programmes.

Table 10.1 Potable water schemes comprising the Integrated Metropolitan System (IMS) of São Paulo

Potable water scheme	Treatment capacity (m^3/sec)	% of IMS
Cantareira-Guaraú	33.0	44.7
Guarapiranga/Billings	15.0	20.3
Alto Tietê	15.0	20.3
Rio Grande	5.5	7.4
Rio Claro	4.0	5.4
Alto Cotia	1.3	1.8
Baixo Cotia	1.1	1.5
Ribeirão da Estiva	0.1	0.1
Total	73.9	

Source SABESP (2015)

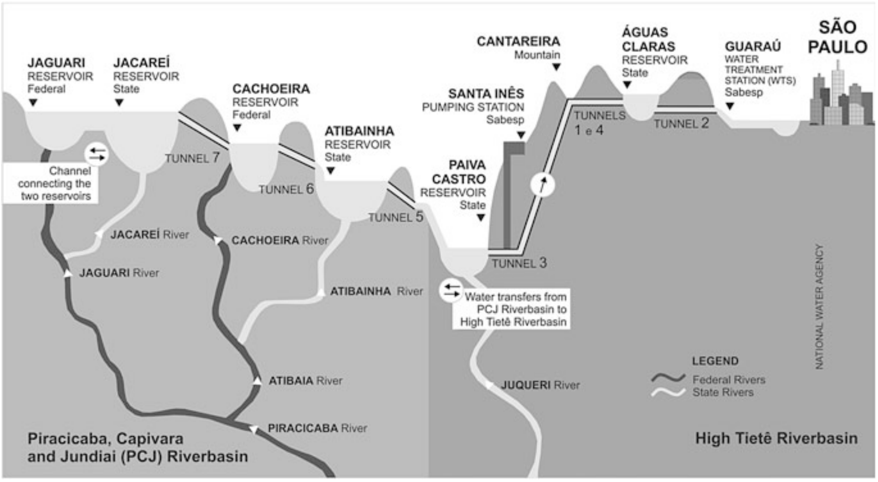

Fig. 10.2 Representative scheme of the Cantareira System. *Source* ANA (2015)

encompassing the Alto Tietê and Piracicaba River basins and their surrounding hydrographic basins, collectively called the São Paulo Megalopolis (Macrometrópole Paulista) (State Decree 52.748/2008). Though human supply was chosen as its highest priority, the main objective of this major plan is to secure bulk water for urban, industrial, and irrigation demands until 2035 within Brazil's largest and most important urban agglomeration.

10.3.2.1 São Paulo Megalopolis

The São Paulo Megalopolis is composed of three metropolitan areas in the state of São Paulo: São Paulo, Campinas, and Baixada Santista—plus the neighbouring hydrographic basins that currently supply or are planned to supply these metropolises. The Megalopolis encompasses 75% of the state's population and 16% of the Brazilian population and is responsible for 83% of the state's GDP and 28% of Brazil's GDP. In 2014, the population of this area was almost 32 million (Table 10.2). The city of São Paulo represents 57% of the entire SPMR population, which constitutes almost 70% of the São Paulo Megalopolis. It is estimated that in 2035 the population of the Megalopolis will be 37 million or more (DAEE 2013).

10.3.2.2 Hydraulic Schemes: Bulk Water Supply Options

The São Paulo Megalopolis Plan was concluded in 2013, before the water crisis in the Cantareira System and the Metropolitan Region. It outlined several water supply alternatives ('hydraulic schemes') to increase bulk water availability to meet the incremental demands of the Megalopolis. The plan considered both old and new solutions. The following are the plan's principal elements.

- *Cantareira System (Piracicaba River basin)*—The main water supply system of the SPMR runs with low levels of water availability and security due to restrictions downstream of the Cantareira System in the Piracicaba, Capivari, and Jundiaí river basins (collectively called PCJ basins), where the state's second-largest metropolis (the Campinas Metropolitan Region) is located. The plan developed several options, including the highly contentious transfer from the Paraíba do Sul River basin, which is under construction. This interbasin transfer contributed to one of the Brazilian Federation's major water conflicts between states, since the Paraíba do Sul basin supplies 75% of the population of Rio de Janeiro State, including the Rio de Janeiro Metropolitan Region (Formiga-Johnsson et al. 2015).
- *Western zone of the SPMR*—The western zone of the SPMR experiences severe water shortage in its urban supply and requires a considerable increase in the capacity of its producing systems. According to the plan, to meet the demands of

Table 10.2 Population of the São Paulo Megalopolis in 2014

Regional unity	Population	Main city	Population
São Paulo Metropolitan Region	20,935,204	São Paulo	11,895,893
Campinas Metropolitan Region	3,043,217	Campinas	1,154,617
Vale do Paraíba and Litoral Norte Metropolitan Region	2,430,392	São José dos Campos	681,036
Sorocaba Metropolitan Region	1,805,473	Sorocaba	637,187
Baixada Santista Metropolitan Region	1,781,620	Santos	433,565
Urban Agglomeration of Piracicaba	1,195,904	Piracicaba	388,412
Urban Agglomeration of Jundiaí	705,000	Jundiaí	397,965
Total	31,896,810		

Source IBGE (2014)

this region, new producing systems to be built in the short term should be given high priority.

- *Billings reservoir (in SPMR)*—The Billings reservoir is currently used for public supply through the Rio Grande branch and through water transfers to the Guarapiranga reservoir (through the Taquacetuba branch). This reservoir constitutes one of the main supply systems of the SPMR. It also contributes to controlling floods in the SPMR through pumping systems in the Pinheiros River channel. Expanding its use for public supply is controversial owing to the issue of water quality and the use of water resources for energy production at the Henry Borden mill in Cubatão. Closing other branches of the Billings reservoir for supply would interfere with water availability for electric energy generation. Within the scope of the São Paulo Megalopolis Water Resources Utilisation Plan, only the closure of the Pequeno River branch was considered, taking into account the studies carried out by SABESP, including the SPMR Water Supply Master Plan.
- *Water deficiency zones in the Médio Tietê/Sorocaba Hydrographic Region*—Surveys made it possible to identify the western regions covered by the São Paulo Megalopolis that also present significant water deficiency in terms of urban, industrial, and irrigation supply: (1) the region of the Sorocaba-Indaiatuba hub, involving, among others, the cities of Sorocaba, Itu, Salto, and Indaiatuba; and (2) the region of the Tatuí-Tietê hub, involving, among others, the cities of Tatuí, Boituva, Cerquilho, and Tietê. For these regions, three water supply hydraulic schemes were considered as supply solutions for the São Paulo Megalopolis: water transfer from the Juquiá River watershed to reinforce water availability in the Itupararanga reservoir; water catchment in the Sorocaba and Sarapuí Rivers; and water catchment in the Jurumirim reservoir, in the Alto Paranapanema watershed.
- *Parts of the PCJ basins*—Isolated catchment points are predominant in the PCJ watersheds, both for urban supply and for industrial and irrigated agriculture uses. Except for the reservoirs of the Cantareira System, the region does not have large reservoirs to regularise river flows, which increases the region's vulnerability in the event of extreme drought. The following hydraulic schemes were considered to meet the water demands of this region: expand outflows from the Cantareira System (with or without partial water withdrawal from the Jaguari River reservoir, in the Paraíba do Sul River watershed); build reservoirs to regulate river flows, highlighting the uses studied for the Jaguari and Camanducaia Rivers; and bulk water withdrawal from the Sorocaba and Sarapuí Rivers in the Médio Tietê/Sorocaba and the Jurumirim reservoir of the Alto Paranapanema watershed.
- *Eastern zone of the SPMR*—This region is under the predominant influence of the Alto Tietê production system. The following alternatives to expanding production in this system were identified: use part of the waters regularised by the Paraibuna reservoir in the Paraíba do Sul River, with adduction to the Ponte Nova reservoir in the Alto Tietê watershed; and water uses in Itatinga and

Itapanhaú, which are part of the water resources from the Serra do Mar seamount in the Baixada Santista watershed.

10.3.3 *The 2014–15 Water Crisis*

To understand the circumstances that led to the water crisis in the SPMR, it is essential to understand what led to the drought. The measures that were taken by the water resources managers (ANA and DAEE) and the state water supply company (SABESP) in response to the crisis will also be outlined.

10.3.3.1 Water Crisis and Conflict Between the Piracicaba Basin and the Metropolis of São Paulo

Rainfall averages in the 2013–14 hydrological year (October 2013–September 2014) were well below historical averages in all basins that are sources for the SPMR's potable water systems, except for the Rio Claro system (Table 10.3). The Cantareira System recorded a total rainfall 43% below its historical average for the same period. In the summer of 2014 and the summer of 2015 (rainy season), rainfall totals were well below the historical average. From December 2013 to February 2014, rainfall was only 32.8% of the historical average. In the same period, one year later (December 2014–February 2015), the region received more rainfall, but still only 77.6% of the historical average for the same period. Figure 10.3 presents the average monthly rainfall and those recorded from October 2012 to June 2015 in the catchment region of the Cantareira System.

In 2014, the average inflow to the Cantareira System's reservoirs was the lowest in 85 years of recorded history. The previous record was in 1953, when the average inflow fell to 24.6 m^3/s—still more than double that observed in 2014. These low discharges during the drought aggravated the already acute conflicts and water-use disputes between the Piracicaba basin and the Metropolitan Region of São Paulo. Except for the Cantareira System, there is no infrastructure for regulating the flow

Table 10.3 Cumulative rainfall (hydrological year 2013/14) compared to the historical average in the same period (in mm)

	Water system					
	Cantareira	Guarapiranga	Alto Tietê	Alto Cotia	Rio Grande	Rio Claro
Average	1586.8	1342.5	1463.6	1386.4	1559.4	2176.6
2013/14	905.2	1189.7	1045.9	768.4	1337.1	2309.1
Difference	−43.0	−11.4	−28.5	−44.6	−14.3	6.1

Source SABESP (2015)

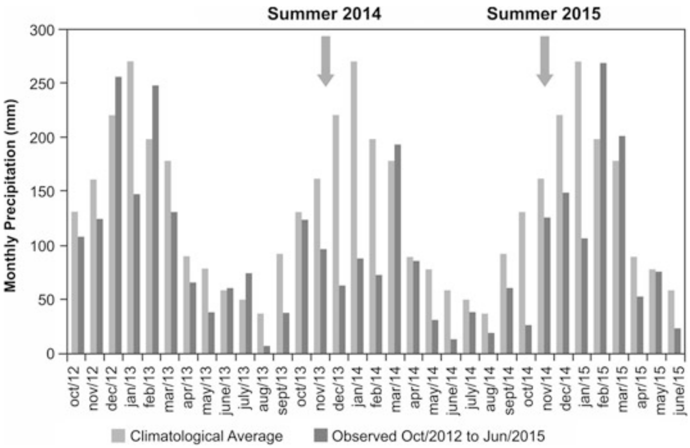

Fig. 10.3 Historical average and observed rainfall in the Cantareira System, October 2012–June 2015. *Source* Marengo et al. (2015)

of rivers in the PCJ basins when the water demand is very high. Of the total demand of 36.3 m^3/s, more than half is for urban supply and is met almost entirely (97%) by surface waters. Among the cities in the PCJ basins, Campinas stands out with more than a million inhabitants (COBRAPE 2011).

In the 2010–2020 Plan for the Piracicaba, Capivari, and Jundiaí Basins (COBRAPE 2011), the surface water availability of PCJ watersheds is estimated at 37.8 m^3/s, while the total demand sums to 34.5 m^3/s. This means that practically the entire flow is already being used in the basin. The situation is mitigated only because some of the withdrawn water returns to the water bodies as wastewater (18.9 m^3/s), which results in a positive balance (Table 10.4). The plan also indicates increasing demands in the future: 41.6 m^3/s by 2020 and 46.5 m^3/s by 2035. Thus, the PCJ basin will be under severe water stress.

10.3.3.2 Drought and Water Resources Management Crisis

As mentioned, the National Water Resources Policy (Law 9.433/1997) gives responsibility for water resources management to ANA for federal waters and to state institutions for state water resources. When the drought began to worsen, ANA and DAEE created the Technical Advisory Group to Support the Cantareira

Table 10.4 Water balance of Piracicaba, Capivari, and Jundiaí watersheds

Available discharge (m^3/sec)	Water withdrawal (m^3/sec)	Wastewater (m^3/sec)	Water balance (m^3/sec)
37.9	34.5	18.9	22.3

Source COBRAPE (2011)

System's Management (*Grupo Técnico de Assessoramento à Gestão do Sistema Cantareira*—GTAG) (Resolução Conjunta ANA/DAEE no. 120, 2 Oct 2014). The GTAG was responsible for managing the Cantareira System during the crisis period, which entailed, among other tasks, daily monitoring of data on reservoirs and other components of the Cantareira System, as well as fluviometric, rainfall, and water-quality monitoring.

One of the GTAG's responsibilities was to allocate water from the Cantareira System between the SPMR and the PCJ basins. It was in this context that the total flow originally granted to SABESP was progressively reduced, beginning 6 March 2014, due to the ongoing water crisis. From that date onward, through joint communications, the GTAG determined the flow that could be transferred to the SPMR (Alto-Tietê basin; Q1 in Tunnel 5, Fig. 10.4) and the sum of the outflows from the Jaguari/Jacareí, Cachoeira, and Atibainha reservoirs for the PCJ basins (Q2; large arrows in Fig. 10.4), except those related to spills. The joint communications were valid for 30 days; the flows Q1 and Q2 were reevaluated each month, resulting in increasingly restrictive values according to the reserves in the Cantareira System.

Seven months later, ANA withdrew from the GTAG and proposed to dissolve the group (Official Letter 228/14, dated 19 September 2014). However, even after the termination of the GTAG, ANA and DAEE continued to jointly determine water restrictions applying to the Cantareira System and its supply to the SPMR. To avoid the collapse of the Cantareira System, the discharge to the SPMR decreased progressively, from 31 m^3/s at the beginning of the crisis to 13 m^3/s in February 2015, equivalent to a 56% reduction in water supply to the metropolis.

10.3.3.3 Coping with the Water Crisis: SABESP's Drought Plan for the São Paulo Metropolitan Region

Brazilian Law 11.445/2007 on water supply and sanitation (Brasil 2007) establishes that each state is responsible for the regulation and supervision of the water and sanitation services within its territory. Therefore, during the crisis of 2014–15, SABESP had the authority to rule on potable water restrictions in the SPMR, with the permission of the State of São Paulo Regulatory Agency (*Agência Reguladora de Energia e Saneamento do Estado de São Paulo*—ARSESP), to compensate for the gradual reduction of bulk water availability from the Cantareira System (from 31 to 13 m^3/s).

10.3.4 Water Security Strategies Adopted by SABESP

In coping with the crisis, SABESP opted not to impose rotating water supply service (*rodízio*), in light of its disadvantages: health risks; the possibility of increased leakage in supply networks; farther and higher regions perhaps going days without water; the necessity of a contingency supply for essential services.

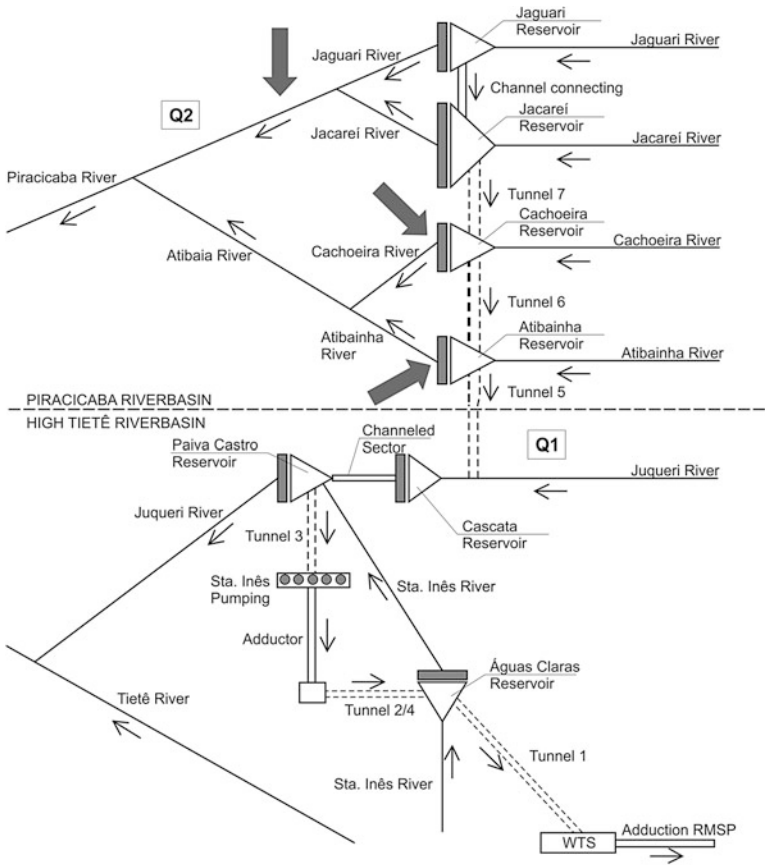

Fig. 10.4 Simplified diagram of the Cantareira System. *Source* ANA-DAEE (2004)

Instead, the company initiated measures aimed at reducing withdrawal flows from the Cantareira System. The main measures adopted were as follows.

10.3.4.1 Bonus Programme

The bonus programme encouraged behavior change in the public towards reducing their water consumption. Beginning in February 2014, the company asked consumers to reduce consumption by 20% from that recorded in the previous 12 months. If successful, the customer would receive a 30% financial bonus, even if their consumption was in the minimum range.

In 2015, after the programme had been in place for one year, it was observed that a portion of the population continued to maintain above-average water consumption in spite of the awareness-raising campaign. To discourage such consumption, a contingency fee was added for customers whose monthly consumption exceeded the average: 40% of the water fee for those who exceeded the average consumption by up to 20%, and 100% of the water fee for those who exceeded the average consumption by more than 20%. The contingency fee was applied even to clients with a firm demand contract, which were mostly in industry and commerce.

Thanks to the population's adherence to the bonus programme, per capita consumption in the SPMR fell from 155 L per inhabitant per day in February 2014 to 118 L per inhabitant per day in March 2015 (SABESP 2015). In March 2015, the water saved by the bonus/burden programme was 6.2 m^3/s. Further performance details follow.

- Consumption reduction: 82% of SPMR clients reduced their water consumption compared to the average value established by the programme. (Some clients slightly reduced their consumption but did not reach the proposed goal and therefore received no bonus.)
- Contingency fee: 18% of clients' monthly consumption was above the average value established by the programme. (The contingency fee did not apply to clients registered as beneficiaries of social tariffs.)
- Participation in the bonus programme according to demand category was as follows:
  - Industrial/commercial users: 49% of connections earned the bonus.
  - Residential users: 36% of connections obtained the bonus, while only 11% of residential condominiums reached the goal.

10.3.4.2 Integrating Drinking Water Supply Systems

As exceptional measures, works were executed to reverse flows in support of the Cantareira System. In 2014, these works and emergency measures were responsible for transferring 6.3 m^3/s of water to areas previously supplied by the Cantareira System (Fig. 10.5).

10.3.4.3 Intensification of the Loss Reduction Programme

SABESP's Loss Reduction Programme is permanent. Its main aims are to reduce the time required to repair leaks, to expand sectorisation, to increase the percentage of the network covered by pressure-reducing valves, and to reduce network pressure with a view to reducing leaks. Reducing pressure was the most efficient action taken in facing the water crisis. It was responsible for a reduction in flow in the Cantareira System of 7.3 m^3/s, equivalent to 41% of all the savings obtained in the system.

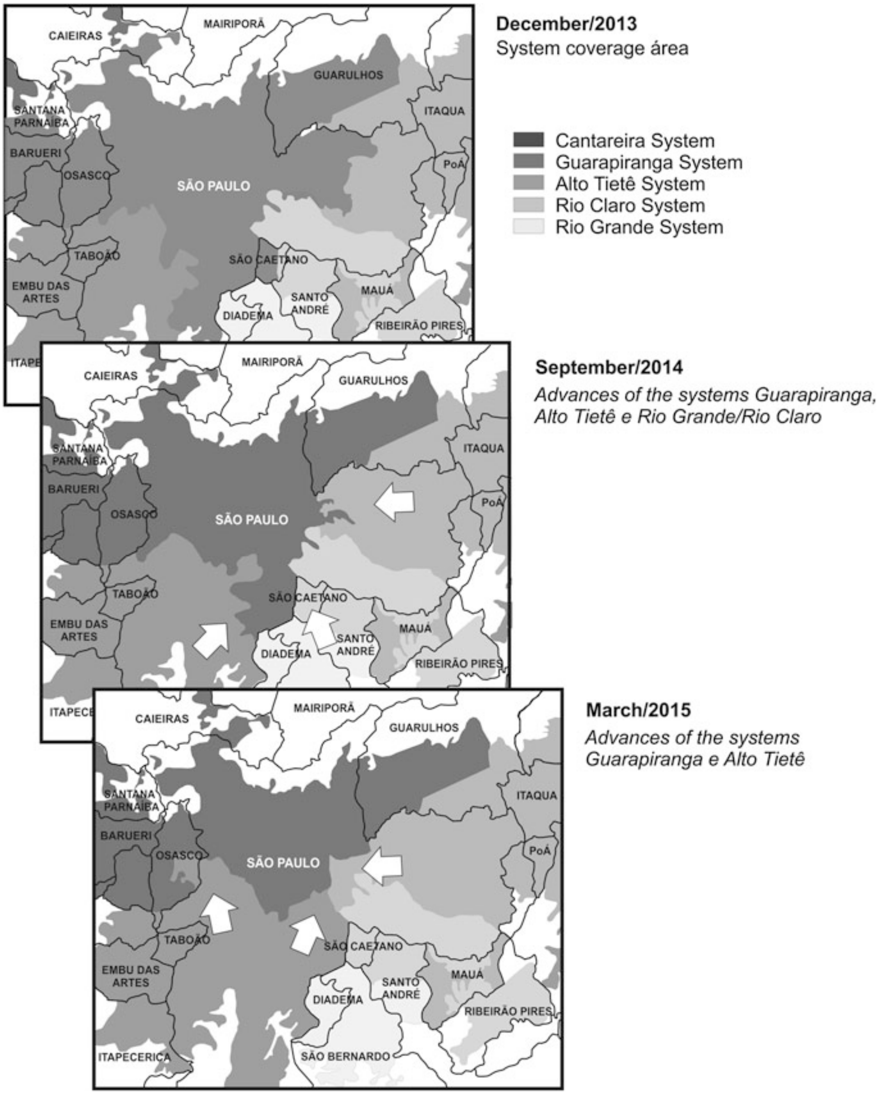

Fig. 10.5 Expansion of drinking water supply systems in the region served by the Cantareira system (drinking water supply redundancy). *Source* SABESP (2015)

10.3.4.4 Use of Technical Reserves (or 'Dead Storage' in the Reservoirs)

Technical Reserve I added 182.5 million m^3 of water to the Cantareira System (part of the 'dead storage' of the Jaguari/Jacareí and Atibainha reservoirs) and started operations on 16 May 2014.

In the Jaguari/Jacareí reservoirs, an 80-metre-long dam had to be built with a motor-pump set fixed in floats. In the Atibainha reservoir, 'water was lifted by the motor-pump set to a dissipation box and drained by gravity through a channel 890 m long, flowing into the Tunnel 5 catchment channel. A 100-metre-long dam was then built whose dammed waters maintain the flow transferred from Tunnel 5 to the Paiva Castro dam, in the Alto Tietê basin' (SABESP 2015).

Technical Reserve II added another 105 million m^3 to the Cantareira System. It started operating on 24 October 2014 with a new 400-metre-long dry structure in the Jacareí reservoir and new motor-pump sets. In this way, the works provided extra water storage equivalent to 287.5 million m^3—more than 29% of the active volume (Fig. 10.6).

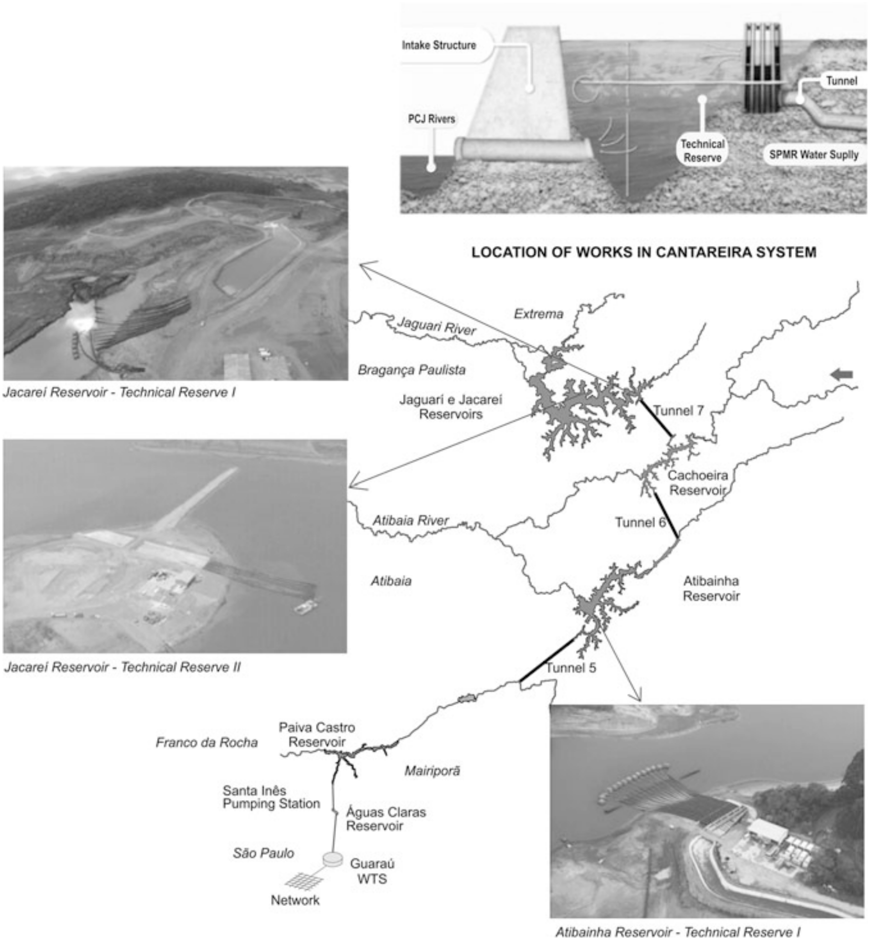

Fig. 10.6 Technical storage schemes in the Cantareira System. *Source* SABESP (2015)

10.3.4.5 Main Results of the Water Security Drought Coping Strategies

Comparing water production levels in February 2014 and March 2015, withdrawals from the Cantareira System were reduced by 56%, from 31.9 to 14.04 m^3/s. The water savings corresponding with each of the adopted programmes are presented in Table 10.5. The action that resulted in the greatest water savings in the period under analysis was the pressure reduction and loss reduction programme, which represented 41% of the total quantity saved. The other significant programmes are water transfers from other systems (36%), the bonus programme (20%), and reducing flows delivered to cities (3%). The bonus programme had the participation of more than 80% of the population of the SPMR.

10.3.5 Water Security After the Water Crisis

The magnitude of the water crisis in São Paulo was unexpected, as was the severity of the drought that occurred mainly in the Cantareira System. However, its impact revealed a crisis in water resources management and governance. Essential measures to increase water availability to the metropolis, which had previously been proposed in different plans, had not been implemented.

In coping with the crisis, water security subsequently assumed great importance in the political agenda of the state of São Paulo. It enabled many technical and operational innovations, both in management of bulk water supply during drought, and in redundancy of potable water infrastructure through expanded interconnections between the supply systems. In addition to investments in new infrastructure to increase water availability, the crisis also highlighted the importance of complementary management actions involving water quality restoration, water demand, and water reuse. Also, water quality can be recovered by protecting and revitalising water sources with greater appreciation for ecosystems. Above all, the water crisis revealed the need to strengthen the institutions that manage water resources to make them more robust and adaptive.

Table 10.5 Water savings in SABESP programmes, February 2014–March 2015

SABESP programme	Flow reduction	
	m^3/sec	%
Pressure reduction/loss control	7.30	0.41
Water transfers from other systems	6.30	0.36
Bonus programme	3.50	0.20
Reduction of flows delivered to cities	0.60	0.03
Total	17.70	

Source SABESP (2015)

10.4 Drought in Ceará State and Water Security in the Fortaleza Metropolitan Region

Ceará is a state with low water availability due to a combination of many factors. Among them are low precipitation (below 900 mm/y), high evaporation (above 2000 mm/y), irregular rainfall (recurrent and sometimes multiannual droughts), and an unfavorable hydrogeological context (80% of the territory is located on crystalline rock, with a shallow soil layer and scarce underground water resources). Thus, most rivers are naturally intermittent.

Therefore, ensuring water security for the state's population of around 9 million and their economic activities during periods of water scarcity depends heavily on sophisticated water infrastructure, including reservoirs, interconnected basins, canals, and pipelines. In Ceará, in addition to hundreds of small reservoirs, 155 particularly strategic reservoirs provide 90% of the state's total storage capacity (or 18.67 billion m^3), distributed across its 12 hydrographic regions. The state's water infrastructure includes 439 km of channels, 1250 km of pipelines and bulk water distribution networks, and 32 pumping stations. In total, there are 2551 km of regulated rivers involving 91 water bodies.

Until the 1990s, water policy and management in the territory of Ceará—and in all of the semi-arid North-East—were essentially conducted by federal government institutions whose main mission was to protect against drought. This political-institutional context was heavily modified from 1992 onward, in the broader context of water sector reforms in Brazil, with the implementation of the Water Resources Management System at the state level.

In Ceará, COGERH, created in 1993, is the main party responsible for the state's water resources management system. One of the reasons for the success of Ceará's model (Ceará 1992) is its adaptation of the management model established by Federal Law 9.433/97. The model was more centralised than that of other Brazilian states, but it also created and instituted decentralised practices for negotiated water allocation (Formiga-Johnsson and Kemper 2005). In cooperation with other federal and state institutions that comprise Ceará's water management system, COGERH and the Ceará State Water Resources Ministry (*Secretaria dos Recursos Hídricos do Estado do Ceará*—SRH) are responsible for making the state one of Brazil's most advanced in water resources management. Significant technical, political and institutional capacities are successfully coordinated in Ceará to execute general water management tasks and deploy strategies to cope with droughts.

It is important to note that, unlike the state of São Paulo, where bulk water infrastructure for metropolitan supply is managed by the water supply service provider (SABESP), Ceará uses an atypical arrangement wherein all bulk water infrastructure—including for metropolitan supply—is managed by COGERH. Ceará's water supply service provider, the Water and Sewage Company of Ceará (*Companhia de Água e Esgoto do Ceará*—CAGECE), is one among multiple users of COGERH-operated waters.

10.4.1 Metropolitan Water Supply

The Fortaleza Metropolitan Region (FMR) does not have large water bodies within its geographic reach. Urban growth and industrial activities in its territory, such as the establishment of Pecém Harbor, have caused greater dependence on water transfers. This dependence started to grow at the beginning of the 1990s and is now concentrated mainly on the Castanhão dam, located 216 km from Fortaleza.

Until the early 1990s, the FMR was supplied by the integrated Pacoti-Riachão-Gavião system. In 1993, the Worker's Channel (Canal do Trabalhador) was constructed and became the first infrastructure for water transfer to the metropolitan area. The waters of the Jaguaribe basin (Orós dam and Jaguaribe River) then became part of the metropolitan supply system. In 2003, the Castanhão reservoir was completed. The largest in Ceará, it is located in the Jaguaribe basin (6.2 billion m^3). Thus, water security in the metropolitan system was progressively reinforced: first, by extending the Jaguaribe River, which already supplied part of Fortaleza; and especially since 2012, with the conclusion of a complex system of

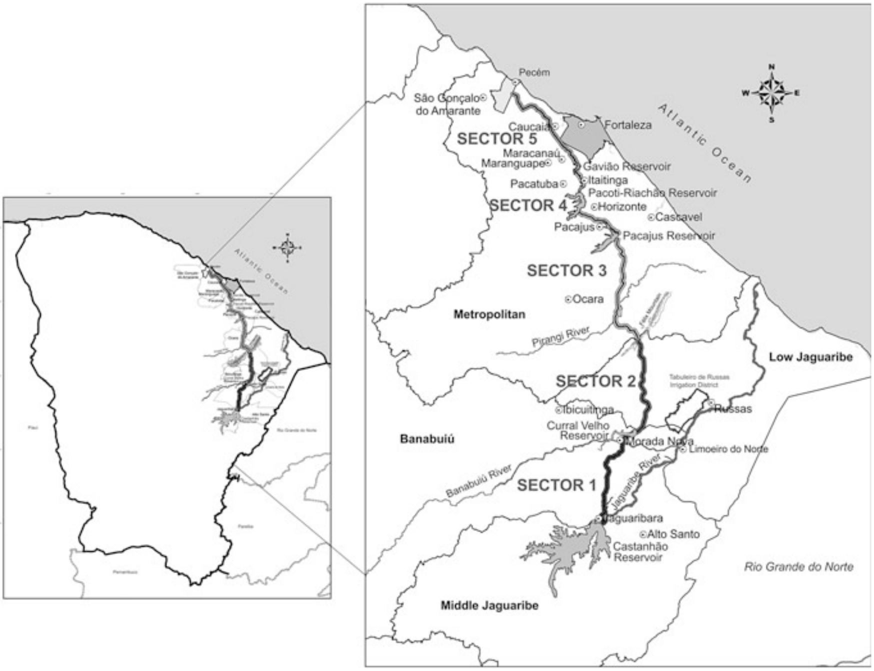

Fig. 10.7 Location of Fortaleza and the metropolitan supply system, including Castanhão dam and the five sections of the Eixão das Águas, which supplies water to Fortaleza and Pecém harbor. *Source* SRH-CE (2017a)

pumping stations, channels, pipelines, siphons, and tunnels named the Integration Channel (Eixão das Águas), which allowed water to be transferred directly from the Castanhão dam to the FMR (Fig. 10.7).

Currently, the metropolitan macro system supplies about 3.2 million people and includes two water treatment plants: the Gavião, which serves around 90% of the FMR population and can treat up to 10 m^3/s; and the Oeste, with a treatment capacity of 1.25 m^3/s.

10.4.1.1 São Francisco Interbasin Water Transfer

Water security in this macro system will be further reinforced on the conclusion of the São Francisco Interbasin water transfer project, scheduled for early 2018. This is a federal government project aimed at transferring a continuous flow of 26.4 m^3/s from the São Francisco River, one of Brazil's most significant rivers, over hundreds of kilometres and through several states of the federation. Its objective is to ensure water supply, from 2025 onward, to 12 million inhabitants of small, medium, and large cities in the semi-arid region of the states of Pernambuco, Ceará, Paraíba, and Rio Grande do Norte.

The project entails the construction of 477 km of canals in two major regions (north and east), as well as tunnels, aqueducts, pumping stations, reservoirs, sub-stations, and transmission lines.

In March 2017, the eastern region of the project, which supplies the states of Paraíba and Rio Grande do Norte, was inaugurated. In Ceará, the project will be concluded in 2018, and the northern region will thus be integrated through the Jaguaribe River basin with the aim of improving water supply to the FMR.

10.4.1.2 Ceará Water Belt

Among the different initiatives to improve water security by integrating river basins and guaranteeing water system redundancy, in 2013 the state government of Ceará began construction of the ambitious Ceará Water Belt (Cinturão das Águas do Ceará). It consists of a large system of channels surrounding a large part of the state and crossing several river basins. Its first section starts at the entry point of the São Francisco River transfer (Fig. 10.8). The Water Belt will allow transposed waters to be adducted in most of Ceará's territory, including the drier regions of the state ('water voids'), as well as regions exploited for tourism and their economic potential. This infrastructure will also allow excess flows from the São Francisco River to be transferred to the Castanhão and Orós reservoirs, the largest in the state. The first section of the Water Belt, which will receive waters transferred over a distance of 145.43 km, is in its final phase of construction.

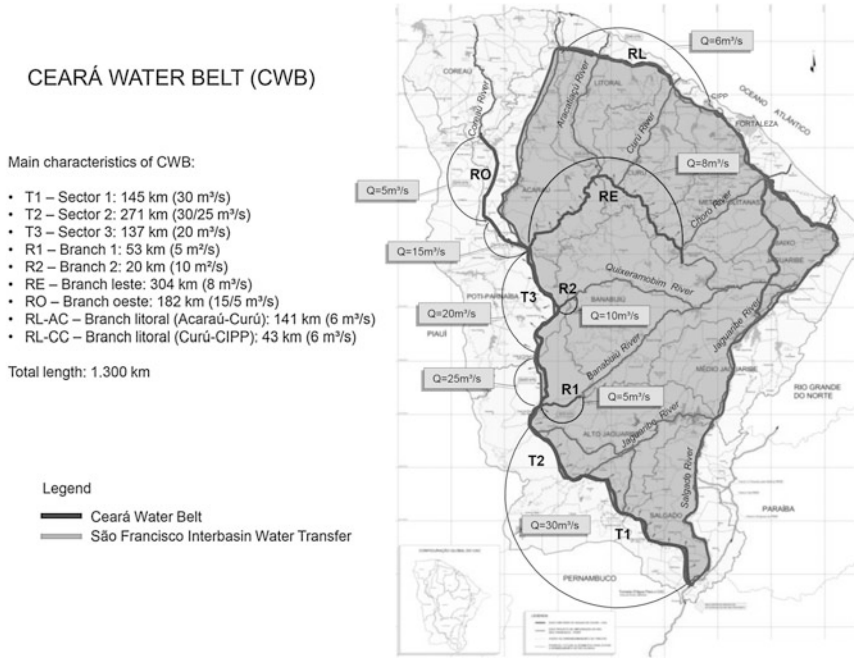

Fig. 10.8 The Ceará Water Belt. *Source* SRH-CE (2017a)

10.4.2 Main Related Institutions

Although most of the rivers in Ceará are state-owned, the essential waters available for multiple uses are of federal domain since they are stored in dams built with Union resources. For this reason, federal institutions also participate in water management, especially the National Department for Works against Droughts (*Departamento Nacional de Obras Contra as Secas*—DNOCS) and the ANA. However, their role is minor, as management of these federal waters is delegated to the state of Ceará.

Therefore, the central institutions involved in water security in the state of Ceará, and in the supply of metropolitan Fortaleza, are at the state level (Fig. 10.9). The water resources management agencies (SRH and COGERH) develop and regulate the use of bulk water throughout the state, are responsible for conflict prevention and mitigation, and have a mandate to oversee the water security of current and future generations. CAGECE, the state water and sanitation company, is responsible for the supply of 151 (out of 184) municipalities in the state, including the FMR. FUNCEME, the state agency in charge of meteorology and water, is responsible for hydrological and climatological monitoring. Operationally, the construction of hydraulic works and water infrastructure is the responsibility of the

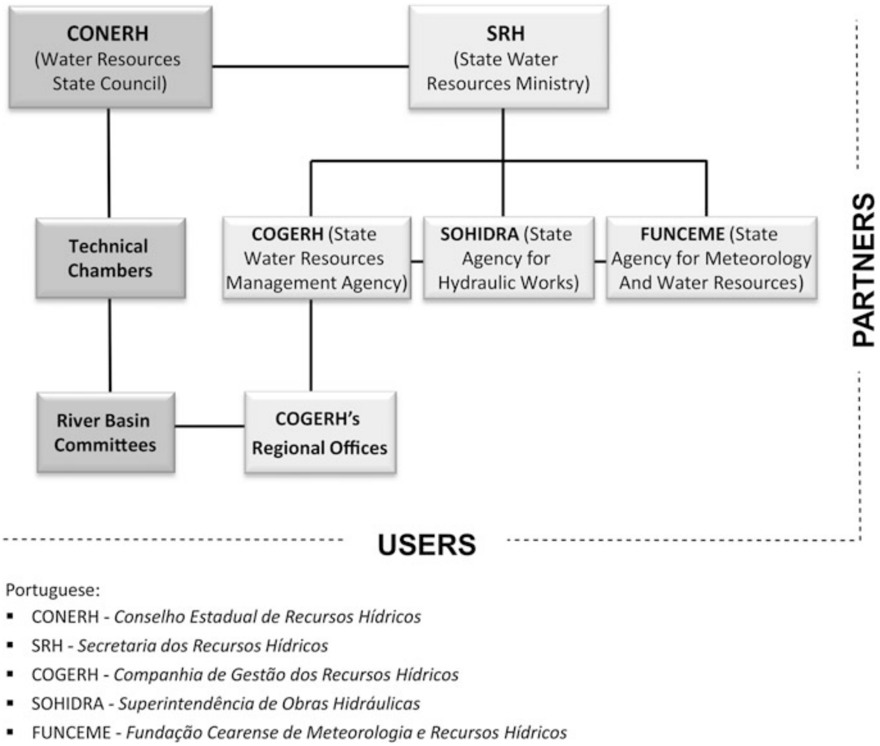

Fig. 10.9 Water resources management system of the state of Ceará. *Source* SRH-CE (2017a)

Superintendent of Hydraulic Works (*Superintendência de Obras Hidráulicas*—SOHIDRA). Municipalities have certain authority and prerogatives regarding water supply and sanitation, and exercise control over land use and occupation. Collegiate bodies—the Water Resources State Council (*Conselho de Recursos Hídricos do Ceará*—CONERH) and river basin committees—bring together users and civil society and are responsible for the negotiated allocation of water.

10.4.3 The Great Drought of 2012–17

Since 2010, Ceará and the North-East Region in general have experienced irregular rainfall. The year 2010 was dry, but the reservoirs were full thanks to the previous two rainy years, so water supply was not yet a problem. The rainy season in 2011 was wetter than average; although no water was accumulated, agricultural production was abundant. Consequently, people were able to subsist on their activities. However, from 2012 to the present, the region has faced multiannual droughts. FUNCEME studies indicate that the four years following 2012 were among the ten driest years since 1950 (SRH-CE 2017b). Experts say that the current drought is probably the most severe in the last 50–100 years.

10.4.3.1 Impacts on Water Storage

An indication of the severity of the water crisis caused by this drought is the variation of equivalent water storage capacity of the 153 strategic reservoirs managed by COGERH, whose total capacity is 18.64 billion m^3. In October 2012, the reserved volumes occupied 56.5% of that capacity, but gradually decreased over the subsequent years to 9.1% in October 2016. In December 2016, 39 dams were empty, and 42 of the 153 monitored dams had reached the dead storage level (SRH-CE 2017b).

During this water crisis, the hardest-hit sector has been irrigated agriculture, which is the most intensive water user in the state of Ceará. Water supply was reduced first and foremost for the main irrigated perimeters, especially those depending on perennial rivers. Total annual outflows fell from 22.95 m^3/s in 2012 to 3.68 m^3/s in 2016, an 84% reduction in water supply to the sector's main users (SRH-CE 2017b).

10.4.3.2 Water Security Strategies During the Crisis

The diversity of contingency initiatives deployed to cope with the water crisis and the management measures to ensure medium- and long-term water security once again singled out Ceará for its outstanding performance nationwide. The initiatives demonstrated technical creativity and political and institutional capacity in confronting and coping with the droughts. They include the strategic expansion of water infrastructure, planning and management measures, and emergency action for water security during particular crisis moments. Considering the severity of the ongoing water crisis, new initiatives are being assessed and studied, such as diversifying supply sources through water reuse and demand management. Constructing more bulk water infrastructure, such as large dams, does not appear viable and may already have been pursued in excess. In light of the irregular rainfall, which is variable both temporally and spatially, emphasis is currently placed on integration between basins to increase redundancy and fill water voids.

There are currently 12 transfer structures covering 426 km. The Worker's Channel is a 100 km water transfer structure that was built in 1994 (in four months) and was fundamental in averting the collapse of the FMR. The Eixão das Águas, a channel of 256 km (divided into five sections), was completed in 2012. It can transport up to 22 m^3/s and is now the main supply infrastructure for Fortaleza. The Ceará Water Belt, currently under construction, is a multi-section system of channels that is about 1300 km long and will receive the waters of the São Francisco interbasin water transfer. Figure 10.10 summarises Ceará's strategic water infrastructure.

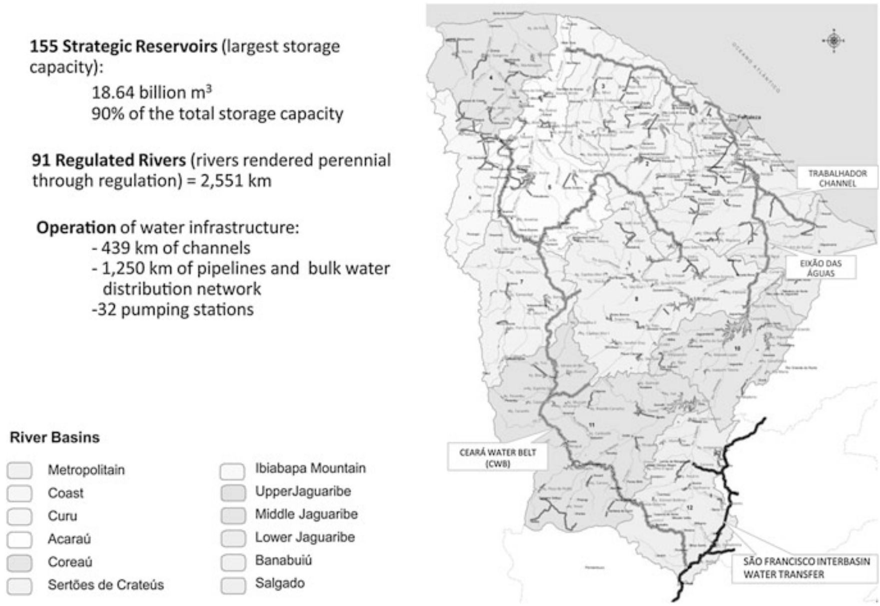

Fig. 10.10 Strategic water infrastructure of Ceará State: Worker's Channel (1993), Integration Channel (2012), São Francisco River Transfer Project integration (scheduled for 2018), and Ceará Water Belt (under construction). *Source* SRH-CE (2017a)

10.4.4 Drought Management Strategies

Planning and management measures are primordial for structural and emergency strategies aimed at coping with drought. In this context, the SRH identified several principal measures (Fig. 10.11). Of these, we can highlight the following.

10.4.4.1 Negotiated Water Allocation

Initiated in 1994, this is a participative solution in which a hydrological system's waters (perennial valley or reservoir) are allocated by management committees (constituted of water users) based on allocation parameters previously defined by the basin committees with the assistance of COGERH. The volumes of water from the reservoirs that will be available to users throughout the year (and the associated risks) are negotiated. The decisions are endorsed by COGERH, which operates the reservoir system and verifies water uses according to the stakes defined in the participative decision-making process. It is an innovative process of water management practice in Brazil and is considered a good strategy to cope with drought

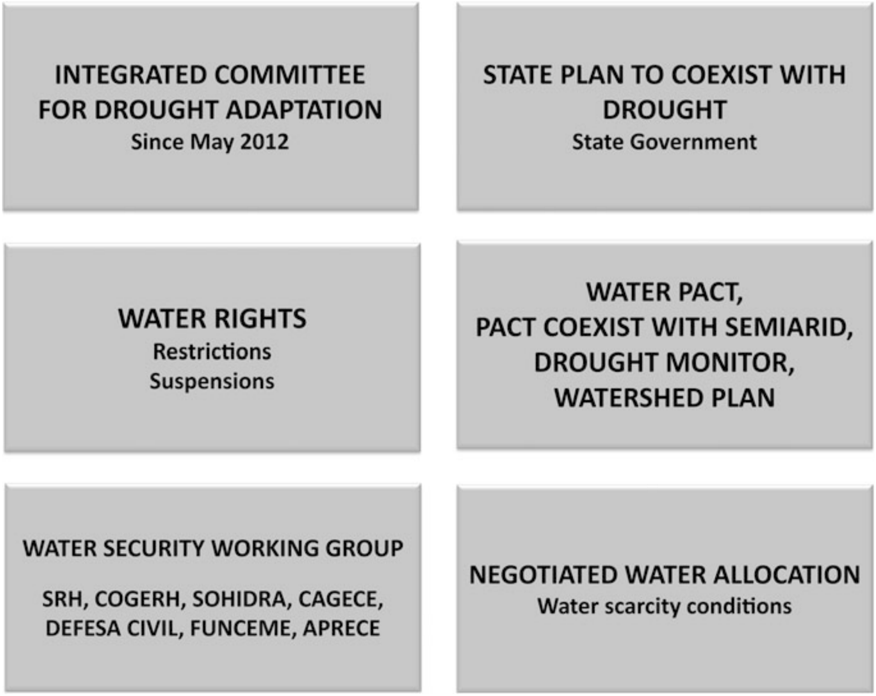

Fig. 10.11 Main planning and management measures related to drought. *Source* SRH-CE (2017b)

and to democratise access to water (Garjulli et al. 2003; Formiga-Johnsson and Kemper 2005).

10.4.4.2 State Water Security Working Group

Created in 2015, the Water Security Working Group is a governmental contingency committee that, on a weekly basis, brings together the state institutions directly involved in deploying emergency measures designed to cope with the severe and prolonged drought in Ceará (SRH, COGERH, SOHIDRA, FUNCEME, Civil Defence, and CAGECE). In these meetings, the committee discusses and plans measures mainly aimed at securing water supply in all municipalities of the state of Ceará during the persistent multiyear drought. The meetings are led by the head of the governor's office and the SRH.

10.4.4.3 Integrated Committee for Drought Adaptation

This is a contingency collegiate body of broader composition. Created in 2012, it is composed of institutions from Ceará as well as federal agencies that operate in Ceará, such as the Ministry of National Integration (*Ministério da Integração*

Nacional—MI) and DNOCS, in addition to civil society organisations. Using a participatory approach, this committee discusses the use of water resources in rural areas to supply the FMR (CEARÁ 2016).

10.4.4.4 State Plan to Cope with Drought

Approved by the government of the state of Ceará in 2015, this plan provides emergency, structural, and complementary measures in five areas: water security, food security, social benefits, economic sustainability, and knowledge and innovation. Implementing the plan is essential to prevent the collapse of water supply in different regions of the state (CEARÁ 2016).

10.4.4.5 Water Security Plan of the Metropolitan Region of Fortaleza

This plan presented strategic measures to guarantee water supply between August 2016 and March 2017 to Fortaleza and other municipalities that are part of the metropolitan water system. Important measures to cope with the water crisis in Fortaleza, such as a contingency fee and the Programme to Reduce Water Losses, were detailed and presented in this document.

10.4.4.6 Emergency Measures

The emergency measures undertaken during this water crisis were impressively diverse. Some had never been attempted before, such as quick-build pipelines (*adutoras de montagem rápida*) and campaigns to promote the rational use of water. They included:

- Quick-build pipelines. These are steel pipes with quick coupling systems and lockable joints, self-anchored on the ground surface (avoiding trenching). They support high water pressure and can be installed along roads, from the point of water abstraction in reservoirs to the water treatment plants of municipalities, in a drought emergency. In 2015 and 2016, the state of Ceará installed 186 km of water mains to serve almost 310,000 people in seven municipalities (SRH-CE 2017b).
- Wells. This solution was significantly exploited during this prolonged drought. More than 3500 wells have been drilled since 2015 by several state institutions.
- Desalination plants. More than 300 have been built since 2015.
- Mobile water treatment stations with ultrafiltration technology from Israel to treat polluted waters (29 units).
- Excavations in riverbeds and dry dams.
- Reuse of backwash water in water treatment stations.

- Extracting groundwater from dunes outside the FMR.
- Operation Water Tanker (*operação carro-pipa*), a last resort for small and isolated communities, was executed by the Civil Defence of Ceará and the Brazilian Army.

10.4.4.7 Main Measures Taken by the Water and Sanitation Company (CAGECE)

CAGECE undertook several measures that led to water savings in the FMR (CAGECE 2017). The main measures were the application of a contingency fee to encourage the end consumer to save water (13.98% in March 2017), reducing losses (mainly leaks) in the amount of 232 L/s, and recirculating backwash water from the Gavião Water Treatment Station’s filters (217 L/s). Starting in December 2016, water extraction in the station was pressurised (transitioning away from gravity extraction), which allowed flow to be managed independently of the level of the Gavião dam. The FMR’s Water Security Plan details all of these measures, and several others.

10.4.5 Water Security Under Severe and Prolonged Drought

Thanks to the robustness of the Ceará State Water Resources Management System, which has been built over the last 25 years, a large proportion of impacts from the persistent multiannual drought have been minimised. Notably, water supply for the FMR was ensured, and the collapse of many rural cities was prevented. Severe droughts in Ceará, like the current one, have historically led to the deaths of many people and animals, as well as to exoduses of rural and small-town dwellers to urban centres. None of these phenomena has been reported to date, although severe impacts have nevertheless been felt, especially by the suffering agriculture sector, as mentioned previously.

The emergency is being handled in a very innovative way at the same time as there have been advances in management. Once the ongoing drought has been overcome, reflections must be made in the future to further improve water resources management and to evaluate more effective practices to cope with drought. The ‘multiple use–urban use’ and especially the ‘metropolis–Jaguaribe basin’ relationships must be reviewed, with the direct involvement of all stakeholders through river basin committees in both hydrographic regions (Metropolitan and Jaguaribe). Above all, there is still a long way to go in terms of additional measures beyond water infrastructure, such as demand management, wastewater reuse, and water source protection.

10.5 From Drought to Water Security: Lessons Learned from the São Paulo and Fortaleza Metropolitan Regions

The water crisis of 2014–15 in the SPMR and the ongoing crisis in Greater Fortaleza (2012–17) provide relevant lessons for the different scenarios in which several social actors (institutions and individuals) operated. From the authors' perspective, the following lessons can be learned from these droughts in terms of water security.

Governance for drought management should be expanded. Drought is a socio-natural phenomenon. Managing its effects requires action with attention to several considerations: public opinion, political-institutional, legal, and technical. Relevant measures in this respect aim to mitigate conflicts and establish sustainable decision-making from the technical, social, political, and institutional points of view.

Allocation rules and rationing levels should be decided under the 'veil of ignorance'. Social actors should express their positions before the drought. This helps mitigate conflicts.

Public participation is the guarantee of legitimacy and social integration. The institutional framework and rules of social participation during the crisis may not constitute a sustainable strategy. Arbitration of conflicts during a crisis without predefined rules can be extremely challenging.

Water resources systems are complex socio-natural systems; they incorporate social, economic, political, climatic, ecosystem, and engineering dimensions. Drought management in these systems requires diverse expertise when designing sustainable solutions. The decision-making process should be supported by legitimate, relevant, and consistent information.

Water resources systems should preferably be analyzed as a whole, the whole being greater than the sum of the parts. The synergetic gains of the system must be recognised by all social actors. Modelling must be performed to analyze the system. The world has an increasing number of uncertainties linked to changes in urban and rural land use, climate, and people's habits and preferences. These uncertainties must be analyzed in order to design more robust and resilient systems.

The operational management of droughts requires agile and continuous decision-making processes. Response time to contextual changes is a decisive variable for the quality of drought mitigation response.

The technical quality of the organisations managing and operating the sophisticated supply system is a decisive factor for drought management.

Drought vulnerabilities of water systems can be mitigated by relatively small interventions in hydraulic structures—for example, adjustment of water intake structures to ensure an adequate submergence level for pumps. These actions can significantly facilitate the operation of hydrosystems.

Drought management measures should incorporate supply management, demand management, and conflict management. Operational flexibility in the system is the golden rule for supply management (for example, ranges of pressure variation and sectorisation of the supply network; redundancy from different sources of supply). Economic incentives that consider willingness to pay (tariffs) or willingness to receive (e.g. tariff bonus) should be analyzed as demand management strategies together with other behavioral-change tactics. The legal-institutional framework for conflict management during drought must be prepared with a view to mitigating conflicts.

Drought management consists of risk management in uncertain future scenarios. Ex ante actions may not be the best ex post, once the future is known. The Public Ministry plays an important role as prosecutor of the law. However, fragmented Public Ministry measures impose high costs for organisations as well as for the technicians who are personally responsible for systems management. Decisions need to be evaluated in the informational conditions in which they occur. This knowledge asymmetry leads to insecurity for the decision-maker, which is accentuated by the possibility of punishment, ultimately, for not being able to predict the future. The establishment of a strategy to enable the continuous and centralised monitoring of the decision-making process by the control agencies—especially by the Public Ministry—could be useful to facilitate a more adequate environment for this process. Institutionally centralising issues of a specific character and of general scope in society enables greater contextualisation and expertise in the responsible authorities. This would reduce the economic and personal costs arising from the legalisation of drought management.

Drought monitoring is essential to identify droughts' beginning, severity, and end. Early warning is of great importance to mitigate the impacts of droughts. São Paulo has a significant hydrometeorological and fluviometric measurement network, but no drought monitoring. As the water crisis unfolded, the drought's evolution was empirically evaluated. The development of a Drought Monitor should be considered.

A proactive drought management plan is needed. It is essential to identify the necessary measures, in advance, for each stage of the drought and to define threshold conditions for those measures to be implemented. Some options become unavailable as a drought increases in intensity. Costs can significantly increase owing to the urgency required to deploy programmed measures in the heat of the crisis. A proactive drought management plan, supported by an early-warning system, can reduce the impacts of drought.

Water resources systems are designed to provide a guaranteed supply. The risk of shortage is defined by the probability that the event will be exceeded. Usually, the reference used is guaranteed supply 90% of the time, with a 10% probability of failure. But this way of defining hydrological risk does not explicitly consider damage. Some extremely critical systems, such as human supply systems, need to be assessed for the lowest probability of failure. Reducing the probability of failure imposes higher deployment and operating costs for water resources systems. The definition of permissible risk is a fundamental criterion for projects that promote water security and must be established in a way that ensures social legitimacy.

The water management process must provide institutional space to arbitrate political disputes concerning regional interests and different worldviews. The Integrated System for Water Resources Management (SIGERH), with the support of the Water Law, allows such mediation spaces to be developed. The system may thus be improved in the spirit of promoting and consolidating arbitration and defining arenas with clear and predictable rules.

Institutions should be transparent and provide access to information, which reduces media opportunism by social actors who seek recognition and social space through the production of communication noise and misinformation. A communication plan that informs the public is of great relevance to the system. This assertion does not ignore the fact that multiple interpretations of the natural and social events which occur during a drought are possible. These interpretations have their legitimacy in the multiplicity of worldviews and analytical perspectives of a complex society that is inherent in democracies. However, these opinions and views should be expressed and discussed in spaces for public participation coordinated by SIGERH.

Water supply and sanitation companies play a central role in drought management in an urban environment. During a crisis, the amount of water distributed and consequently billed by the companies is significantly reduced. This can reduce the company's financial sustainability. Ensuring sustainability through a significant tariff increase may not be the best strategy. Drought planning should consider financial mechanisms that reduce this impact on the company and the public.

The role of the water concession should be analyzed as either an administrative instrument or to define profile uses and induce public policies more broadly. This is not a trivial analysis, as it requires the role of water policy to be identified either as a sector policy or as a space for coordinating several public policies. Moreover, the roles of agencies and management organisations, not only in the water sector but also in related sectors, must be determined.

Water conservation habits should be encouraged, reinforcing the culture of water conservation fostered by the period of scarcity. This is a system with hysteresis. The social fabric was deformed under the circumstances of drought, and when those circumstances were no longer present, the public did not return to their initial condition. This can be understood as a positive externality from an environmental and water security point of view. The temptation to return to previous levels of consumption, which are less conservative habits, must be tackled.

Drought management should take place in different domains (technical, political, public opinion, legal). Drought management requires technical expertise to deal with inherent complexity and uncertainty, institutional mechanisms for conflict arbitration, supply management in favor of efficiency, and efficient and equitable demand management. To this end, the establishment of a governance framework for drought management in the water sector is required. Monitoring and early-warning systems, in association with proactive drought management plans, are essential tools to build such a governance framework.

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Chapter 11
California: Water Security from Infrastructure, Institutions, and the Global Economy

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Abstract California's water system has immense seasonal, annual, and geographic variability in hydrology and water demands and tremendous historical growth in population and dynamism in economic structure. Although California's situation would normally make it highly vulnerable to water shortages and floods, California has adapted effectively. An extensive set of semi-autonomous local, regional, and statewide water management institutions supports extensive and diverse water management infrastructure and operations. These diverse facilities and institutions are coordinated by an extensive web of regulations, water rights, contracts, and incentives, despite continuing challenges. The resulting institutional and physical system has always suffered from the semi-aridity and variability of California's climate, and is continuously challenged by long-term growth in population and shifts in economic structure and social objectives. However, the political decentralisation of the system has brought steady local innovation, with larger episodic regional and statewide innovations accompanying the additional attention and focus brought by extreme events. The high variability of California's climate also provides frequent political motivation for large- and small-scale innovations in water management. The result is a form of far-sighted incrementalism, driven by continuing problems and providing an unusual degree of water security for most of the state, though not all.

11.1 Introduction

Effective water management is a foundation for public health, economic prosperity, and political stability. Civilisations have risen and fallen with their ability to manage water. People are naturally concerned that the management of water

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supports their overall security. Water and other aspects of security are fundamentally important, so much so that some small level of water anxiety and perceived threat is useful for sustaining attention and resources for the operation and maintenance of such fundamental systems.

Although effective water management is essential for health and prosperity, it may be that prosperous societies manage water effectively because these societies function well generally. Without this general effectiveness and organisation any water system will soon break down due to accumulating operation and maintenance problems.

Water management usually reflects the prosperity and the problems of a society, and is also a cause of prosperity and problems. Effective water management is necessary for a society's success, but not sufficient.

California has one of the world's largest and most prosperous economies, with a sizable population and tremendous agricultural production. It is prosperous despite being in a semi-arid region with one of the world's most hydrologically variable climates. Fundamental to California's successes has been the development of water management infrastructure and institutions.

This chapter reviews California's water development, the reasons for this development, its successes and failures, contemporary challenges, and future prospects. Overall, California still faces great challenges regarding water, as it always has. The prospects for addressing these challenges are good so long as this diverse state and its highly decentralised governance remain focused and organised to address the ever-present and ever-changing weaknesses of the system.

11.2 California's Water System

California has immense variability in its hydrology and water demands. Figure 11.1 shows average annual runoff, with two-thirds coming from 20% of the state's surface area and 90% coming from 40% of the surface area. At the other extreme, the driest 30% of the state provides only 0.1% of the annual runoff. This geographic variability in water supply is accentuated by California's Mediterranean climate, with a very long summer dry season, from late April until November, and a shorter wetter season. Human water demands for these resources are substantially mismatched to this pattern of water availability, with most agriculture and cities being in the drier parts of the state and using the most water during the long dry season (Hanak et al. 2011).

This mismatch is exacerbated by the state's unusually large annual variability in precipitation. Of the entire United States, precipitation in California has the greatest annual coefficient of variation (Dettinger et al. 2011). Effectively, California has the most extreme dry and wet years per average year of any part of the United States.

California's long, flat Central Valley has allowed the gathering of water from most major rivers and the construction of major canals from wetter areas to drier parts of the state. This strategy has addressed much of the geographic mismatch between water availability and demand in California.

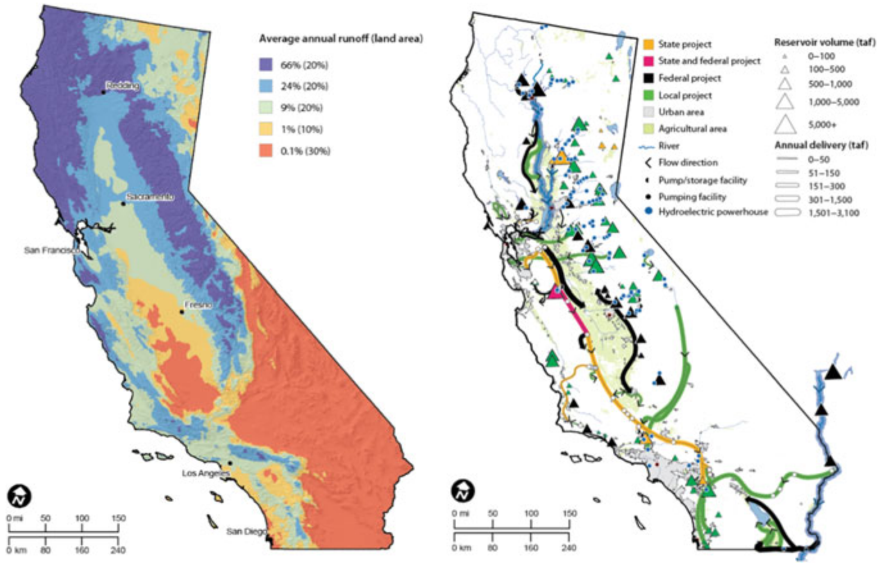

Fig. 11.1 Water availability and major water management infrastructure in California. *Source* Hanak et al. (2011)

California's mountainous terrain and extensive sedimentary geology have also provided unusual geologic opportunities for substantial surface water storage, significant hydropower production, and immense aquifer storage. These storage features have helped address California's seasonal and interannual water variability, allowing both water and hydroelectric energy to be stored in the wet season for use in the dry season, and enabling substantial water storage for droughts.

The development and operation of this extensive infrastructure, serving the entire state, have been substantially decentralised, with some centralised elements, but involving thousands of local, regional, state, and federal agencies. Almost all local and regional water agencies in California are governed by boards that are locally elected or that are appointed by locally elected officials. This locally empowered system brings extraordinary local accountability as well as local water utility funding for these districts to engage in larger statewide and regional system management and policymaking. The coordination of this often-confusing set of institutions rivals the physical marvels of California's water infrastructure.

11.3 Policy Change and Time

California's water management system is constantly evolving. Historically, it has changed tremendously, and will continue to do so into the future. Figure 11.2 summarises the history of this water system and the eras of local, regional, and statewide infrastructure, legal, and policy development.

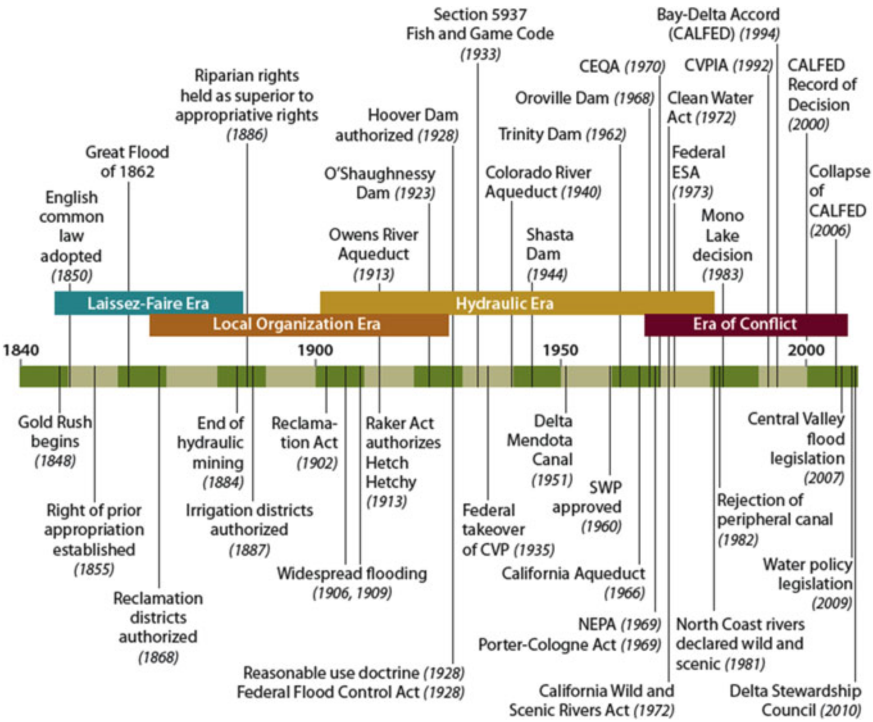

Fig. 11.2 Historical eras of water management in California. *Source* Hanak et al. (2011)

Water management in California began as extremely decentralised actions by individual landowners and businesses, and maintains much of that character to this day. Additional local organisation became necessary to address local flood control problems with local levees and for the construction of local irrigation and drainage ditch and diversion systems. In some cases this infrastructure was developed by local private interests, such as irrigation companies developing land to sell off to farmers, or mutual water districts formed by local farmers. In other cases infrastructure was developed increasingly by local special units of government, with locally elected governance, such as irrigation and levee districts (Kelley 1989; Pisani 1984).

As local resources became inadequate to support local water supply or protect areas from larger floods, larger, more regional agencies, organisation, and arrangements were sought and implemented. This resulted in several regional projects, initially begun by cities, such as the Los Angeles Aqueduct (1913) and San Francisco's Hetch Hetchy water supply (1928), followed by consortia of local agencies combining to form regional agencies to import water, such as Oakland's Mokelumne Aqueduct and the Metropolitan Water District of Southern California's Colorado River Aqueduct in the late 1920s and the 1930s. As these sources became inadequate for economic and population growth, statewide water projects emerged, such as the federal Central Valley Project and the State Water Project, as well as additional regional projects, including several US Army Corps of Engineers dams serving the Tulare Basin region from the 1940s until about 1980.

Regionalisation of flood management began a bit earlier in California's Sacramento Valley, with local levee districts being given new roles within a regional state and federal flood control project in the early 1900s, as competing local levee districts were overwhelmed in handling large regional floods (Kelley 1989). This regional project followed decades of local-agency levee development and competition among levee districts for flood protection. The current Sacramento flood bypass system overcame most local levee competition by diverting most floodwater away from the main-stem river system. Today, local districts perform most levee maintenance in the regional system, with some funding and inspections by state and federal authorities.

11.3.1 Droughts and Floods Precipitate Innovation

Droughts and floods have been instrumental in driving strategic changes in water management at all levels of government, but particularly at regional and state levels. The history of drought-driven innovations is summarised in Table 11.1. Each

Table 11.1 Historical droughts in California, their impacts, innovations, and leading innovators (after Lund 2014)

Date	Impacts	Innovations	Leading innovators
1800s	Herds and crops devastated	Local irrigation, 1873 Federal Central Valley study	Local, private
1924	Crop devastation	Local reservoir projects, major water project plans (regional/state)	Local, public and private diversions
1928–1932	Delta salinity, crop losses	Major dam and canal project plans, statewide scale	Regional and statewide dams and canals
1976–1977	Major urban and agricultural shortages	Urban conservation, early markets	Local urban conservation, trades
1988–1992	Urban and agricultural shortages, endangered fish	Interties, conjunctive use, markets, conservation, regions	Interties, conjunctive use, water markets, new storage (regional, local)
2007–2009	Shortages of agricultural and fish supplies	New requirements for reporting water use, new delta planning institutions, urban water conservation mandates	More data collection, new delta planning institutions, urban water conservation mandates
2012–2016	Warm drought, little delta water, major agricultural shortages, damage to fish and forests	Groundwater sustainability legislation, delta barrier, more water use reporting	Groundwater (local region w/state), state urban conservation mandates

drought has been hydrologically distinct, with a different geographic pattern, duration, and intensity; the most recent drought also brought much higher temperatures (Hanak et al. 2015). Each drought in California also has encountered a substantially different economy, water demands, water management infrastructure and institutions, and social organisation.

Droughts in the 1800s directly impacted an economy that substantially relied on rainfed agriculture and roaming cattle, which supported trade in hides. The economic limitations of these water supplies became clear with California's long dry seasons and frequent droughts, and farmers sought to develop local irrigation systems, mostly depending on local rivers. By the early 1900s, increased capability and comfort with dam construction led to major water storage and regional and interregional water canal projects being planned in response to droughts. The deep and prolonged drought of 1928–1932 led to more serious water project plans, at local, regional, and statewide scales. Many of these dams were in fact constructed between 1940 and 1980, particularly the federal Central Valley Project and the State Water Project.

The 1976–1977 drought lasted only two years, but included the driest year on record. It occurred at a time of sustained population and economic growth, and good use was made of much of the capacity produced in the era of major water project development. Yet, these projects were unable to supply the San Francisco Bay Area and many farmers with water throughout this drought. Deep (up to 40%), widespread urban water conservation was required for the first time, plus emergency interties, water market transactions, and other actions. Tremendous amounts of water conservation were quickly achieved, and with disproportionately small economic losses (Department of Water Resources 1978). Following this drought, all major urban water utilities developed significant water demand management programmes, and use and development of water market trades increased. This drought marked a change in emphasis from infrastructure construction to supply and demand management in California, as the most economical reservoirs had already been built.

The 1988–1992 drought brought renewed attention to water supply operations, markets, and water conservation. The drought also brought several species to the point of collapse and their designation as threatened or endangered. The drought led to extensive expansion of urban water conservation, water market contracts and activities, conjunctive use of surface and groundwater, several new surface water reservoirs, and new local system interties, which added great flexibility and capacity to the system.

The 2007–2009 drought was moderate and not long, but coincided with another major decline in native fish species, which brought additional restrictions on pumping from California's Sacramento–San Joaquin Delta. The combined drought and loss of flexibility caused substantial agricultural losses in some areas. However, cities and most agriculture, while stressed, did rather well.

The 2012–2016 drought was deep, prolonged, and unusually warm, perhaps a harbinger of future droughts. Major water shortages were experienced by agriculture, ecosystems, and cities. However, cities, with a few exceptions, avoided emergency conditions thanks to interties, water stored in aquifers and reservoirs, water market agreements, and long-term water conservation. Agriculture experienced only modest losses, thanks to the availability of groundwater and strong global commodity prices. The environment fared variably. Many forests were devastated by the long, deeply dry, and warm conditions, which more quickly depleted soil moisture and snowpack, resulting in the death of more than 100 million trees. Native fish also suffered declines in already-weakened populations. However, waterfowl suffered much less, thanks to some well-timed winter storms and to effective organised actions by a mix of private, state, federal, and non-governmental agencies to provide sufficient habitat for bird migrations throughout the drought. This most recent drought will lead to many long-term innovations, among which groundwater management by a mix of local and regional agencies under state supervision is likely to be the most transformative.

California's history of floods has left a similar trail of innovations and improvements, which have made management of subsequent extreme events easier and less damaging (Kelley 1989).

11.3.2 Portfolio Management

A major evolving innovation in water management is the development of a "portfolio" management approach. This consists of integrating a wide range of water supply and demand management options, along with actions that help the diverse entities involved work effectively together. A summary of the portfolio of actions available for water supply appears in Table 11.2. Similar ranges of actions are available for flood management (Lund 2012), water quality, and environmental management. The development of a portfolio of actions for water management provides many opportunities to reduce costs, balance and integrate water use across wet and dry years, and effectively integrate a wide range of beneficiaries and institutions, to their mutual benefit.

This diverse range of potential supply and demand actions, particularly when implemented across a range of geographic conditions with diverse infrastructure and water demands, has supported an increasingly robust water management system in California. This system has shown that it can substantially withstand major flood and drought years while still growing much more in economic terms. The portfolio approach, when implemented across water agencies at regional and larger scales with contracts and other agreements, has also provided incentives for tremendous cooperation among water agencies, and greatly dampened debilitating water conflicts. California now has numerous examples of urban water agencies paying agricultural areas for water conservation (with water savings sold to cities) and paying irrigation districts to store water banked in wet years for use in drier years. Some of this banked water, stored under agricultural areas, is made available by additional urban water conservation (Hanak et al. 2011).

Table 11.2 Portfolio of water management actions applied at local, regional, and statewide scales (after Hanak et al. 2011)

Water supply	
Water source availability	*Treatment*
Capture of fog, precipitation, streams, groundwater, wastewater	Existing water and wastewater treatment
Protection of source water quality	New water and wastewater treatment
Conveyance capacities	Wastewater reuse
Canals, pipelines, aquifers, tankers (sea or land), bottles, etc.	Ocean desalination
	Contaminated aquifers
Storage capacities	*Operations*
Surface reservoirs, aquifers and recharge, tanks, snowpack, etc.	Reoperation of storage and conveyance
	Conjunctive use
Water demands and allocation	
Agricultural use efficiencies and reductions	Ecosystem demand management
Urban water use efficiencies and reductions	Recreation water use efficiencies
Incentives for water managers to work well together	
Pricing	Subsidies, taxes
Markets	Education
"Norming," shaming	Mutually beneficial contracts

11.4 Relative Effectiveness

Compared to other developed and developing arid and semi-arid places with Mediterranean climates, California has been relatively successful in balancing economic, food production, and ecosystem goals (Table 11.3). With only 5% of wetlands remaining (compared to the 1800s), and most fish passages blocked by dams and other water supply and flood protection infrastructure, recent droughts have not dampened water supply restrictions to protect fish habitat. Ecosystems remain one of the most vulnerable sectors in securing water during dry periods, and they continue to decline. California as a whole does relatively well, but many areas remain in need of substantial improvement.

11.5 Ongoing Water Security Issues

California will always have serious water problems. The most serious water problems have varied historically with weather, economic, infrastructure, policy, and environmental conditions. Today, California's most serious water management weaknesses, and sources of insecurity and anxiety, are in several areas.

Table 11.3 Comparison of population, wealth, food production, and native aquatic ecosystems in global mediterranean climates

Country/state	Population (millions)	Wealth (GDP PPP/person) ($)	Food production ($ billion)	Native freshwater aquatic ecosytem condition
California	39	62,000	45	Struggling, much diminished
Algeria	39	13,000	8	Largely eliminated
Australia	24	68,000	25	Substantially eliminated
Chile	18	22,500	8	Substantially eliminated
Greece	11	26,000	6	Largely eliminated
Israel	8	36,000	3	Largely eliminated
Italy	61	35,600	29	Largely eliminated
Morocco	33	7000	9	Largely eliminated
S. Africa	54	12,500	13	Struggling, much diminished
Spain	46	43,000	32	Largely eliminated

Source Lund (2016)

We summarise the most salient aspects of water security for some of California's major water-use sectors.

- Urban areas have proven to be mostly well prepared for water extremes and the future. Urban water agencies are mostly well organised, accountable, reasonably well funded, and autonomous enough to address local and sometimes regional problems effectively. Improvements are still needed, but prospects are excellent for maintaining future prosperity if systems continue to be managed responsibly.
- Agriculture is diverse in California; in most areas it has become quite prosperous and remains robust. Some exceptions exist, particularly in the San Joaquin Valley, where groundwater overdraft will now be ending with new regulations, and major imported water supplies from the Sacramento–San Joaquin Delta are in jeopardy. Statewide, perhaps 10–15% of irrigated agricultural lands will be fallowed; these will come out of the least productive and profitable and more saline lands, with therefore a proportionately smaller loss of economic value. Growth and concentration of value in statewide agriculture are likely, due to continued crop improvements and shifts to higher-valued export crops.
- Rural water supply is a major problem area. Although many rural areas have enough water, many suffer from nitrate (mostly from agriculture) and other forms of groundwater pollution, and groundwater tables are sinking in some areas. These problems are severe, but mostly localised in areas with low population density, limiting economies of scale and hampering organisation.
- Ecosystem management is perhaps California's deepest and most widespread water management problem. Ecosystem objectives generally have not benefitted

from many years of mistakes and improvements, lack steady adequate funding, and lack effective organisation of interests. Waterfowl interests are perhaps the most organised and effective groups, as is evident from their successes during the last drought. Forests and forest management systems have deteriorated significantly in recent decades, which exacerbated forest losses in the last drought. Native fish interests have also not been effective at organising solutions or support for their widespread implementation.

- Floods are another area which will always remain problematic in California, given its extensive settlements in floodplains and its high hydrologic variability. Flood management organisation suffered for decades, but has become better organised and funded with state bonds in recent years, resulting in significant physical improvements in the system. It remains to be seen whether this progress and recent successes will continue. Some significant infrastructure maintenance and rehabilitation issues remain.
- An area of continuous concern is also the Sacramento–San Joaquin Delta, which hosts a conundrum of conflicting water management objectives, including local and statewide water supply, flood protection, and habitat. This fragile element in the California water system challenges the water security of the thirsty agricultural and urban areas south and west of the Delta, which rely on it for water supply, as well as the ecosystems that rely on this highly altered habitat.

Several concerns transcend all these areas, though in varying degrees, mostly varying with the degree of organisation and preparation in each sector. These transcendent concerns include climate change and groundwater. Several studies show that even dramatic forms of climate change plus the end of groundwater overdraft need not fundamentally threaten California's statewide economy (Medellin-Azuara et al. 2011, 2015; Nelson et al. 2016). However, agriculture and the environment will suffer in some areas, even with good management, under unfavorable future climate conditions.

For the most part, water security should not be a major issue for a well-organised, prosperous region like California that is part of a global economy. California has always benefited from this condition, and its benefits have increased with global economic ties and improvements in the organisation of its water management. However, as a major dynamic economy with large agricultural water needs in a semi-arid Mediterranean climate, California will always have some water anxiety. Such anxiety can help California continue and improve on its successes in water management and help us better address its ever-present weaknesses in water management.

11.6 Drought Security and Globalisation

Globalised transportation, communication, and trade have greatly reduced the public health and economic impacts of drought in the growing number of regions connected to the global economy. Modern weather forecasts, evacuation

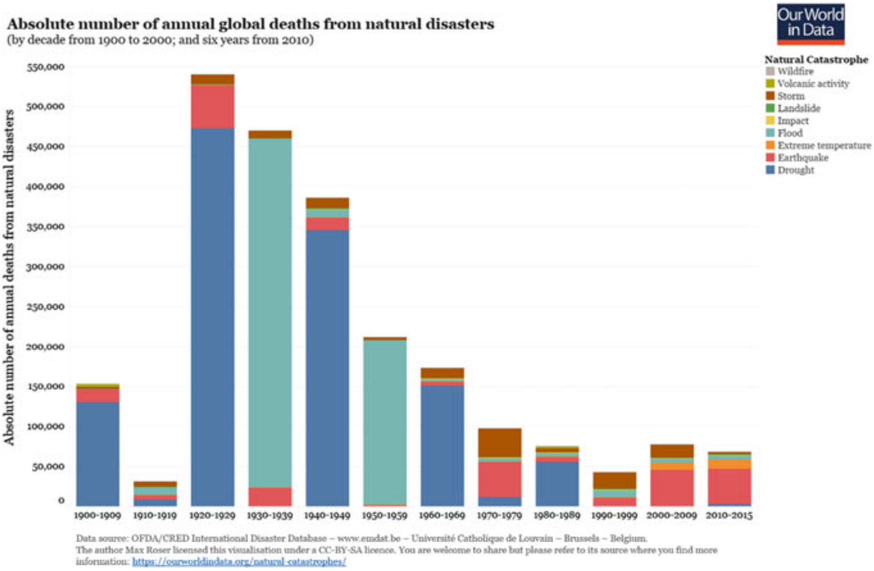

Fig. 11.3 Global reductions in fatalities from droughts and floods. *Source* Roser and Ritchie (2017)

communications, and transportation improvements have also greatly reduced flood deaths and property damage. Globally, both total and per capita deaths from water-related causes have diminished dramatically in recent decades (Fig. 11.3). Although local and regional water management improvements can greatly improve water security, it is remarkable how much economic globalisation and global weather forecasts and communications have improved regional water security. Most reductions in deaths due to drought are probably due to improvements in transportation and global food trade, and most reductions in deaths due to flooding are due to improved global and local weather forecasts, evacuations, and increasing attention to zoning.

11.7 Conclusions

Despite its semi-arid Mediterranean climate, California has managed to attain considerable water security to support public and economic health with a very dynamic economy through a combination of effective substantially decentralised organisation and extensive infrastructure.

The globalised nature of California's economy has contributed considerably to its water security by supporting overall economic prosperity and providing inexpensive substitute food supplies normally and during time of drought.

California's water security can be maintained on a statewide basis with good management of the portfolio of actions available and an otherwise strong economy, even with dire and enduring drought conditions (Harou et al. 2010). Indeed, fears of water insecurity in these situations often seem to be more like water anxiety.

The era of massive infrastructure development to support water security objectives is long gone in California. Innovations in storing and wheeling water using existing physical and institutional infrastructure will mostly satisfy the future water needs of agriculture, cities, and ecosystems. Updates adding flexibility to the system will continuously be implemented in this highly dynamic and diversified system.

Continued anxiety about water security, if well managed, can support effective operation and maintenance of water systems and continued improvements to help water systems adapt to changing conditions. Droughts and other extreme water conditions provide opportunities to turn general water anxiety into innovations useful for adapting water management to changing conditions.

The high variability of California's climate provides frequent political motivation for large- and small-scale innovations in water management. The result is a form of far-sighted incrementalism, driven by continuing problems and providing an unusual degree of water security for most of the state, though not all.

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