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WWF

Drought risk management

A strategic approach

Part of a series on strategic water management

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Published in 2016 by the United Nations Educational,
Scientific and Cultural Organization
7, place de Fontenoy, 75352 Paris 07 SP, France

ISBN 978-92-3-1000942

Website: www.unesco.org

Layout: Marie Moncet
Printed by UNESCO
Printed in Paris, France

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Citation

Sayers, P.B., Li Yuanyuan, Moncrieff, C, Li Jianqiang, Tickner, D., Xu Xiangyu, Speed, R., Li Aihua, Lei Gang, Qiu Bing, Wei Yu and Pegram G. (2016) *Drought risk management: A strategic approach.* Published by UNESCO, Paris on behalf of WWF.

Acknowledgements

This book is the result of the combined efforts of a number of contributors, all of whom have provided insights into international experience of drought management and the associated live issues and emerging trends. This work is a collective expression of this process.

This volume and its companion volumes were drafted as part of an extensive dialogue between a team of international experts led by WWF and the policy team at the General Institute of Water and Hydropower Planning (GIWP), in the Ministry of Water Resources of the People's Republic of China. The international team leader was **Paul Sayers** (United Kingdom). The team from GIWP was led by **Professor Li Yuanyuan** and **Professor Li Jianqiang**. In addition to those listed as co-authors, specific thanks goes to **Huw Pohlner** (University of Oxford, for providing an excellent contribution on reserve capacity); **Edoardo Borgomeo** (Environmental Change Institute, University of Oxford, for contributing to the discussion on risk); **Clare Wilkinson** (WWF, United Kingdom for her support on the extensive literature review); and the insightful regional case study contributions from **Lei Wen** (McGill University, Canada); **Guy Jobbins** (consultant, United Kingdom); **Suresh Babu** (WWF India); **Indira Khurana** (India); **Mario Mendiondo** (Brazil); and **Jose Tirado** (Mexico).

The advice and guidance provided by a number of reviewers is also gratefully acknowledged. In particular:

- **Dr Donald Wilhite** (Professor of Applied Climate Science in the School of Natural Resources at the University of Nebraska-Lincoln, US and the founding Director of the National Drought Mitigation Center in 1995)
- **Chris Lambert** (Senior Technical Adviser, Thames Water, England)
- **Eva Hernandez Herrero** (WWF-Spain)
- **Dr Guido Schmidt** (Water Adviser at Fresh Thoughts Consulting GmbH for Europe).

The following people have contributed to the layout, figures and final editorial of the book:

- **Kate Hodge from Hodge Environmental**, Australia for the system diagrams.
- **Justine Gannon**, from *proof etc* for providing an excellent copy edit.

Disclaimer

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ISBN: 978-92-3100094-2

EXECUTIVE SUMMARY

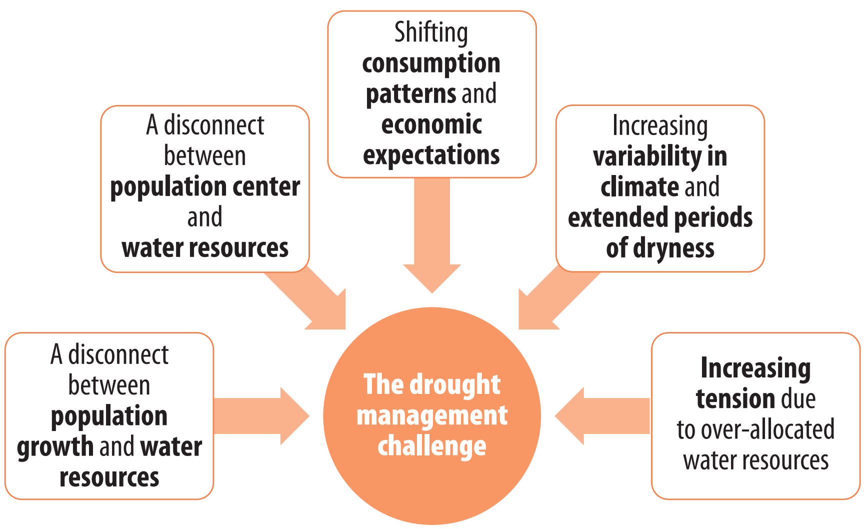
…the worst time to respond to a drought is in the midst of one. At that point, there are few, if any, good options available to avoid the worst impacts of drought, and combined with enflamed passions and politics, reaching consensus on solutions is nearly impossible. We need to start planning for future droughts so that we have more options available to us when the next drought hits and we are less likely to suffer significant economic or ecological harm.

The Nature Conservancy and others, open letter to US Senate, 5 October 2015

Introduction

As populations increase and incomes rise, patterns of consumption shift to a demand for products and services with greater water footprints. In the absence of improved management, water resources are increasingly likely to become a source of tension; a tension that will be at its highest during periods of drought (Figure A).

Figure A. Significant future challenges demand a change in approach



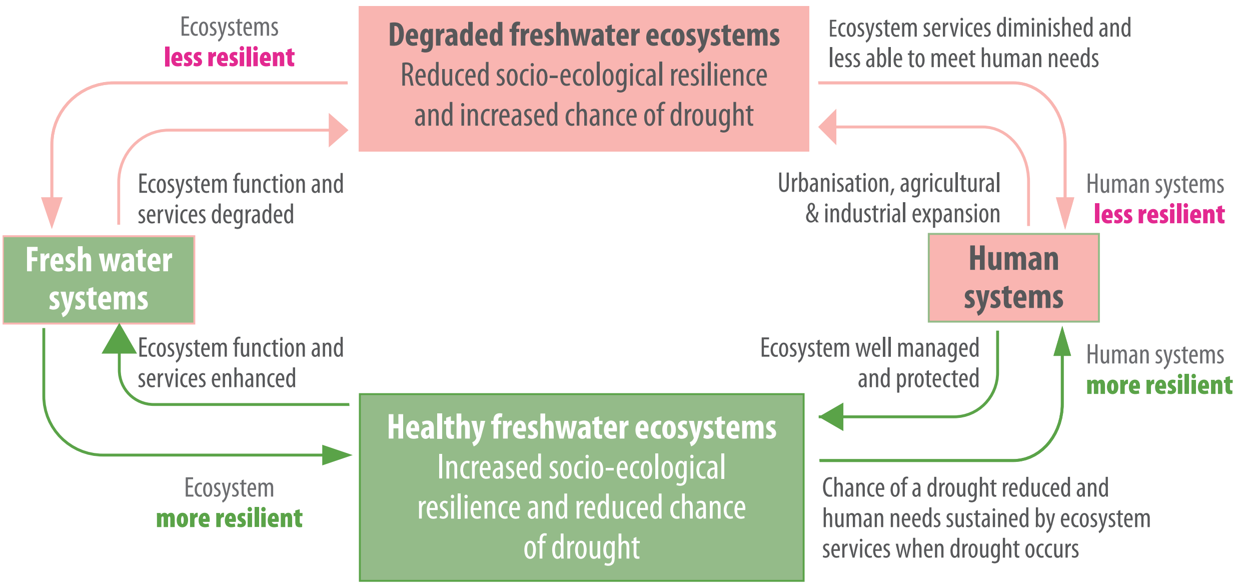
Current approaches

Why are current approaches inadequate?

The inadequacy of current drought management practice, as observed through the continued impacts of droughts, underpins a consensus that a transformational change in approach is required – away from an episodic process that **reacts** to an emergency to a continuous process that **proactively** manages risk. Although some progress has been made, the transition to a more strategic and risk-based approach to drought management is only in its infancy. There are a number of reasons for this slow progress including, for example:

- ambiguity in the terminology of 'drought' hampers communication and often conflates hazard and impact
- failure to recognize drought as an extreme event
- reliance on historical analogues
- failure to recognize the interdependencies between freshwater ecosystems and the well-being of human systems (as illustrated in Figure B).

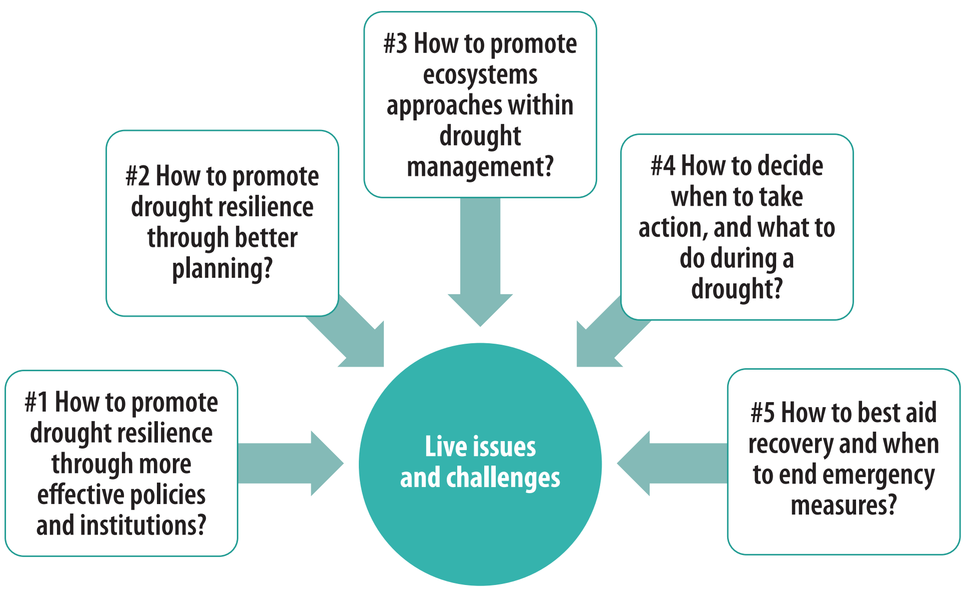
Figure B. Freshwater ecosystems and human systems are interdependent; failure to recognize this linkage undermines current efforts to manage droughts and their impacts



What are the issues and challenges to overcome?

Drought management practice has primarily evolved in response to drought events. It has also been influenced by advances in science and philosophy such as ecosystem-based approaches and adaptation planning, practices in other sectors such as integrated water resources management and disaster risk reduction. Yet no single blueprint for good drought management has emerged. There is, however, consensus over the challenges still faced by modern drought managers. The most important of these challenges are summarized in Figure C.

Figure C. Summary of issues and challenges facing international practice



Strategic Drought Risk Management

Droughts are always context specific and the response to drought needs to reflect specific circumstances. A common understanding of what constitutes 'sound' Strategic Drought Risk Management (SDRM), however, is now starting to emerge. In recent years, there has been a convergence on the concepts of risk that underpin the definition of SDRM:

Strategic Drought Risk Management (SDRM)

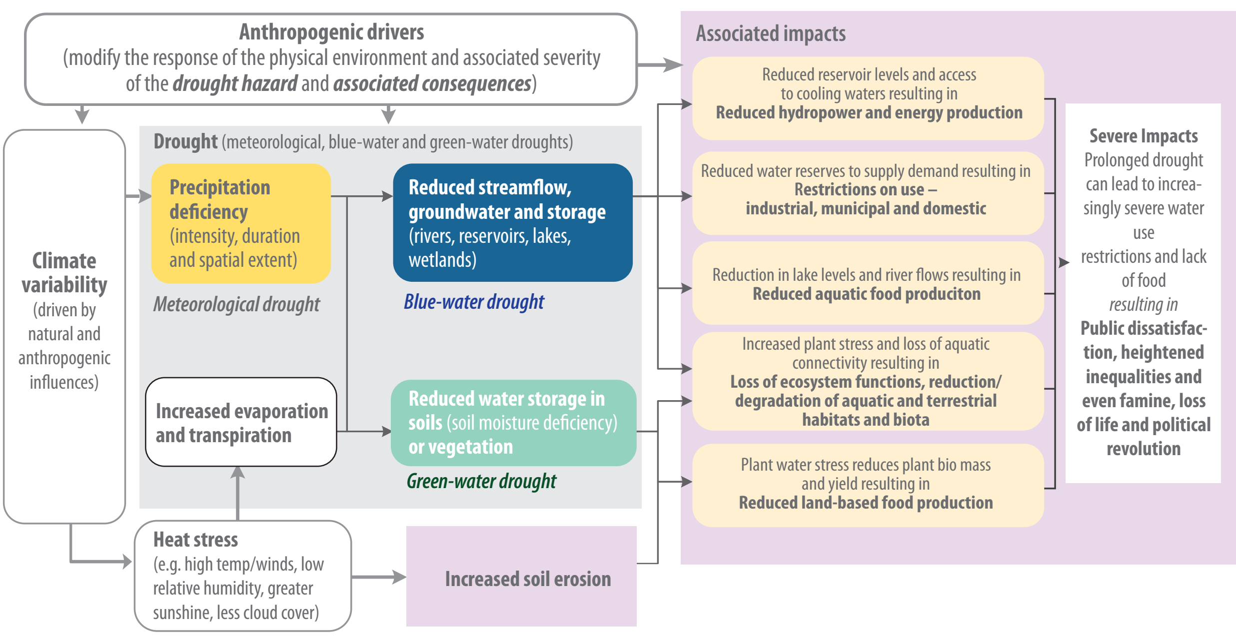
Strategic Drought Risk Management (SDRM) is the process of data and information gathering; risk analysis and evaluation; appraisal of options; and making, implementing, and reviewing decisions to reduce, control, accept, or redistribute drought risks. It is a continuous process of analysis, adjustment and adaptation of policies and actions to reduce drought risk, including modifying the probability of a drought and reducing the vulnerability and enhancing the resilience of the receptors threatened. SDRM forms part of the wider approach to water security and water-related basin planning and allocation activities. It focuses on delivering a drought-resilient society by reducing drought risks and promoting environmental, societal and economic opportunities now and in the longer term. It recognizes that risks can never be removed entirely and that reducing risk may be at the expense of other societal goals.

A modern definition of drought

The traditional classification of drought types has evolved primarily from the meteorological and hydrological sciences (meteorological and hydrological droughts) to reflecting agricultural and socio-economic impacts. Today, a myriad of drought types exist with few accepted definitions. This book proposes definitions that more explicitly distinguish different aspects of the 'hazard' (Figure D):

- A **meteorological drought** (hazard) is defined here as: a temporary, negative and severe deviation from the average precipitation values for a significant period of time across a river basin or region.
- A **blue-water drought** (hazard) is defined here as: an unusual and significant deficiency of groundwater, stream flow, or lake storage.
- A **green-water drought** (hazard) is defined here as: an unusual and significant deficiency in water stored in or on top of the soil or vegetation.
- **Drought risk** is defined here as: an emergent property of the human and natural system, reflecting the interaction between climate (meteorological drought), the hydrological response of the basin (blue-water drought and green-water drought) and the vulnerability of the people, ecosystems and economies exposed to it. Drought risk reflects two components: the chance that a drought hazard will occur and the magnitude of the associated impacts.'

Figure D. Classification of drought types and associated impacts



Role of Strategic Drought Risk Management

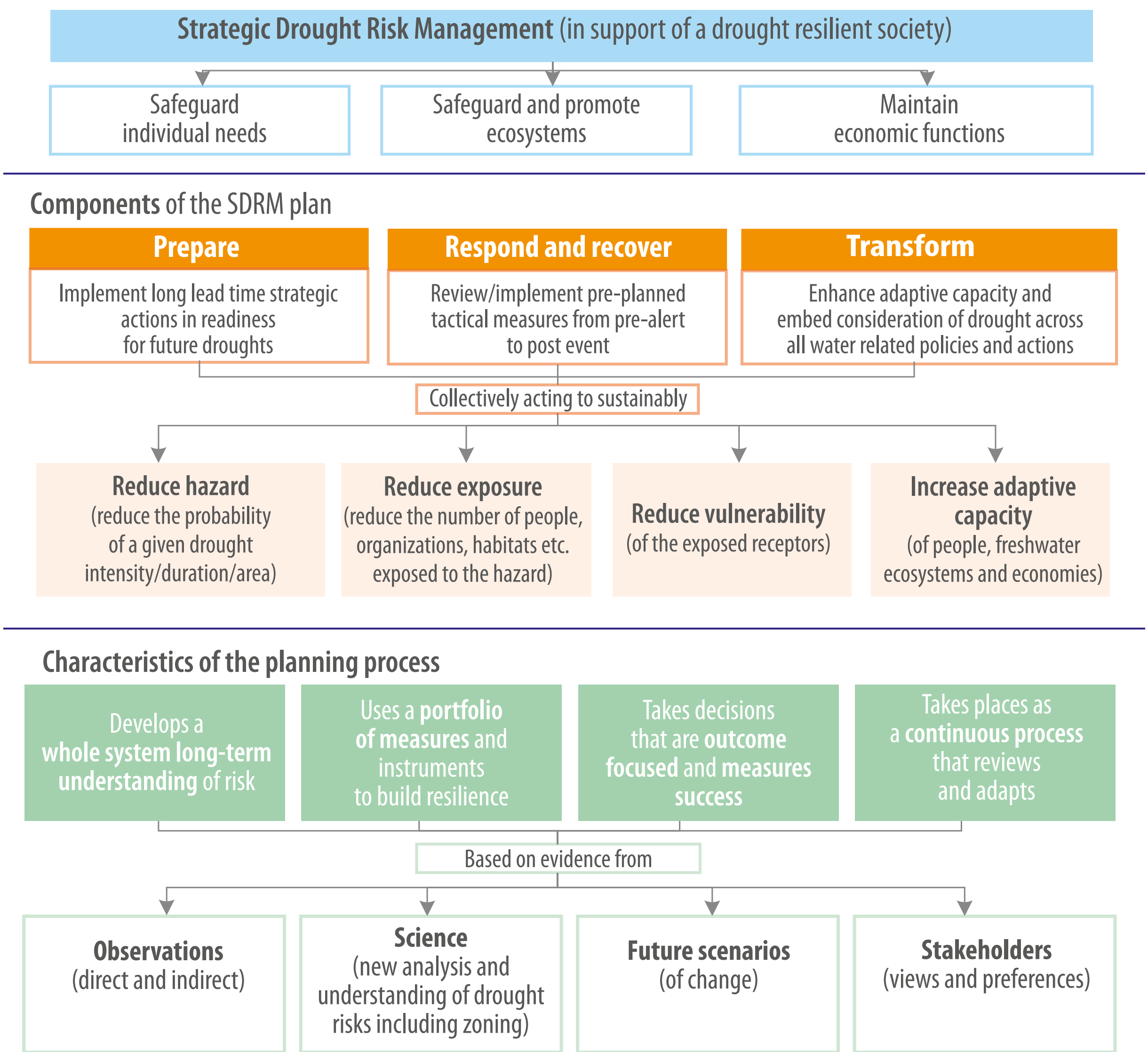
The overarching role of SDRM is to develop a drought-resilient society so that during drought individual needs and ecosystem services are safeguarded and economic impacts minimized. A drought-resilient society requires more than preparing for drought with physical infrastructure or responding to drought by motivating communities. It involves delivering multiple outcomes for people, freshwater ecosystems and economies to embed drought resilience in all sectors of society.

Components of a strategic drought management plan

A drought resilient society develops a new relationship with water – one that recognizes the mutual dependence between human development and freshwater ecosystems. This is an ambitious goal that requires society to consider drought risk alongside broader water resource and development issues and to adopt ongoing learning and adaptation.

Achieving this transition needs a political understanding and acceptance of drought risks, widespread awareness of those risks and momentum to implement a portfolio of measures to reduce or remove risks (Figure E).

Figure E. The framework of Strategic Drought Risk Management

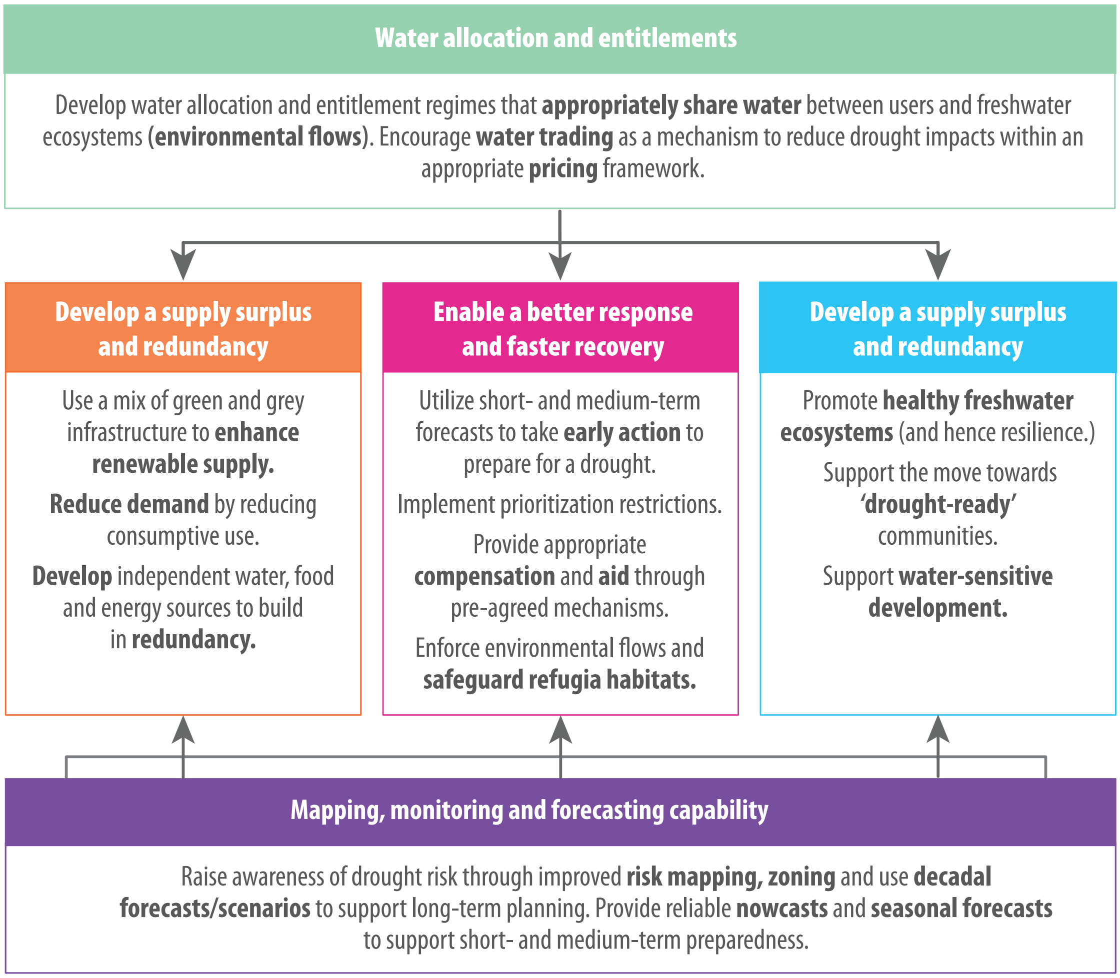


A portfolio of measures and instruments to manage drought risk

SDRM involves taking a long-term approach to managing risk using a portfolio of measures (Figure F) to:

- establish appropriate systems for water allocations and entitlements
- develop a supply–demand surplus and redundancy
- enable a better response and faster recovery
- promote a sustainable water future
- establish credible mapping, monitoring and forecasting services.

Figure F. Typical considerations in developing a portfolio approach to Strategic Drought Risk Management



Safeguarding and enhancing freshwater ecosystems through Strategic Drought Risk Management

Ecosystems provide critical provisioning, regulating, cultural and supporting services. Drought management choices can have a devastating impact if safeguarding these services and working with natural processes is not taken into account early in the management process. A shift in emphasis is required to safeguard and promote ecosystems through SDRM, making working with natural processes a central consideration. As river basins become increasingly water scarce and degraded by pollution and other impacts, their sensitivity to variability in precipitation, and their vulnerability to drought, is likely to increase. Table A summarizes ecosystem-based measures for SDRM.

Table A. Summary of ecosystem-based SDRM measures

	Non-drought conditions	During drought	After drought
Catchment processes	Analyze and map critical areas for biodiversity and/or provision of ecosystem services, especially run-off/recharge. Protect critical areas, and prioritize measures for them in SDRM plan. Improve landscape permeability (e.g. agro-forestry, rotational grazing, and restore small water bodies).	Implement SDRM measures for critical areas set out in the plan. Protect key areas for water resource generation. Maintain landscape permeability measures.	Review and adapt protection of critical areas and measures in SDRM plan.
Flow regime	Map priority areas for environmental flows (e.g. hydropower dams, major inland fisheries, reaches prone to sedimentation or eutrophication, tributaries/wetlands of high conservation value, water holes, and species refugia). Prioritize environmental flows for these areas in water allocation plans.	Maintain environmental flows for priority areas (e.g. through infrastructure operation and/or modified water abstraction).	Maintain temporary abstraction restrictions and storage operation rules until river flows return to optimal levels. Pro-actively restore ecosystems that are close to or have passed tipping points.
Water quality	Reduce/eliminate water pollution (e.g. through progressively tighter ef uent discharge permits, improved farming practice, enhanced spatial planning). Maintain environmental flows.	Temporary restrictions on some types of discharge where river flow is low. Allow some types of ef uent discharge that might support maintenance of environmental flow without disproportionate damage to ecosystem. Maintain environmental flows to priority areas that are sensitive to pollution, e.g. for drinking water abstraction, species refugia.	Revert to normal ef uent discharge regime once river flows return to optimal levels. Maintain temporary abstraction restrictions and storage operation rules until river flows return to optimal levels.
Habitat	Identify and, where necessary, protect networks of priority refugia through SDRM plan (e.g. headwaters, springs, pools and backwaters).	Safeguard environmental flows to and between refugia and limit pollution. Maintain riparian vegetation and prevent removal of fallen trees in priority refugia/protected areas to keep water temperature within a suitable range and create micro- habitats. Prevent conversion of dry streambeds or dehydrated wetlands into farm land Restrict fishing and livestock access to water in priority refugia/ protected areas.	Maintain temporary abstraction restrictions and storage operation rules until river flows return to optimal levels. Pro-actively restore ecosystems that are close to or have passed tipping points. Revert to normal ef uent discharge regime once river flows return to optimal levels.
Biodiversity	All measures outlined above. Research and plan for potential last- resort ex-situ conservation measures (e.g. translocation, captive breeding, and seed banks).	Implement careful ex-situ conservation, e.g. through translocation, captive breeding, seed banks.	All measures outlined above. Reintroduce captive bred or translocate species providing habitat has returned to normal conditions.

Enabling environment of Strategic Drought Risk Management

To successfully implement SDRM, greater coordination and cooperation between those with an interest in water-related issues is required to develop and implement more innovative strategies. Drought managers must:

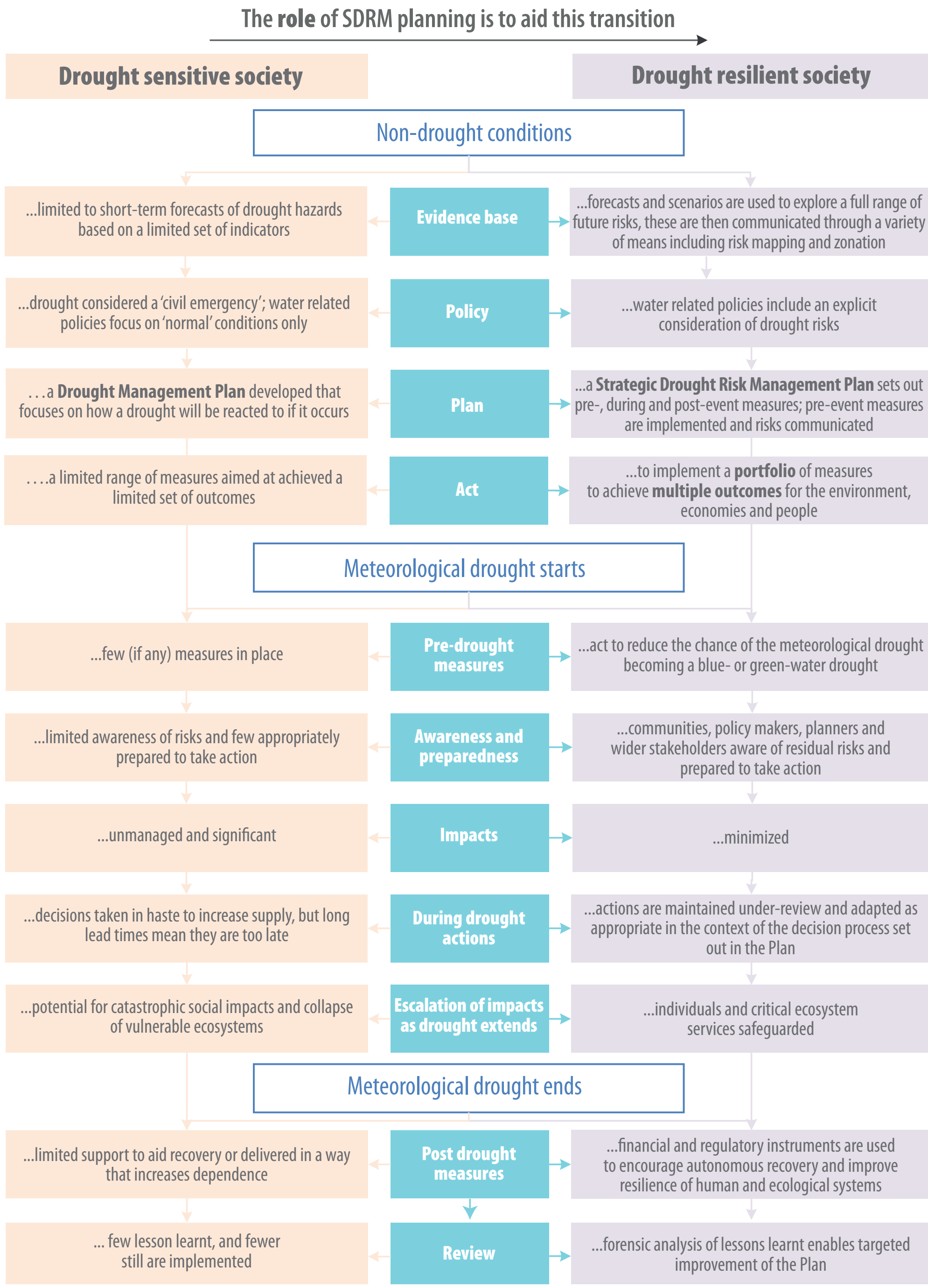
- establish and maintain political momentum
- engage a broad range of stakeholders
- support other water and development policies and regulations, as appropriate
- be honest about the evidence on drought hazards and risks.

How SDRM supports the transition to a drought-resilient society

A drought-resilient society evolves to develop a new relationship with water that recognizes the mutual dependence between human development and freshwater ecosystems. This goal requires more than simply 'preparing for' and 'responding to' drought; it considers drought risk alongside broader water resource and development issues.

In practice, transitioning to a drought-resilient society requires political acceptance of drought risks, widespread awareness of those risks and momentum to act. The nature of this transition is summarized in Figure G.

Figure G. Making the transition from a drought-sensitive society to a drought-resilient society is the role of Strategic Drought Risk Management



1.1. Eight Golden Rules to support Strategic Drought Risk Management

Underpinning a strategic framework of risk analysis and management is recognizing the *drought risk system* as a construct of climatic, hydrological, socio-economic and ecological systems.

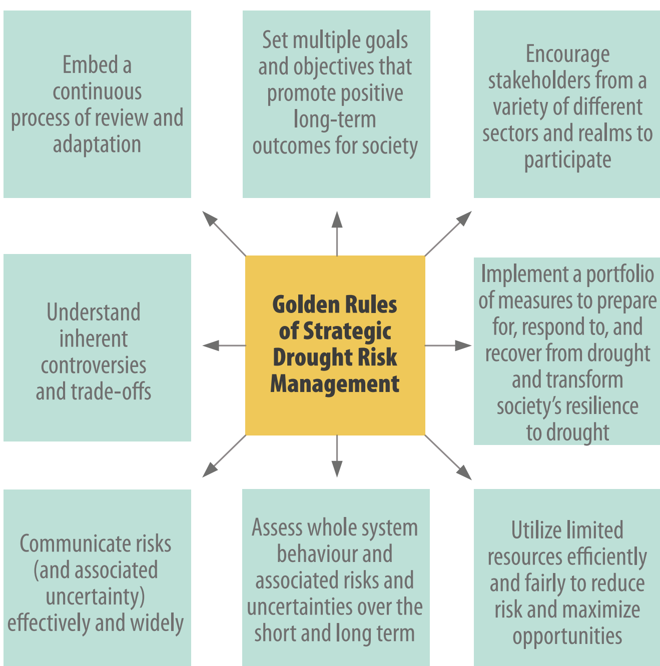
This approach is well developed for many other natural hazards (for example, Sayers *et al.*, 2013 and 2014a) but is yet to emerge for drought. However, it is possible to identify a small number of principles that are prerequisites for the successful delivery of SDRM. These 'golden rules' are summarized in Figure H.

1. **Set multiple goals and objectives that promote positive long-term outcomes for society:** SDRM is more than securing emergency drinking water supplies. It is about

reducing drought impacts across society – including households, agriculture and industry – and safeguarding biodiversity and ecosystem services. SDRM delivers long-term outcomes and avoids short-term solutions that may have negative impacts. The success of SDRM is measured against multiple objectives achieved over different timescales.

2. **Encourage stakeholders from a variety of different sectors and realms to participate:** Good decisions rely on governments, businesses and communities being active participants. SDRM fosters a framework of collaboration that supports political momentum for change and sharing responsibility and fiscal support for implementing measures.
3. **Implement a portfolio of measures to prepare for, respond to, and recover from drought and transform society's resilience to drought:** Integrated management of drought risk involves considering the widest possible set of management actions, including measures to reduce the probability of blue-water droughts, incentivizing to adapt to drought risks and enhancing reserve capacity through appropriate green or grey infrastructure.
4. **Utilize limited resources efficiently and fairly to reduce risk and maximize opportunities:** The level of effort to manage drought risk must be context specific and not based on universal or generalized standards of supply reliability. SDRM considers the efficiency of management measures for risk reduction, resources, fairness and ability to maximize ecosystem opportunities.
5. **Assess whole system behavior and associated risks and uncertainties over the short- and long-term**: The drought risk system is more than meteorology and hydrology. It consists of climatic sources, hydrological pathways and receptors that may be harmed (i.e. people, ecosystems and economies). An appropriate understanding of this whole system, and how it might respond to external influences and management responses over the long-term is a prerequisite to making good choices. However, uncertainty within the data and models must be acknowledged and the choices made must be robust despite that uncertainty.
6. **Communicate risks (and associated uncertainty) effectively and widely:** Decision makers and the public must understand drought risks. Risk and the associated uncertainty must be communicated effectively to enable both communities and individuals to prepare and support risk reduction measures. Initiating communication during a drought is too late.
7. **Understand inherent controversies and trade-offs:** Managing trade-offs that will inevitably arise requires extensive discussion and the preferred approach may require significant changes in practice that challenge the status quo. Efforts to understand these trade-offs and how they will be managed are a core component of any SDRM plan. Decisions made in haste during a drought seldom balance competing needs adequately and often produce ineffective, inefficient or inequitable results.
8. **Embed a continuous process of review and adaptation:** The world is changing. Climate change, demographic change, changes in the hydrological response of the basin and other societal changes mean that planning processes that maintain the status quo are no longer adequate. Strategic drought risk management is a continuous process of review and adaptation and is a pre-requisite for delivering desired outcomes.

Figure H. Golden rules of Strategic Drought Risk Management



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List of acronyms

ACSAD	Arab Center for Study of the Arid Zones and Dry Areas
AMO	Atlantic Multidecadal Oscillation
ALARP	As low as reasonably practicable
ALC	Active Leakage Control
CBD	UN Convention for Biodiversity
CDC	Center for Disease Control and Prevention
CIWEM	Chartered Institute for Water and Environmental Management
CONAGUA	National Water Commission, Mexico
DCP	Drought Contingency Plan (California)
Defra	Department for Environment Food and Rural Affairs (UK)
DMP	Drought Management Plans
DPSIR	Drivers-Pressures-State-Impact-Response
DRR	Disaster Risk Reduction
EAD	Expected Annual Damage
EADr	Estimated Annual Drought risk
EBA	Ecosystem-based adaptation
Eco-DRR	Ecosystem-based Disaster Risk Reduction
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization
FAPAR	Fraction of Absorbed Photosynthetically-Active Radiation
GAR	Global Risk Assessment
GCM	Global Circulation Models
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GI	Green Infrastructure
GIDMaPS	Global Integrated Drought Monitoring and Prediction System
GIWP	General Institute of Water Resources and Hydropower Planning and Design, Ministry of Water Resources, People's Republic of China
HFA	Hyogo Framework for Action
HSE	Health and Safety Executive
ICARDA	International Center for Agricultural Research in the Dry Areas
ICE	Institute of Civil Engineers, UK
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Risk Reduction
IWRM	Integrated Water Resources Management

ICUN	International Union for Conservation of Nature
MAR	Managed Aquifer Recharge
MCA	Multi-Criteria Analysis
MDGs	Millennium Development Goals
MEA	Millennium Ecosystems Assessment
MENA	Middle East and North Africa
MWD	Mediterranean Water Scarcity and Drought Working Group
NADM	North American Drought Monitor
NDMC	National Drought Mitigation Center (US)
NDP	National Drought Plan (Australia)
NGO	Non-Government Organization
NIDIS	National Integrated Drought Information System
NWP	National Water Policy
Ofwat	Office for Water Services (Water regulatory, UK)
PDI	Pacific Inter-Decadal Oscillation
PDO	Pacific Decadal Oscillation
PDSI/PDI	Palmer Drought Severity Index/Palmer Drought Index
PEDRR	Partnership for Environment and Disaster Risk Reduction, UN
PRONACOSE	National Drought Management Programme, Mexico
RBP	River Basin Plans
RCM	Regional Circulation Models
SDG	Sustainable Development Goal
SDRM	Strategic Drought Risk Management
SELL	Sustainable Economic Levels of Leakage
SFA	Sendai Framework for Action
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standard Precipitation Index
SOI	Southern Oscillation Index
TEEB	The Economics of Ecosystems and Biodiversity - A global initiative
TVA	Tennessee Valley Authority
UN	United Nations
UNESCO	United Nations Education Scientific and Cultural Organization
US	United States of America
USACE	United States Army Corps of Engineers
WFD	Water Frameworks Directive (EU)
WMO	World Meteorological Organization
WSandD	Water Scarcity and Drought
WWF	World Wide Fund for Nature

Glossary

Acceptable risk — The level of risk a society or community considers acceptable given existing social, economic, political, cultural, technical and environmental conditions. An understanding of acceptable (and hence unacceptable) risk helps guide the level of investment that may be appropriate to reduce the risk (where possible).

Adaptation — The ongoing adjustment in natural, engineered or human systems in response to actual or perceived changes in climate or other drivers of risk. Adaptation may be either autonomous (i.e. achieved through unplanned change) or managed (i.e. achieved through purposeful adaptation planning based on expectations of future change).

Aridity — An arid region is characterized by a severe lack of available water, to the extent of hindering or preventing the growth of plant life and the development of animal and human life.

Blue-water — Freshwater found on the surface (in lakes and rivers) or in the ground (in aquifers).

Blue-water drought (hazard) — An unusual and significant deficiency in the water stored in freshwater lakes, rivers, aquifers and wetlands.

Consequences (of drought) — The adverse impacts of a drought event on the economy, environment, individuals or society. Consequences can be expressed in many valid forms, either quantitatively (in monetary or native terms) or qualitatively (by category or description). The magnitude of the consequence will be influenced by the vulnerability of the exposed receptors and the value society places on the harm caused. Not all drought impacts are adverse and in some case droughts may provide opportunities, but the focus is primarily on adverse impacts.

Consumptive use — Water use that reduces the water available from a given source. For example, most thermoelectric withdrawals are returned to the water source after cooling (non-consumptive), while most irrigation withdrawals are 'used up' (consumptive) by the processes of evapotranspiration and plant growth.

Coping capacity — The ability of a system (natural or human) to respond to and recover from a shock (such as a drought event). Coping capacity is one element of resilience.

Desertification — Desertification refers to a loss of productivity in the landscape. The process may be driven by a combination of influences such as deforestation, improper or inappropriate agriculture or through prolonged drought.

Distribution losses — Loss of drinkable water between the treatment works and the point of use.

Drought zoning — The process of partitioning a region according to the severity of the drought hazard and associated risks to better understand the spatial characteristics of the drought risk and support drought management choices.

Dry spell — A period of abnormally dry weather, but shorter and less severe than a drought.

Ecosystem — A system that includes all living organisms in an area as well as its physical environment functioning together as a unit.

Ecosystem structure — The composition of the ecosystem and the physical and biological organization defining how those parts are organized. For example, different plant and animal species are considered a component of an ecosystem and therefore part of its structure. The relationship between primary and secondary production is also part of the ecosystem structure, as this reflects the organization of the parts.

Ecosystem function	The different physical, chemical and biological processes that occur as a result of the interactions of plants, animals and other organisms in the ecosystem with each other or their environment. These processes include decomposition, production, nutrient cycling and fluxes of nutrients and energy. Ecosystem structures and functions, together, provide ecosystem services.
Ecosystem services	The benefits people obtain from ecosystems. These include four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits.
Effective rainfall	The difference between precipitation and evapotranspiration.
Environmental flows (e-flows)	Environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.
Exposure (of a receptor)	The people, livelihoods, habitats, species, infrastructure, or economic, social, or cultural assets that could be adversely affected by a drought.
Freshwater ecosystem	A freshwater ecosystem can be defined as the river channel and the water within it; the floodplains, lakes and aquifers; and the plants and animals that live in and around those systems. For the purposes of this book, the term 'freshwater ecosystem' is also used to include ecosystems that are closely connected with freshwater ecosystems, both spatially and in terms of the influence they have on each other. These include watershed forests that influence run-off and agro-ecosystems that depend significantly on freshwater habitats.
Green-water drought (hazard)	An unusual and significant deficiency in the water stored in the soil layer (from which plants and crops normally draw their water) and / or in vegetation itself.
Grey infrastructure	Conventional, built infrastructure such as water treatment plants, reservoirs, dams and desalination plants.
Green infrastructure	Natural or semi-natural systems that are purposefully used to influence the hydrological processes within a basin with the view of providing equivalent (or similar) benefits to grey infrastructure. Green infrastructure involves a deliberate and conscious effort to utilize the natural functioning of a system to manage water and provide broader benefits.
Green-water	The precipitation on land that does not run off (to rivers or lakes) or recharge groundwater but is stored in, or on top, of the soil or vegetation. Eventually, this part of precipitation is lost through evaporation or transpiration.
Hazard (drought)	An unusually dry period (of sufficient duration or intensity) that has a significant adverse impact on the environment, economies or society (adapted from NDMC, 2013).
Headroom (in context of water supply)	The difference between the amount of water that is available to supply for municipal use and the expected demand.
Headroom (target)	The minimum headroom considered necessary for an appropriate security of supply, given uncertainties in future volumes of available water and demand requirements.
Meteorological drought (hazard)	A temporary, negative and severe deviation from average precipitation values that persists for a sufficient period of time to significantly reduce blue-water or green-water resources in a river basin or region.
Pathway (of risk)	The connection between the source of the risk (the hazard) and the receptor that may experience harm.
Receptor (of risk)	The individual, organization, social group, flora or fauna that may be harmed by a drought.
Refugia	Geographical locations where natural environmental conditions remain relatively constant or stable during a period of drought enabling a population of organisms to survive when unfavourable conditions are experienced elsewhere.

Reference drought A historical drought used as the basis for drought preparedness planning within a traditional standards-based approach to drought management. A reference drought may no longer be valid given climate change and may not represent a credible worst case.

Risk A combination of (i) the chance of the drought hazard occurring and (ii) the impacts on people, economics and ecosystems that result. As such drought risk is an emergent property of the human and natural system, and reflects the interaction between climate (meteorological drought), the hydrological response of the basin (blue-water drought and green-water drought) and the vulnerability of the exposed people, ecosystems and economies.

Risk analysis A structured method to determine risk by analysing and combining probabilities and consequences with the minimum of subjectivity.

Risk assessment The process of understanding, evaluating and interpreting the evidence (quantitative and qualitative) of drought risk and societal tolerances of that risk to inform drought risk management decisions.

Risk communication Any exchange of information on drought risks between interested parties (formal and informal).

Risk management A continuous process of data gathering, analysis, adjustment and adaptation of policies and actions to manage drought risks (over the short and long-term). It takes place as part of a wider approach to water resource planning and allocation. It recognizes that risks can never be removed entirely and that reducing risk may be at the expense of other societal goals.

Risk-management measure A physical action that is taken to reduce either the probability of a drought hazard occurring or the consequences should a drought occur.

Risk-management instrument A policy, regulatory or communication action taken to reduce either the probability of a drought hazard occurring or the consequences should a drought hazard occur.

Risk mapping The process of differentiating drought risks in space and time and communicating those risks through a map. Risk mapping requires consideration of both hazard and consequence (exposure and vulnerability).

Risk system A structured description of the Sources, Pathways and Receptors of drought risk with a given basin or region.

Resilience The ability of social, economic and environmental systems to cope with a meteorological drought hazard by reducing the chance of a subsequent blue-water drought or green-water drought occurring, limiting the significance of any associated harmful consequences should they occur, and having the capacity to adapt in a way that reduces future risks.

Shadow crops Taller plants that provide shade for others.

Source (of risk) The initiating driver of risk; this could be, for example, a meteorological drought or a pollution incident.

Stationarity (and non-stationarity) 'Stationarity' refers to the constancy (in time) of the laws and processes that govern a response of interest (e.g. flow). In contrast, a non-stationary process varies over time. This may occur due to direct influences within a basin (deforestation, urbanization etc.) or due to global climate change. Long-term, naturally occurring, cyclic trends that may take place over decades, centuries or even millennia (and may or may not be known to us) are not examples of non-stationarity in the scientific sense (although they may be important influences and must be accounted for in any analysis of observed records).

Total freshwater resource The total combined volume of (i) the river discharges and groundwater recharge generated annually by precipitation within a region, and (ii) the volume of inflow from neighbouring regions (as either surface or groundwater). This resource may be supplemented by access to inter-annual sources, such as fossil groundwater or paleowater.

Vulnerability (of a receptor)	The propensity or predisposition of a given receptor (or group of receptors) to be adversely affected by a drought. Vulnerability encompasses a variety of concepts and elements including susceptibility to harm, recoverability (and the ability to recover or adapt in a timely manner without significant aid) and value (the value society places on the harm caused).
Water abstraction license trading	The transfer of licensable water rights from one party to another for mutual benefit.
Water allocation plan	An instrument – usually issued by government or a government agency – that defines the water available for allocation and sets out the rules for managing the take and use of water resources. The plan may allocate water directly to regions or sectors. Alternatively, the plan may define a process for allocating available resources.
Water scarcity	A human-induced imbalance between the available supply and demand that arises when the average demand is higher than the long-term renewable availability.
Water security	An overarching philosophy that seeks to appropriately manage water-related risks to people, economies and the ecosystems in a way that maintains peace and political stability (adapted based on Grey and Sadoff, 2007 and UN-Water, 2013).
Water stress	A moderate imbalance between the naturally renewable water supply and demand.
Water foot print	The total volume of freshwater that is used to produce the goods and services consumed by the individual or community.
Water shortage	A major temporary demand or loss of supply, for example through a collapse or dam failure.

Reference sources for the glossary

The majority of definitions are taken or adapted from Sayers *et al.*, 2013 and Speed *et al.*, 2013. Others are based on a review of multiple sources.

PREFACE

Context

This book is the result of a collaboration between WWF and the General Institute of Water and Hydropower, China (GIWP). It presents a new approach to drought management for water managers and policy makers, in China and globally, to deliver better social, economic and ecological outcomes.

The research underpinning the new approach is based on (i) a review of international best practice from Australia, North Africa, Europe, North America and Latin America; (ii) lessons from historical droughts; (iii) leading academic articles; and (iv) various face-to-face expert working sessions with WWF (UK and China); leading specialists in China from the GIWP; and international experts from Australia, South Africa, US and Europe.

This book is part of a series on strategic water management. Other topics covered in the series include strategic basin planning, basin water allocation, flood risk management and river restoration.

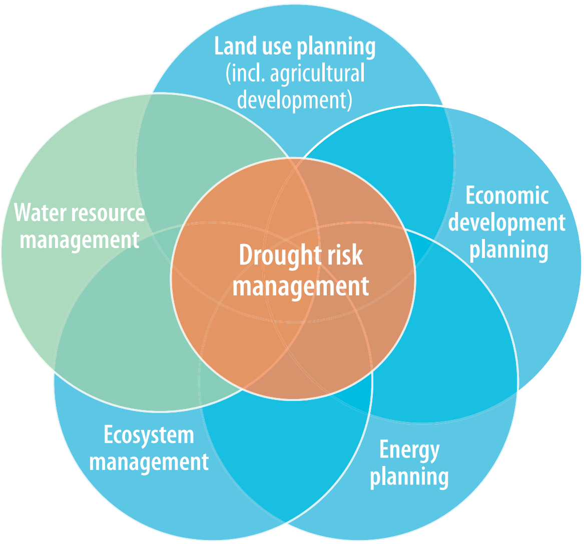
Scope

This book seeks to address water resource-related challenges during periods of drought. It outlines a new framework of **Strategic Drought Risk Management** (SDRM) that builds resilience to drought using a combination of actions to better prepare for, respond to, and recover from a drought in a way that aids the transition towards a drought resilient society. Implicit within this framework is the recognition that to manage water resources in the context of drought requires multiple responses to achieve multiple outcomes.

SDRM challenges current practices that focus on meeting an ever-increasing supply requirement through engineered infrastructure such as dams and reservoirs. These practices are ineffective at providing long-term solutions and often have serious impacts on ecosystems.

Within this book we recognize that SDRM covers a broad suite of issues linked closely with broader water resource management activities and overlaps with other elements of planning (Figure 0.1). These broader activities and elements are outside the scope of this book, although it is recognized that, in many areas of the world, famine and drought go hand in hand. Famine and developing contingency measures to ensure food supply is a fundamental consideration for drought risk managers. Given this book's focus on the long-term management of water resources, however, short-term humanitarian aid activities are not considered here. Equally, activities focused on food security (for example the promotion of drought resistant crops) or energy security (diverse energy supplies to mitigate the impact of drought), although mentioned, are also outside of the core scope of this book. Although it is recognized that policies and practices that mitigate climate change (for example through reduced greenhouse gas emissions) have multiple benefits, including reducing drought risks, these actions are outside the scope of this book.

Figure 0.1. Drought is considered here in the context of water resource management: broader connections are acknowledged but are outside the direct scope of this book



Layout of the book

The book is structured in three parts:

Part A – the nature of drought and the management challenge presents the background to our current understanding of drought and the management challenge.

Part B – the framework of Strategic Drought Risk Management presents the new approach promoted here.

Part C – Supporting evidence presents the evidence gathered through a series of international case studies.

PART A

THE NATURE OF DROUGHT AND THE MANAGEMENT CHALLENGE

CHAPTER 1
DIFFERENT TYPES OF DROUGHT AND THEIR IMPACTS

1.2. Drought hazards

THE NATURE OF THE DROUGHT HAZARD

Droughts are said to be a 'creeping hazard' (Gillette, 1950). A drought can persist for many years, extend across large areas and have multiple impacts on economies, ecosystems and societies. Droughts are typically associated with large-scale impacts, often driven by regional or even global-scale climate features. As a result, droughts can be widespread, influencing multiple basins simultaneously (Figure 1.1).

Drought is also persistent. An extended single event or a series of successive 'dry spells' may mean water resources, ecosystems and economies are not able to fully recover before the next drought occurs. For example, the 1930s 'Dust Bowl' drought in the US, although viewed as a single drought episode in terms of its devastating impacts, was driven by several distinct 'dry' periods, each of which was an individual meteorological drought episode, embedded within a larger-scale drought pattern. Each period of dryness occurred in such rapid succession that affected regions were unable to recover adequately before the next drought began. The Millennium Drought in Australia is also often considered a single event, but it is the result of multiple meteorological drought events.

In other natural hazards such as hurricanes, floods and earthquakes, simple observations provide a means of determining the onset and end of the event. The severity of a drought, however, develops subtly over time. As a result, the onset of drought can often only be defined in hindsight. This is perhaps a unique characteristic of drought and is part responsible for the ambiguity of what constitutes drought and how drought intersects with water policy more generally.

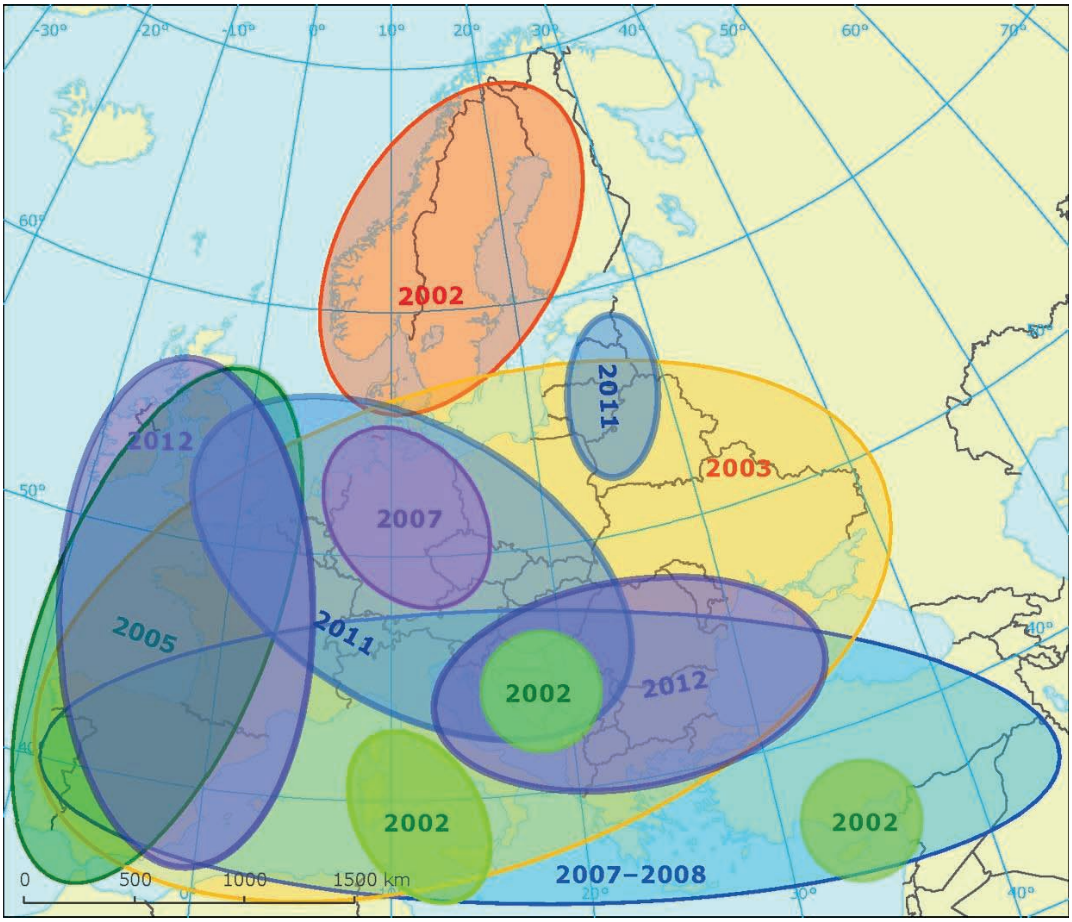
TRADITIONAL DEFINITION OF DROUGHT

Drought is ultimately about a lack of water. Throughout history there has been little disagreement about the general meaning of drought. Beyond this general understanding, the definition of drought becomes more diffuse. Palmer (1965) wrote:

> *Drought means various things to various people depending on their specific interest. To the farmer drought means a shortage of moisture in the root zone of his crops. To the hydrologist, it suggests below average water levels in the streams, lakes, reservoirs, and the like. To the economist, it means a shortage which affects the established economy.*

Throughout the 1950s, 1960s and 1970s definitions of drought were primarily associated with the hydrological cycle, 'a deviation from the normal hydrological conditions' (Palmer, 1965). Definitions subsequently evolved to reflect the importance of meteorological persistence ('an extended deficiency in precipitation' (WMO, 1986)), and severity ('precipitation significantly below normal recorded levels' (United Nations, 1994)). In the latter half of the 1990s, definitions also started to include 'impacts'. At first, agricultural impacts were the key concern ('adversely affect land resource production systems' (United Nations, 1994)) before a broader socio-economic perspective was adopted ('insufficient to meet the demands of human activities and the environment' (Wilhite and Buchanan-Smith, 2005)). The recognition that droughts are a feature of all climates and can and should be planned for was also introduced more directly from the mid-2000s ('a normal, recurrent feature of climate, although often erroneously considered an unexpected and extraordinary event' (MWD, 2007)). As a result, a multitude of definitions of drought has evolved that reflect changes in perception and context of time (Table 1.1, based on a review by Belal *et al.*, 2012).

Figure 1.1. Droughts are widespread as highlighted by the drought events in Europe over the past decade



Source: Europe Environment Agency (http://www.eea.europa.eu/data-and-maps/figures/main-drought-events-in-europe)

Table 1.1. Drought and its definitions

Definition	Reference
Drought as a sustained period of time without significant rainfall.	Linsely *et al.* (1959)
Drought as the smallest annual value of daily stream flow.	Gumbel (1963)
Drought as a significant deviation from the normal hydrologic conditions of an area.	Palmer (1965)
FAO defines a drought hazard as 'the percentage of years when crops fail from the lack of moisture'.	FAO (1983)
Drought means a sustained, extended deficiency in precipitation.	WMO (1986)
Drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.	UN Secretariat General (1994)
An extended period – a season, a year, or several years – of deficient rainfall relative to the statistical multi-year mean for a region.	Schneider (1996)
Drought is a normal part of climate, rather than a departure from normal climate.	Glantz (2003)
Drought is not a word with a precise definition. A drought is simply a period during which rainfall is markedly lower than the average for that time of year in that place, and consequently, water is in such short supply that domestic and industrial users, farmers, and wildlife are affected.	Allaby (2003)
Drought is an insidious natural hazard that results from a deficiency of precipitation from expected or 'normal' that, when extended over a season or longer, is insufficient to meet the demands of human activities and the environment.	Wilhite and Buchanan-Smith (2005)
Drought is a normal, recurrent feature of climate, although often erroneously considered an unexpected and extraordinary event. It is a temporary aberration within the natural variability and can be considered an insidious hazard of nature; it differs from aridity, which is a long-term, average feature of climate.	MWD (2007)
Drought is a period of drier-than-non-drought conditions that results in water-related problems. It is the period when rainfall is less than normal for several weeks, months or years, the flow of streams and rivers declines and water levels in lakes and reservoirs descent and the depth of water in wells increase.	Nagarajan (2009)
Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid areas.	Dai (2011)
Drought is by far the most important environmental stress in agriculture, causing important crop losses every year.	Mastrangelo *et al.* (2012)
Drought is a normal, recurrent climatic feature occurring in all climatic regimes, usually characterized in terms of its spatial extension, intensity and duration. Conditions of drought occur when the rainfall is deficient in relation to the statistical multi-year average for a region, over an extended period of a season or year, or more.	Khurana and Baba, (2012)
A period of excessive dryness long or intense enough to affect agriculture, habitats, or people.	NDMC, 2013

Source: extended from Belal et al., 2012.

A MODERN CLASSIFICATION OF DROUGHT

The traditional classification of drought types has primarily evolved from the meteorological and hydrological sciences and more recently the classification has extended to reflect agricultural and socio-economic impacts. Today, a myriad of drought types exist with few accepted definitions; this lack of clarity has hindered progress in managing drought. A more proactive, whole-of-system management of drought risk (as promoted throughout this book) requires traditional drought types to be challenged and alternative definitions proposed that distinguish different aspects of the hazard. A new classification is proposed here that highlights this distinction and avoids the arbitrary sub-division of the hydrological cycle imposed by traditional drought types. This new classification is highlights how drought impacts have the potential to cascade and escalate through the freshwater ecosystems and human systems (Figure 1.2). A meteorological drought may, for example, result in reduced infiltration to groundwater and reduced stream flow. A blue-water drought may restrict habitat connectivity and reduce water quality with consequences for riparian ecosystems, groundwater-dependent ecosystems, and in-stream ecological processes such as fish spawning. Fish abundance may decrease as the ability of a river to dilute pollution load decreases. Loss of reservoir storage and access to cooling waters is likely to impact energy production. These impacts, together with restrictions on water use, can slow economies and livelihoods can be lost. Crops will fail with a reduction in soil moisture in a green-water drought and soil cover will be lost and the threat of wildfires will increase. In a prolonged drought, the combined effects can lead to ecosystem collapse, famine and severe societal conflict. Although this escalation of impacts will be different in each basin, and the important ecosystem services impacted will vary by sector, an interaction between human systems and freshwater ecosystems will always exist.

Meteorological drought

Precipitation deficiency (often coupled with increased heat stress but not always) is the fundamental driver of a drought and is traditionally referred to as a meteorological drought. Although defined similarly in many documents (e.g. Belal *et al.*, 2012; Mishra and Singh, 2010; Quiring, 2009) no single definition prevails.

A meteorological drought is defined in this book as:

A temporary, negative and severe deviation from the average precipitation values that persists for a sufficient period of time to significantly reduce blue-water or green-water resources in a river basin or region.

Blue-water drought

Absence of, or reduction in, available water stored in freshwater lakes, rivers, aquifers and wetlands (WWAP, 2009) is referred to here as a blue-water drought, often traditionally referred to as a hydrological drought (e.g. Belal *et al.*, 2012; Mishra and Singh, 2010; Quiring, 2009).

A blue-water drought is defined in this book as:

An unusual and significant deficiency in the water stored in freshwater lakes, rivers, aquifers and wetlands.

A meteorological drought may or may not lead to a blue-water drought – it depends on the nature of the meteorological drought and the hydrological response of the basin. The intensity, duration and spatial extent of the meteorological drought is important. For example, if the meteorological drought is relatively short and, at the onset of the meteorological drought, groundwater aquifers and reservoirs are full, a blue-water drought may not occur. The temperature and season of the meteorological drought are also important. For example, a blue-water drought also depends on the demand for consumptive water use, particularly from the agricultural sector, and evapotranspiration. Other factors, such as domestic and industrial consumption or dam infrastructure will also affect the hydrological characteristics of the basin and the relationship between meteorological droughts and blue-water droughts. In larger basins, it is also possible that a meteorological drought in a specific location and time (e.g. upstream and in winter) will have a more significant impact than the same meteorological drought occurring elsewhere within the basin or at a different time (for example, the absence of snow fall upstream may limit the spring snow melt and future downstream flows). Blue-water droughts can have major impacts on irrigated agriculture, industry, energy production and domestic water availability, and reduced aquatic food production.

Green-water drought

A green-water drought refers to the absence of, or reduction in, available water stored in or on top of the soil or vegetation (WWAP, 2009). Green-water is vital for crop and plant growth. A reduction or absence of green-water is traditionally referred to as an agricultural drought (e.g. Belal *et al.*, 2012; Mishra and Singh, 2010; Quiring, 2009) and typically defined as a deficiency of moisture in the soil layer from which crops normally draw their water. This definition is narrow and implies impacts are limited to agriculture, whereas direct effects may also be felt across other land uses (e.g. forestry) and freshwater ecosystems and reduction or degradation of aquatic and terrestrial habitat.

Indirectly, green-water drought can impact on the availability and pricing of agricultural produce.

A green-water drought is defined in this book as:

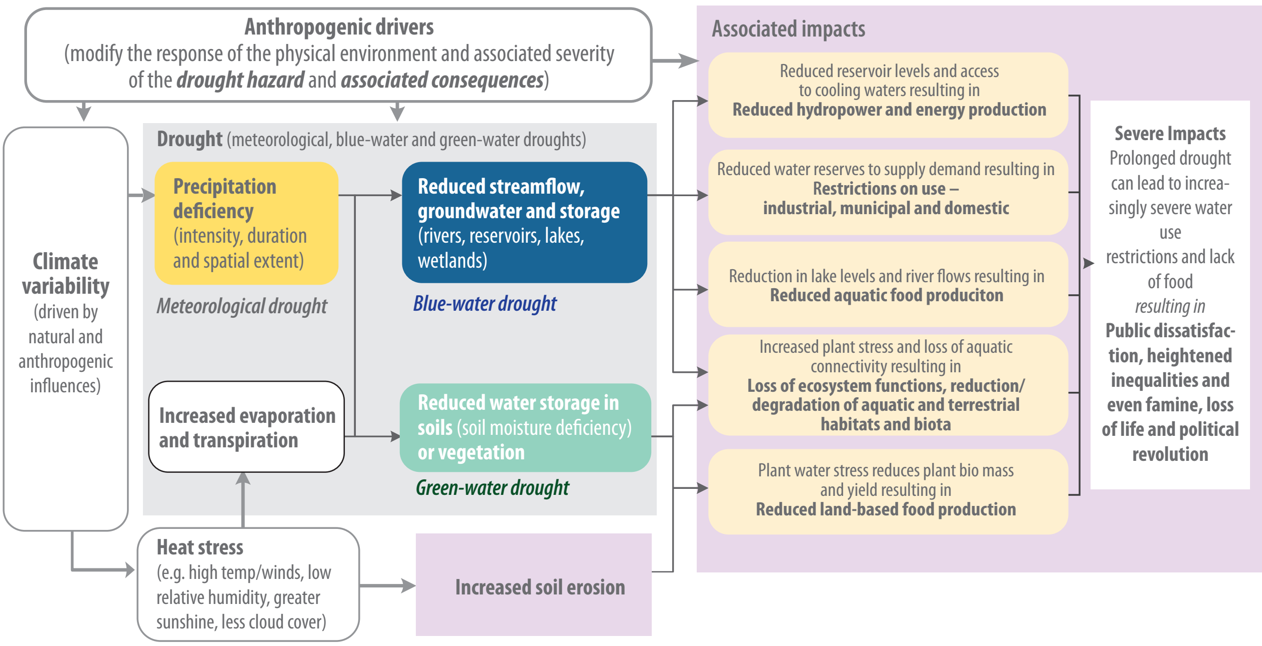
An unusual and significant deficiency in the water stored in the soil layer (from which plants and crops normally draw their water) and/or in vegetation itself.

The onset of a green-water drought will reflect the balance between precipitation, evapotranspiration, soil moisture deficits and limitations on irrigation. Therefore, although a meteorological drought is a prerequisite for a blue-water or green-water drought, it is not necessarily sufficient.

The impact of a green-water drought on agricultural production, other land uses and freshwater ecosystems depends on the timing of the drought. For example, deficient soil moisture when a crop is planted may stop germination, leading to low plant populations. During other times, crops may be better able to cope with reduced access to water.

A 'socio-economic drought' has traditionally been used to describe a drought hazard that is sufficiently severe to cause socio-economic impacts. This definition has no place in the context of the risk approach used in this book because the impact of a drought is considered explicitly in the estimate of drought risk that is, by definition, concerned with hazard and impact. This concept is elaborated in Part B of this book.

Figure 1.2. Defining water security, scarcity, drought and related concepts



DEFINING WATER SECURITY SCARCITY DROUGHT AND RELATED CONCEPTS

Water security, drought (as a hazard), water scarcity and other related terms are often muddled. Table 1.2 sets out the conceptual distinction between (i) the philosophy of water security, (ii) the climate- driven issues of dry spells, droughts, aridity and associated desertification and (iii) the human-induced issues of water shortages, stress and scarcity. Extending these qualitative distinctions to standard quantified definitions is more problematic because they are likely to be context specific. However, the conceptual relationships set out in Table 1.2 remain valid across contexts.

1.3. Climate drivers of drought

LARGE-SCALE CLIMATE FEATURES

Drought is a climate response. Droughts do not develop during a single weather event, but develop over a period of time. Large-scale features that carry continental, rather than oceanic, air masses and ridges of high pressure can block or restrict the development of thunderstorm activity or rainfall over a certain region. These features often cause prolonged periods of dryness, typically associated with unusual heat and wind that exacerbate the drying effect (Box 1).

Table 1.2. Defining water security, scarcity, drought and related concepts (adapted from Schmidt, 2012)

Water security: seeks to appropriately manage water-related risks to people, economies and the ecosystems in a way that maintains peace and political stability (adapted based on Grey and Sadoff, 2007). At a conceptual level this includes consideration of issues of drought and water scarcity.			
Driver	Timescale		
	Short-term (days, weeks)	Mid-term (months, seasons, years)	Long-term (decades)
A climatic event	**Dry spell** A period of abnormally dry weather, shorter and less severe than a drought.	**Drought (as a hazard)** An unusually dry period of sufficient duration or intensity to have a significant adverse impact on ecosystems, economies, or society.	**Aridity and desertification** A permanent and severe lack of available water, to the extent of hindering or preventing the growth and development of plant and animal life (aridity). This may lead to the severe and persistent loss of biological productivity for a region (desertification). Desertification may be driven by climate or human influences, such as deforestation or unsustainable agriculture (beyond the limits of the renewable water sources) or through prolonged drought or a period of aridity (Geist, 2005).
An imbalance in the naturally renewable supply and demand driven by human activity	**Water shortage** A significant, temporary increase in demand (due to socio-economic drivers, such as staging of Olympic Games, fighting a major fire etc.), loss of supply (due to human factors such as collapse of a dam or pollution) or climate factors (such as a short-term reduction in precipitation).	**Water scarcity (and stress)** A persistent imbalance between the available supply and demand that arises when the average demand is higher than the long-term renewable availability. The distinction between water stress and water scarcity reflects the degree of the severity of the imbalance. In water-stressed areas, the imbalance is less severe.[1]	

Source: adapted from Schmidt (2012)

Box 1: The climate driver of the Californian drought – 2013-2014

Periodic drought is endemic to California, even mega droughts between ~900 AD and 1350 AD and paleodroughts in the past millennium are evident. With a population of around 38 million people and as a major location for food production, the demand for water resources in California has grown substantially while the impact of droughts has become more profound conditions in 2013-2014.

A symptomatic cause of the drought conditions was a persistent and high-amplitude, upper-level ridge anchored over the Gulf of Alaska from late fall to winter; this ridge prevented synoptic disturbances from reaching and affecting the West Coast of the US. While the winter climate on the West Coast is known to respond to the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), the winter circulation anomalies did not correspond with either of these oscillations, as ENSO was in a near neutral state and the PDO was not strong in either phase.

Analysis undertaken by Wang *et al.*, (2014) suggests the ridge emerged from continual sources of Rossby wave energy (giant meanders in high-altitude winds with major influence on weather) in the western North Pacific starting in late summer, and subsequently intensified into winter. The causal mechanisms appear to have become stronger since the 1970s, and may be attributed to increased greenhouse gases (GHG) suggesting a traceable anthropogenic footprint in the associated drought and its intensity.

Source: Wang *et al.*, (2014).

El Niño Southern Oscillation

ENSO refers to a sequence of changes that are induced when warming is particularly strong across the Pacific Ocean and the Indonesian archipelago, on average every three to eight years. Two variations of the ENSO exist (i) the warm oceanic phase (known as El Niño, 'the boy-child'[2]) that accompanies high air surface pressure in the western Pacific, and (ii) the cold phase (known as La Niña, 'the girl-child') that accompanies low air surface pressure in the western Pacific. Such events drive wetter than normal weather in some regions and drier than normal weather in others. For example, El Niño episodes are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean and a decrease in the strength of the Pacific Trade Winds. This can cause, for example, a reduction in winter and spring rainfall over much of eastern and northern Australia (Power *et al.*, 1999) and droughts conditions in India (Kumar *et al.*, 2006). During La Niña episodes, the Pacific Trade Winds strengthen resulting in warmer seas to the north of Australia, while waters in the central and eastern tropical Pacific Ocean become cooler. Together, this effect gives an increased probability that eastern and northern Australia will be wetter than normal and droughts will be less likely.

1. Some authors distinguish between physical water scarcity and economic water scarcity. Physical water scarcity is a situation where there is not enough water to meet all demands, including that needed for ecosystems to function effectively. Physical water scarcity occurs frequently in arid regions and in areas where water seems abundant but resources are over-committed. Economic water scarcity defines situations where demand for water is not satisfied because of a lack of investment in water infrastructure or a lack of human capacity. This distinction is not necessary in the context of the strategic risk management approach set out in this book.
2. Peruvian anchovy fishermen first used the reference in relation to the Christ child to describe the appearance, around Christmas, of a warm ocean current off the South American coast, adjacent to Ecuador and extending into Peruvian waters.

Plate 1. Low water levels at Lake Hume, on the Victoria–NSW border, Australia, during the dry summer of 2007 during El Niño

Source: Guardian, 2014. Phototaken by Ashley Whitworth

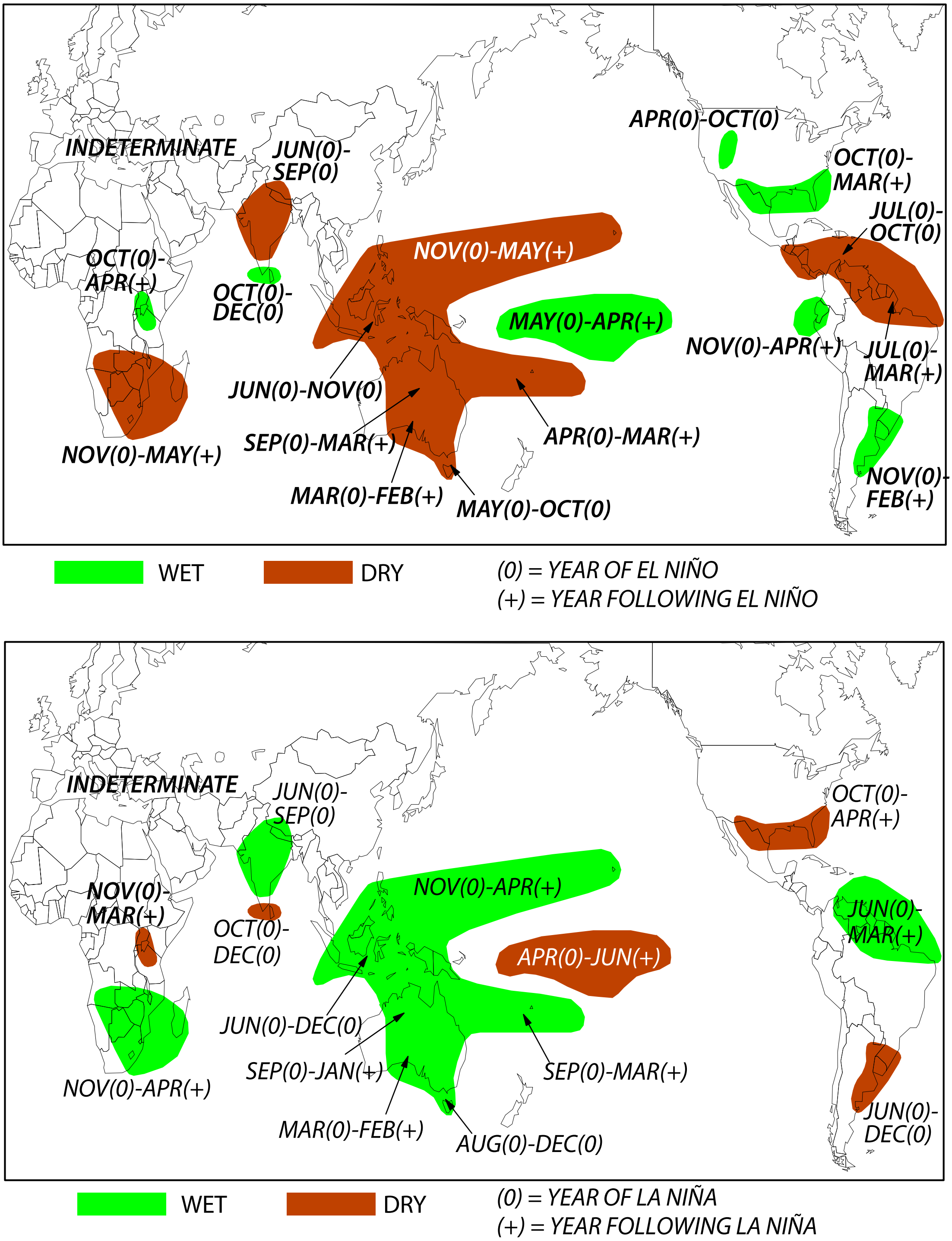
Pacific Decadal Oscillation and Interdecadal Oscillation

The PDO and the Interdecadal Oscillation are patterns of change in the Pacific Ocean's climate. During a 'warm' phase, the eastern ocean warms and the west Pacific becomes cool; during a 'cool' phase, the opposite pattern occurs. The oscillation shifts phases on at least an inter-decadal timescale, usually about 20 to 30 years. The spatial patterns and impacts are similar to those associated with ENSO events and, during the 'warm' phase, warm, humid air is advected along the North American west coast and temperatures are higher than usual from the Pacific Northwest to Alaska, but below normal in Mexico and the south-eastern US. The PDO is also considered to strongly influence the multidecadal droughts pattern in the United States, with drought frequency increased over much of the northern US during the warm phase and over the south-west US during the cold phase (McCabe *et al.*, 2004).

Atlantic Multidecadal Oscillation

The Atlantic Multidecadal Oscillation (AMO) has an influence on sea surface temperature in the Atlantic Ocean and is correlated to air temperatures and rainfall over much of the Northern Hemisphere, in particular, North America and Europe. Major droughts in the US midwest and the southwest have been correlated with the AMO's warm phase with two of the most severe droughts of the 20th century occurring during the positive AMO between 1925 and 1965: The Dust Bowl of the 1930s and the 1950s drought. Elsewhere, the warm phase of the AMO can increase summer rainfall (for example over India and Sahel), a pattern reversed during its cold phase (ShuangLin *et al.,* 2009).

Figure 1.3. Typical rainfall impacts from El Niño (top) and La Niña (bottom)



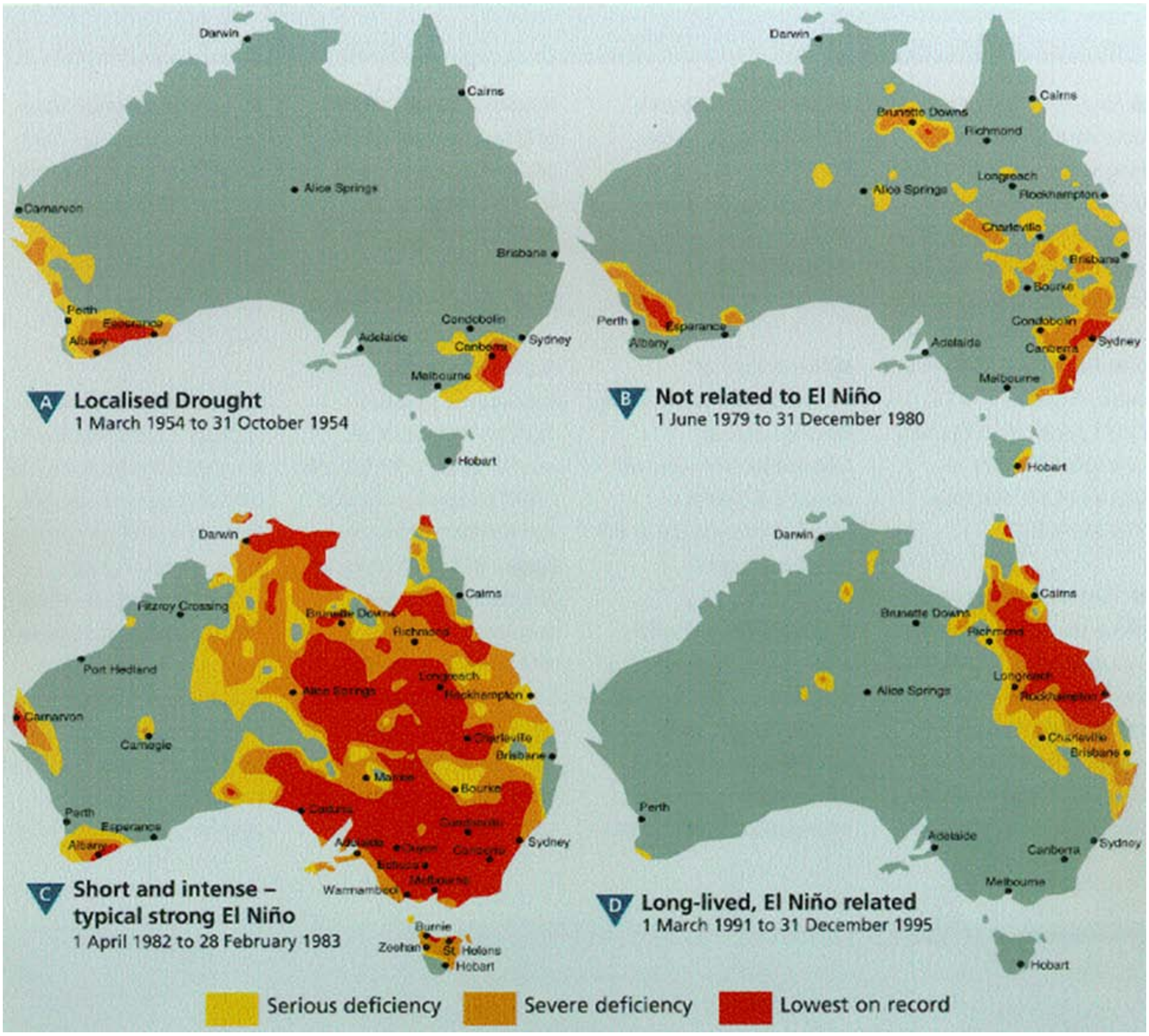
Source: Prepared by the Joint Agricultural Weather Facility Source, US after Ropelewski and Halpert (1989)

LOCAL HYDRO-METEOROLOGICAL PROCESSES

At a local scale, various hydro-metrological processes are important for determining the level of water vapour in the atmosphere and whether or not precipitation forms. These processes include temperature, radiation, wind stress, relative humidity, and pressure. In some regions, the seasonal timing of lack of precipitation can be crucial. For example, a lack of snowfall during the winter can have a significant impact on water availability the following spring and summer in catchments that rely of snowmelt. In England, for example, groundwater levels are crucially dependent on winter rainfall and are less affected by changes in summer rainfall (Marsh *et al.*, 2007).

Box 2: El Niño and drought in Australia – examples of historic droughts in Australia

Of the multiple causes of rainfall variability in Australia, the most influential is the Southern Oscillation, that is, the oscillation in surface air pressure between the tropical eastern and the western Pacific Ocean waters. El Niño events, which occur at one extreme of the oscillation, have typically coincided with extended, widespread periods of drought in Australia including both short, intense and extended events.



Source: Australia Bureau of Meteorology

1.4. Drought impacts

Droughts are pervasive; individuals, companies, habitats and species are all affected. The most severe droughts can be devastating. The 1942 drought in Bengal, India was the underlying cause of a widespread famine the killed 1.5 million people. The 1976–77 drought in the US has been estimated to have lost the US economy US$1.775 billion (California Department of Water Resource, 1978). Widespread ecosystem impacts have also been observed, evidenced by the increase in tree mortality across Canada's boreal forests after a series of regional droughts from 1963–2008, (Peng *et al.*, 2011). Even less severe droughts have an impact on agricultural productivity, urban water supplies and ecosystems. Drought also plays a role in shaping ecosystems. Many ecosystems are well adapted to some degree of drought, and some species have evolved mechanisms to take advantage of drought conditions.

Some of the most important impacts and interactions, are discussed in the following sections and in more detail in Chapter 8.

IMPACTS ON FRESHWATER ECOSYSTEMS

Freshwater ecosystems are defined here as river channels and the water within them, the floodplains, lakes, aquifers and upstream catchments including, for example, watershed forests that influence run-off as well as the plants and animals that live in and around those systems and agro-ecosystems that depend significantly on freshwater habitats. Freshwater ecosystems provide benefits to people and society, including natural resources to support human development; ecological functions such as nutrient cycling and carbon sequestration that sustain the planet; and intrinsic values such as wildlife and scenic areas that people can appreciate and enjoy. The term 'ecosystem services' is often used to describe these benefits and is commonly considered in four categories (MEA, 2005):

- **Provisioning services** provide food, fibre, medicines, and freshwater flows for key economic activities such as power generation and agriculture, as well as services on which individual lives and livelihoods may depend, such as river and lake water for domestic use and subsistence farming, fish stocks, and water flows for tourist activities such as rafting.
- **Regulating services** provide filtration of pollutants by wetlands, climate regulation through carbon storage and water cycling, pollination, and protection from disasters such as drought by regulating groundwater recharge, water storage and releases.
- **Habitat and supporting services** provide functions for the production of other ecosystem services such as soil formation, photosynthesis, pollination and nutrient cycling.
- **Cultural and amenity services** provide benefits through interaction with the natural environment such as education, recreation, spiritual values and aesthetic values.

Drought threatens all four categories of ecosystem services (Table 1.3). The Global Assessment Report (ISDR, 2011), for example, highlights that between 1999 and 2005 droughts contributed to the loss of at least 100,000 hectares of salt marshes along Florida's coastline in the US and in Spain the 1991–1995 drought indirectly resulted in draining wetlands, causing saltwater intrusion of coastal aquifers.

Droughts also play a positive role in ecosystems with minimal anthropogenic disturbance or that experience regular dry seasons. For example, low-flow periods are believed to be a major force in maintaining biodiversity (Everard, 1996): they enable some species such as certain floodplain plants to be successfully recruited (Humphries, King, and Koehn, 1999); purge invasive species that are less well adapted the local setting (Lake, 2003) (MEA, 2005); and can also benefit predators by concentrating prey into limited areas. Drought also impacts terrestrial ecosystems and there is an interaction between terrestrial and freshwater ecosystems, especially during green-water droughts that increase the chances of wildfires, dieback of forests and grasslands, impacts on terrestrial animals that, for example, die off from thirst or starvation.

Direct and indirect impacts on freshwater biota

Droughts can cause progressive loss of freshwater habitat, decline in water quality and depletion of food resources, which may result in a number of biotic responses including changes in population densities, species richness, life-history schedules, species composition, patterns of abundance, type and strength of biotic interactions, food resources and trophic structure (Lake, 2003). The impacts of a drought on freshwater biota can also persist for some time after the end of a meteorological drought. For example, the 1976–77 drought in California eliminated a population of the caddisfly (Resh, 1992), taking 10 years for the original population structure to be restored (Lake, 2003).

Droughts have both direct and indirect impacts on freshwater biota:

- direct impacts are those caused by loss of water and connectivity, as well as habitat reduction and reconfiguration;
- indirect impacts are those caused by the changes in water quality, biotic interactions (especially predation and competition), and other ecosystem elements or processes as a result of loss of water and connectivity.

The impacts drought may have on freshwater ecosystems are discussed in more detail in Chapter 8.

Table 1.3. Impacts of drought on freshwater ecosystem services

Freshwater ecosystem services	Impact of drought on ecosystem services
Provisioning services – products from freshwater ecosystems Impact of drought	
Fish and other aquatic products (used for food, medicinal and ornamental purposes)	Loss of freshwater habitat and connectivity leads to fish die-offs and death of other important aquatic flora and fauna.
Water (e.g. for drinking, irrigation, cooling)	Water levels fall below levels possible for abstraction, cutting off water supply to homes, industry and agriculture; natural water sources dry up; loss of connectivity means water storage such as reservoirs are not naturally replenished, reducing water available.
Supply of sediments	Loss of flow and connectivity means nutrient-rich sediment is not transported downstream.
Regulating services – positive results of freshwater ecosystem processes	
Climate regulation	As water bodies dry-up, their cooling effect diminishes.
Regulation of water flows (e.g. through natural drainage, groundwater recharge, natural storage)	Drying and compaction of soil caused by higher temperatures can impede soil infiltration and groundwater recharge; drought-induced wildfires can destroy forested areas, reducing their role in the regulation of water flows.
Water purification through nutrient and pollution uptake, retention, and particle decomposition	Drying of wetlands reduces their ability to purify water.
Biological control (e.g. seed dispersal, pest and disease control)	Habitat loss due to reduced water levels and lost connectivity means biological control services are diminished.
Habitat and supporting services – functions necessary for the production of other services	
Maintenance of life cycles of migratory species (including by providing suitable reproductive habitat and nursery grounds)	Habitat loss due to reduced water levels and lost connectivity means reproductive habitats and refugia are lost.
Maintenance of genetic diversity, especially gene pool protection	Species loss means genetic diversity is reduced.
Photosynthesis, primary production, nutrient cycling	Habitat and species loss leads to the loss of these services.
Cultural and amenity services – non-material benefits from interacting with freshwater ecosystems	
Aesthetic, spiritual and cultural experiences	Reduction in water levels and connectivity often leads to loss of aesthetic value of freshwater ecosystems and diminishes the use of freshwater ecosystems for spiritual and cultural purposes.
Opportunities for recreation and tourism	Reduction in water levels and connectivity often reduces the appeal of surface water bodies for tourism and recreation. Some recreational activities such as boating may stop.
Opportunities for use in science, education and other knowledge systems	Reduction in water levels, connectivity and species loss means the ability to use the freshwater ecosystem for these purposes is diminished.

Table 1.4. Drought impacts on human systems are exacerbated when freshwater ecosystem services are impacted by drought

Sector	The impact of drought on ecosystem services	Direct impact of drought on the economy and society	Escalation of impacts of drought	
			Stage I	**Stage II**
Agriculture	Reduced soil moisture and flows for irrigation	Damage to and diminished crop growth or yield production, resulting in income loss for famers and others affected and lowered food production	Increased importation of food (higher costs of food) Unemployment from production declines Agricultural water-user conflicts Loss of livelihoods for subsistence fishermen and farmers Food shortages and famine	Loss of national economic growth, slowing down of economic development Malnutrition and related health issues and diseases Enhanced social inequity Social unrest and political conflicts, including over water and food
	Reduced soil moisture and water for livestock	Loss from dairy and livestock production (due to reduced capacity and limits on food and water)		
	Degradation of ecosystem processes leading to increases in insect infestation and plant disease	Crop damage and predation of livestock		
	Reduced fish stock due to degradation of fish habitat	Loss from fishery production		
Tourism	Reduced recreation and tourism due to reduction in flows and surface water levels	Losses to recreational and tourism industry	Unemployment as tourism declines and loss of livelihoods	Loss of national economic growth, slowing down of economic development
Power, industry and navigation	Reduced flows through hydropower dams and reduced availability of water for cooling	Loss of production from hydroelectric and thermal power stations	Unemployment as industrial production declines Increased importation of food (due to reduced food processing) Water-user conflicts	Loss of national economic growth, slowing down of economic development Social unrest and political conflicts, including over water and food
	Reduced levels in rivers and canals for navigation	Reduced transport of goods		
	Reduced flows and surface water levels for industrial abstraction	Shortages of water for industrial users – reduced industrial output and export earnings		
Domestic uses	Reduced flows and surface water levels for domestic abstraction	Shortage of water for domestic use	Small-scale user conflicts Enhanced social inequity	Dehydration and related health issues and diseases Social unrest and political conflicts, including over water and food.
Other	Reduced flows and surface water levels for water-related cultural activities	Loss of cultural sites	Public dissatisfaction	Loss of national economic growth, slowing down of economic development Social unrest and political conflicts.
	Reduction in soil moisture	Wild fires	Damage to land and property	

Impact on the stability of freshwater ecosystems of prolonged drought

Prolonged drought can lead to tipping points or thresholds that, if crossed, result in abrupt, non-linear shifts in freshwater ecosystem states. For example, ecological changes may be gradual while a rif e dries, but cessation of flow causes abrupt loss of a specific habitat, alters physicochemical conditions in pools downstream, and fragments the river ecosystem. Crossing such geomorphological or hydrological thresholds causes abrupt changes in biological community structure and ecological processes, resulting in a stepped response – between a gradual change while a threshold is approached followed by a swift transition when a habitat disappears or is fragmented (Humphries and Baldwin, 2003). When certain critical thresholds are crossed, impacts on freshwater biota may be disproportionately severe (Boulton, 2003), which may hamper the recovery of a species. Such dramatic changes in freshwater ecosystems rarely occur because of drought alone, but typically result from a combination of gradual alterations in drivers of environmental change, external shocks (such as a drought, flood, fire or disease outbreak), and anthropogenic degradation.

IMPACTS ON HUMAN SYSTEMS

Almost all human activities rely on water. Human systems include strategic priorities for, and demands on, the freshwater system and the services it provides. Droughts can therefore have a significant impact on human systems. Some of the most important impacts are summarized in Table 1.4. The public health concerns raised in connection with the California drought by the Center for Disease Control and Prevention (CDC) are summarized in Box 3.

HUMAN AGGRAVATION OF DROUGHT IMPACTS

A range of pressures can aggravate the severity of the impacts on the freshwater ecosystem or slow (or even prevent) its recovery (Figure 1.4). The root causes of this is often poor planning, including:

Box 3: Public health concerns associate with the California drought, 2010 ongoing (CDC, 2010)

In 2010, the Center for Disease Control and Prevention (CDC) highlighted that droughts have far-reaching effects, including many effects on human health. They highlight seven potential health concerns in associated with the California drought.

Bad air: Droughts can reduce air quality and compromise the health of people with certain conditions. During a drought, dry soils and wildfires increase the amount of airborne particles, such as pollen and smoke. These particles can irritate the airways and worsen chronic respiratory illnesses, such as asthma. Poor air quality can also increase the risk of respiratory infections, such as bacterial pneumonia.

Valley fever: Drought increases the risk of people catching the fungal infection called 'coccidioidomycosis', or Valley Fever. The disease is transmitted when spores in the soil become airborne and are inhaled. The condition causes a range of symptoms, including fever, chest pain, coughing, rash and muscle aches.

Spread of infectious disease: In a drought, people reduce hand washing and other hygiene practices to conserve water. This may increase the spread of infectious diseases, such as acute respiratory and gastrointestinal illnesses. Conservation efforts during a drought should not hinder proper sanitation and hygiene. If well planned, for example, installing low-flow faucet aerators can reduce water use without compromising hygiene.

Mental health effects: People whose livelihood is directly tied to the water supply – including farmers, horticulturalists and nursery owners – may suffer adverse mental health effects during a drought. Financial-related stress and worry can cause depression, anxiety, and a host of other mental and behavioral health conditions. Studies have found an increased rate of suicide among people living in farming areas during droughts.

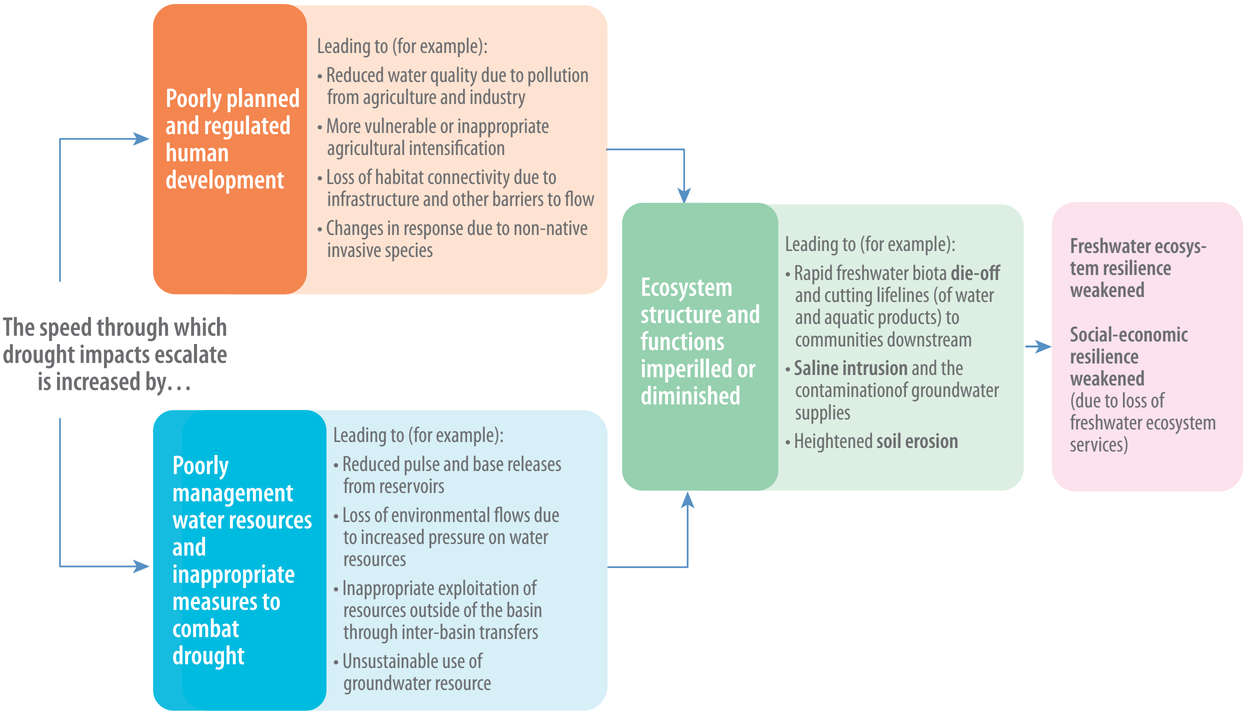
Unhealthy eating: Reduced rainfall can limit the growing season for farmers, and crop yields can be reduced creating increased in food prices, or shortages of certain foods, potentially leading to malnutrition. In a drought, farmers may also use recycled water. If the process is not properly monitored, crops can become contaminated with pathogens such as salmonella and E. coli.

Mosquito-borne diseases: Increases in diseases transmitted by insects, such as West Nile virus, which is spread by mosquitoes, is linked with drought. Drought can shrink bodies of water, and cause water to become stagnant, providing breeding grounds for mosquitoes. Droughts can also change the behavior of mosquitoes and allow unusual interactions between certain types of mosquitoes and birds, which can cause outbreaks of diseases such as St. Louis encephalitis.

Recreational injuries: Lower water levels may also mean an increase in injuries. Lower water levels are often difficult to perceive, and people may injury themselves by diving into shallow waters or striking objects while boating.

Source: Center for Disease Control and Prevention (2010)

Figure 1.4. The impact of a drought on a freshwater ecosystem may be aggravated by poorly planned human development and water resource management



- **Poorly planned and regulated human development.** Many development activities if poorly planned or poorly implemented can aggravate drought impacts. For example: (i) *Extractive activities* such as water abstraction for irrigation, livestock, industry and domestic purposes reduces river flows, increasing the vulnerability of freshwater ecosystems to drought. During drought, increased demand for water may lead to higher levels of water abstraction, exacerbating impacts, particularly in sensitive habitats; (ii) *Pollution* including chemicals, heavy metals, and nutrients all have an impact. Agricultural activities, for example, reduce riparian vegetation and increase the input of nutrients and sediments into surface waters, causing marked declines in habitat and water quality; (iii) *Land use and land cover change* can lead to habitat fragmentation due to urbanization or infrastructure development, reduced infiltration and groundwater recharge and base flows to rivers as well as encouraging lower biodiversity farming practice that increase vulnerability to drought; (iv) *Biological disruptions* such as the introduction of non-native invasive species, disease, and pests may increase stress on habitats and species and reduce their ability to cope with drought.
- **Poorly management of water resources and inappropriate measures to combat drought.** Examples include: (i) *Failure to provide environmental flows* leading to reduced pulse and base releases from reservoirs; (ii) *A driver for intensiificaiton* leading to more vulnerable or inappropriate agricultural practices; (iii) *Regional impacts* due to inappropriate exploitation of resources outside of the basin through inter-basin transfers; and (iv) *Unsustainable use* of groundwater resources.

When both development and water resources are poorly planned a range of impacts can threaten ecosystem structure and function. These include for example the rapid die-off of biota, saline intrusion and contamination of groundwater sources and even loss of soil cover.

Underlying these processes is the role of human influence on climate. Despite considerable uncertainty about how climate change will influence droughts, it is generally accepted that the severity of future droughts will increase (Pachauri, 2008). For example, globally, the proportion of land surface in extreme drought is likely to increase; some estimates suggest this could be by a factor of 10 to 30 by the 2090s (Burke *et al.*, 2006). At a more regional scale, developing an understanding of the potential impacts of climate change requires a detailed understanding of the hydrological resources of the basin. For instance, as temperatures have warmed over the past century, the prevalence and duration of drought has increased in western North America (Konstantinos and Leetenmaier, 2006). This impact reflects a number of climate change factors. For example, there is high confidence that increased temperatures lead to more precipitation falling as rain rather than snow, earlier snow melt, and increased evaporation and transpiration. Much of the mountainous western states of the US have experienced a decline in spring snowpack, especially since the 1950s (Mote, 2006). Earlier snowmelt, associated with warmer temperatures, can lead to water supply being increasingly out of phase with water demands. While there is some variability in the models for western North America as a whole, climate models unanimously project increased drought in the southwest. The southwest is considered one of the more sensitive regions in the world for increased risk of drought caused by climate change (Sheffield and Wood, 2008). Drought management therefore has a legitimate interest in the mitigation of climate change as well as adapting to it.

Summary

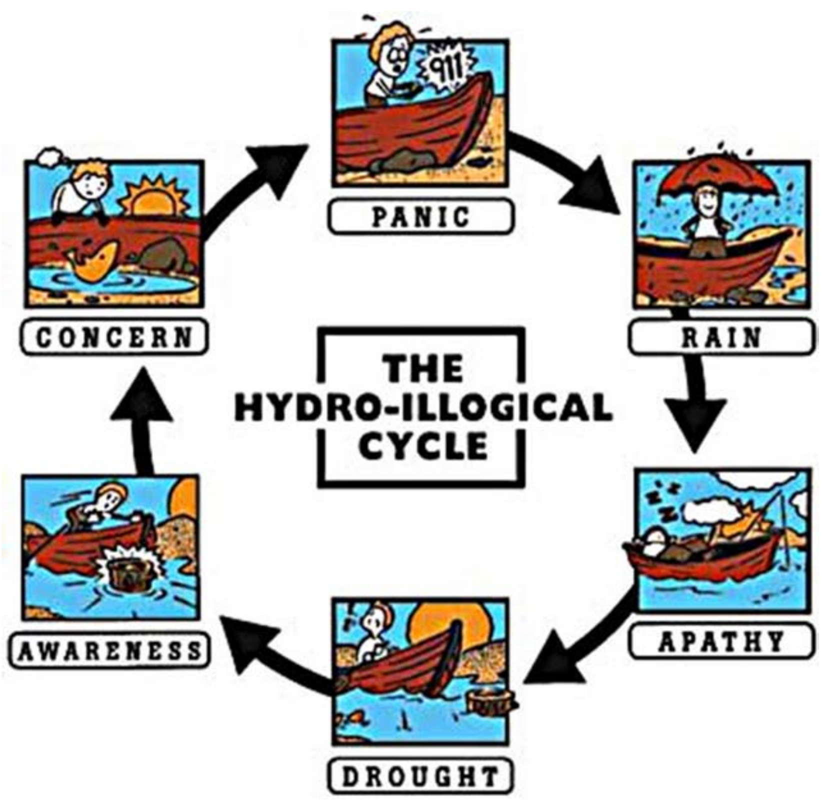
This chapter has explored what is meant by 'drought', the climate drivers of drought, including large-scale climatic features such as La Niña and El Niño, and the range of impacts a drought can have on human systems and freshwater ecosystems. The discussion reaffirms that drought is an extreme event and presents a new classification of 'drought hazard' based on meteorological, blue-water and green-water considerations. The new definition does not conflate hazard and risk as traditional definitions often imply; it distinguishes drought from issues of water scarcity while highlighting the interactions between the two. The impact drought has on human systems and freshwater ecosystems, which sometimes leads to profound impacts such as famine and ecosystem and societal collapse, are also explored.

CHAPTER 2
LESSONS LEARNT, LIVE ISSUES AND CHALLENGES

2.1. Introduction

Droughts are an ever-present threat in almost all countries. The majority of droughts have been responded to 'as they happen' with authorities and communities often struggling to deliver emergency relief. In response, drought planning and management has largely developed on an *ad hoc* basis, reflecting lessons learnt from particular drought episodes and the capacity of communities to react to those lessons. As lessons are learnt, drought management practice and policy evolves. Often, when rain returns, the impacts of drought are soon forgotten and society loses the momentum to better prepare for the next drought episode (Figure 2.1).

Figure 2.1. The hydro-illogical cycle: Drought risks are all too often forgotten and societies persistently fail to prepare



Source: Nebraska Drought Monitoring Center. http://drought.unl.edu/Planning/HydroillogicalCycle.aspx

This does not mean that drought events have had no influence on policy or practice. Society's approach to drought management has undergone significant change throughout history in response to the lessons learnt from past events and as a result of advances in science (Figure 2.2). This evolution (from nomadic–disaster–emergency–strategic) also links closely to humans' evolving relationship with ecosystems during droughts from learning to live with the changing ecosystem as the drought unfolds, to exploiting ecosystems, to recognizing interlinkages between societal well-being and ecosystem health, and the role that ecosystems can play in reducing drought risk.

This chapter concentrates on both the lessons from past droughts and parallel advances in science and philosophy that shape this evolutionary path as well as the live issues and challenges that are still to be overcome.

Figure 2.2. The evolution of drought risk management

Nomadic	**A natural event to be adapted to.** • The lifestyles of individual and communities inherently adapt to natures rhythms. • Resilience through nomadic existence. • Use of ecosystem services implicitly regulated.
Disaster	**An unforeseeable natural disaster to be endured.** • Droughts seen as inevitable but unpredictable. • Significant action is only taken after the emergence of the drought. • Actions focus on immediate and local issues to secure drinking water and avoid famine. • Commitment to prepare is based on community memory of recent droughts and is fundamentally unable to manage prolonged drought. • Ecosystems exploited during a drought with little regard to future recovery.
Emergency	**A hazard to be monitored, forecast and responded to.** • Monitoring and early warning systems provide some foresight of the developing drought. • Drought alerts are issued and steps taken to limit drought losses. • Recovery of key sectors, such as agriculture, seen as vital and aided through financial compensation. • Reactive actions taken to protect priority species and ecosystem services.
Strategic	**A proactive process of long-term risk based planning, response and recovery.** • A **'standards-based'** approach (current good practice) (i) Acceptable restriction frequency pre-defined based on historical events of reference; (ii) infrastructure developed to provide necessary reserve capacity; (iii) minimum flow requirements set to protect ecosystems. • A **'risk-based'** approach **(the focus of this book)** (i) A broadly based portfolio of measures –applied at a range of scales -are used to deliver fair and sustainable outcomes; (ii) long-term, broadly based, benefits and costs traded to make best use of limited resources; (iii) impacts on economies and ecosystems understood and managed.

2.2. Historical droughts: lessons learnt

DROUGHTS IN ANCIENT TIMES: 4000 BC TO 500 AD

The decline of Bronze Age civilizations in Egypt, Greece and Mesopotamia has frequently been attributed to a succession of drought events and associated famines between 3000 BC and 1000 BC (Bernhardt *et al.,* 2012; Weiss, 1982).

Recent studies suggest drought may have played a similar role in the demise of the Harappan Civilization within the Indus Valley (Marris, 2014; Dixit *et al.*, 2014). Analysis of Oxygen-16 and Oxygen-18 isotopes taken from the sediment of an ancient lake suggest that the monsoon cycle, vital to the livelihood of all of South Asia, stalled for as long as two centuries. From around 1800 BC, the Harappan Civilization slowly lost urban cohesion, and their well-planned cities with advanced municipal sanitation systems were gradually abandoned (Plate 2).

Dendrochronology studies have highlighted evidence for a persistent period of European drought from around 124 AD to 210 AD (Bungten *et al.*, 2011). This is likely to have weakened the Roman Empire economically, depopulating marginal agricultural areas and reducing farm production in general. Throughout this period, China also experienced a number of large-scale droughts, resulting in significant loss of life (Table 2.1). These extreme droughts had deadly consequences. Crops failed, millions of people died from the resulting famines, economies collapsed and civil unrest often followed.

Plate 2. Drought may have been a contributing factor to the demise of the Harappan Civilisation (2000 BC)

Source: European Pressphoto Agency/Alamy

The earliest communities implicitly accepted these risks as part of life. They adapted to nature's rhythms through a nomadic existence, always moving to find food and water. Resilience was achieved through flexibility. As communities became more settled, they had little ability to protect themselves from the worst effects of drought. Although droughts were seen as inevitable, early civilizations did attempt to prepare for them. With a focus on saving lives and avoiding famine, many of the reactive approaches used would be familiar to us today:

- **Use of historical reference droughts.** Often, preparing for drought reflected the collective memory of past drought events.
- **Food stockpiling.** Food stockpiling has always been a core strategy to mitigate the worst impacts of drought and prevent famine. There is evidence in the Old Testament (Genesis, Chapter 41) that food stockpiles date back more than 4,000 years, it provides details of how the Egyptians stockpiled enough food for two years.
- **Water restrictions.** Prioritizing the use of water has also always been a natural response to periods of drought. The start of the evolution of urban water management can be seen in Ancient Greece when the early Minoan civilisations attempted to balance supply and demand (Koutsoyiannis *et al.*, 2008). It is unclear if water restrictions were implemented as a management option during periods of drought, but it is likely that they were.
- **Developing inter-regional transfers.** There is evidence that early civilizations used water transfers from one basin to another as part of water management and drought planning. For example, the Hangou waterway was operating in ancient China in 486 BC (Liu and Zheng, 2002). The Romans built extensive networks of aqueducts, the first of which was built in Rome in 200 AD (Fantham, 2010). The Ancient Greeks constructed large-scale hydraulic projects for water transport during the oligarchic periods (Angelakis and Koutsoyiannis, 2003). Although on a significantly smaller scale than some of the mega-transfers developed in recent years, such are the south–north transfer scheme in China, these smaller-scale, inter-regional transfers often made an important contribution to overall resources.

Table 2.1. Selected droughts in China: 0 AD to 500 AD: impact on society

Year	Impact
134	The drought occurred in spring, summer and winter in Henan, Inner Mongolia and the central part of Shaanxi. Large areas of crops were affected.
301	The drought occurred from summer to autumn in Hebei, Shandong, Liaoning, Shanxi, Henan, Jiangsu, Anhui, Hubei, and Inner Mongolia. The Yellow River and other rivers in the area dried up, insect infestation occurred, and 60% of grain was lost.
309	A severe drought occurred in the summer in Henan, Shaanxi, Gansu, Jiangsu, and Sichuan. Most of rivers in the area dried up.
464	The drought occurred in eastern Hebei, Jiangsu, Zhejiang, and Inner Mongolia. Impacts included rising food prices due to reduced harvests, and a famine impacted 60%–70% of the population.

DROUGHTS IN THE MIDDLE AGES: 500 AD TO 500 AD

In England and across Europe, environmental shocks were instrumental in restructuring of the economy and society (Gerrard and Petley 2013), including the Great Famine (1315–22) and the Black Death (1348–9). In China, a severe drought (1637-1646) during the reign of Emperor Chongzhen of the Ming Dynasty affected more than half of the population. Agricultural production collapsed and prices rose, eventually leading to revolution and the collapse of the Ming Dynasty in 1646 (GIWP, 2013).

In many ways Medieval Society however was a risk-based society with an increasingly sophisticated toolkit in hazard mitigation, adaption and development of measures of protection. The measures taken to manage the flooding in the Netherlands and China are well documented (e.g. Sayers *et al.*, 2013). Although less well recorded, it is clear that non-structural and structural responses were all features applied to the management of drought too, for example:

- **Non-structural measures.** Cooperative and collective action was a particular feature of medieval life. Economic losses were often shared across the community. For example, after the 1333 flood in Florence, city authorities formed a committee to oversee the repairs, lowered taxes on imported foodstuffs, organized tax relief for those in need, and helped the distribution of food supplies. Attempts were also made to spread the burden of loss over longer periods to reduce the immediate severity of an event. Across medieval Europe, monastic estates provided centralized storage for unthreshed grain, while supplies of threshed grain were piled in cellars and upper storeys as well as in civic granaries (Gerrard and Petley, 2013). Margins were tight and quantities insufficient to ride out a long crisis (Claridge and Langdon, 2011), but localized shortfalls could be overcome temporarily by releasing a portion of what was held in store. An alternative, if costly, strategy was to purchase grain from outside the local area. For example, in the winter of 1316, English merchants bought up stores of corn, and even went abroad to buy more (Kershaw, 1973). This option was preferred when impacts were geographically widespread and demand could not be met locally. Following the eruption of Mount Rinjani in Indonesia (1258–1261), a combination of dust and drought plunged England into famine as crops failed. Grain was then shipped from Germany and Holland into London (Stothers, 2000). To avoid profiteering, permanent community stockpiles of grain that could be used on demand also started to emerge, such as the Leadenhall Granary, built in the 1440s in London (Samuel, 1989).
- **Structural measures.** Infrastructure responses to water resource issues such as storage reservoirs and water transfer schemes feature as societies developed. Specific consideration of drought risks is more difficult to discern but are likely to have been considered.
- **Adaptation.** Cooperation and sharing was also common in Medieval times. For example, in parts of Medieval Spain villages were dependent on a network of hydraulic or gravity-flow canals that required cooperation between upstream and downstream irrigators to operate successfully.
- **Resilience.** The degree of preparedness and resilience of societies was a function of collective experience of the hazard. Greater resilience was found in communities frequently exposed to natural hazards, for example in regions prone to frequent flooding and among so-called 'seismic cultures' that learnt to live with frequent earthquakes (Gerrard and Petley, 2013). As a consequence, low-frequency, high-magnitude events (such as droughts) generated higher losses, at least in part because preparedness was lower.

DROUGHTS AND INDUSTRIALIZATION: 00S TO 0S

During the period 1700s to 1930s, droughts were perceived as a disaster to be endured. With limited capability to forecast drought and little capacity to prepare, in most cases droughts were responded to as they occurred. Efforts were concentrated on limiting the worst of the impacts. Other than investment in storage infrastructure, there was little evolution of drought policy or practice throughout this period. Although some droughts would have yielded important lessons, few seem to have been acted upon.

Instead the focus was on satisfying the growing industrial demand as many societies transitioned from cottage-based industries to machine-based economy and from a subsidence agricultural sector to a rapidly growing urbanized and industrialized society. As a result, significant investment was directed towards securing water resources. Despite the additional supply that resulted, the margin between supply and demand tended to worsen increasing vulnerability to drought; a vulnerability exposed by a number of major droughts (Table 2.2).

Table 2.2. Selected droughts: 1700 to 1930: impact on society and influence on drought management policy and practice

Year	Country	Impact and influence on policy and approach
1637–45	China	The Great Famine The 1637–45 drought resulted in crop failure, famine and widespread loss of life. Civil unrest followed, eventually leading to the overthrow of Emperor Chingzhen and the fall of the Ming Dynasty.
1769–73	India (Bengal)	The Bengal Famine Estimated to have killed 10 million people, or a quarter of the population in Bengal. Large areas were depopulated and returned to the jungle for decades, as the survivors migrated in a search for food.
1854–60	England	The Long Drought A sequence of dry winters in both the lowlands (seven winters in succession at Oxford) and northern England had a devastating impact on groundwater levels and agricultural production.
1876–79	China	The Great Famine China, Iran and Russia were all impacted by this period of drought. In China, more than nine provinces were affected and approximately 9 million people died as a result of the associated famine. The Chinese people were increasingly dissatisfied with the rule of the Qing Dynasty as they became aware of their material inferiority compared to foreigners, which insulted cultural pride and opened China to the preaching of foreign missionaries.
1877–88	Brazil	The Great Drought The most severe drought ever recorded in Brazil, caused approximately half a million deaths and forced thousands of people to migrate to the cities. The mass migration generated fear among the elite, prompting a call for state intervention. Drought management was linked to a state obligation, rather than a natural disaster and was removed from public responsibility.
1895–03	Australia	The Federation Drought One of Australia's most devastating droughts in terms of stock losses, with more than 40% of cattle lost and sheep numbers halved. The drought started a focus on providing reliable irrigation.
1899–1900	India	A widespread drought impacting all of India. Between 1.25 and 4.5 million people died due to food shortages and accompanying disease. Over 1 million cattle also died in the famine.

DROUGHTS FROM THE GREAT DEPRESSION TO THE LATE 0TH CENTURY: 0S TO 0S

From the Great Depression to the late 20th Century, governments and international aid agencies acted in response to a drought. This emergency management approach focused on acute (i.e. severe and brief) impacts to humans, with little attention given to impacts on ecosystems and their services, and the longer-term knock-on impacts for society. Little attention was given to preparedness, mitigation, and prediction or early warning actions that could reduce future impacts. As in previous centuries, the focus on emergency management meant countries often experienced severe impacts when drought occurred (Table 2.3). Almost without exception, the reactive nature of the emergency management approach was exposed as ineffective and drought relief measures were often poorly targeted and did little to reduce vulnerability to the next drought. In fact, drought relief efforts often increased vulnerability to future events by reducing the level of self-reliance and increasing dependence on external assistance such as penalising efforts to prepare for future droughts by rewarding those that who failed to prepare with financial compensation. The conflicts in Sudan and Chad that continue today are, in part, a response to decades of poorly managed droughts that continue to force pastoralist communities (and their livestock) south in search of water and onto land mainly occupied by settled farming peoples (Xavier, 2008).

Some important lessons and changes in approach did however start to emerge. The Dust Bowl Drought (1931-39) acted as a catalyst for many of the most significant changes, including the need to:

- **Provide forecasts.** The need to be able to detect the onset of a drought and provide more reliable forecasts became more central to planning from the 1950s. Various indicators were established to detect and monitor droughts. During this period, indices such as the Palmer Hydrological Drought Index and the Palmer Drought Severity Index (Palmer, 1965) became well established globally.
- **Provide f nancial aid to speed recovery.** It was recognized that the time taken for key sectors to recover is reduced if financial and humanitarian aid is provided quickly, which led to the establishment of the US Drought Relief Service in 1935.
- **Have clear decision making powers.** The need for a decision making process emerged, with the need for powers to implement emergency measures. For example, the Drought Emergency Task Force was established during the 1976–77 drought in California.
- **Agree priority water restrictions.** The use of water restrictions as part of the drought management approach become commonplace during the late 1970s in the UK (Grafton and Ward, 2008), Australia (Brennan *et al.*, 2007) and the US (Shaw and Maidment, 1987). In most developed countries, essential water uses were defined as drinking, flushing toilets, cooking, and emergency use such as firefighting with restrictions applied to outdoor non-essential water uses.

- **Manage short-term emergency supplies effectively.** Short-term responses included additional extraction licences, relaxing planning for emergency construction of reservoirs and interconnections to existing supply, and tankering supplies all featured during this period. Difficulties associated with the control of additional water abstraction (both illegal and illegal) emerged as an important issue. The recognition of the damage to ecosystems that could arise from temporary relaxation of environmental protections was also increasingly recognized.
- **Develop inter-regional transfers.** Inter-basin transfers were recognized as way of enlarging the scale water resources could be managed (extending beyond the confines of the natural basin). Inter-basin water transfers were constructed in several nations (e.g. US) as a means of evening out natural spatial variability, shifting water from areas of oversupply to regions where agricultural, industrial, power and domestic water demands are comparatively higher and natural water resource availability is lower.

Table 2.3. Selected droughts from the Great Depression to the 1970s: impact on society and influence on drought management policy and practice

Year	Country	Impact and influence on policy and approach
1931–39	US	The Dust Bowl (1934, 1936, and 1939) The Dust Bowl was caused by sustained drought conditions compounded by years of land management practices that left topsoil susceptible to the forces of the wind. The primary area of impact was on the southern plains of the US. The agricultural devastation was so significant it lengthened the Depression and lead to a mass migration of people away from the plains. The need to provide financial support to farmers and manage soil erosion was recognized which directly led to the formation of the Drought Relief Service in 1935.
1939–45	Australia	The Forties Drought 1940 was one of the driest years on record across southern Australia and between 1942 and 1945 nearly 30 million sheep died.
1942	India (Bengal)	It is estimated that 1.5 million people died as a result of the famine that followed the drought (although various other issues contributed to the famine).
1951–56	USA	Six-Year Texas Drought Characterized by both low rainfall and high temperatures, this drought devastated the region's agriculture. Many counties across the region were declared Federal Drought Disaster Areas, including 244 of the 254 counties in Texas. Crop yields in some areas dropped by up to 50%.
1959–61	China	Great Chinese Famine Drought, economic mismanagement and radical change in agriculture policy contributed to a three-year famine. Although the estimates vary, between 15 and 45 million people died. The Great Leap Forward, a campaign devised to rapidly transform China from an agrarian economy into a communist society through rapid industrialization, was heavily criticized for its role in causing the famine. As a result, Mao Zedong was forced to stand down as State Chairman, although this later led him to initiate the Cultural Revolution in 1966. This famine highlighted the fragility of political ideals when they fail to prepare for drought.
1965–66	India	An estimated 1.5 million people died as a result of the drought and associated famine and 100 million people were affected. The drought induced a restructuring to the approach to drought disasters and promoted a public distribution system to ensure availability of food during periods of drought. The Drought Research Unit started functioning at Pune in 1967.
1972	India	Some 100 million people were affected by this drought that impacted all of India. The drought highlighted the importance of stimulating economic activity and employment in drought-affected areas to provide access to food.

DROUGHTS IN THE MODERN ERA: 0S TO PRESENT DAY

Since the 1970s, major droughts have continued to have profound impacts on people, economies and ecosystems (Table 2.4). In many cases, the approach to drought management continues to be inadequate. In some case, drought events have led to specific shifts in the management approach. For example, the 1976 drought in the England had a fundamental impact on the way water resources are planned and preparation for future droughts were made, requiring privatized water companies to plan to deliver specified levels of service under various drought scenarios based on a 'drought of reference' (Box 4). Throughout this period, the approach to drought management has started to be influenced by a number of parallel advances in water and environmental management more generally. These advances, discussed in section 2.3, together with the increasing recognition of the need to provide a more holistic management of water-related hazards and risks (as seen by the UK 'flought' in 2012) and a long-term and more comprehensive approach to preparing for drought as promoted in the aftermath of major droughts in Brazil, US, Europe and China as the basis new 'strategic' approach to drought risk management promoted in Part B of this book.

Table 2.4. Selected droughts from the 1970s to present day: their impact and their influence on drought management

Drought event	Impact and influence on thinking, policy and practice
1976: England	Severe impacts on surfacewater and groundwater resources leading to widespread restrictions. This event was the catalyst to set standards of service in water provisions that take account of plausible worst-case drought scenarios.
1976–77: US (California)	The driest year in the state's recorded history (at the time) causing significant economic loss: $888.5 million in 1976 and $1.775 billion in 1977. The need for clear decision making processes emerged with an authority to act during the drought (a Drought Emergency Task Force was established) and the recognition of the need for a more complete drought strategy based on both preparing for and responding to drought events.
1979–83: Brazil	This drought was identified as a contributing factor to more than 700,000 deaths from starvation and associated conflicts. The event highlighted the civil unrest and political corruption in the distribution of ad hoc emergency aid – ultimately leading to the recognition of drought and flood issues with the 1985 the Civil Defence Plan.
1987–92: US (California)	The most costly drought in US history, estimated at $80–$120 billion in damages. Initially affecting the whole of the country the drought continued to persist in California for a further three years. The event highlighted the need for flexible trading of water between voluntary buyers and sellers. The Water Conservation in Landscaping Act (1990) set evapotranspiration goals for new and renovated landscapes. The need for better forecasting led to the formation of US Drought Mitigation Center in 1995, the US Drought Monitor in 1999, and the National Integrated Drought Information System in 2006.
2004–5: Syria 2000–1: China 2002: India 2003: Europe 2001–2012: Australia (Millenium Drought) 2007–09: Spain	The need for national drought regulations and regional or national strategic planning emerged as central to. Key principles for addressing water scarcity and drought were outlined by the European Community in 2007. Drought observatories were established in various regions, including the European Drought Observatory, established by the Joint European Research Center.
2001: Africa	Severe drought affected the entire East Africa region causing a severe food crisis across Somalia, Djibouti, Ethiopia and Kenya that threatened the livelihood of 9.5 million people. This event highlighted the significant financial aid needed to provide basic a humanitarian response across large areas and the difficulties of raising sufficient funds in a short time.
2011–12: England	The prospect of a drought impacting the London Olympics had the potential for economic losses of £300 million per day across the region. In fact, the period of exceptionally dry conditions was followed by a period of extremely heavy rainfall and major drought losses were avoided. However, flooding did occur. The 'flought' highlighted the need for more integrated drought and flood management and highlighted the challenge of communicating water-related risk.
2010 (on-going): US (California)	As the drought entered its fourth year, a State of Emergency was declared in January 2015. At the time of writing the significant economic and environmental impacts continue to be felt. This event has highlighted the need for improved long-term planning with clearer understanding of water priorities, better awareness of water saving and the need for long-term strategic drought planning and policy.
2012 (on-going): Brazil	Three concessive years of significantly below average precipitation has lead to Brazil's worst drought in 80 years. The drought has left the Cantareira system, which provides greater Sao Paulo with most of its water, with the lowest water level on record, with daily rationing becoming common in the region's smaller cities. The solutions to the severe drought in Brazil must go deeper than water rationing and pressure changes. Broad and longer-term landuse and catchment water resource management is also emerging as an important lesson.

Box 4: The 1976 drought in England was the catalyst for more proactive drought planning in London

The lowest 16-month rainfall on record in England and Wales (since 1766) peaked in summer 1976 with associated severe impacts on surfacewater and groundwater resources. This event provided the catalyst to improve drought planning and water resource provision. The event is used as the 'drought of reference' across much of England and Wales for drought planning today. Without groundwater recharge during the wetter winter months, baseflows in the River Thames quickly depleted and Thames Water, the water utility company serving London and much of south-east England, was unable to abstract sufficient water to maintain reservoir storage levels and ensure security of supply. The drought was unprecedented and the maintenance of water supply in London became an increasing concern. Reservoirs were emptying and drastic water conservation measures were introduced.

The drought broke in late August, with winter rain arriving early; severe water use restrictions were not required but measures were ready to be implemented. The management of the drought had been reactive and there was no prescribed process for managing water supply. The unprecedented nature of events provided a strong impetus to put robust processes and policies in place for a more proactive management approach. Following the drought, a public inquiry was held and The Lower Thames Operating Agreement was written. This agreement set out a procedure for proactively managing water supplied during drought. It includes protocols to ensure action is taken early to conserve water while preserving base flows at Teddington Weir, the downstream boundary of the Thames River basin. The agreement also includes prioritized restrictions that are progressively implemented based on an assessment of water resources on the assumption that only 60% of the average rainfall occurs in the coming months.

This agreement is still in place today and, in association with the government water regulator (OFWAT) of the private water companies, the acceptable frequency of the progressive restrictions (Levels I to 4) are agreed as detailed in the Levels of Service table below. Under Level 4, 'never' means that, providing future droughts are no more severe than the most severe in the historic record, extreme restrictions are not required and the Company would never plan to include this measure as part of its operating strategy.

Levels of Service provided by Thames Water

Restriction Level	Frequency of Occurrence	Water use restrictions
Level 1	1 year in 5 on average	Intensive media campaign
Level 2	1 year in 10 on average	Sprinkler and unattended hosepipe ban, enhanced media campaign
Level 3	1 year in 20 on average	Temporary Use Ban (formerly Hosepipe ban), Drought Direction 2011 (formerly non-essential use bans) requiring the granting of an Ordinary Drought Order
Level 4	Never	If extreme measures are necessary, their implementation would require the granting of an Emergency Drought Order

Source: Thames Water website: http://www.thameswater.co.uk/ accessed Apirl 2015

2.3. Parallel advances of relevance to drought management: 1970s to present day

Approaches to drought management have not evolved in isolation. Broader concepts influence evolution of drought management (Figure 2.3). The most important of these concepts, and how they have shaped drought management, are discussed.

SUSTAINABLE DEVELOPMENT

In 1987, the United Nations released the Brundtland Report (WCED, 1987) that defined sustainable development as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs' and subsequently agreed Agenda 21, a non-binding, voluntarily action plan to support sustainable development (United Nations, 1992). The simple concepts embedded in these documents emphasize the linkage between economic development, environmental health and social well-being (Figure 2.4).

It also promotes a long-term, broadly based view of the benefits and, impacts of any decision.

Figure 2.3. Important inter-related concepts and trends that form the basis the Strategic Drought Risk Management

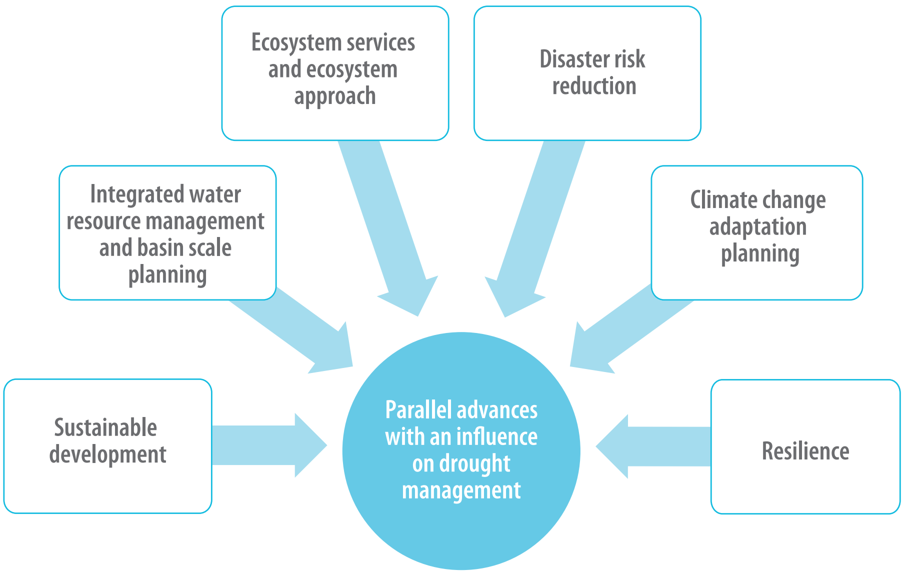
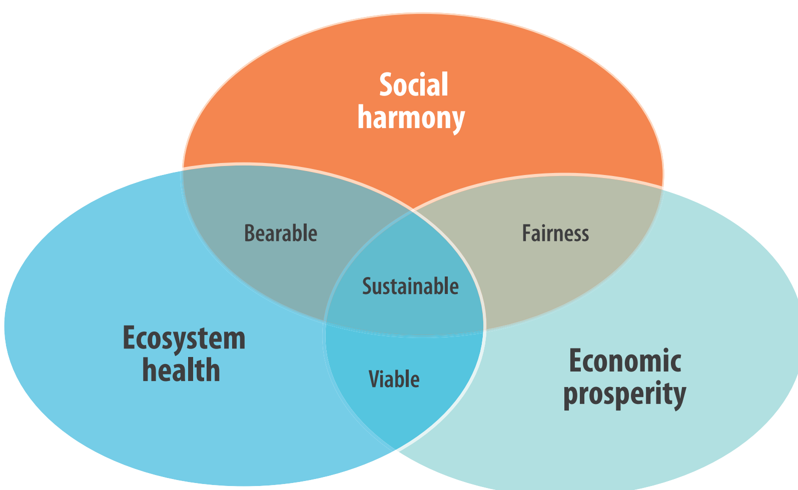


Figure 2.4. Pillars of sustainable development



Source: United Nations (1992)

In 1992, the UN Conference on Environment and Development (the Earth Summit) held in Rio de Janeiro set out a blueprint to achieve sustainable development in practice (Agenda 21). Agenda 21 reinforces the notion of integration, and stresses a move away from sector-centred approaches to cross-sectoral coordination and integration. Broad public participation in decision making as a fundamental prerequisite for achieving sustainable development is also emphasized.

In 2000, at the Millennium Summit of the United Nations, all United Nations member states committed to supporting the principles of sustainable development and set out eight Millennium Development Goals (MDG) to be achieved by 2015:

1. to eradicate extreme poverty and hunger
2. to achieve universal primary education
3. to promote gender equality and empower women
4. to reduce child mortality
5. to improve maternal health
6. to combat HIV/AIDS, malaria and other diseases
7. to ensure environmental sustainability
8. to develop a global partnership for development.

Water, and the management of drought, is relevant to many of these goals and features in the specific targets set out under MDG 7: To ensure environmental sustainability (Box 5). A series of Sustainable Development Goals (SDGs) (draft at the time of writing) are expected to follow-on from, and expand upon, the existing MDGs (that are due to expire at the end of 2015). The SDGs will frame international agendas and political policies for the next 15 years to 2030. Although the SDGs are yet to be confirmed, initial proposals reinforce the importance of well-managed water resources and the need to protect, restore and promote healthy ecosystems. For example, draft SDG6 specifically targets sustainable management of water:

Goal 6. Ensure access to water and sanitation for all

- by 2030, achieve universal and equitable access to safe and affordable drinking water for all
- by 2030, achieve access to adequate and equitable sanitation and hygiene for all, and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
- by 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally
- by 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity
- by 2030 implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
- by 2020 protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
- by 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
- support and strengthen the participation of local communities for improving water and sanitation management.

INTEGRATED WATER RESOURCE MANAGEMENT AND BASIN-SCALE PLANNING

The concept of Integrated Water Resources Management (IWRM) emerged in response to the recognized shortcomings of massive water resources infrastructure developed across the world between 1920 and 1970. In particular, it became increasingly clear that:

- technical engineering solutions alone would not solve complex water resource issues
- functioning freshwater ecosystems are a prerequisite to sustainable development
- without more innovative approaches the cost of water supply and waste management would continue to increase
- without a more decentralized management and greater stakeholder engagement it is difficult to deliver sustainable outcomes.

The principles of IWRM, as enshrined by the so-called Dublin Principles (ICWE, 1992), represent a move away from water resource development and emphasizes environmental protection, stakeholder participation and identifies water as an economic good. The IWRM encompasses sustainable use of water resources to support ecosystems, societies and economies.

Although progress towards the IWRM has been slow, accepted frameworks of good practice based on basin planning are starting to emerge (Pegram *et al.*, 2013). These frameworks provide useful lessons for managing drought risks. They highlight the need to: (i) focus on maintaining critical ecosystem functions and services; (ii) make choices within the context of limited information and imperfect institutions; (iii) implement multiple management responses (including but not limited to infrastructure); (iv) develop basin-scale environmental management; and (v) reflect future change (economic, environmental and social) within the decision making process.

Box 5: Millennium Development Goals and Sustainable Development Goals and their relationship with water issues

The UN Millennium Declaration sets out eight MDGs. Water, and its appropriate management, is central in achieving all of these. These specific MDGs included:

- Goal 1: Eradicate Extreme Hunger and Poverty: Access to water for domestic and productive uses (agriculture, industry, and other economic activities) has a direct impact on poverty and food security.
- Goal 2: Achieve Universal Primary Education: Incidence of catastrophic but often recurrent events such as droughts, interrupts educational attainment.
- Goal 3: Promote Gender Equality and Empower Women: Access to water, in particular in conditions of scarce resources, has important gender related implications, which affects the social and economic capital of women in terms of leadership, earnings and networking opportunities.
- Goal 4: Reduce Child Mortality and Goal 5: Improve Maternal Health: Equitable, reliable water resources management programmes reduce poor people's vulnerability to shocks, which in turn gives them more secure and fruitful livelihoods to draw upon in caring for their children and hence maternal stability.
- Goal 6: Combat HIV/AIDS, Malaria and other diseases: Access to water, and improved water and wastewater management in human settlements, reduces transmission risks of mosquito-borne illnesses, such as malaria and dengue fever.
- Goal 7: Ensure Environmental Sustainability: Adequate treatment of wastewater contributes to less pressure on freshwater resources, helping to protect human and environmental health.
- Goal 8: Develop a Global Partnership for Development: Water scarcity increasingly calls for strengthened international cooperation in the fields of technologies for enhanced water productivity, financing opportunities, and an improved environment to share the benefits of scarce water management.

As 2015 approached, the MDGs were discussed at the Rio+20 Conference and member states agreed to launch a process to develop a set of Sustainable Development Goals (SDGs), which will build on the MDGs. The draft SDGs are now available and tackling water issues, as in the MDGs, is a significant theme throughout the majority of the 17 draft SDGs:

- Goal 1: End poverty in all its forms everywhere
- Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Goal 3: Ensure healthy lives and promote well-being for all at all ages
- Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
- Goal 5: Achieve gender equality and empower all women and girls
- Goal 6: Ensure availability and sustainable management of water and sanitation for all
- Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- Goal 10: Reduce inequality within and among countries
- Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable
- Goal 12: Ensure sustainable consumption and production patterns
- Goal 13: Take urgent action to combat climate change and its impacts
- Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
- Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
- Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development

Sources:
UN http://www.unmillenniumproject.org/goals/
UN Sustainable Development Platform: https://sustainabledevelopment.un.org/focussdgs.html

ECOSYSTEM SERVICES AND AN ECOSYSTEM APPROACH

As early as the 1960s, concerns over the loss and deterioration of wetlands and their impact on people increased the profile of freshwater ecosystems and led to the Convention on Wetlands (1971), commonly known as the Ramsar Convention. In the 1970s and 1980s the concept of 'ecosystem services' emerged – the many benefits human society receives from natural systems. The concept of 'ecosystem functions' also emerged – the functions that give rise to these ecosystem services. These two terms provided a formal basis for recognizing the importance of natural systems. The concepts received much greater interest after the 2005 Millennium Ecosystem Assessment (MEA, 2005), an international effort to understand the societal dependence on ecosystems and assess the consequences of ecosystem change on human well-being and the scientific basis for action. Ecosystem services now underpin an 'ecosystem approach' advocated by the UN Convention for Biodiversity. The ecosystem approach seeks to develop 'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.

The approach has lead to the associated has concepts of 'ecosystems-based disaster risk reduction' (Renaud et al., 2013) and 'ecosystems-based adaptation' that aim to 'use biodiversity and ecosystem services to help people adapt to the adverse effects of climate change as part of an overall adaptation strategy' (CBD, 2009).

Despite the international recognition of the importance of ecosystems and their role in disaster-risk reduction (Box 6), there continues to be limited progress in utilizing ecosystem-based approaches (Renaud *et al.*, 2013). Drought strategies in particular fail to recognize the full range of interdependencies between human systems and freshwater ecosystems, and hence do not capitalize on the potential for the positive feedbacks between the two. Indeed, evidence from the case studies undertaken suggests that most countries have failed to develop strategies capable of managing the effects of drought on freshwater ecosystems (focusing primarily on essential needs and agricultural and industrial requirements), let alone actively promoting freshwater ecosystems to reduce drought risk.

Box 6: Ecosystems-based approaches are recognized as providing a valid contribution to disaster risk management

Ecosystem-based approaches and the role of ecosystems in disaster risk reduction (DRR) are now well acknowledged in the International Strategy for Disaster Risk Reductions (ISDR), which involved the international community in promoting global DRR by implementing the Hyogo Framework for Action and the Sendai Agreements. The ISDR Global Assessment Reports on DRR in 2009 and 2011 (UNISDR, 2009, 2011) as well as the Chair Summaries of both the 2009 and 2011 Global Platforms for DRR highlighted the importance of integrating ecosystem management as a key component in DRR strategies. The recent International Panel on Climate Change Special Report (2012) has echoed this message, stressing the value of investing in ecosystems as part of climate change adaptation strategies, and ecosystem-based adaptation has been formally endorsed by the Subsidiary Body for Scientific and Technological Advice, under the auspices of the Nairobi Work Programme of the UN Framework Convention on Climate Change.

Environmental flows

The concept of allocating a flow to the environment, a so-called 'environmental flow', emerged in the 1970s, but evolved significantly in the early 2000s to describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems (Brisbane Declaration, 2007). Today, managing water resources to ensure environmental flows are maintained is increasingly recognized as a key part of water resources management and there are many examples of progress with environmental flow policies around the world. For example, recent revisions of China's River Basin Master Plans aspire to introduce environmental flows across the country and restore flows to the Yellow River stands as the world's largest-scale reallocations of water. The South African National Water Act 1998 is one of the most ambitious international attempts to integrate environmental flows into the core of water policy reform (Le Quesne *et al.,* 2010a). Over the past decades, water allocation planning has evolved from making no allowance for environmental water needs, to the provision of some basic reserve for the environment, to the point where contemporary plans may now incorporate detailed environmental objectives and management arrangements to deliver the necessary flows (Speed *et al.*, 2013).

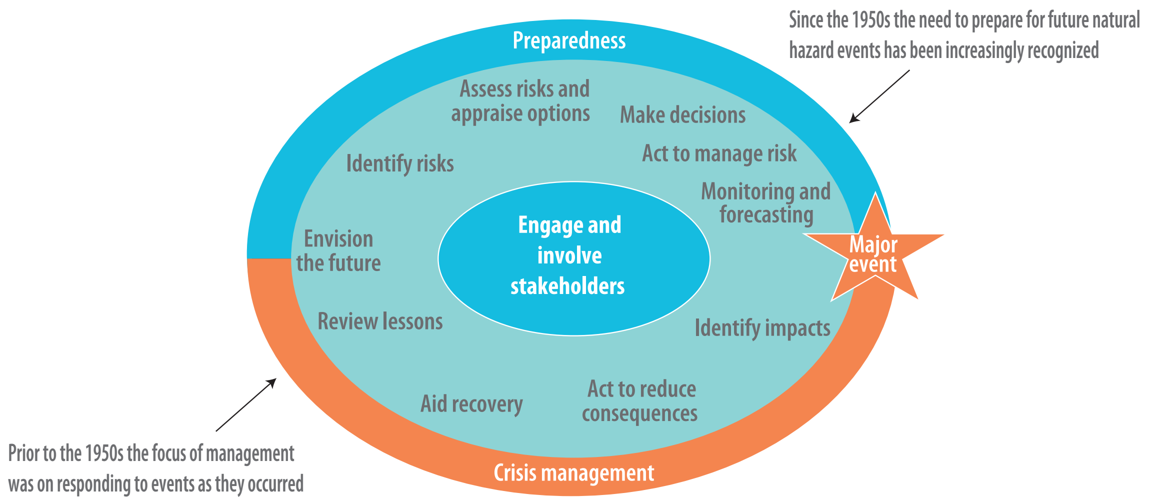
Although environmental flow considerations have begun to be incorporated in water resources management and river basin planning more broadly, in many cases environmental flows are still at the stage of policy and debate with little progress, even under non-drought conditions, for on-the-ground implementation (Le Quesne *et al.*, 2010). There is, therefore, little practice in comprehensive environmental flow management during drought.

DISASTER RISK REDUCTION

From the 1950s onwards, the approach to disaster risk reduction (DRR) has progressively evolved, shifting from 'crisis management' (responding to major events as they happened) to a 'preparedness' approach (forecasting the event and taking early action to response (Figure 2.5). Sustainable development, basin planning and ecosystems approaches have all influenced this development. For example, the ISDR and the associated Hyogo Framework for Action and Sendai Framework for DRR (Box 7) all reinforce the need to be better prepared.

Approaches to drought management have, in a limited way, echoed this change. Regional drought strategies have started to emerge that try to manage both supply and demand, before and during a drought. For example, the National Plan for Water Security, Australia was developed in response to the Millennium Drought and includes a more comprehensive consideration of water-related risks and their management (Box 8). In Spain, the National Water Strategy and in the US the California Drought Contingency Plan also promote being better prepared. The economic case for being prepared is also increasingly clear. If done well, for every $1 spent on planning and preparation in the US, for example, it is estimated that $4 are saved (NIBS, 2005).

Figure 2.5. Disaster risk reduction has moved from 'crisis management' to 'preparedness'



Box 7: The Hyogo Framework for Action 2005–2015 and The Sendai Framework for Disaster Risk Reduction 2015–2030

After the 2005 World Disaster Reduction Conference, the UN General Assembly endorsed a 10-year plan to make the world safer from natural hazards. The resulting *Hyogo Framework for Action 2005–2015: Building the resilience of nations and communities to disasters* (Framework for Action, (ISDR, 2005)) sets out the principles for reducing the impact of disasters as:

- ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation
- identify, assess and monitor disaster risks and enhance early warning
- use knowledge, innovation and education to build a culture of safety and resilience at all levels
- reduce the underlying risk factors
- strengthen disaster preparedness for effective response at all levels.

The *Sendai Framework for Disaster Risk Reduction 2015–2030* was adopted by UN Member States on 18 March 2015 at the World Congress on Disaster Risk Reduction. The Sendai Framework is the first major agreement of the Post-2015 development agenda, and sets four priority actions that build on and add to the Hyogo Framework:

1. Understanding disaster risk
2. Strengthening disaster risk governance to manage disaster risk
3. Investing in disaster risk reduction for resilience
4. Enhancing disaster preparedness for effective response, and to 'Build Back Better' in recovery, rehabilitation and reconstruction.

Box: 8 Changes in water resources and drought management following the Millennium Drought, Australia

Approaches to water resources management in Australia have evolved over time as a result of drought. The major water reforms that commenced in the early 1990s followed a period of significant drought across much of Queensland and New South Wales. This was coupled with problems resulting from over-allocation of water resources, especially in the Murray–Darling Basin and associated environmental issues such as an algal bloom stretching more than 1000 km along the Darling River. While there were many factors that drove Australia's water reforms, water shortages, including periods of drought, were a key factor in promoting a new approach to planning for water allocation and allowing more flexibility for water users by water trading.

The major drought that struck much of Australia during in the first decade of the 21st Century, referred to as the Millennium Drought and widely regarded as the worst drought on record for south-eastern Australia, highlighted many of the benefits of the new water management framework. Water trading, in particular, become commonplace. At the same time, the severity of the drought highlighted many of the shortcomings of existing plans and systems. Many urban centers, including Australia's largest cities, were exposed to the effects of drought in a way they had not been before, severe water restrictions were imposed, and there was serious concern that some cities could literally run out of water.

The Millennium Drought led to a range of changes to the way water is managed. The Australian Government responded with a 'National Plan for Water Security' in January 2007 at the height of the drought. The plan was accompanied by a commitment of $10 billion funding over ten years to improve water management, with a focus on the irrigation sector, particularly in the Murray–Darling Basin. The plan included proposals for modernising irrigation through infrastructure upgrades and improved operations, addressing over-allocation in the Murray–Darling Basin (including scheme to buy back water entitlements), and investment in better water-use information (DPMC, 2007).

The Millennium Drought also triggered a range of responses to address urban water shortages. These responses included developing more climate-independent water supplies (such as desalination), more rigorous water supply and water security planning, institutional reforms to clarify responsibilities for water supply, and changes to the way water service providers defined reliability of supply and levels of service. In some regions, the end of the drought has produced other institutional changes to improve on reforms that were implemented in great haste in a time of crisis.

Source: Speed, 2013

Advances in drought forecasting and warning systems have played a central role in supporting disaster risk reduction. In 1995, for example, the US established the National Drought Mitigation Center and developed the Drought Monitor (Figure 2.6). Since the establishment of the Drought Mitigation Center, and the publication of the first drought maps in 1999, the regionally applicable drought observatories to detect and forecast drought have become central to good drought management worldwide. Despite such improvements, in many cases, the approach to drought management is still 'crisis management' (Box 9).

Figure 2.6. The categories of drought used in the USA Drought Monitor

			Ranges				
Category	Description	Possible Impacts	Palmer Index Drought	CPC Soil Moisture Model (Percentiles)	USGS Weekly Streamflow (Percentiles)	Standardized Precipitation Index (SPI)	Objective Short and Long-term Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered	-1.0 to -1.9	21-30	21-30	-0.5 to -0.7	21-30
D1	Moderate Drought	Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested	-2.0 to -2.9	11-20	11-20	-0.8 to -1.2	11-20
D2	Severe Drought	Crop or pasture losses likely; water shortages common; water restrictions imposed	-3.0 to -3.9	6-10	6-10	-1.3 to -1.5	6-10
D3	Extreme Drought	Major crop/pasture losses; widespread water shortages or restrictions	-4.0 to -4.9	3-5	3-5	-1.6 to -1.9	3-5
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0-2	0-2	-2.0 or less	0-2

Source: National Drought Mitigation Centre, Nebraska

CLIMATE CHANGE ADAPTATION PLANNING

Both developed and developing countries are promoting communities that can adapt to an uncertain future. In the past 20 years the concept of adaptation planning has evolved and is now generally accepted as an important concept in responding to climate change and other changes. Planners are increasingly recognizing the need to include preventative measures to slow down the progression of climate change (mitigation) and measures to reduce the impact of change (adaptation). In support of this, the process of adaptive management continues to evolve but some accepted principles are starting to emerge (Sayers *et al.*, 2012). For example, an adaptation approach:

- uses responses that do not close off or constrain future choices
- uses responses that are effective under the widest set of all plausible scenarios
- observes change through targeted monitoring and reassessed scenarios
- appropriately modifies policies, strategies and structure plans
- stresses the value of investing in ecosystems as part of climate change adaptation strategies (IPCC Special Report, 2012).

Drought management has been slow to embrace adaptation planning, and is typically based on two concepts that are counter to an adaptive approach. The first is the assumption of a stationarity climate. This is changing, but slowly, and drought plans often adopt a specific historical drought event as the basis for planning. In England, for example, privatized water companies must show they would be able to cope with a recurrence of the 1976 'reference drought'. The second is using target standards of service, or levels of service, for acceptable frequency of water restrictions or other measures taken during a drought (Box 10). As a result, the standards of service are often not flexible enough for adaptation as impacts and relative priorities emerge.

Box 9: Last-minute scramble – Yunnan, 2010

Government officials scrambled to deal with the drought emergency in Yunnan, China during 2009–10. Most of Yunnan's reservoirs were built more than 50 years ago, and half were either disused or did not function properly. Many of Yunnan's natural lakes were severely polluted and unusable without enough small-scale infrastructure — ponds, small reservoirs and canals — to distribute clean water to the hardest-hit areas. Local officials were quoted as saying '*There is an urgent need to develop an effective hydrological network in the province*'.

In recent years, the region had focused on building huge reservoirs and hydropower stations; a focus that reflects the economic and political capital that such projects offer with little attention paid to the proactive management of drought.

During the 2009–10 drought, the focus switched to drilling new wells across south-east China. But groundwater was difficult to locate due to limited preplanning and few geological surveys. Hao Aibing, a geologist at the China Geological Survey in Beijing, who is helping to locate groundwater in Yunnan, Guizhou and Guangxi provinces stated 'It's a last-minute scramble because only 10% of the drought-ridden region has been surveyed . . . even if we get live water wells, the water quality remains an issue,' he said. 'We just know so little about the groundwater in the region.'

A severe drought hit southwest China's Yunnan Province, leaving more than 16 million people and 11 million livestock with drinking water shortages

Image source: Qiu J (2010)

Box 10: Example target standards of service applied for a hierarchy of uses – Australia and China

Standards of Service in Southeast Queensland, Australia: The Southeast Queensland Water Supply Strategy (QWC, 2010) sets out the levels of service (i.e. standards) to be met. These include: (i) During normal operating mode, sufficient water will be available from the SEQ Water Grid to meet an average regional urban demand of 375 l/p/d (including residential, non-residential and system losses); (ii) Sufficient investment in the water supply system will occur so that: (a) Medium Level Restrictions will not occur more than once every 25 years, on average; (b) Medium Level Restrictions will only reduce consumption by 15% below the total consumption volume in normal operating mode and drought response infrastructure will be not be required to be built more than once every 100 years, on average; (c) Combined regional storage reserves do not decline to 10% of capacity more than once every 1000 years, on average; (d) Regional water storage does not reach 5% of combined storage capacity; (e) Wivenhoe, Hinze and Baroon Pocket dams do not reach minimum operating levels; and (iii) It is expected that Medium Level Restrictions will last longer than six months, no more than once in 50 years on average.

Standards of Service (water quotas) in China: Drought episodes are classified into the four categories of slight, moderate, severe and extremely severe drought disasters according to the area and extent of impact of a drought on regional arable land and crops and the number of people who suffer water shortage due to a drought. Under each classification water quotas for different types of water use are defined with the national Drought Control Regulations (see table below).

Water supply quotas for security objects according to the Drought Control Regulations (China)

Security Objective		Moderate Drought	Severe Drought	Extremely Severe Drought
Living	Urban residents' basic drinking water	Normal water consumption quota	Normal water consumption quota	30~40L/ person-day
	Basic drinking water consumption of rural residents	Normal water consumption quota	20~30L/ person-day	20~30L/ person-day
Industry	Water consumption of key departments, units and enterprises in cities and towns	Normal water consumption quota	Reducing water consumption quota according to the actual conditions	Basic water consumption
Agriculture	The critical period of crop growth and water use	20~40 m^3/mu(Irrigation areas), 20~30 m^3/mu(non-irrigation areas)	20~30 m^3/mu (basic food grain crop fields)	20~30 m^3/mu (basic food grain crop fields)
Ecology	Basic ecological water consumption of the core ecological areas of the national key natural ecological protection zones	Water quantity for maintaining ecological balance	Out of consideration	Out of consideration

Source: (i) QWC (2010). Southeast Queensland Water Supply Strategy. Queensland Government. (ii) A case study of China based on research on risk management of drought resistance and drought evaluation supported by the Ministry of Water Resources of China.

RESILIENCE: PROMOTING A RESILIENT SOCIETY

In response to a series of major disasters (e.g. Hurricane Katrina, 2005, the India Ocean Tsunami, 2004 and, at the time of writing, the ongoing drought in California, 2010 ongoing) the concept of 'resilience' has emerged as a central consideration in preparing for natural hazards. What constitutes resilience is evolving, but some agreed principles are emerging (Sayers *et al.,* 2012):

- **Resist:** an ability to resist a wide range of threats, including ones that are not necessarily foreseen during the planning or design process and does not fail catastrophically when hazard events more severe than those planned for.
- **Recover:** an ability to recover rapidly with limited aid from a disruptive event supporting the rapid return to normality.
- **Adapt:** an ability to adapt to a changing environment and institutional arrangements and policies.

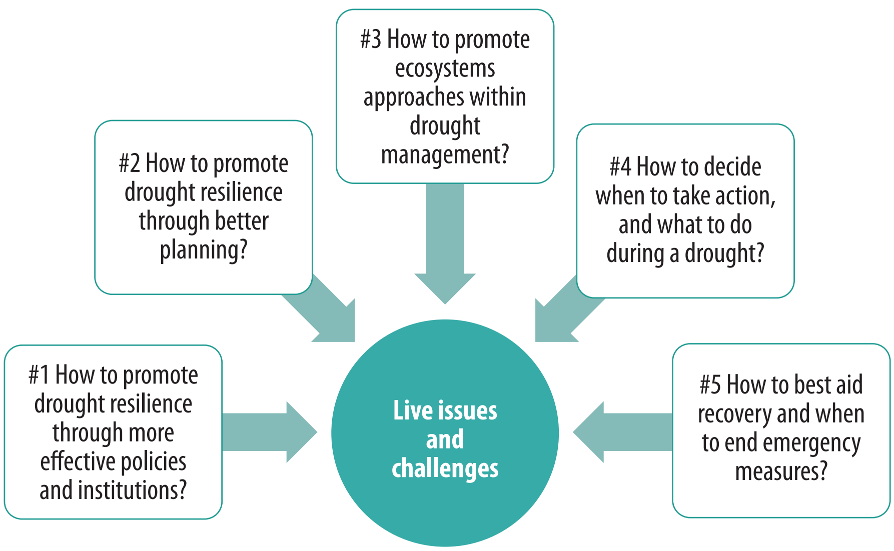
Resilience is not achieved in isolation. Ecosystems approaches that promote the use of biodiversity and ecosystem services to reduce natural disasters and respond to climate change are central to achieving long-term resilience. The concept of building resilient societies has also become increasingly recognized by the DRR community and is reflected as a goal in, for example, the ISDR and the associated Hyogo and Sendai Frameworks.

Resilience concepts have also started to impact the theory, if not the practice, of drought management. In 2013, more than 300 government decision makers, development agencies and leading scientists and researchers from 87 countries came together in Geneva to discuss approaches to improving resilience to drought (Wilhite *et al.*, 2014; Sivakumar *et al.*, 2013). The result reinforced the need for a change in current drought management approaches and highlighted the lack of coherent national drought management policies as a major barrier to change.

2.4. Live issues and challenges in drought management today

Drought management has evolved, and continues to evolve, in response to the drought events, advances in science and changes in philosophy as outlined in the preceding sections. This evolution had been a chaotic process and, to date, no single blueprint for what constitutes good drought management has been agreed. There is, however, an emerging consensus over the challenges faced by modern drought managers in translating the initiatives discussed in the preceding chapter and the lessons from past drought into good, strategic management. The most important of these challenges are summarized in Figure 2.7 and discussed below.

Figure 2.7. Summary of issues and challenges facing international practice



HOW TO PROMOTE DROUGHT RESILIENCE THROUGH MORE EFFECTIVE POLICIES AND INSTITUTIONS

The complex nature of drought means that effective actions require cooperation and coordination at all levels. This is difficult to achieve and in many countries institutions often have limited capacity to comprehensively prepare for droughts. In some jurisdictions progressive laws are emerging. For example, the English Water Bill underlines the primary duty of water providers as 'to ensure resilience of water supplies' (Defra, 2012 & 2016). Basin-scale organizations, such as river basin authorities, or national scale bodies, such as the environmental agencies, increasingly have a remit to take a strategic oversight of drought issues. However, existing water laws and institutions often fail to support good drought planning. The challenge is to provide a framework of water resource management that promotes a broad consideration of drought issues and management responses to:

- **Promote drought resilient communities and societies:** as yet a blueprint for a drought resilient society does not exist. As a result, developing a practical long-term strategy to support societies to become more drought resilient remains a challenge.
- **Reform allocation and promote f exible trading:** in many countries water allocations are fixed. During periods of drought this can lead to inefficient and inappropriate allocations.
- **Ref ect the true value of water in the choices made:** many water users have little economic incentive to conserve because water is either underpriced or not priced at all.

HOW TO PROMOTE RESILIENCE THROUGH BETTER PLANNING

Failure to appropriately plan for drought can lead to expensive, sub-optimal measures when governments respond in haste during the middle of a crisis. However, developing better plans is difficult. It presents challenges in both the planning process and determining the nature of the plan itself.

A better planning process:

- **Integrates drought and water resource planning:** drought management plans and national drought strategies are now routine in many countries in Europe, the US and Australia. But few plans are statutory and few are well integrated into broader river basin and wider water management planning.
- **Engages a wider range of stakeholders:** public bodies, private sector organizations and individuals increasingly expect to be engaged in the decisions that affect them. This engagement can be difficult because the provision of information is often asymmetrical with different stakeholders having access to different data. Given that drought management occurs in the context of both competition and collaboration between stakeholders, this asymmetry may promote mistrust of the evidence and a reluctance to act. Without agreement, significant investment can be wasted (Box 11).
- **Recognizes the political dimension of managing impacts of drought:** the challenge for water resource managers is to ensure that political leaders make planning decisions based on the best available information about options and trade-offs.

Box 11: Failure to engage stakeholders in major investment choices often leads to sub-optimal approaches

The 2001 Water Plan for Spain, which was based on a national-scale hydrological analysis, estimated that the water demand on the Mediterranean Coast was more than 1 billion m^3/year. The Water Plan set out an infrastructure solution based on a water transfer scheme, which transferred water over 1000 km, without a proper environmental or cost recovery calculation. As a result prices were significantly underestimated. The water transfer project created significant social conflict and was repealed by a new government in 2004. A new proposal was put forward based on local desalinization solutions, but without revising demand estimates. Although prior commitments with future beneficiaries on water amounts and prices were initially planned, this planning step failed due to the resistance of the irrigators and regional and local pro-transfer institutions. By 2015, desalinization facilities with a cost of €600 million and the capacity to desalinate more than 500 million m^3/year of seawater had been built without agreeing prices with recipients; as a result, just 20% of the desalination capacity is used. In Andalusia, the Marbella, Almeria and Carboneras desalinization plants have a combined capacity of 82 million m3/year but deliver only 14.1 million m^3 on average (unpublished Draft Mediterranean River Basin Management Plan, 2014).

Source: Personal communication with Guido Schmidt and advice provided to him from Abel La Calle (Fundación Nueva Cultura del Agua, Spain).

Better plans:

- **Move away from crisis management:** Despite the widely held desire to move away from a crisis approach to drought management towards a proactive approach, progress is slow (Box 12 and Plate 3). In part, this is due to difficulty in:
  - assessing the chance of future droughts and their severity
  - understanding and valuing potential impacts
  - determining the relative priorities
  - quantifying the benefits a particular action has for people, ecosystems and economy
  - communicating risks and uncertainty effectively, particularly low-probability drought events.

Plate 3 Future solutions to drought will need to be proactive

Image source: Courtesy Guymon Daily Herald

- **Avoid reactive infrastructure development**: Many cities have looked to improve water security through the construction of climate-resilient infrastructure. While these measures have undoubtedly resulted in more secure water supplies, they have come at a very high cost, particularly where new infrastructure has been built hastily in response to emergency conditions. For example, in Queensland, Australia a desalination plant and recycled water treatment plant were both constructed during the height of the Millenium Drought (2007-12) at a combined cost of A$3.8 billion (QAO, 2013). A recent review was critical of the process for deciding to proceed with construction and found that better planning may have avoided such drastic and costly action. The review also found that a thorough and rigorous assessment of all costs and of the social, economic and environmental benefits in all likely modes of operation should have been undertaken (QAO, 2013).
- **Accepts that future drought may be more severe than historical drought:** In most cases, drought plans continue to be based on a reference drought. In the US, for example, the Dust Bowl drought (1934–1939) is often used as the reference drought. In England, the drought of 1976 is used by regulators to confirm the adequacy of water authorities' drought planning. The use of historical events as the basis for planning is starting to be challenged. More extreme drought than that experienced in the past is possible and probable in the medium to longer term due to the stochastic nature of drought events and, with the increasing impact of climate change, past events are unlikely to be an appropriate analogy for future conditions.
- **Recognize the future as uncertain and plan accordingly:** Data on drought hazards and impacts, and how these might change in the future are very uncertain. Yet within current approaches there is an underlying assumption of 'perfect knowledge' and a reluctance to actively manage uncertainty. Non-stationarity in climate and socio-economic complexities add to the difficulties and it is impossible to predict longer-term changes in drought risk with any degree of precision. This high level of uncertainty can lead to inaction. Understanding how to embrace this uncertainty within the decision making process is an important challenge.

HOW TO PROMOTE ECOSYSTEM APPROACHES AND GREEN INFRASTRUCTURE WITHIN DROUGHT MANAGEMENT

Despite the international recognition of ecosystem-based approaches, as discussed in detail in Chapter 10, and recognition of the advances of green infrastructure (GI) for DRR, there has been limited progress in applying ecosystem approaches and realizing the benefits at scale; the majority of ecosystem approaches have only been implemented at project or pilot-demonstration levels (Renaud *et al.*, 2013). This seems to be the case in drought management where approaches have often failed to recognize the interdependencies between human systems and freshwater ecosystems and, as a result, have not capitalized on the potential for the positive feedbacks between the two. The evidence from the case studies completed for this book suggest that most countries have failed to develop strategies capable of managing the effects of drought on ecosystems, let alone actively promote freshwater ecosystems to reduce drought risk. This seems particularly the case in catchments where human disturbances have reduced the natural resistance and resilience of freshwater ecosystems, and where the demand for consumptive water use is high and rising. For example, the Millennium Drought in Australia had detrimental effects on critical ecosystems in the heavily abstracted Murray–Darling Basin.

Box 12: Californian drought – crisis management in the 21st Century

At the start of 2015, California was in the midst of one of the worst droughts in its history, with less rainfall than at any point since 1850, rivers at record lows and mountain snowpack at only 20% of expected levels. In response, on 19 February 2014, California announced an aid programme of $687m to provide immediate assistance to communities, including more than $180m to help both ranchers who lost livestock and communities suffering extreme hardship because of lack of crops. The rest of the aid programme was to be focused towards local water conservation and recycling efforts, including capturing stormwater.

The severity of the drought and the need to develop a short-term crisis response prompted calls for a more strategic, longer-term response to drought risks. Questions were raised over appropriateness of exporting 'virtual water' within cash crops, such as hay, which was sold to China, Japan and elsewhere. In the midst of the crisis, calls for increased infrastructure construction (more reservoirs and basin transfers) were significant; these calls reflected the perceived inequality between the Imperial Valley, where agriculture continued to thrive, and areas of Central Valley (that relies on more local groundwater and surface water supplies) that suffered. The broader merits and disadvantages of water transfers, including the costs and environmental impacts, were difficult to debate as the crisis deepened.

Conflicts between environmental, human and economic uses were also central to the debate. Republican lawmakers in Congress proposed rolling back several environmental regulations in an effort to end what they called a 'man-made drought', whereas Democrats in the House of Representatives urged President Obama to protect more land using his Presidential Authority. These conflicts continue to be debated at the time of writing.

Drought-hit California was warned that water companies might not have been able to supply any water in 2014.

Image source: Getty Images

Seeking to change this situation presents a number of significant challenges:

- **Promoting the take-up of ecosystem approaches:** Ecosystem-based approaches to water resource management are increasingly being accepted in theory that has not yet translated to practice in water resource management generally or in drought risk management more specifically. Often, protecting ecosystems and biodiversity is a low priority in droughts, due to poor valuation of ecosystems, a disconnect between expert communities and policy sectors, difficult trade-offs between short-term needs and long-term needs in moments of crisis, and difficulty in securing environmental flows.
- **Valuing the benef ts derived from freshwater ecosystems:** Bringing protection of freshwater ecosystems to the drought risk management agenda requires an appreciation of the benefits these systems bring to society. Ecosystem valuation approaches transparently assess ecosystem services and therefore help to provide robust arguments for protecting and using them in drought risk management. However, despite the increasing acceptance of ecosystem valuation approaches (both monetary and non-monetary), the value freshwater ecosystems bring to society is poorly reflected in decisions about how they are used and managed. Failure to account for the real value of natural systems and their services is thought to be a significant factor in their continuing loss and degradation (TEEB, 2010).
- **Securing environmental f ows during a drought to protect priority ecosystems:** Perceived conflicts between the needs of nature and the needs of people are at their most acute during a drought. It is often hard to mount a compelling case that water should be set aside for the natural environment when the impact on a business or community is urgent. In Spain, the regulatory framework (Instruction for Hydrological Planning, 2008) allows a less demanding environmental flows regime as long as certain conditions are met and fish habitat availability remains above a 25% threshold (lower than the 50–80% threshold that must be respected during non-drought conditions, although this exception does not include protected areas). Despite these concessions, maintaining even reduced environmental flows is difficult; for example, the draft 2016–2021 Guadalquivir River Basin Management Plan recognizes that 31% of the minimum flows and 88% of the maximum flows have not been respected in the recent years (Benítez anz and Schmidt, 2012). This example highlights the increasingly difficult challenge of maintaining an inclusive and constructive debate to agree water allocations (and restriction priorities) as a drought extends, often leading to poor outcomes for all.

WHEN TO TAKE ACTION

Ever since the establishment of the US Drought Mitigation Center in the mid-1990s, significant effort has been directed towards improving drought monitoring and forecasting. Today, many countries have some form of monitoring and provide warnings, reflecting the drought conditions 'now' or a short time into the future. There are also ongoing efforts to provide early warning at a global scale. Drought, however, reveals itself in many different ways. Detecting the gradual onset of drought in a way that is useful for individual, community, basin and national decision makers before the drought becomes a crisis, is still problematic and significant further advances are needed for information that is better directed towards the needs of decisions makers, and is honest about uncertainty. Challenges include:

- **Monitoring and forecasting the 'right' indicators:** Various countries, most notably Spain and the US, routinely monitor a range of indicators, often focusing on meteorological data, blue-water data (e.g. reservoir levels) and green-water data (e.g. soil moisture). Determining the most meaningful indicators for specific contexts is an area of debate and research.
- **Extending the period of credible forecasts:** Despite significant advances in short-term forecasting of drought-driving events and the hydrological response, little attention is given to forecasting how the developing drought hazard may lead to impacts in the coming weeks, months or years. This lack of foresight makes decision making difficult and can lead to acting too early and wasting resources, or to acting too late. The lack of ability to forecast droughts more than three to six months in advance constrains the implementation of mitigation and response measures. Significant research needs to be devoted to understanding the causal factors and teleconnections that drive drought development.
- **Declaring the onset and cessation of drought: The** onset of a drought is typically declared through a process based on judgment and debate in the midst of the crisis itself. Once a drought is declared, water restrictions can be implemented and, in many cases, legally enforced. In some regions (England, Australia and some parts of the US, such as California) drought management plan supports the process of 'declaration' and set out in detail who should be consulted, the ultimate arbiter of the drought, and the evidence that should be used to declare the drought. Although a drought management plan aids openness and encourages buy-in from stakeholders, the declaration of drought continues to be seen as a political choice, biased towards a limited number of stakeholders, typically from farming and industry. Wider groups of stakeholders, especially those representing environmental interests, are often excluded from the declaration process. In many other countries, where drought management plan do not exist, the process of declaration is more aligned to a 'crisis' situation with a civil protection agency (or its equivalent) having the power to 'declare', and 'deactivate', the drought declaration with limited understanding of the risks and relevant stakeholders.
- **Implementing water restrictions:** Water restrictions are an effective measure for reducing demand during periods of drought and typically form a key element of all drought plans. The reality of a drought, however, is invariably different to that planned for. Planning for a greater range of drought scenarios and embedding an adaptive, but open and transparent, process of adjustment as the drought extends is a challenge.
- **Delivering drought relief and the potential for perverse incentives:** Drought relief is often given first to those who have not adequately planned adequately for drought. Those that have planned often experience reduced losses and perhaps are not eligible for drought relief. This is further evidence of the need to move away from the crisis management approach.
- **Taking the opportunity to promote positive, longer-term changes without committing to poorly planned infrastructure:** Droughts can be an opportunity to put longer-term demand side measures in place. For example, the drought in southern Queensland significantly raised awareness of drought issues and changed behaviors, leading to a significant reduction in per capita daily water consumption. Drought events can also be catalyst for more strategic action, as highlighted through the California droughts of the 1970s and the drive to establish a more strategic approach to drought management through the establishment of the National Drought Mitigation Center. The aftermath of a drought often provides a key opportunity to break the 'hydro-illogical cycle'. In general, however, making significant decisions at the height of drought is a high-risk strategy; this is a criticism of the response to the 1991–95 drought in Spain (Box 13).

HOW TO BEST AID RECOVERY AND WHEN TO END EMERGENCY MEASURES

Managing drought does not stop when the rains start. Understanding how best to aid recovery and transition to non-drought conditions presents a number of challenges:

- Stopping illegal or temporary abstractions: There is a perception that illegal (or unregulated) abstractions are common in many countries. Such abstractions are particularly problematic during periods of drought and can make allocation planning difficult and recovery slow. Revoking temporary abstraction agreements can be problematic as water users become used to accessing the additional supplies.

- **Relaxing temporary restrictions:** Restrictions imposed during a drought are usually temporary. There may be a temptation to make temporary measures permanent to reduce long-term demand. However, this means that temporary restrictions are no longer available to managing the supply-demand balance during drought (Chong *et al.*, 2009).
- **Distributing financial compensation:** Financial compensation for those affected by drought is widely used and accepted to promote recovery. In the US, for example, farmers increasingly turn to the Federal Crop Insurance Corporation to manage weather-related risks, including crop loss due to drought. Financial compensation has also been a feature of drought responses elsewhere (Box 14). This approach is not without problems as it can be difficult to encourage best practice water management. Questions of who should pay and who should benefit, and the mechanism to pay compensation through are debated.
- **Recovery of freshwater ecosystems:** During drought, water for environmental purposes can be the first to be affected. Curtailing environmental flows impacts freshwater ecosystem function and its ability to deliver services for key economic sectors and to sustain livelihoods and well-being. It is crucial to reinstate environmental flows as soon as water reserves increase to viable levels. Reinstating environmental flows may require abstraction restrictions and storage operation rules in place until water reserves and river flows return to their usual levels.

Box 13: The 1991–1995 drought in Spain – beware of the opportunity drought provides for long-term infrastructure development

A prolonged drought across southern Spain from 1991–1995 had severe impacts. By the end of the drought in September 1995, the stored water resources in the Tajo, Guadiana and Guadalquivir basins had fallen to below 10% of their normal capacity. Because water supply was limited for such a long period, various sectors experienced significant impacts, including restrictions in domestic water supply, over-exploitation of aquifers, decrease of hydro-electrical energy production, reduction in agricultural yields and productive land, reduced arable production, high forestry mortality rates and forest fires, high fish mortality in reservoirs and high bird mortality in the interior wetlands.

In 1992, as the drought deepened and, in the absence of a pre-agreed drought management plan, the authorities implemented a series of readily actioned measures (such as water restrictions) but also measures that were more difficult to change once implemented. The emergency response to the drought provided an opportunity to fund long-term infrastructure projects with limited consultation and to fast-track established decision processes. The long-term sustainability of some of the actions were criticised, such as developing new water infrastructure using emergency funding, introducing new abstraction licences, and implementing compensation payments.

Source: Sayers, 2013

Box 14: China: Financial compensation plays an important role in recovery from the 2010 drought

The State Flood Control and Drought Relief Headquarters started an emergency drought response to moderate-drought level on 5 February 2010, which rose to a severe-drought level by 24 February according to the drought response plan. To supplement emergency supply measures, such as diversion and additional abstractions, the central and local governments raised a drought relief fund through a combination of state aid and donations. The government invested more money in water conservancy construction, but also arranged a financial subsidy and consolidated drought relief capital of more than ¥1 billion (0.17 billion $US). The government also organized a series of fund-raising activities (the donation raised in Yunnan Province and Guangxi Province was about ¥0.86 billion and the money was used to subsidize the affected farmers and help restore production.

PART B

FRAMEWORK OF STRATEGIC DROUGHT RISK MANAGEMENT

CHAPTER 3
DROUGHT AS A RISK

3.1. Introduction

Establishing a common language of risk is a vital first step towards managing it. Within drought management, stakeholders often use different definitions of risk which leads to methodological confusion and difficulties in communicating assessment results to decision makers. In part, this situation reflects the established traditions within the scientific disciplines engaged in drought issues.

To provide the foundations for developing a more common understanding of drought as a risk, this chapter presents a structured discussion of what is meant by risk, probability, exposure and vulnerability. The units of risk, together with the supporting concepts of stationarity, uncertainty and residual and tolerable risk are also discussed.

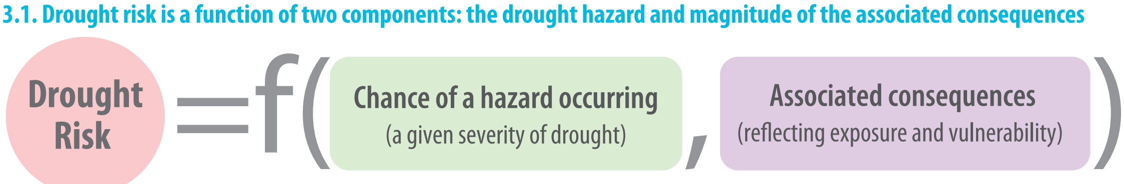
3.2. What is drought risk?

Despite risk being a well-established concept in the management of many natural hazards (e.g. Willows and Connell, 2003; Sayers *et al.*, 2013) no accepted definition of 'drought risk' exists. This partly reflects the traditional focus on drought as a natural hazard rather than a risk.

Drought risk is a combination of natural and human inf uences and is defined in this book as:

An emergent property of the human and natural system, and ref ects the interaction between climate meteorological drought hazard, the hydrological response of the basin (blue-water and green-water drought hazards) and the vulnerability of the exposed people, ecosystems and economies. As such, drought risk ref ects two components: the chance that a drought hazard will occur and the magnitude of the associated consequences.

Figure 3.1. Drought risk is a function of two components: the drought hazard and magnitude of the associated consequences



This definition embeds two widely accepted components of 'risk': (i) the chance that a situation with the potential to cause harm may occur (i.e. a reduction in reservoir level, a reduction in river flow etc. and referred to here as the 'drought hazard') and (ii) the magnitude of the economic, ecosystem and social consequences should it occur (i.e. that reflects the vulnerability of the exposed people, habitats, businesses etc. and referred to here as the 'drought consequence'). The functional relationship in Figure 3.1 is an important concept, and reflects the complexity of risk. As discussed later in the chapter, both qualitative and quantitative approaches have a valid role to play. The assessment of risk is always incomplete because uncertainties and complexities may make a comprehensive understanding of risk challenging, if not impossible. Care must be taken to avoid the impression that the risk is fully understood.

3.3. The components of the drought hazard probability

Drought hazard is defined here as:

The combination of the atmospheric processes and hydrological response that yields a reduction (or complete loss) of water in lakes, ponds, streams or aquifers (blue-water drought) or in the water stored in soils or plants (green-water drought).

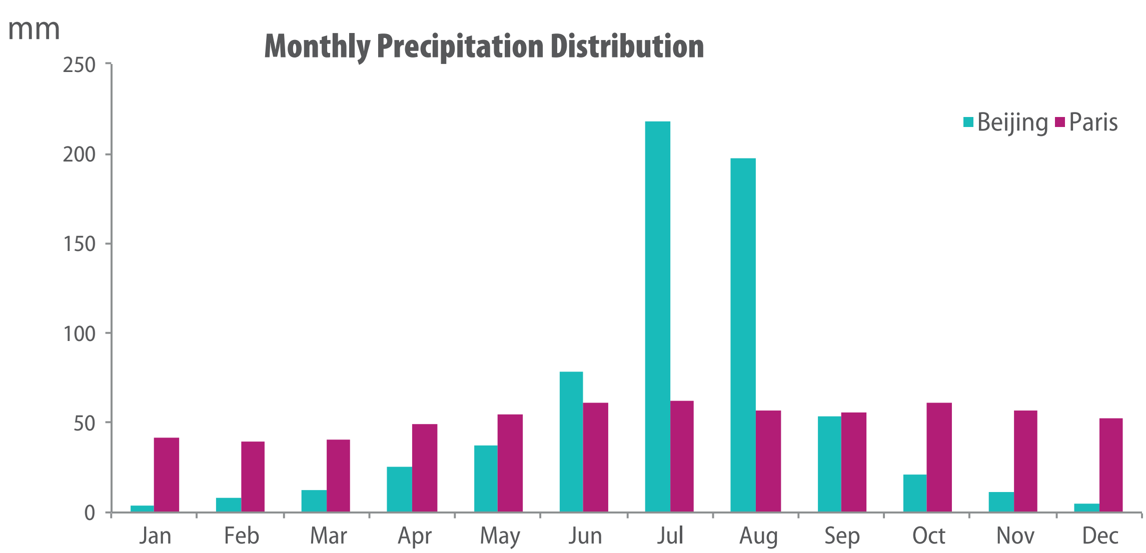
To understand the drought hazard in the context of risk (Figure 3.1), the chance of the hazard occurring must also be considered. An understanding of the chance of the meteorological event (i.e. the source of the drought hazard) therefore provides only part of the answer. To assess appropriately the chance of the drought hazard, the hydrological pathways through which the meteorological events are transformed to a reduction in blue- or green-water drought are also important (Figure 3.2).

Considering both the meteorological event and hydrological response enables the generation of drought hazard to be better understood and, importantly, supports the identification of appropriate management measures. The relationship between climate and hydrological responses varies from basin to basin. For example, in a tropical monsoon climate, water resources may rely on a single 'wet' season. If this fails to appear, there will be few opportunities for natural replenishment until the same time a year later (for example as in Beijing, see Figure 3.3). A similar problem may be experienced if winter snowfall fails to materialize in a basin that relies on snowmelt to maintain downstream river levels later in the year. Regions that experience climates with a more uniform monthly precipitation or secondary peaks often have more opportunity for subsequent replenishment and a speedier recovery of resources (as in Paris, see Figure 3.3).

Figure 3.2. The components of drought hazard and its probability of occurring

Probability of a hazard occurring (a blue- or green-water drought) = f(**Source: Meteorological event(s)** (sequence, intensity and duration – including precipitation, heat and wind) , **Pathway: Hydrological response** (including surface and groundwater pathways, human and natural demands))

Figure 3.3. Monthly precipitation distribution for Beijing compared to Paris, (both average about 630 mm per year)



Source: GIWP

3.4. The components of consequence

The severity of the consequence (for a given reduction in available water) reflects the vulnerability of the freshwater and human receptors that are exposed (Figure 3.4).

Figure 3.4. The components of consequence

Consequences (economic, ecosystem and social harm) = f(**Exposure** (the scale of potential impact, e.g. the number of people, ecosystem services and economic sectors that may be harmed) , **Vulnerability** (an agreed means of expressing the harm that would be incurred if exposed to a given hazard))

To understand the potential consequences of drought, it is therefore necessary to understand both exposure and vulnerability:

- **exposure** describes and quantifies, where possible and useful the receptors (i.e. individuals, organizations, habitats, etc.), that would be either directly or indirectly exposed to a given drought hazard.
- **vulnerability** describes the potential for a given receptor to experience harm when exposed to a given drought hazard. To understand **vulnerability** more fully it is important to distinguish three aspects (Figure 3.5):
    - **susceptibility** describes the propensity of a particular receptor to experience harm as a result of a given reduction in available water. For example, a green-water drought of a particular severity, as expressed by a soil moisture deficient, may reduce crop yield by 90%)
    - **value** is the agreed value of the harm that has been experienced. Some of the harm caused by drought may be perceived as more serious than others. The means by which different harm is valued should be transparent and well understood. For example, attempts could be made to monetize all harm into a common currency (the basis of valuation should be clear) or harm could be kept in native parameters (e.g. number of people impacted by water restrictions, or loss of lake habitat in hectares) and appropriately weighted. Simpler approaches may provide a qualitative scale of value (e.g. high, medium or low). In all approaches the evidence on which the value is based (from expert opinion to observation) must be recorded to support decision making.
    - **recoverability** reflects the inherent ability of a receptor to recover, without significant additional external assistance, within a reasonable timeframe. Adaptability is implicit within this definition. A receptor that can adapt autonomously to changed conditions (i.e. change or reorganize behavior without external assistance to reduce its susceptibility to harm) has little vulnerability. Taking steps to promote the ability of a receptor to recover directly reduces vulnerability and underpins effective drought risk management.

Figure 3.5. The components of vulnerability

Vulnerability = f(**Susceptibility** (the inherent propensity of a given receptor to experience harm as a result of a given reduction in available water) , **Value** (an agreed expression of the importance of the harm that has been experienced) , **Recoverability** (the inherent ability of a receptor to recover, without significant aid))

3.5. Primary, secondary and tertiary risks

Numerous disasters have highlighted the interconnected character of the infrastructure society relies on (water, industrial, transportation etc.) and the potential for impacts to cascade through these connections (Little, 2002). Understanding how risks cascade from a primary source to a secondary source or through the supply chain and how such interconnections may escalate the risk is needed to develop a 'whole system' view and is a central requirement in understanding how best to manage risks.

Drought is no exception. For example, a lack of available water for abstraction may lead to losses in agricultural and industrial production. Domestic use and energy production may also be affected and illegal abstractions may increase, stressing water resources further. Secondary impacts may follow, including, for example, an increase in the price of food and energy. A decrease in agricultural production due to failed crops may have impacts that cascade through increasingly globalized supply chains, leading to rising food prices elsewhere as competition increases for limited resources. For example, droughts around the globe in 2007 led to a second year of significant reductions in production of grains and oilseeds, leading to record highs in the price of corn and other grains (Trostle, 2010).

3.6. Non-stationarity of risk

The future will be different from the past. Climate change and socio-economic development can affect the probability and associated consequences of a drought. Accepting drought risk as a non-stationary phenomenon is an important concept for drought management and implies the need for continual review and adaptation as our understanding for the future changes.

3.7. Understanding the units and significance of risk

The units used for describing risk will depend on how the chance of the hazard occurring and the associated consequences are defined.

- **Chance.** Chance (or probability) is dimensionless, as it represents the chance of occurrence of one particular event occurring from the population of all possible events. It is always related to a given timescale. For example, the chance that the water level in a reservoir will fall below a given value within any given year (an annual exceedance probability) or within any 100-year period (100-year exceedance probability). Over long timescales, questions of stationarity within the statistics become increasing important – as discussed in Section 3.8. Chance can be expressed either qualitatively or quantitatively. In either case, the evidence that the estimated chance is based on must be clearly communicated, enabling a transparent assessment of associated uncertainty and avoiding a false sense of precision.
- **Consequences.** Consequences are typically considered as the negative economic, social or environmental impacts that may result from a drought. Consequence can be expressed in many valid forms, either quantitatively in monetized or native terms or qualitatively by category (e.g. high, medium, low) or description. Consequences are typically considered as harmful and therefore negative. Alternative actions may have positive outcomes for the economy, society or ecosystem. Such 'gains' are also consequences.

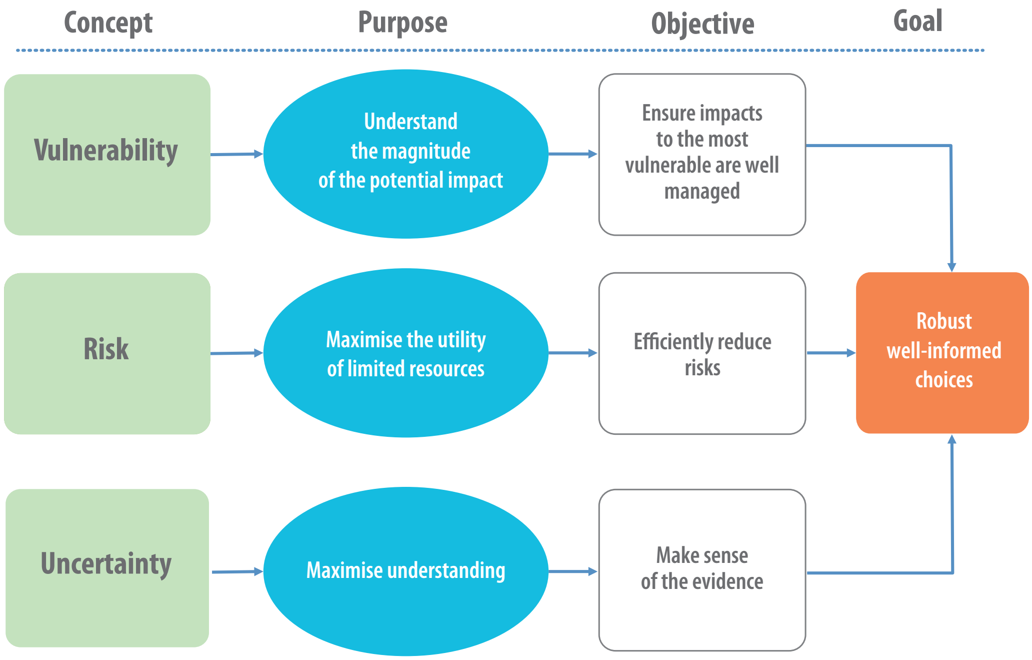
To understand the significance of a risk, it must be viewed through multiple lenses:

- **Expected annual or decadal damage.** Expected annual or decadal damage reflects the consequences that are expected within a given time frame. The Expected Annual Damage (EAD) is used as a convenient measure of the average damage in a given year. Alternative timescales such as the expected 10-year damage can be used; that is the average damage that would be expected to occur over any given decade assuming conditions to be stationary. The 'expected damage' is a useful term when looking to compare the economic or financial efficiency of various management options, such as within a benefit–cost analysis. However, it does not provide a full picture of the significance of the risk faced. Intuitively, it might be assumed that expected annual risks with the same quantitative value have equal significance when evaluated simply as the product of the probability and consequence. This is often not the case. For example, low probability/high consequence events are not the same as high probability/low consequence events, even though the 'calculated' risk would be the same. For high probability/low consequence events, the associated impacts may be tolerated without the need for action, even though the annual expectation of risk is numerically the same as that associated with a much more severe (rare) event.
- **Event risk.** Event risk reflects the consequences that would be expected to occur if a meteorological drought of a given severity occurred. In determining the event risk, it is assumed that the meteorological drought occurs and only the hydrological response and the potential consequences are considered. This is useful, for example, in exploring the present day impact of a historical drought, for example 'What if the 1976 England drought occurred again today?'.
- **Risk prof ling.** Risk profiling reflects the consequences that would occur as the severity of the source meteorological event increases (and its chance of occurrence decreases). Understanding this relationship is as important, if not more so, than simply understanding the expected value. By understanding the risk profile, risks with the same numerical value (i.e. low probability/high consequence events and high probability/low consequence events) can be distinguished.

3.8. The role of vulnerability, risk and uncertainty in decision making

Vulnerability, risk and uncertainty are closely related concepts (Figure 3.6). An understanding of all three of these elements is a prerequisite for making well-informed choices. For example, an understanding of risk helps decision makers to identify actions that maximize the utility of any (necessary) limited resources that may be invested, but says little, on its own, about the completeness or appropriateness of the assessment. An associated assessment of vulnerability enables decision makers to understanding the magnitude of potential impacts and provides insights into the most vulnerable areas. Recognizing uncertainty in assessments of risk and vulnerability supports the decision maker to understand the nature of the evidence – its credibility, relevance to the decision, and confidence that the desired outcomes will be achieved.

Figure 3.6. An understanding of vulnerability, risk and uncertainty is needed to make informed choices



3.9. Sources of uncertainty in decision making

Uncertainty arises from many sources (Table 31). To understand, the influence of uncertainty on a decision, the evidence presented must contain an unambiguous communication of the uncertainty within it. This includes being clear on the definition of the uncertainty, the associated sources of uncertainty and the contribution each source makes to the overall lack of confidence in a particular result or course of action. Typically, three important categories of uncertainty can be distinguished:

- **Natural variability** (or aleatory uncertainty). Natural variability refers to randomness observed in nature, such as those associated with natural variability of meteorological events and the hydrological response of the basin. For example, for a given meteorological event the reduction in river flow or soil moisture will vary not only in response to the characteristics of the meteorological event (intensity, duration, spatial variation, etc.) but also due to local temperature and wind effects influencing the micro-physics of soil and vegetation drying.
- **Knowledge uncertainty** (or epistemic uncertainty). Knowledge uncertainty is that uncertainty associated with a lack of knowledge that could, in principle, be overcome. Knowledge uncertainty reflects uncertainty within the parameters and relationships used in the meteorological model (to explore present and future climates), the hydrological transfer functions that links inputs to outputs (infiltration rates, evaporation, etc.) and the socio-economic and ecosystem impacts. The concept and importance of *knowledge uncertainty* – in the data and models – has been less commonly considered and formally assessed compared to *natural variability*.
- **Decision uncertainty**. Decision uncertainty is a state of doubt as what to do. A well-informed approach to drought risk management demands that all uncertainties are explicitly stated and their importance determined in the context of the decision being made. This is a radical departure from traditional approaches but presents significant opportunities to better manage the inherent trade-offs in selecting one course of action over another.

Seeking to eliminate all uncertainty is impractical and philosophically impossible. It is more important to understand how knowledge of uncertainty influences preferred choice. Understanding uncertainty gets to the heart of our value system and the trade-offs we are prepared to make: acceptable and unacceptable risks; the priority given to social equity and fairness; ecosystems and economics; as well as how much we are prepared to invested to reduce future risks.

Table 3.1. Example sources of uncertainty in assessing drought risks and making a management choice

Typical sources of uncertainty	Sources of uncertainty in understanding behavior of the drought system risk	Additional sources of uncertainty in estimating future risks
	Routine uncertainties typically considered through quantified probabilistic expressions	Severe uncertainties typically considered through non-probabilistic scenario based exploration
Naturally renewable supply	The variation within present day climates	The influence of future climate change on renewable sources
Demand	The variation within present day demand – including legal and illegal abstraction/use	The influence of socio-economic change on demand patterns
Catchment response	Run-off generation processes, sediment flushing and soil erosion	Land use changes (e.g. urbanization and rural land management practice)
Crop yield reduction	Relationship between the selected drought index (e.g. Standardized Precipitation Index) or water stress and crop yield	Climate change and increasing CO_2 concentrations affecting yields
Soil moisture and irrigation water deficit	Simulation and estimation error and crop water demand estimation	Changes in catchment land use and future demand
Loss estimate	Vulnerability of people, number of properties located in drought prone area	Land planning, migration
Changing public risk acceptability	Statistical and hydrological uncertainty in estimating discharge	Changing rainfall patterns
River discharge	Statistical and hydrological uncertainty in estimating discharge	Changing rainfall patterns
Drought return period	Statistical and hydrological uncertainty in estimating return periods	Climate change and changing rainfall patterns and long-term variability
Domestic water use restrictions	Effectiveness of restriction measures and fraction of water saving	Public behavior and water consumption patterns and expectations
Pumping costs	Groundwater table depth and rate of water table lowering	Falling water tables
Livestock losses	Pasture availability and feed crop prices	Loss aversion in farmers
Ecosystem response (damage and recovery)	The interaction between different aspects of the ecosystem and the duration, intensity and spatial extent of the drought (including tipping points)	Changing expectations on moderating impacts on ecosystems and valuation of ecosystem services
Drought warning	Effectiveness of warning and uncertainty in meteorological forecasts	Public behavior

3.10. Residual and tolerable risk

Drought risk cannot be totally eliminated. There will always be a future drought event that will be worse than all previous droughts or which will cause unforeseen or unmanageable impacts. **Residual risk** is an expression of the risk that remains after taking account of the likely effectiveness of all measures to prepare for, respond to, and recovery from a drought should it occur. The degree to which the residual risk can be tolerated (**tolerable risk**) reflects the perceived significance of that risk, the resources required (both monetary and non-monetary) to reduce it and the benefits that may be accrued elsewhere by accepting it (for example drawing down a reservoir at the end of the summer may increase the risk of a winter drought but decrease the chance of a flood).

In some cases a risk may be deemed so significant that it is simply unacceptable, such as communities denied access to drinking water. In these circumstances it may be appropriate to act regardless of the cost or heightened risks elsewhere. In most cases, however, determining the most appropriate approach to managing drought risk requires an understanding of multiple trade-offs and how limited resources can be used to maximize a range of positive outcomes. A consensus from many studies involving the management of risk is that a framework of risk acceptability is a prerequisite for the implementation of a rational approach in the context of such trade-offs. This does not imply a need to define a common standard, but rather to be explicit as to how decisions will be made when faced with complex choices.

To assist this process, the seminal paper by the Health and Safety Executive (HSE) in the UK (HSE, 2001) sets out a framework within which both the risk to individuals and society as a whole could be considered and traded against the benefits secured. The HSE introduced the concept that risks should be managed to a level that is 'as low as reasonably practicable' (ALARP). Within ALARP, 'practicability' is described by consideration of both costs (monetary and non-monetary) and benefits (monetary and non-monetary). The HSE also introduced the concept of 'unacceptable' risks. In this case, efforts must be made to reduce the risk unless the costs of doing so can be demonstrated to be disproportionate to the risk reduction achieved.

CHAPTER 4
ROLE OF STRATEGIC DROUGHT RISK MANAGEMENT

4.1. Introduction

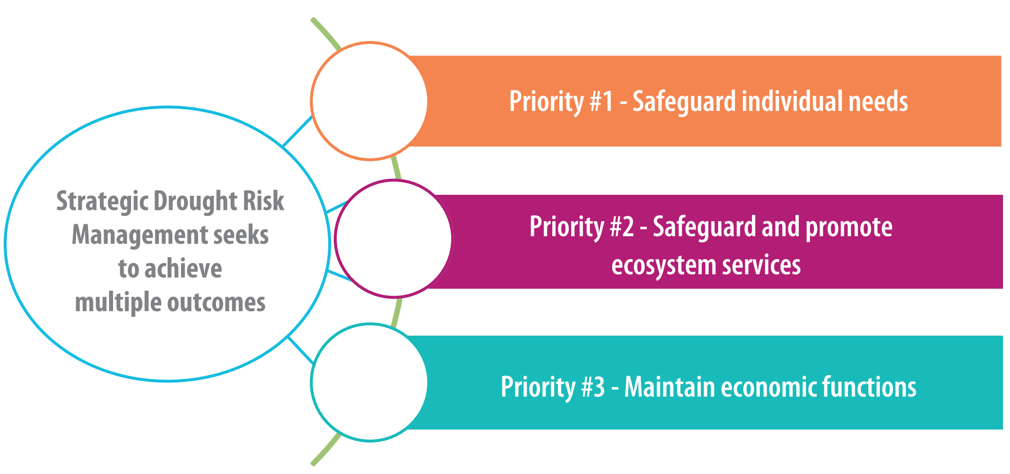
The overarching role of Strategic Drought Risk Management (SDRM) is to develop a drought-resilient society so that, during drought, individual needs and ecosystem services are safeguarded and economic impacts minimized. This approach requires more than simply developing reserve water capacity through physical infrastructure or motivating communities to respond to drought events. It involves delivering multiple outcomes for people, freshwater ecosystems and economies and embeds drought resilience in all sectors of society. This chapter sets out the role SDRM plays in this transition.

4.2. Delivering multiple outcomes

SDRM seeks to achieve multiple outcomes for people, freshwater ecosystems and the economy by prioritizing the personal water needs of the most vulnerable groups, critical ecosystems and economic functions and services such as hospitals, firefighting and energy generation (Figure 4.1).

Inevitably conflicts arise in seeking to achieve all of these, and any solution is unlikely to satisfy all equally well. Actions taken in one location or to prioritize water for one particular sector are likely to have knock-on consequences for others. Managing drought risk well is therefore a balancing act to understand these inherent controversies and trade-offs and agree the relative priorities with a broad range of stakeholders.

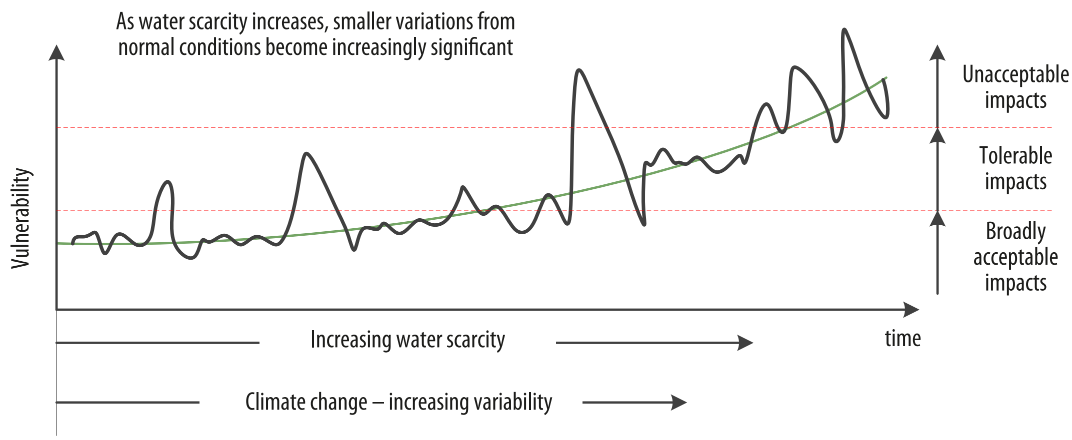
Figure 4.1. A drought risk management approach focuses on outcomes for individuals, ecosystems and economies



This view underpins SDRM and its role in adjusting society's relationship with water, in particular contributing positively to:

- **Water sensitive sustainable development:** Issues of water scarcity and drought interact. The degree of water scarcity within a basin (i.e. the difference between the average water demand and the renewable supply) will influence the underlying drought vulnerability and how best to manage it. The impact of a drought is amplified when water resources are already overstretched within water-scarce basins. Reducing the underlying water scarcity through improved water resource management can also reduce vulnerability to drought (Figure 4.2).

Figure 4.2. Underlying water scarcity increases vulnerability to drought



- **Fair and equitable access to water during a drought:** Water allocations during drought are necessarily restricted. Progressive water-related regulations, such as the South African National Water Act, 1998[3], set out clear priorities for water that reflect a hierarchy of water needs from safeguarding basic human needs, to maintaining an environmental reserve and providing for the economic uses of water. Within these broad need categories, it is important that restrictions are prioritized in a fair and equitable way that recognizes the most vulnerable. People and organizations, however, do not necessarily behave rationally in adhering to agreed priorities. Non-priority use and lack of equity in sharing are common and, as is the case with many hazards, the most vulnerable individuals and communities are often impacted the most severely. Often, poor people can lose access to the ecosystem services that they rely on as continued demand for water from wealthier populations takes precedence. For example, the rural poor in India are often disadvantaged in times of drought (Khurana and Babu, 2014). Illegal abstractions can also undermine allocation priorities (Sayers, 2013). To be effective, allocations need to be managed 'on–the-ground' as well as set out in a plan.

3. http://www.orangesenqurak.org/UserFiles/File/National%20Water%20Departments/DWEA-DWAF/RSA_NationalWaterAct_1998.pdf Accessed 1 September 2015.

SAFEGUARDING BASIC HUMAN NEEDS

The cornerstone of any drought risk management policy is the right to safe, clean, affordable and accessible water for essential personal use (drinking, cooking, personal hygiene and sanitation). The primary purpose of SDRM is to ensure these essential needs are met during a drought. A legitimate part of SDRM is to encourage individuals to prepare for future droughts and to understand the role they can play in reducing their drought risk.

In the most severe cases, drought can lead to hunger, disease and even death. Associated economic disruption and population displacement can also a have profound impact on individuals and families. Strategic action is needed to:

- **Ensure water is available to meet essential needs**. Measures must be taken to protect a share of the total water resources to meet basic human needs throughout a drought. This will be allied with broader measures to reduce demand and increase renewable supply.
- **Ensure water is affordable.** In developing regions, the price of water on the informal market can rise significantly during periods of drought and disproportionally disadvantage the most vulnerable (e.g. Jackson, 1985). In the developed world, the increased costs of water during a drought (for example tankering in temporary water supplies or providing alternative supplies through desalination) are typically met by private companies or central governments, with the consumer experiencing little or no change in price. Nonetheless, emergency action is expensive and can add

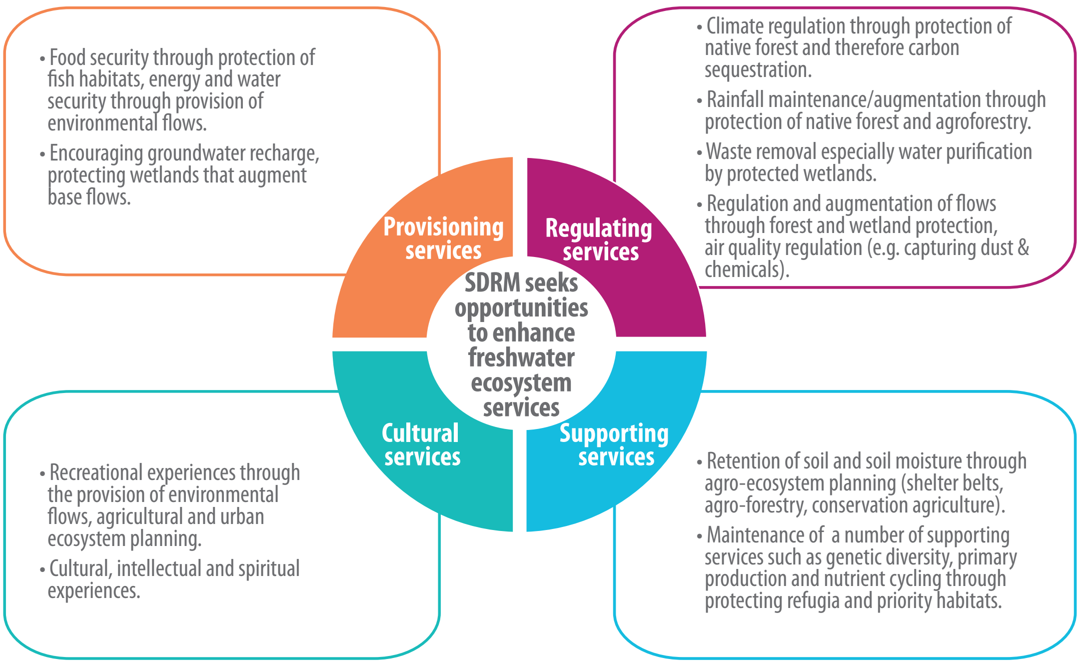
significantly to annual costs and getting the price right in a way that recognizes the true value of water (and promotes water saving) while ensuring everyone has equal access to it for essential use, is a fundamental consideration.

- **Maintain water quality.** The impact of naturally occurring substances and industrial or agricultural pollution on water quality is often at its highest during a drought. In India, for example, high fluoride concentration levels significantly reduce the available resource during periods of drought as well as causing chronic illness and malformations in the longer term (Sharma, 2003). Acting to remove the source of the pollution or treating water requires concerted action over the long-term. Waiting to address pollution issues during a drought makes the task significantly harder.
- **Avoid saline intrusion into groundwater.** During periods of drought, reliance on groundwater often increases significantly, as witnessed, for example, during the contemporary droughts in Bangladesh and California. In coastal areas, over-abstraction can quickly lead to saline intrusion. Although the removal of salt from groundwater sources is possible, it is costly and energy-intensive, and in all but the very wealthiest of regions may render groundwater sources unsuitable for drinking.

SAFEGUARDING AND PROMOTING FRESHWATER ECOSYSTEMS AND THEIR SERVICES

Safeguarding freshwater ecosystems during drought not only protects endangered habitats and species but protects the vital services that they provide to society and economies (Figure 4.3).

Figure 4.3. Drought management presents an opportunity to safeguard freshwater ecosystem services



As a minimum, SDRM seeks to:

- **Identify and protect important species and habitats from the impacts of droughts**. Protection should focus on seeking to purposefully build ecosystem resilience under non-drought conditions, as well as safeguarding species and habitats and promoting their recovery during and after drought. Effort should be directed to protecting endangered species as specified by the International Union for the Conservation of Nature's (IUCN) Red List, species of national importance, and species from which key ecosystem services are derived, as well as endangered habitats.[4] During drought, critical actions can include maintaining a minimum flow through rivers and wetlands for species' survival and maintaining key refugia for species. In addition, incidents

4. See IUCN Red List of endangered ecosystems: a working group established by the IUCN has begun formulating a system of quantitative categories and criteria, analogous to those used for species, for assigning levels of threat to ecosystems at local, regional and global levels. A final system will require definitions of ecosystems; quantification of ecosystem status; identification of the stages of degradation and loss of ecosystems; proxy measures of risk (criteria); classification thresholds for these criteria; and standardized methods for performing assessments.

during drought that threaten priority species and habitats must be actively managed. For example, the heightened chance of colonization by invasive species due to water transfers between basins, or salt-water intrusion resulting from excessive groundwater pumping to secure emergency water supplies need to be managed

- **Identify and protect priority ecosystem functions and the essential services they provide to the human system**. Short-term benefits such as flow for hydropower and navigation, water purification, soil retention, aquatic products and fisheries, need to be indemnified and protected along with benefits delivered over the longer term, such as sediment flow to deltas. Freshwater ecosystems that contribute these services (e.g. wetlands that act as spawning grounds or contribute to groundwater recharge) should be identified as priority areas for protection during drought. Ensuring environmental flows in these priority areas underpins their ability to continue to provide these services and quick recovery when the drought ends.
- **Identify and promote the contribution freshwater ecosystems can make to reducing drought risk.** There is growing evidence that healthy and well-managed freshwater ecosystems can contribute to reducing drought risk by, for example:
  - serving as natural infrastructure to reduce the probability or chance of drought, for example, at a regional scale, protecting forests can help maintain regional rainfall patterns; more locally, wetlands in some contexts can help regulate flows and improve water quality
  - reducing the consequences of drought on humans and their productive assets, for example, native vegetation in shelter-belts and green belts can act as barriers against drought impacts such as soil erosion, sandstorms and wild fire propagation (Campbell *et al.*, 2009; Krysanova *et al.*, 2008)
  - sustaining human livelihoods and providing for basic needs such as food, fuel, shelter and water before, during and after drought events.

Maintaining or enhancing the natural resilience of the freshwater ecosystem is vital. Healthy ecosystems are considered more resilient to extreme weather events and more likely to recover from the impacts of such events than degraded systems (Sudmeier-Rieux & Ash, 2009). If ecosystem health is ensured through protection and management, then the ecosystem's resilience is maintained, enabling it to continue to deliver ecosystem services and promote the recovery of livelihoods that depend on these services.

MAINTAINING ECONOMIC FUNCTIONS

All economies rely on water and all economies are vulnerable to drought. Ensuring sufficient water to safeguard critical economic activities through good contingency planning, and developing sustainable economies in the longer term are central outcomes of SDRM. In association with other plans, SDRM supports economic functions in a way that:

- **Supports agricultural production and promotes water-sensitive agricultural practice.** In many countries, consumptive water use is dominated by agriculture. It is estimated that 70% of water worldwide is used for irrigation (ranging for 90% in many developing nations, to 70% in countires such as Spain and Portugal to less than 1% in England, WBCSD, 2006). It is also estimated that 15–35% of irrigation withdrawals are unsustainable (WBCSD, 2006). Improvements in water efficiency go hand-in-hand with modern agricultural practice. Examples of improvement in water efficiency for agriculture include changes in irrigation to achieve 'more crop per drop', raising the ratio between the quantity of an agricultural product (biomass, yield) and the amount of water depleted or diverted. From a drought risk perspective, these improvements can be a double-edged sword, often increasing vulnerability to drought because the 'water saved' may be used to increase production rather than increase headroom or safeguard ecosystems. In doing so, the agricultural production may become more vulnerable to variations in climates. SDRM therefore has a role to ensure that:
  - *During a drought:* (i) water is made available to meet critical food needs and more broadly for agriculture subject to other priorities; (ii) irrigators have a clear understanding of what water will, or is likely to, be available to allow informed decisions about the crops they grow, how they manage livestock, and to encourage farmers to prepare for future water shortages.
  - *During non-drought conditions,* it is important that awareness of drought issues within the farming community promotes water sensitivity practices and a wider appreciation of drought risks. In particular, recognizing that the impact of restrictions will vary between agricultural sectors. For example, a green-water drought may mean there is insufficient water to maintain permanent crops such as grapes or fruit trees. Therefore, the consequences for those farmers will be more significant and longer lasting that for production focused on annual crops like rice or cotton. SDRM has a role to ensure the broader implications of choosing to adopt high-value crops with high consumptive water use and a broad range of stakeholder views are taken into account the development of priority restrictions (Box 15).

- **Maintains industrial output and promotes low water use and clean industries.** It is estimated that 22% of the naturally renewable water worldwide is used in industry (WBCSD, 2005), including hydroelectric dams, thermoelectric power plants, ore and oil refineries, and manufacturing plants. Although water withdrawal can be very high for these industries, direct consumptive use is generally much lower than for agriculture. Without appropriate treatment, however, pollution of return flows means that effective reduction in available water can be much higher. Given proper incentives, at industry can cut its water demand by 40–90% using existing techniques and good practice (United Nations, 2006). Influencing industrial practice may include, for example, promoting water sensitive development zoning to avoid additional pressure on resources in drought-prone regions; reforming abstraction licences to promote flexibility and reflect priority uses during drought; and introducing policies to reduce industrial pollution.

Box 15: Water pricing and water exports – a dif cult question for California during the ongoing drought (2010 ongoing)

By October 2014, three-quarters of the state of California was formally rated in a 'severe' or 'exceptional' drought by the US Drought Monitor. Over the past two decades, there has been a shift away from traditional crops (lettuce, tomatoes and other annual crops) to high-value nut trees, including almonds and pistachios. The orchards planted throughout the Central Valley require decades-long investments and year-round watering. This has left farmers highly vulnerable to drought and has brought the sustainability of a farming practice that relies on subsidized water provision into question. It has been estimated that if Californian farmers paid the real cost of managing water sustainably, the wholesale price of almonds would triple[51].

An almond orchard in Los Banos, California, is affected by extreme drought, with the suggestion that subsidized water pricing may have increased the vulnerability of farmers to drought

Image source: Justin SullivanGetty Images

Long-term planting, together with the need to maintain water supply, reduces crop flexibility. During drought, farmers can leave fallow fields of lettuce and other crops, then replant them years later if water supply improves. That is not an option for nut trees, which need ten years to mature and a steady supply of water before they yield enough to pay for themselves.

The focus on cash crops also raises the question of water exports. Almonds alone use about 10% of California's total water supply each year, but almonds are a lucrative export with California producing 80% of the world's supply. Equally up to 30% of the Alfalfa hay grown in California (grown largely for livestock feed) is exported to land-poor Asian countries like Japan. Such behavior presents complex water arguments and it is unclear how explicitly such considerations are represented in water resource and drought policy.

5. Jennifer Rankin, Sept 2014. http://www.theguardian.com/business/2014/sep/14/alarm-almond-farmers-drain-california-dry

- **Appropriately diversif es energy production.** Hydroelectric and thermoelectric power can be at risk during periods of drought with the potential to lead to economic hardship and conflict. During the 2013 drought in Maharashtra, India for example, political conflict focused on the relative priority for water between six thermal power plants and the continued provision of water for essential personal use (Greenpeace, 2013). The California drought (2010 ongoing) has also impacted on hydropower output. Between October 2011 and on October 2014, California's ratepayers spent $1.4 billion more for electricity than in average years because of the drought-induced shift from hydropower to natural gas. In an average year, hydropower provides 18% of the electricity needed for Californian agriculture, industry and homes. Comparatively, in this three-year drought period, hydropower comprised less than 12% of total California electricity generation (Gleick, 2015).
- **Provides effective insurance and compensation.** The speed of the economic recovery after a drought will, in part, reflect the degree to which risk has been transferred either to private or government-backed insurers. SDRM has a role to play in establishing insurance protocols that help economies and individuals recover. Care is needed to ensure any compensation arrangements encourage appropriate behaviors and avoid perverse outcomes. Subsidizing inputs and outputs through such schemes as 'yield-based subsidization', can encourage farmers to: over-produce using intensive methods including using more fertilizers and pesticides; grow high-yielding monocultures; reduce crop rotation; shorten fallow periods; and promote exploitative land use change from forests, rainforests and wetlands to agricultural land leading to severe environmental degradation (Robin *et al.*, 2003). Similarly, compensation paid for production losses due to drought can reward farmers who failed to prepare appropriately or who grew highly vulnerable crops and penalize farmers who were better prepare. SDRM uses compensation and financial aid in a way that encourages good behaviors, focusing on outcomes achieved.

4.3. Promoting a drought-resilient society

To transition towards to a drought-resilient society a more ambitious and comprehensive approach to managing droughts than has traditionally been the case is required. Drought risk managers need to think more strategically and influence water-related activities across all sectors and stakeholders to:

- embed a consideration of drought risk within all national, regional and local water related policies
- align drought-related activities across all sectors and stakeholders
- recognize and manage the links between the human system and freshwater ecosystems
- manage inherent conflicts and trade-offs
- to use limited resources efficiently and in a socially just manner.

The nature of this transition is summarized in (Figure 4.4) and further discussed below.

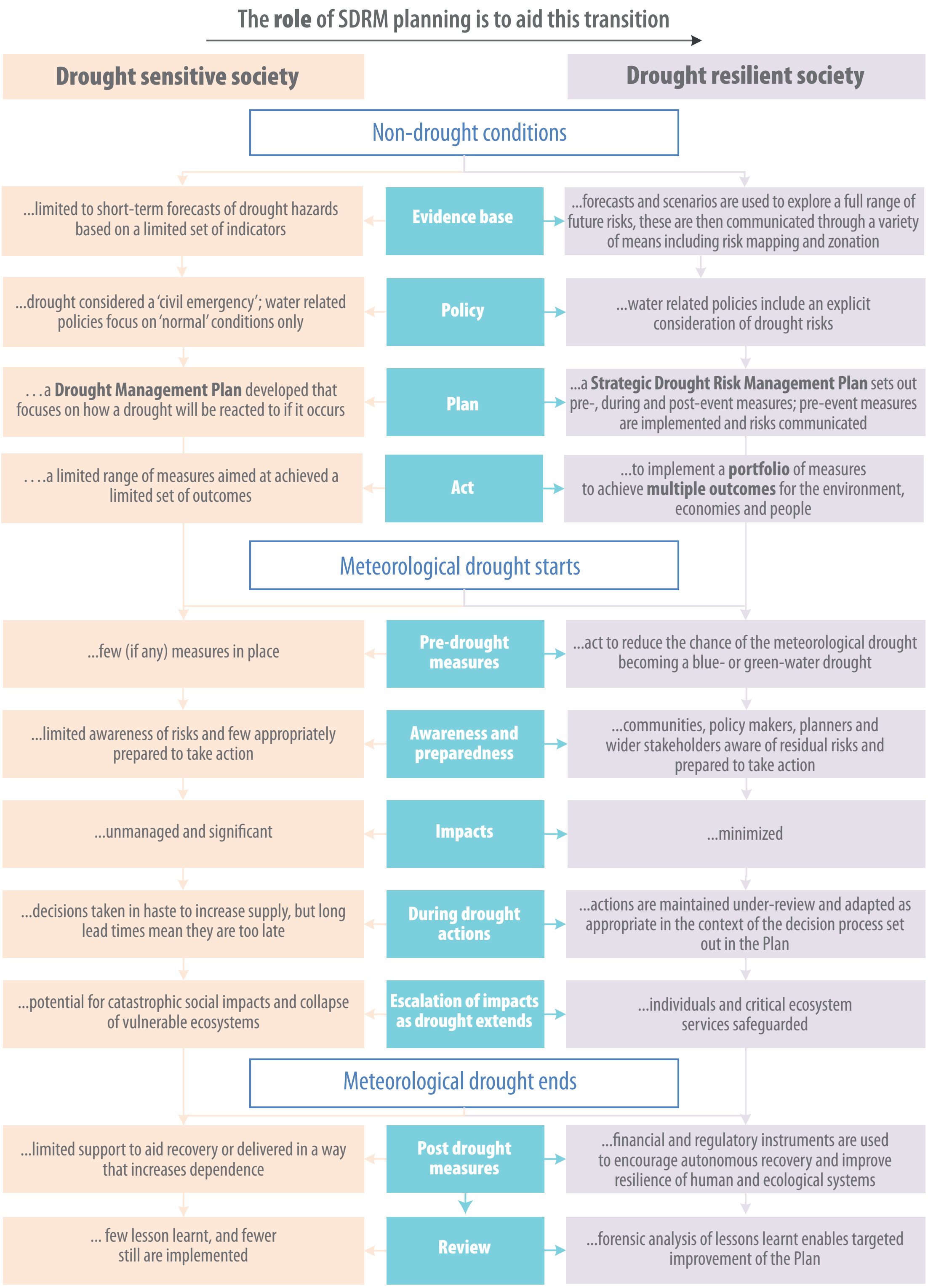
EMBEDDING A CONSIDERATION OF DROUGHT WITH ALL WATER-RELATED POLICIES

Drought-related decision making takes place at multiple governance levels and linking policy and practice relies on drought issues being emphasized throughout all aspects of water-related governance (National Drought Policy Commission, 2000) by:

- **ensuring water resources plans explicitly consider drought** and seek to reduce future drought risks through a portfolio of measures taking account of the uncertain and complex nature of the risks;
- **improving the collaboration between physical and social scientists and water managers** to enhance the evidence base available to decision makers on present and future risks;
- **reconnecting water users with the value of water by incentivizing water saving** through strengthening the moral obligation for, and financial rewards in support of, sustainable water use;
- **protecting ecosystems and promoting their role in managing drought risks** by understanding and appropriately valuing ecosystem services, managing ecosystems to enhance their natural resilience and role in reducing drought risk, and encouraging the maintenance of refugia and environmental flows to protect key habitats and species during drought;
- **maintaining a safety net of emergency relief** that emphasizes self-help and avoids dependence;
- **providing a clear process of decision making as a drought extends** that sets out responsibilities for declaring the onset and cessation of a drought, the enactment of measures (e.g. restrictions, establishing additional supplies etc.) and the inevitable adaptation of pre-drought plans;
- **engaging national and local stakeholders in the decision process** by developing political momentum at a national and local level; without this the imperative for integrated action, particularly during 'wet' periods, is quickly lost.

Embedding a risk-based approach to drought management within broader water-related policies, although difficult, is possible. In England, for example, water resource planning is seeking to address water scarcity and drought issues (e.g. Borgomeo *et al.*, 2014). Australia has also started to make some progress in this area with some success in improving self-reliance and minimizing the need for emergency relief during and in the post-drought period by encouraging a change in farming practice and changing community understanding of how best to manage drought risks (Wilhite *et al.*, 2005).

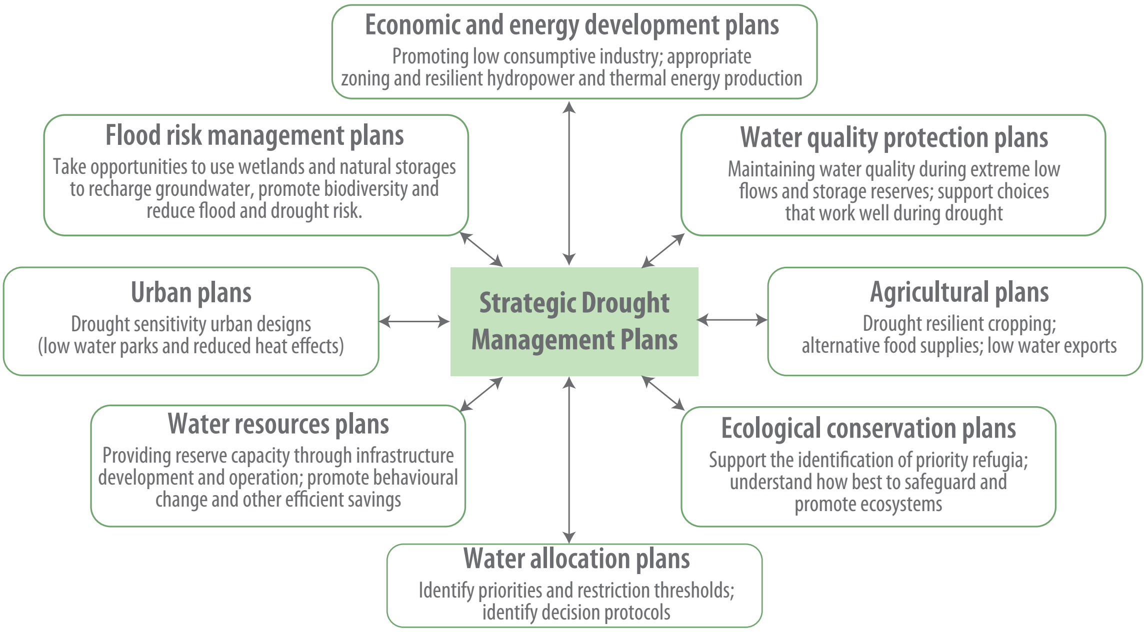
Figure 4.4. Making the transition from a drought-sensitive society to a drought-resilient society is the role of Strategic Drought Risk Management



ALIGNING DROUGHT-RELATED ACTIVITIES ACROSS ALL SECTORS AND STAKEHOLDERS

Managing drought risk is a collective endeavour. As such, SDRM planning is informed by, and seeks to influence, a full range of thematic plans including economic development, energy, flood risk management, water quality planning, and has a central role in delivery of the integrated action needed to build drought resilience (Figure 4.5).

Figure 4.5. Strategic drought risk management is informed by and seeks to influence many other planning processes



Achieving this concerted action requires individuals, businesses, communities and government to work together. This involves: (i) encouraging individuals to act rationally to use less water (Box 16); (ii) empowering farmers to adopt sustainable abstraction and agricultural practices and be 'drought ready'; (iii) helping communities and businesses to be 'drought ready'; and (iv) supporting governments to provide policies that avoid increasing societies vulnerability, encouraging adaptation and promoting socio-ecological resilience.

Box 16: Individuals – incentivizing water-sensitive behavior

A programme started in 2009 incentivizes residents of Los Angeles to replace their green lawns with drought resistant turf. As the drought deepened in 2014, the Los Angeles authorities tried to reinforce the message that individuals should avoid excess water use outdoors. This message was supported with neighbourhood patrols to identify excess water users and through modification of the incentive programme. When it started in 2009, the programme originally gave only \$1 per square foot, by May 2014 the incentive had increased to \$3 per square foot and nearly 9 million square feet of lawn has been replaced.

Source: USA Today: http://www.usatoday.com/story/news/nation-now/2014/07/16/california-drought-extreme-effects/12727163/ accessed 20 November 2014.

RECOGNIZE LINKS BETWEEN HUMAN DEVELOPMENT AND FRESHWATER ECOSYSTEMS

SDRM focuses on resilience. This shifts attention towards enhancing the capacity to adapt and remain flexible in the face of changing conditions, recognizing that 'Growth and efficiency alone can often lead ecological systems, businesses and societies into fragile rigidities, exposing them to turbulent transformations under the pressure from unavoidable fluctuations and surprises (e.g. dry spells and droughts)' (Falkenmark and Rockström, 2008).

Underlying this understanding is the recognition that freshwater ecosystems and human systems do not exist in isolation. Urbanization, agriculture and industrial expansion all act to modify and degrade natural rivers and wetlands. Deforestation, use of chemicals in farming, abstraction for irrigation or industry and dam construction compromise ecosystem functions and reduce the natural capacity (both persistence and recoverability) of freshwater ecosystems to withstand drought (Bond *et al.*, 2008). Socio-economic resilience is weakened due to a loss of freshwater ecosystem services. Poor communities are particularly vulnerable, as their livelihoods tend to depend heavily on natural resources (MEA, 2005).

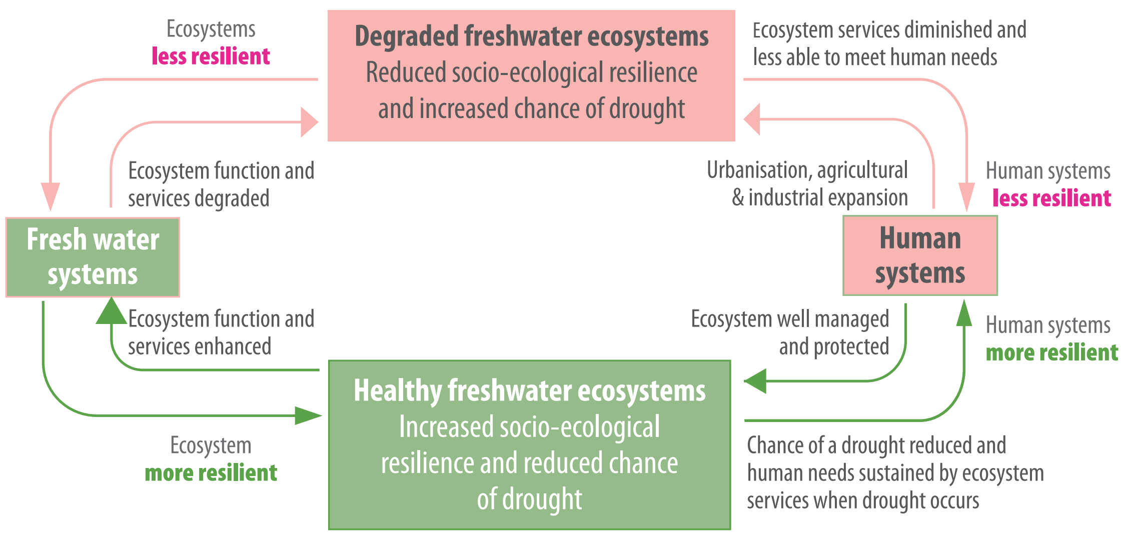
As well as reducing the natural capacity of freshwater ecosystems to cope with drought, degraded ecosystems also aggravate the chance of droughts by altering the physical processes that affect the magnitude, frequency and timing of drought (PEDRR, 2010).

This interaction between freshwater ecosystems and human systems is illustrated in Figure 4.6. In the top half of the figure, human activities are shown to degrade ecosystem functions, diminishing ecosystem services and increasing socio-economic vulnerability to drought. If ecosystems are well managed and protected, a more positive relationship develops, as illustrated in the bottom half of the figure —healthy freshwater ecosystems deliver functions and services that work to significantly reduce the chance and consequences of drought. This has a positive feedback effect on the resilience of the human system. For example, restoration of wetlands can increase groundwater recharge, thereby decreasing the chance of a blue-water drought and bolstering groundwater supplies during dry periods; agro-ecosystem practices can improve soil structure and moisture and reduce drought consequences such as crop failure and dust storms.

Healthy ecosystems are considered more resilient to extreme weather events such as droughts and more likely to recover from the impacts of such events than degraded systems (Sudmeier-Rieux and Ash, 2009), enabling recovery of the livelihoods that depend upon the services they provide.

Meanwhile, developing the resilience of the human system is important for maintaining ecosystem resilience. It ensures the socio-economic system is less reliant on water resources, and is therefore less likely to exploit and degrade freshwater ecosystems before and during drought. Human system resilience to drought can be increased, for example, by diversifying industry away from heavily water consumptive sectors or conserving soil moisture to reduce abstraction for agricultural water use.

Figure 4.6. Drought risk management provides a link between freshwater and human systems



MANAGE INHERENT CONFLICTS AND TRADE-OFFS

Understanding and managing trade-offs is a key part of any water-related planning. Increasing water supply to one sector or user by taking it away from another (the so-called 'zero sum game of water management') almost invariably leads to discontent. Drought events sharpen these water-related conflicts, some of which may have been tolerated or even gone unnoticed, and expose poor water management choices made in the past.

Understanding these conflicts and the implications of different options is at heart of SDRM:

- Short-term economic gain vs. long-term water security. Periods of drought can bring community needs into direct conflict with strategic economic needs, such as government incentives to prioritize economic development.
- Hydropower vs. other sectorial demands. During a drought, alternative choices for reservoir operation and the volume of reserve maintained can profoundly influence the severity of the downstream impacts. Some of the most challenging conflicts arise in relation to the operating rules that govern the wet season releases, the timing of restrictions, and the relative priority given to maintaining environmental flows.
- Water quality vs. economic opportunities. The available water resource during a drought is influenced by both the quantity and quality of water. Improving water quality can be expensive, but without it the availability of useable water and the impacts of a drought can be significantly affected.

- Ecosystem services vs. natural resource exploitation. During a drought the perceived conflicts between the water needs of nature and people are at their most acute. Mounting a compelling case that water should be set aside for the environment is hard, particularly when the impact of not providing water to a business or community is readily apparent, whereas the impact on the environment may not be. SDRM recognizes the socio-economic benefits that functioning ecosystems deliver, and plans the allocation of water reserves during drought accordingly.
- Grey infrastructure vs. green infrastructure. A key component of an ecosystems approach (introduced in 2.2.5) is the use of 'green' infrastructure such as wetlands to promote groundwater storage or run-off management, rather than built or 'grey' infrastructure. Each infrastructure type has advantages and disadvantages. Despite the clear benefits of green infrastructure (see Chapter 8), there has been limited progress in using green infrastructure, except at the demonstration project or pilot-demonstration levels (Renaud, Sudmeier-Rieux, & Estrella, 2013). In most cases, grey infrastructure solutions tend to be favoured, often for poorly founded reasons. Overcoming conceptual barriers and enabling combined grey and green infrastructure to be strategically planned and implemented together will be a vital step towards the transformation needed to develop drought resilience in the longer term.

USE LIMITED RESOURCES EFFICIENTLY AND IN A SOCIALLY UST MANNER

Droughts can have both local and regional impacts on society. In the most severe cases, these impacts can be directly due to hunger, disease and even death, and indirectly through economic disruption and population displacement. Historically, poor people have been disproportionately disadvantaged, losing access to water and other ecosystem services as demand from wealthier populations has grown. Many major cities in India, for example, have their water supplies prioritized and piped water from rural areas, putting tremendous pressure on the rural population during periods of drought (Khurana and Babu, 2014).

Drought risk managers have an obligation take 'fair' decisions and to preferentially support the most vulnerable and marginalized groups. Achieving this in practice is not always straightforward, especially given the political nature of such trade-offs. Every intervention in drought risk management tends to prioritize one group over another, creating further inequality and unfairness. The spatial variation in the frequency and extent of drought, plus the underlying inequalities in social development and the legacy of interventions, mean that droughts are not fair.

Philosophers have analyzed fairness and 'social justice' for centuries (e.g. Rawls, 1971). From this debate three social justice models emerge as the most relevant to drought risk management, namely: (i) ensure that any investment is distributed through an equitable process; (ii) ensure that the most vulnerable members of society are protected; (iii) to maximize the utility of any investment made. These requirements (summarized in Table 4.1) raise a number of practical problems. Simply putting most effort into providing additional reserve capacity for economic use for a limited number of wealthier communities, for example, is demonstrably unfair. Effort devoted to demand management measures alongside appropriate social safeguards offers a more equitable and fair approach.

Table 4.1. Social justice ('fairness' and 'equity') and drought risk management

Justice principle based on Rawls, 1971	Rule / Criteria	Meaning	Potential implications for drought risk management
Equality (procedural)	All citizens to be treated equally (noting that equal treatment is not equivalent to identical treatment).	Every citizen should have the equal opportunity to influence the approach to, and outcome of, DRM	A greater focus on vulnerability reduction and state-sponsored self-help adaptations that can be provided for all – avoiding the inherent unfairness in providing structural solutions that benefit the few.
Maximin rule (distributive)	Options chosen to be those that favor the worst-off best	Resources should be preferentially targeted towards aiding the most vulnerable	Need to identify, and target assistance at the most vulnerable members of society, even when greater economic returns can be found elsewhere.
Maximize utility (distributive)	Options chosen to be those that secure the greatest risk reduction per unit of resource input	Assistance provided to those members of society to which the benefits offer the greatest gain to society.	Likely to promote a broadly based DRM approach that achieves the greatest risk reduction for the most vulnerable freshwater ecosystems and individuals, for example securing affordable drinking water and environmental flows as well as state-assisted self-help adaptations to improve drought preparedness, etc. More capitally intensive structural solutions might be provided to areas of strategically important economic activity.

Source: adapted from Sayers et al., 2013

CHAPTER 5
FRAMEWORK OF STRATEGIC DROUGHT RISK MANAGEMENT

5.1. Introduction

SDRM takes a multi-scale view of risk (short- to long-term, local to basin) and uses a portfolio of actions to better prepare for, respond to and recover from drought in a way that helps make the transition towards a drought resilient society. The SDRM approach is in contrast to the narrow focus on increasing reservoir headroom or improving the emergency response that is typical of traditional approaches.

This comprehensive approach demands more of the planning process. It requires: (i) the development of **whole-of-system, long-term understanding of risk** recognizing risk as an emergent property of the climate, hydrological response and the interaction between human systems and ecosystem; (ii) the implementation of a **portfolio of responses** to manage these risks; (iii) clarity on the **outcomes delivered** for people, freshwater ecosystems and economics and measurement of these outcomes; and (iv) acceptance that SDRM takes place as a **continuous process** of progressive adjustment.

This chapter describes the framework summarized in Figure 5.1 and concludes with a set of 'golden rules' that underpin the successful delivery of SDRM.

5.2. Understanding the context of the drought challenge

UNDERSTANDING THE INTERACTION BETWEEN DROUGHTS AND WATER SCARCITY

The climate and hydrological functioning of a basin, together with the basin's stage of socio-economic development, will determine the nature of the drought risks faced and the capacity for governments and individuals to act. Underlying water scarcity issues will influence the likely health of the freshwater ecosystems and the sensitivity of human system and freshwater ecosystems to variability in the climate. These interactions demand integrated action to address both chronic water issues and acute water issues. Recognizing this interaction in the delivery of SDRM is central to its success – taking action that simply focuses on managing a drought when it occurs will have missed significant opportunities to reduce drought risk.

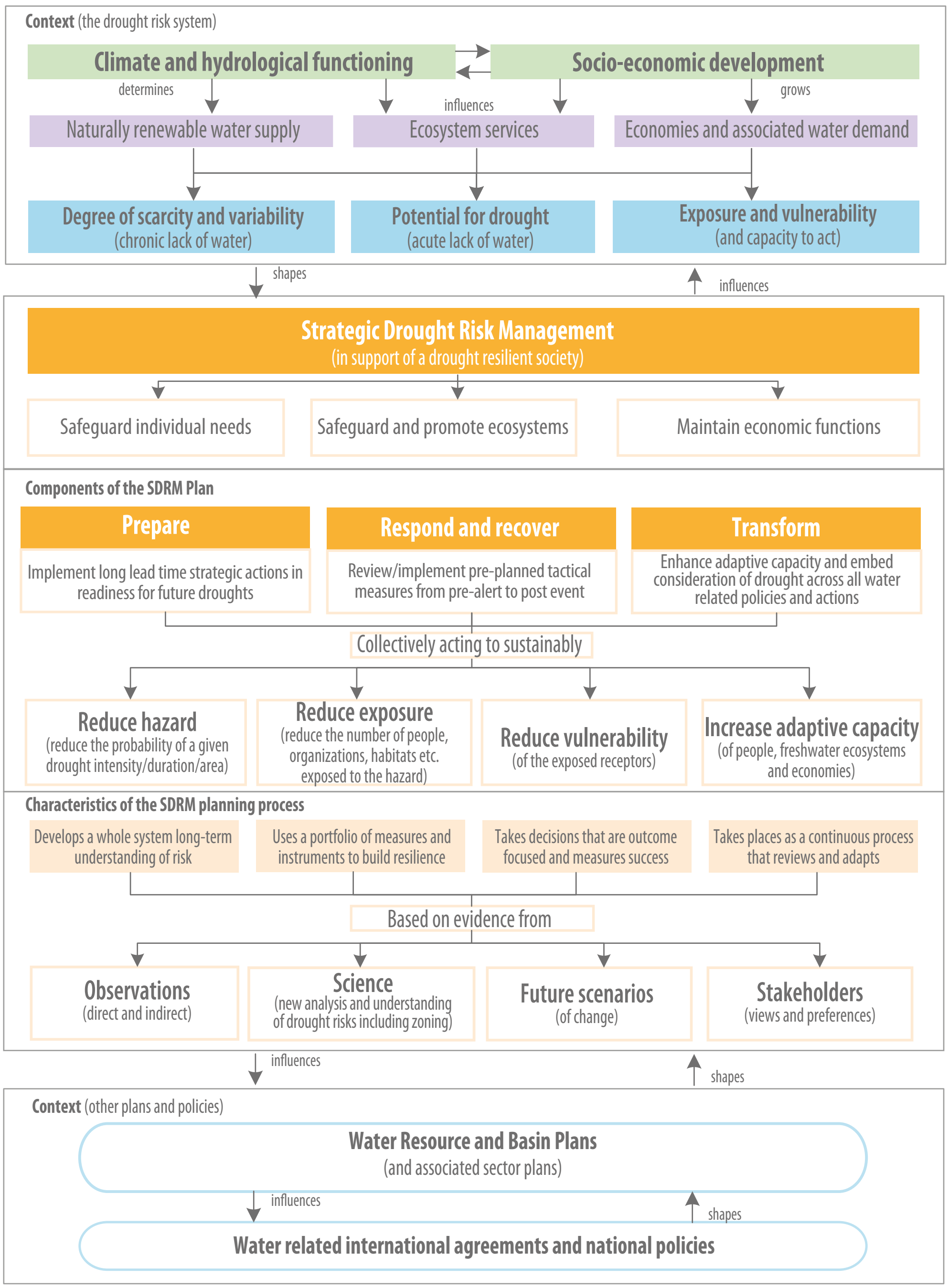
UNDERSTANDING THE IMPACT OF DROUGHT ON DIFFERENT WATER USERS

Different users will have varying capacities to autonomously adapt to drought (and an associated reduction in supply) and the social, economic and environmental implications can vary significantly. For example:

- **Agriculture**. The implications of a drought can vary significantly across the agricultural sector. In the case of annual crops, costs are also annual, meaning that production can be increased or decreased annually without writing off previous years' investments or subsequent years' profits. In the case of permanent crops, such as fruit trees or grapes, a lack of water can result in the loss of established plants and recovery may take many years.

- **Industrial**. Industrial water use tends to be more economically productive than alternative uses and any shortfall in supply can have immediate and significant economic impacts.
- **Urban.** The capacity of urban water users to respond to water restrictions can vary. In low-income communities where water use is already low, any reduction can have a high social and public health impacts. In wealthier communities, there may be more discretionary water usage, allowing water usage to be reduced with limited hardship.
- **Power generation**. A large percentage of power generation is dependent on water supply and any reduction in availability can have major consequences for generation and related economic activities.
- **Freshwater ecosystems**. Healthy freshwater ecosystems have the capacity to cope with some variability in water supply. However, their ability to cope with drought will reflect pre-drought health and can significantly reduce with ecological degradation. There are also thresholds of drought and low flows beyond which irreversible ecological harm may occur (Box 17).

Figure 5.1. The framework of drought risk management includes planning for, responding to, and recovering from drought



Understanding how a shortfall in the available water will impact water users is a pre-requisite to identifying the most vulnerable and taking appropriate action to minimize the associated risks.

Box 17: Impacts of the Lower Lakes during drought, Australia

The Coorong, Lake Alexandria and Lake Albert wetland is a Ramsar-listed site located at the terminus of the Murray River. The Coorong is a long, shallow saline lagoon, while Lakes Alexandrina and Albert comprise fresh to brackish/saline waters (DEWHA, 2010). The region supports a wide variety of water birds and wetland types.

Significant abstraction of water for irrigation from the Murray–Darling Basin has led to average annual flows at the Murray mouth being reduced by around 61% (CSIRO, 2008). Flows were further reduced during the Millennium Drought and coupled with ongoing abstraction of water from the lakes resulted in water levels falling to unprecedented levels. This in turn exposed thousands of hectares of acid sulphate soils (DEWHA, 2010).

Lower water levels resulted in the loss of vegetation and reductions in shorebird and threatened fish species numbers. More significantly, studies suggest that if lake levels had continued to drop there was a risk of permanent, catastrophic impacts from acidification.

It was the combination of the significant over allocation of water, together with extended, below average rainfall, which resulted in these serious ecological impacts.

5.3. Components of Strategic Drought Risk Management

A portfolio of measures is used within SDRM to manage to better prepare society for future droughts and enable an improved response and faster recovery from a drought event when it occurs. SDRM takes action (i) to better prepare for future droughts; (ii) to enable an improved to response to and a faster recovery from drought when it occurs; and (iii) to transform society towards a more sustainable relationship with water. SDRM tries to reduce the chance of a drought hazard occurring, reduce the exposure to a given hazard and reduce the vulnerability of the individuals, ecosystems and economics exposed, while maximizing the broader opportunities actions taken may have.

This planning framework is summarized in Table 5.1 and discussed further. More detail on the individual measures and instruments is in Chapter 7.

PREPARE

The most significant opportunity to reduce drought risk is during normal climatic conditions because improving resilience takes time and relies on a broader range of measures to be planned and implemented. Delaying action until a drought event has been forecast (or declared) is too late to implement many of these activities. For example, measures to reduce routine demand, determine water sharing rules, and increase reserve capacity all have a role to play and all require considerable consultation and time to implement. Equally, improving monitoring, forecasting and communication systems to provide better long-term climate projections and seasonal forecasts as well as decision focused now-casts all make crucial contributions to drought preparedness.

All of these issues must be debated and implemented on an on-going basis and in close interaction with broader basin planning activities. For example, establishing an appropriate water entitlement and allocation regime is a central element of preparing for drought. Establishing an entitlement and allocation regime however requires consultation with a variety of stakeholders, from the community to regional and national level stakeholders to consider drought risks as a core component of the water allocation process (Speed, 2013). Equally, engineered infrastructure and changes in land management practice may take ten years or more to develop and implement to have a lifespan of more than one hundred years, reinforcing the need to incorporate future change, including climate and socio-economic scenarios, into any analysis.

RESPOND AND RECOVER

No matter how much effort is devoted to preparation, drought will inevitably occur. Actions taken during drought should be guided by a pre-agreed strategy that escalates as the drought extends through the following stages (Box 18):

- **Pre-alert:** During the pre-alert stage of drought, freshwater and human systems start experiencing stress and have a heightened vulnerability should the dry period persist. Based on seasonal outlooks or early direct observations, actions taken at the pre-alert stage should limit the deterioration of water bodies while continuing to meet water demands. Measures taken may include awareness raising and encouraging voluntary water saving measures, as well as increased monitoring and evaluation of possible future drought scenarios. Actions to protect key refuge habitats for species and other low-regret actions should be taken. The range of potential actions should be, as far as possible, well-practised and familiar to the communities at risk.
- **Alert:** An 'alert' stage of drought signals the need to increase the focus on saving-water and demand-management restrictions. The onset of drought may be declared and actions may extend to including low-cost direct and coercive (voluntary) measures to reduce water demand

and use. Revised tariffs, with appropriate social safeguards, may help reduce non-essential use. Water allocation trading may also support redistribution if an active market for water already exists. Pre-planned measures may be implemented to ensure an environmental flow is sustained for key ecosystem services and species, and areas with high ecological value may be monitored more intensively with action taken to prevent their deterioration if needed.

- **Emergency:** The goal of SDRM should be to avoid getting to the 'emergency' stage of drought, however, in some circumstances this may be unavoidable and enforced restrictions on water use and other measures may be needed to minimize impacts on freshwater and human systems. These measures should have been rehearsed within the strategic planning process and may include measures to save certain species through, for example, emergency releases of water to translocate species to refugia. Temporary large-scale water transfers may be required and new infrastructure projects may be accelerated. However, these measures may fail to be operational in time to alleviate drought impacts and may have high and unnecessary costs, long payback periods and environmental impacts.

Table 5.1. Summary of a planning framework for Strategic Drought Risk Management

	Prepare	Respond and recover				Transform
		Pre-alert	Alert	Emergency	Recovery	
Context	A normal water resource situation.	An initial period of dryness.	Direct impacts on people, business and the environment. Voluntary restrictions may be appropriate.	Severe impacts occur or are likely to occur. Mandatory restrictions are needed and water supply is not guaranteed.	A non-drought water resource situation, but drought continues to have residual impacts on people, businesses and environment.	A non-drought water resource situation provides the opportunity to consider lessons and implement long-term transformations to develop a drought resilient society.
Status of indicators	Show a normal non-drought situation.	Highlight an increased vulnerability to future drought.	Suggest impacts will occur if measures are not taken.	Confirm severe impacts are likely.	Show a return to the non-drought situation.	Show a non-drought situation.
Objective	To build resilience to future droughts by taking a long-term, whole-of-system view of risks.	To ensure acceptance of measures to be taken in case of alarm or emergency.	To limit the impact of a drought through implementing agreed demand management measures and ensuring appropriate preparations are made for alternative supplies.	To limit the impact of a drought on essential needs (such as drinking water, food and energy) and the most vulnerable ecosystems.	To ensure recovery of freshwater and human systems as quickly as possible.	To support the transition towards a water secure and drought resilient society.
Measures	Develop and implement a portfolio of measures and instruments, for example: i. Devise and implement a monitoring and early warning system. ii. Develop appropriate reserve capacity (using natural and build storage). iii. Appropriately reform abstractions. iv. Communicate priorities for restrictions and raise awareness of drought risks. v. Take action to build resilience of freshwater ecosystems including maintaining system connectivity and priority refugia and preserving habitat heterogeneity. vi. Develop water allocation and sharing plans that address a range of scenarios, including make provision for environmental flows during droughts.	i. Promote low cost, indirect and/or voluntary actions. ii. Initiate non-structural measures to reduce water demand. iii. Increase communication and awareness raising. iv. Intensify monitoring and evaluation of possible scenarios. v. Initiate actions to protect key refuge habitats for species. vi. Normal water sharing rules apply.	i. Declare drought. Extend to include low cost direct and coercive measures to reduce demand/use including water restrictions for some uses and users (that do not affect drinking water). ii. Revised tariffs (with social safeguards) may play a role in encouraging a reduction in non-essential use. iii. Water allocation trading may also support redistribution (where an active market for water already exists). iv. Implement pre-planned measures to ensure an environmental flow to ensure key ecosystem services and species are sustained.	i. Extend to include high cost direct and coercive measures to reduce demand (including urban users). ii. Implement pre-approved infrastructure responses including intra- and inter-basin transfers. iii. Initiate emergency supplies (desalination and additional groundwater sources, etc.). iv. Implement measures to save certain species – this could include emergency releases of water to translocate species. v. Water sharing rules for extreme drought implemented and/or water sharing rules suspended and real-time decision making (involving multiple stakeholders) used to allocate water	i. Actions required to monitor and manage the recovery of water resources and to learn lessons. ii. Declare end of drought. The ending of emergency measures and normal systems (and water sources) reinstated. iii. Promote ecosystem recovery by reinstating temporary restrictions, restoring water systems and restocking.	i. Develop zonation plans to guide future developments. ii. Develop a political acceptance of risks and widespread awareness of those risks. iii. Promote the co-dependence of human systems and ecosystems iv. Embed a process of ongoing learning and adaptation.
Review and adjustment	On-going process of review and adjustment based on evidence (scientific and practical). Involving all levels of government, communities, organizations and individuals.	In event review and adjustment through an appointed and empowered Drought Committee (involving governments, water provider and stakeholder representatives)			Post-drought review and adjustment to preparatory measures for next drought	

The end of a meteorological drought does not necessarily signal an end of a green-water drought or blue-water drought. The recovery phase that follows a meteorological drought is vital in re-establishing the health of freshwater and human systems:

- **Recovery:** Communities, businesses, economies and freshwater ecosystems will continue to be in a heightened state of vulnerability for some time after a meteorological drought ends. Action to speed recovery is an important component of the SDRM approach. Predetermined recovery plans should be reviewed with stakeholders and revised to take account of the reality of the drought. Agreed actions are likely to include, for example, monitoring and managing the recovery of water resources and, when appropriate, formally declaring the end of the drought, ending emergency measures and reinstating normal systems. Proactive actions may also be needed to aid the recovery of freshwater by, for example, reinstating temporary restrictions, restoring water systems and restocking. The recovery phase also provides an opportunity to capture lessons learnt and break the hydro-illogical cycle (Figure 2.1), using the recent experience to promote the development of a more drought-resilient society.

TRANSFORM

A drought-resilient society evolves to develop a new relationship with water that recognizes the mutual dependence between human development and freshwater ecosystems. This goal requires more than simply 'preparing for' and 'responding to' drought; it considers drought risk alongside broader water resource and development issues.

In practice, transitioning to a drought-resilient society requires political acceptance of drought risks, widespread awareness of those risks and momentum to act.

Box 18: Trigger points and the South East Queensland water supply strategy

A critical aspect of drought response is understanding the trigger points at which different actions are required to mitigate the potential impacts of drought. In South East Queensland, Australia, the *2010 Regional Water Supply Strategy* identifies a number of such triggers. Prepared in the aftermath of the Millennium Drought, the strategy is a 50-year planning document, which identifies future water and is designed to:

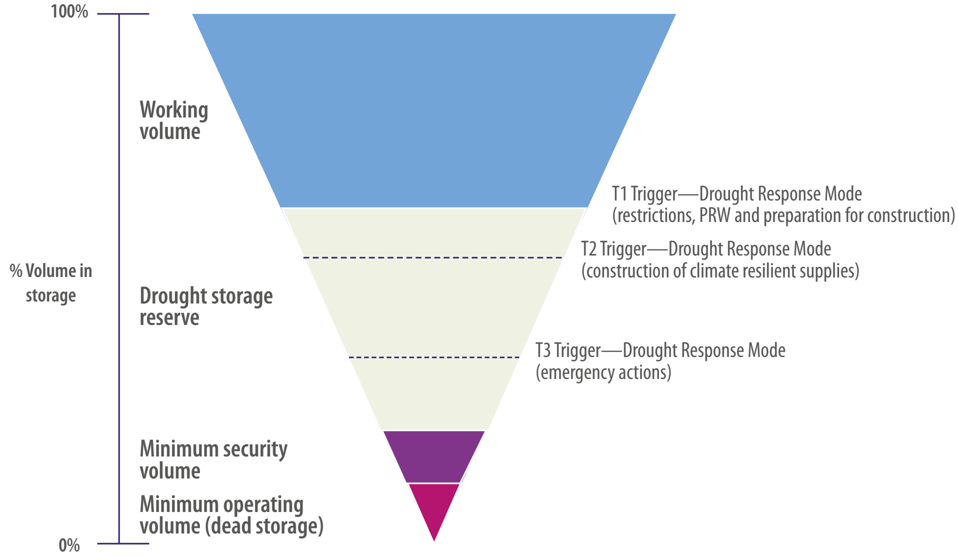
- ensure capacity to maintain water supply over the long-term
- establish a drought response plan to protect against water shortages through planned implementation of appropriate demand management measures and the construction of new climate resilient supply facilities
- establish a contingency plan to ensure basic water needs can be met during extreme drought.

The strategy establishes level of service objectives for water supply in the region, which are related to the frequency and severity of future water restrictions.

The strategy identifies how and when responses to drought will be implemented, including setting a series of trigger points, based on water supply levels (see figure below). Triggers include the introduction of water restrictions, the construction of new supply facilities and emergency responses.

Annual reporting is required under the strategy to review the planning assumptions that underpin the strategy (climate, population growth, etc.) and to report on progress. Annual reporting also describes water supply levels and projections for the next six years, including assessments of a 'worst case scenario'. The strategy is reviewed on a five-year cycle aligned to reviews of the South East Queensland Regional Plan 2009–2031.

Partitioning of water storage under the SEQ Water Supply Strategy.



Source: QWC, 2010

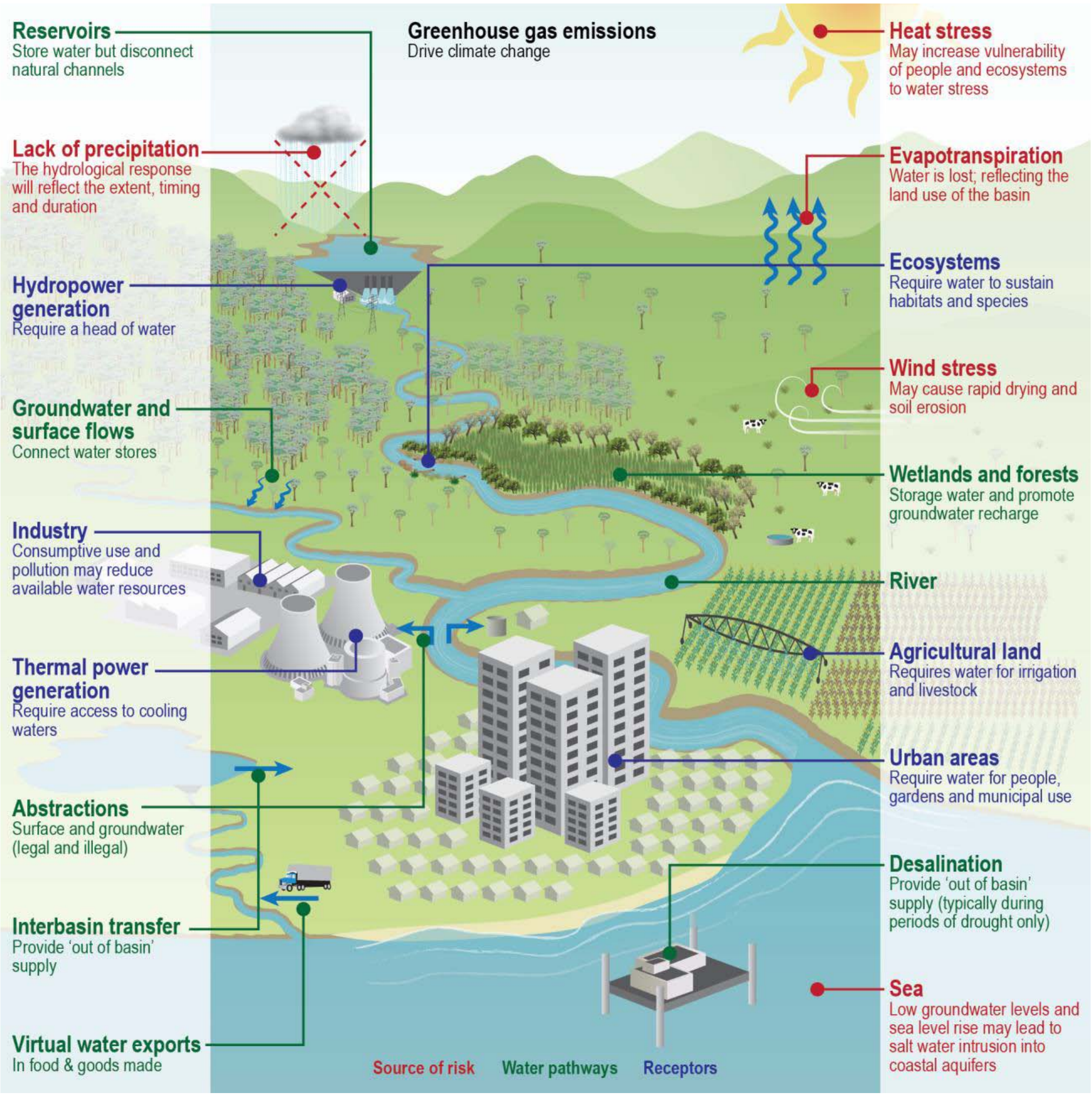
5.4. Characteristics of Strategic Drought Risk Management

Strategic planning for drought is based on understanding the whole system and it might change in the long-term. Decisions are outcome-focused and seek to reduce risk through a portfolio of measures, with costs in proportion to the significance of the risk as understood through the perceptions and perspectives of a range of communities and stakeholders. Strategic planning is a continuous process of review and adaption. These characteristics of good practice are expanded in the following sections.

WHOLE SYSTEM AND LONG-TERM VIEW

For drought risk, the 'whole system' (Figure 5.2) includes the **source** of the drought hazard, the hydrological **pathways** within the basin and the **receptors** that may experience harm. The interactions between natural systems and human systems within this drought risk system can be complex. For example, drought that affects a freshwater ecosystem that is an important spawning ground may have knock-on effects for downstream communities and economies that rely on fisheries.

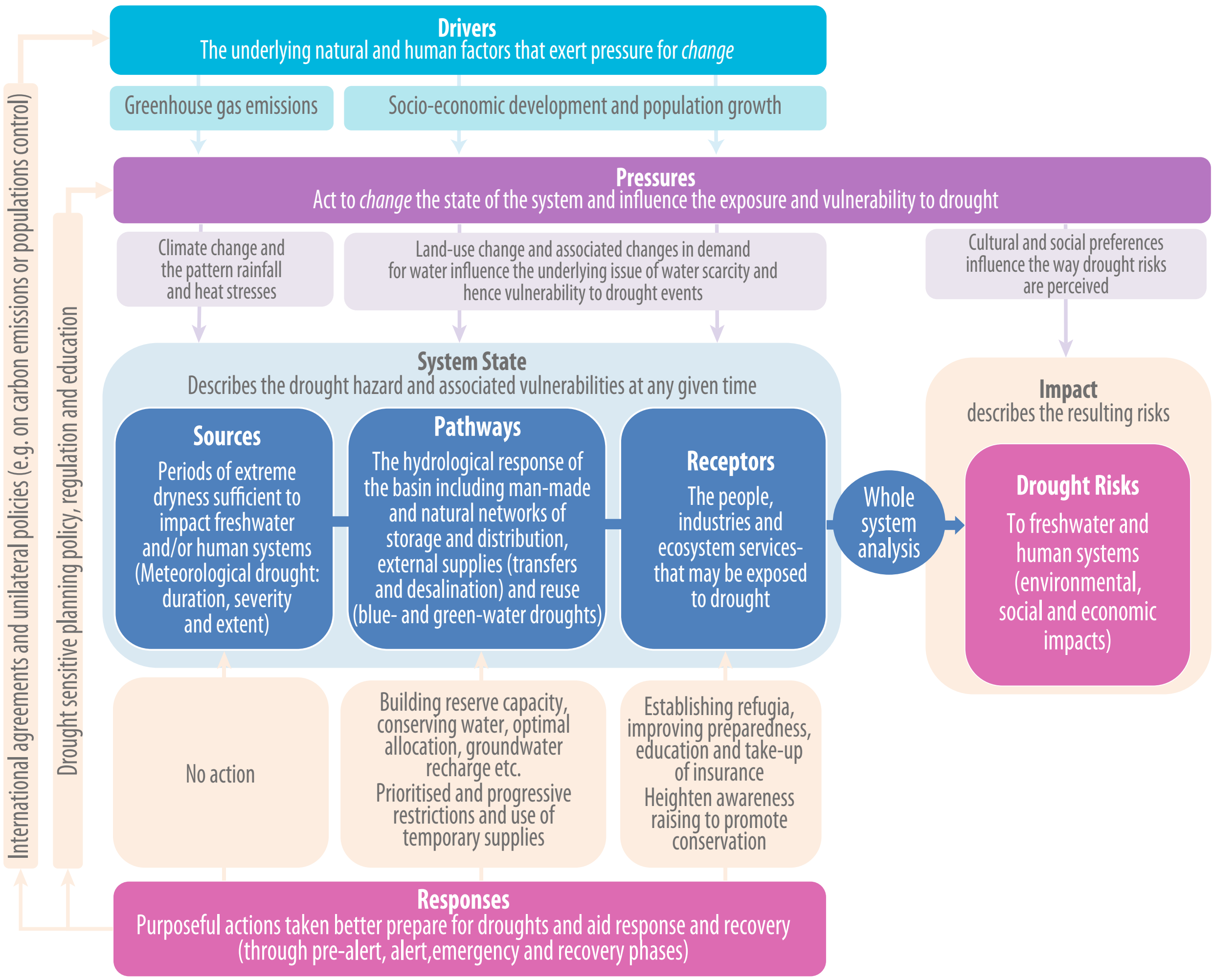
Figure 5.2. Drought risk system: SDRM takes a whole-system view



Understanding the present and future vulnerabilities across the whole system can be daunting; but, it is a prerequisite to developing a better understanding of how all these elements link together and how risks can be best managed. The drivers-pressure-state-impact-response (DPSIR) framework (OECD, 1993) used in managing other environmental hazards (e.g. air pollution), provides a useful framework to help make sense of complex interactions and determining the relationship between a change in the 'system state' and a change in risk.

For example, a change in system state may occur in response to external drivers and pressures such as climate change or population growth. A system state may also change due to a purposeful management actions than may either increase demand, such as urban development, or increase supply, such as wetland development to encourage groundwater recharge. These changes will modify the sources, pathways or receptors (see Figure 5.3).

Figure 5.3. Understanding the interactions between drought risk management activities and their influence upon the drought risk system



Adopting a whole-system and long-term approach has already been shown to be useful in the context of other natural hazards (Sayers *et al.*, 2002, 2013). This approach underpins the concept of an ecosystems approach that seeks to understand the interactions between ecosystems and human systems to safeguard and foster the benefits of these interactions. More specifically, SDRM seeks to:

- **Strengthen socio-ecological resilience:** By requiring society to use less of the naturally renewable water resource, it will be less likely to exploit and degrade freshwater ecosystems before and during drought and provides the necessary space to ensure sufficient environmental flows during drought. Requiring society to use less of the naturally renewable water resource helps to identify areas where human activities are degrading freshwater ecosystems and reducing their natural capacity to cope with drought, and promotes taking action before drought to address anthropogenic threats.

- **Foster a relationship between nature and society:** Strengthening socio-ecological resilience requires efforts to improve the relationship between people and freshwater ecosystems and foster environmentally sensitive communities. The importance of freshwater ecosystems to society can be demonstrated by appropriately valuing services that underpin human well-being, such as water purification and key sectors of the economy. Understanding how these services might be used to help reduce drought risk, in combination with grey infrastructure, also helps capitalize on human-ecosystem connections.
- **Recognize the importance of landscape-scale processes and the local context of action:** Resilience of agricultural systems to drought is dependent on the ecosystem functions and services provided by the catchment (Falkenmark and Rockström, 2008). Building resilience of rural communities should be approached from a landscape perspective. However, farm-scale approaches to increase socio-ecological resilience are also important, because agro-ecosystems are managed at farm-scale levels and impacts are felt first-hand at this level. Taking account of local socio-political drivers and knowledge, and fostering local social support networks is fundamental to changing attitudes.
- **Take a long-term view:** Measures need to be developed that recognize the short-term political realities of drought and to protect the public against immediate hazards, while also yielding disaster risk reduction outcomes for society and natural systems in the longer-term. Taking a longer-term view allows the status quo to be challenged and to investigate more integrated approaches to water management that address drought and flood risks alongside broader water management strategies.

OUTCOME FOCUSED

An outcome-focused approach compares alternative strategies based on an assessment of:

- risk reduction achieved over the short- and longer-term
- opportunities realised in the short- and longer-term
- effectiveness, efficiency and equity of the resources used.

By focusing on the outcomes of a given investment of financial or human capital, the long-term benefits (monetary and non-monetary) and costs of alternative strategies can be rationally compared. In this context, outcomes refer to the risk reduction achieved and opportunities gained. This is in contrast to a strategy based on 'standards'. Within standards-based approaches to drought management, the focus is on delivering pre-determined standards of performance without necessarily understanding the benefit of achieving the standards or, more crucially, whether resources could be better deployed through alternative strategies to provide better outcomes.

The move towards an outcome-focused approach is in line with advances in the management of other natural hazards, particularly flood risks, where standard-based approaches are increasingly being seen as restricting the freedom of the decision maker to achieve the best outcomes for the resources available (e.g. Sayers *et al.*, 2013). This lack of optimality is because standard-based approaches tend to:

i) **Def ne a limited range of impacts.** Impacts and trade-offs outside those with a defined standard are difficult to incorporate into the decision making process and the focus of effort is directed to achieving targets that may fail to reflect the importance that emerges from the analysis.

ii) **Set standards without necessarily understanding the likely benef ts or foregone opportunities.** Standards-based approaches make it difficult to trade off impacts and recourses and the opportunities foregone if the resources were directed differently. For example, it may be preferable to allow more restrictions on non-essential water use (i.e. lower standard) to support higher flows in a river for longer. At best, standards-based approaches simply hide the benefits of action, but more often the use of pre-defined standards can mis-direct finite resources and lead to sub-optimal outcomes.

iii) **Address local issues poorly.** Regional or national standards often fail to capture locally specific issues and trade-offs.

iv) **Assume the future will be a version of the past.** Standards-based approaches often lack the flexibility to incorporate future uncertainty in the decision making process. In conditions of change, fixed standards and the trade-offs they include, will not, necessarily, remain suitable.

A risk-based, outcome-focused approach is better placed to respond to: (i) a non-stationary climate; (ii) a drought planning process that is increasingly complex and links closely with broader basin planning and national policies (Schwab, 2013); and (iii) an acceptance that drought risks are best managed through a portfolio of measures from major infrastructure through to local actions to build drought-ready communities (e.g. Svoboda *et al.*, 2011).

The differences between a standards-based approach and a risk-based approach are summarized in Table 5.2.

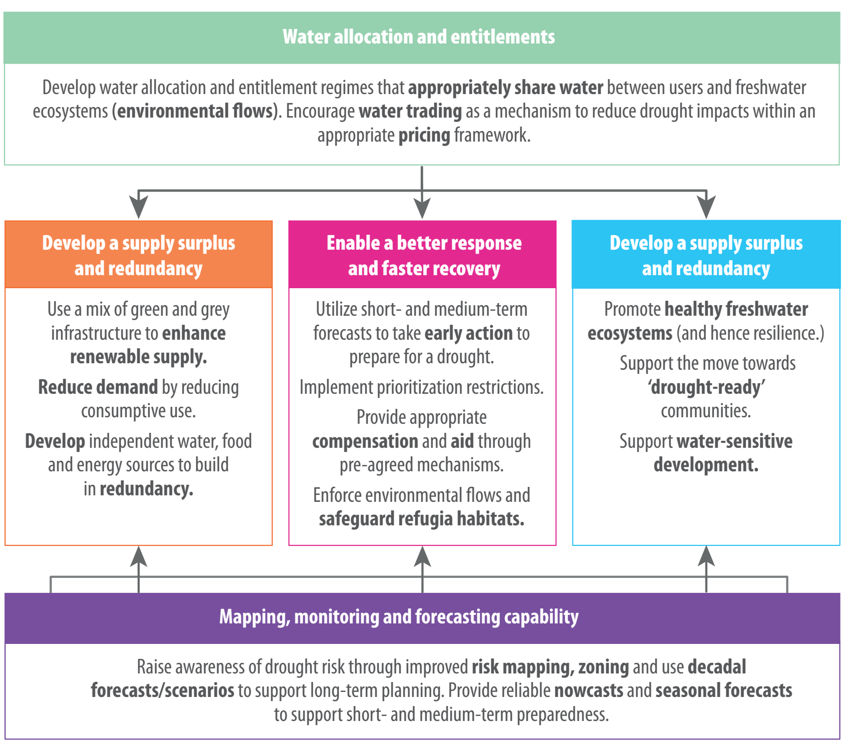
Table 5.2. Drought planning – moving from a standards-based approach to towards a risk-based approach

		Basis	Characteristic motivation	Example objective
Standards approach	Probability	Historical event	The consequences of drought during a repeat of a specified historical event.	Ensure sufficient headroom to maintain supply during a repeat of the 1976 UK drought.
		Single design events	The consequences of drought during a drought event of a specified return period.	Ensure sufficient headroom to maintain supply during a 1:100 year return period drought.
		Multiple design events	The consequences of drought according to the nature of the land use/asset protected.	Ensure drinking water restrictions are avoided in all droughts with a return period of less than 1:100 years, to avoid industrial restrictions on water use for all events less than 1:10 year return period and maintain environmental flows in droughts of a return period up to 1:100 years.
	Consequence	Level of services	To limit the consequences of drought during the given design drought to a specified level regardless of the cost of doing so.	During the historical drought of reference, the supply will be maintained at 20~30 L/person/day.
Risk approach	Risk	Resource optimal and multi-criteria	To reduce drought risks to an acceptable level taking account of the likely resources required and range of benefits accrued over the long-term.	To reduce risk effectively and efficiently while achieving societal preferences for equity, safety, and ecosystem health. The increased resource inputs required to provide progressively greater reductions in risk should not be disproportionate to the additional benefits secured.

PORTFOLIO OF MEASURES AND INSTRUMENTS

A strategic response to managing drought risk uses a combination of instruments and measures across a basin and staged across time to reduce the chance of drought and its associated consequences. This response requires a long-term approach to managing risk and taking action to: (i) promote appropriate national policy and regulatory instruments; (ii) establish mapping, monitoring and forecasting to provide early warning of developing droughts, and to invoke communication and engagement mechanisms; (iii) enhance or restructure supply measures and reduce or restructure demand; (iv) secure environmental flows and establish refugia habitats; and (vi) encourage behavioral change to promote water sensitivity development. Each of these measures and instruments play a role in helping society better prepare for, respond to, and recover from drought in a way that supports a long-term transformation towards a drought-resilience society. These considerations are summarized in Figure 5.4.

Figure 5.4. Typical considerations in a portfolio approach to drought risk management



Developing and implementing a wide-ranging portfolio requires drought risk managers to challenge the status quo and promote innovative and more comprehensive approaches than have been traditionally used. In particular, drought risk managers should consider how an appropriate combination of actions can be taken to:

- **Manage drought risk at multiple spatial and temporal scales** using a mix of: (i) large-scale actions through to encouraging changes at the individual business level and modifying personal behaviors; (ii) actions with long-lead times; and (iii) short-term responses.
- **Provide built-in redundancy** including the alternative supplies and progressive demand management measures.
- **Provide solutions that continue to perform well** regardless of future uncertainties (climate, demographics, finances, etc.).
- **Deliver multiple co-benef ts** through active integration with water allocation, flood management activities and hydropower, for example.
- **Consider the relative merits of green infrastructure compared to conventional grey infrastructure measures** to reduce risk is a key component of a portfolio approach. This requires understanding the role, benefits and costs of providing green infrastructure relative to conventional grey infrastructure for the same risks. It also requires greater consideration of the interdependency between freshwater ecosystem services and grey infrastructure: firstly, because grey infrastructure relies on ecosystem services to function correctly (Dalton *et al.*, 2013), and secondly because grey infrastructure can have adverse impacts on ecosystem services.

REVIEW AND ADAPT

Accepting that drought risk management is a continuous process of planning, acting, monitoring, reviewing and adapting can help manage the uncertainties associated with drought planning (see Section 3.9). The adaptive management approach is particularly relevant to ecosystems and SDRM given the inherent uncertainties: the relative lack of data on ecosystem responses to drought; the infancy of ecosystem approaches in SDRM; and the context of changing environmental conditions due to climate change and other anthropogenic stresses.

This process of adaptive management facilitates a culture of continuous learning and dynamic adjustment, enabling managers to better accommodate uncertainties rather than focusing on finding optimal solutions. Such an approach avoids choices that 'lock-in' maladaptation that may be expensive to reverse. Such a philosophy contrasts to the assumed single future and 'construct and maintain' approach typical of traditional drought management (Table 5.3). A managed, adaptive approach offers distinct advantages, in particular providing the opportunity for innovative 'win–win' and 'low regret' actions to be identified, reviewed and adapted in a continuous process as the reality of drought risks become better known.

Table 5.3. The recognition of uncertainty has a profound impact on strategy development, forcing the traditional linear design model to be replaced with adaptive strategies

Stages of strategy development	Traditional (certain) model of strategy development and decision making	Adaptive (uncertain) model of strategy development and decision making
Deciding what is needed	Pre-defined system of goals, objectives and desired outcomes. Defined set of activities and resource demands.	Emerging pattern of goals, objectives and desired outcomes – not only within drought risk management but broader sustainable development goals. Flexible configuration of resources and priorities. Significant investment in monitoring, evaluation, learning and adaptive management.
Deciding how to achieve it	Sequential process of planning, programming and implementation. Top-down strategy development.	Continuous alignment of plans, programmes and implementation activities with the changing world. Continuous reconciliation of bottom-up initiatives and top-down strategies.
Understanding the external and internal influences	Stable system of decision making. Predictable (deterministic) future change – climate, demographics, deterioration, preferences, etc.	Changing decision processes and priorities. Unknown future change - climate, demographics, deterioration, preferences, etc.

Source: adapted from Hutter and McFadden, 2009.

EVIDENCE-BASED DECISION MAKING

Many uncertainties are associated with assessing drought risks. Good decisions rely on credible and transparent evidence. Meaningful monitoring and analysis are at the heart of evidence-based decision making. 'Hindcasts' of the past climate and impacts provide the context within which present-day risks are understood through, for example, drought zonation maps; 'nowcasts' of the current state of the system provide vital evidence to manage a drought as it develops; 'forecasts' or short- to long-term estimates of future risks support the early declaration of drought and underpin long-term planning choices; and 'scenarios' of longer-term change form the basis of developing strategic risk management.

Evidence of the importance of freshwater ecosystems to society is also crucial in promoting and protecting freshwater ecosystems; it helps change mindsets about priorities for SDRM, as well as how SDRM should be approached. Assessing the value of ecosystem services provides decision makers with the economic arguments for protecting and restoring ecosystem services (Shepherd, 2008). Credible evidence on the relationship between ecosystems and drought risk reduction is also useful to dispel beliefs and contradictory scientific information about the benefits of ecosystem services approaches (see Chapter 8).

Appropriately communicating all evidence to the full range of interested stakeholders allows for an informed debate. Many counties provide regular updates on a range of indicators to help communities, businesses and local governments prepare for drought. Understanding and communicating probabilistic drought risk maps is also increasingly being recognized as an important step and an evolving science.

Drought risk managers should focus on the uncertainties that are important in the context of the specific decision being made, recognizing that funds should only be invested in investigating uncertainties where the answer might influence the choice to be made.

5.5. The Golden Rules of Strategic Drought Risk Management

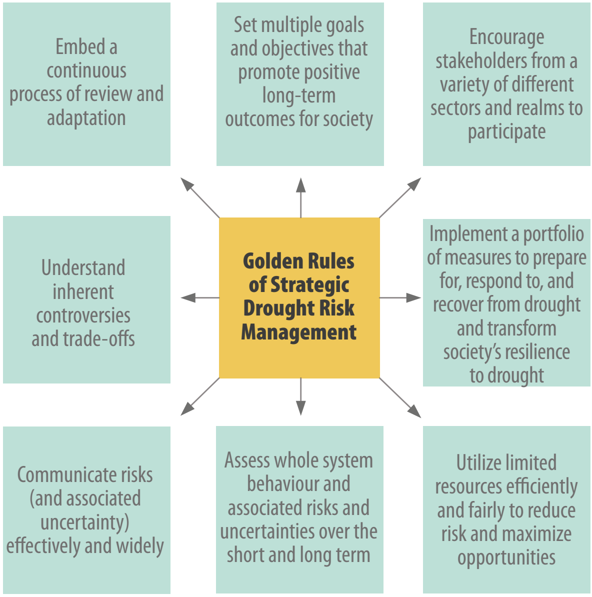
Droughts are always context specific. As a result, SDRM plans be context-specific in the combination of actions they prescribe. A common understanding of what constitutes 'sound' SDRM is starting to emerge with a general convergence on the concepts of risk (see Chapter 3) and a definition of SDRM:

Strategic Drought Risk Management (SDRM)

Is defined here as the process of data and information gathering; risk analysis and evaluation; appraisal of options; and making, implementing, and reviewing decisions to reduce, control, accept, or redistribute drought risks. SDRM is a continuous process of analysis, adjustment and adaptation of policies and actions to reduce drought risk, including modifying the probability of a drought as well as reducing the vulnerability and enhancing the resilience of the receptors threatened. SDRM forms part of the wider approach to water security and water -elated basin planning and allocation activities. It focuses on delivering a drought-resilient society by reducing drought risks and promoting environmental, societal and economic opportunities, both now and in the longer term. SDRM recognizes that risks can never be removed entirely and that reducing risk may be at the expense of other societal goals.

A small number of principles are central to delivering good SDRM. These 'Golden Rules' are summarized in Figure 5.5 and discussed below.

Figure 5.5. Golden Rules of Strategic Drought Risk Management



1. **Set multiple goals and objectives that promote positive long-term outcomes for society**: SDRM is about reducing drought impacts across many sections of society and safeguarding biodiversity and the ecosystem services on which society depends. SDRM delivers long-term outcomes and avoids seeking short-term solutions that may have negative impacts. The success of SDRM is measured against multiple objectives achieved over different timescales.
2. **Encourage stakeholders from a variety of different sectors and realms to participate:** Good decisions rely on governments, businesses and communities being active participants in the process. SDRM fosters collaboration that supports the necessary political momentum for change and sharing of responsibility and fiscal support for implementing measures.
3. **Implement a portfolio of measures to support the transition to a drought resilient society:** Strategic management of drought risk involves considering the widest possible set of management actions to prepare for, respond to, recover from drought. These actions should include measures to reduce the probability of drought (by increasing the supply-demand surplus through green and grey infrastructure and actions to reduce demand) and measures to reduce the consequences should a drought occur (by promoting healthy ecosystems, and continuing to safeguard environmental flows and refugia habtiats, whilst encouraging communities and business to adapt to drought risks and providing effective recovery mechansims – from fish re-stocking to financial compensation).

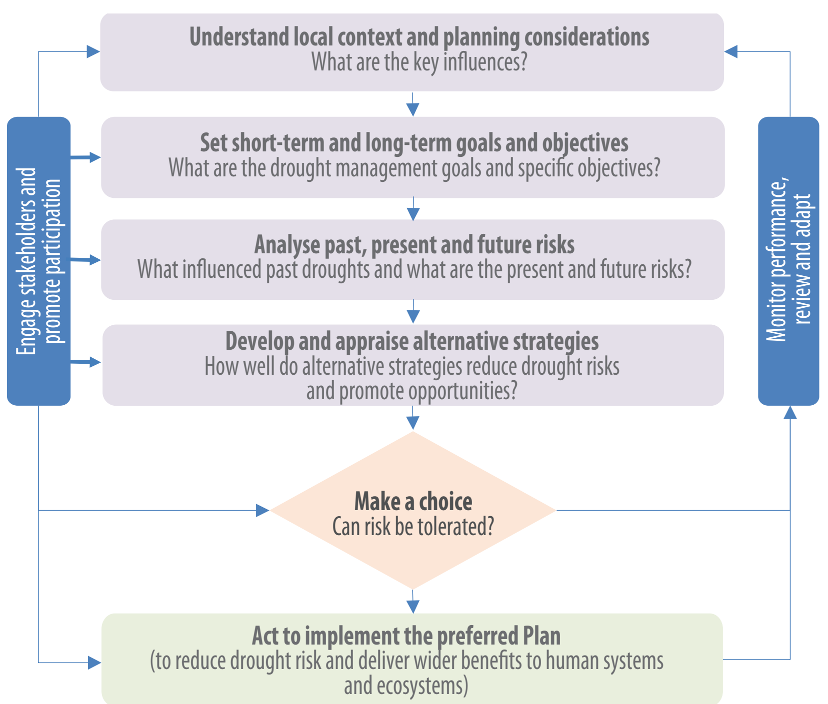
4. **Utilize limited resources efficiently and fairly to reduce risk and maximize opportunities:** The level of effort used to manage drought risk must be related to the context-specific significance of those risks and not based on universal or generalized standards of supply reliability. SDRM considers the efficiency of management measures, not only for risk reduction and resources required, but also their fairness and ability to maximize broader ecosystem opportunities.
5. **Assess whole system behavior and associated risks and uncertainties over the short and longer term:** The drought risk system consists of the climatic sources, hydrological pathways and the receptors that may experience harm, such as people, ecosystems and economies. An appropriate understanding of this whole system, including physical and socio-economic factors, and how it might change due to external influences such as climatic and demographic change and management responses over the long-term is a prerequisite to making good choices. However, the uncertainty within the data and models must be acknowledged and the choices made must be robust despite that uncertainty.
6. **Communicate risks and uncertainties effectively and widely:** Both decision makers and the public must understand drought risks. Effectively communicating risk and uncertainty in an accessible way enables both communities and individuals to prepare for and support risk reduction measures. Initiating this dialogue during a drought is too late.
7. **Understand inherent controversies and trade-offs:** Managing the trade-offs that will inevitably arise during SDRM requires extensive discussion and the preferred approach may require significant changes that challenge the status quo or the development of infrastructure solutions with significant lead times. Efforts to understand these trade-offs and how they will be managed is a core component of any SDRM plan. Decisions made in haste during a drought seldom balance competing needs adequately and often produce ineffective, inefficient or inequitable results.
8. **Embed a continuous process of review and adaptation:** The world is changing. Climate change, demographic change, change in the hydrological response of the basin and other societal changes mean that planning processes imagine a future that resembles the present are not fit-for-purpose. Accepting SDRM as a continuous process of review and adaptation is a pre-requisite for continuing to deliver the desired outcomes.

CHAPTER 6
THE ADAPTIVE PROCESS OF STRATEGIC DROUGHT RISK MANAGEMENT PLANNING

6.1. Introduction

This chapter focuses on the process of preparing an SDRM plan (Figure 6.1). It considers the key steps in developing the plan, recognizing that it should be context specific and be a continuous process of setting goals and objectives, identifying risks and opportunities, assessing the significance of those risks, exploring and appraising the performance of alternative strategies, selecting and implementing the preferred approach and establishing a process of monitoring, review and adaptation. This process accepts that risks can never be removed entirely and that any action to reduce risk in one sector (or location) may increase risk in another. To help manage these trade-offs, SDRM seeks stakeholder participation throughout the process and favours approaches that achieve multiple benefits.

Figure 6.1. The process of Strategic Drought Risk Management is a continuous process of adjustment and adaptation

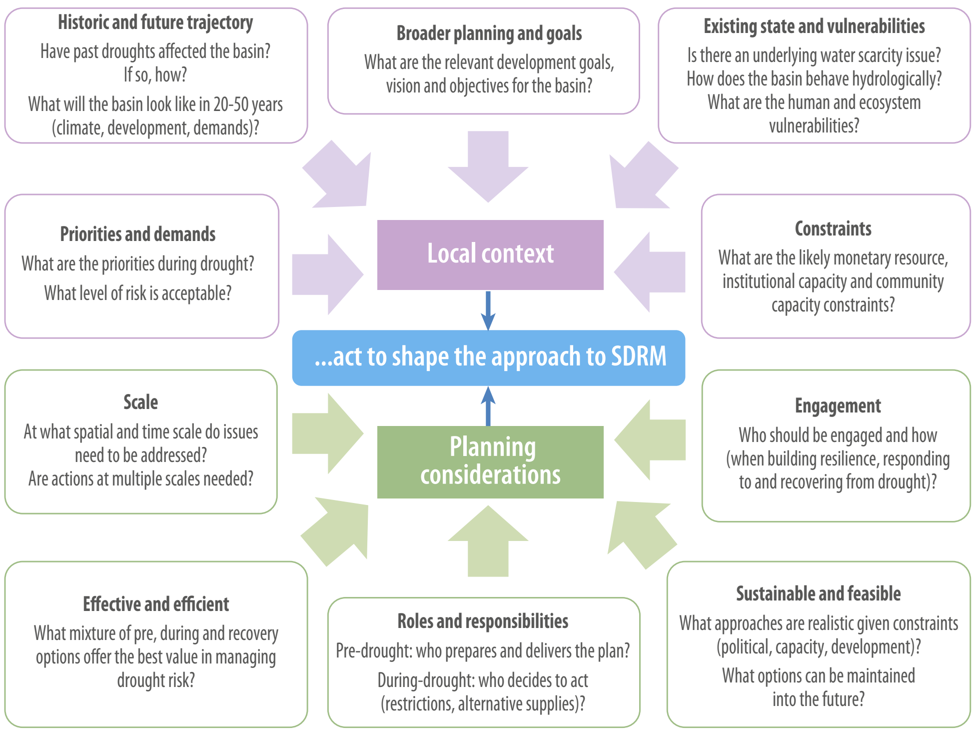


6.2. Understand the local context and planning considerations

Both the local context, such as local water priorities and hydrological pathways within the basin, and planning considerations will shape the SDRM (Figure 6.2). From a socio-political perspective, a whole-system approach coordinates and collaborates across jurisdictions, with opportunities for partnerships based on shared goals and trust. However, retaining a local focus is important: increasing socio-ecological resilience is about changing attitudes and fostering social and community support networks. SDRM takes account of local social and political drivers, as well as local knowledge, while promoting a comprehensive, long-term approach.

River basin plans (RBPs) are important for establishing the context of the SDRM. RBPs set priorities for the basin that should shape SDRM considerations (Pegram *et al.*, 2013). The RBP should coordinate with other thematic plans. Because of the time involved in developing and executing SDRM plans, parallel plans for irrigation or navigation may change. Unless there is continuous exchange of information between planning agencies, efforts can be in conflict. At each step in the SDRM process, information must be exchanged with agencies most affected by drought planning. Similarly, drought risk managers should expect other sectors to inform them of changes that might impact on SDRM plans.

Figure 6.2. A comprehensive view of the context within which drought risks arise and are managed is a pre-requisite of SDRM



6.3. Set short-term and long-term goals and objectives

IDENTIFY PERCEIVED RISKS AND OPPORTUNITIES

Before specific goals and objectives can be set for the SDRM plan, all potentially important risks and opportunities should be identified. The importance of this phase should not be underestimated as it is a powerful force in shaping the subsequent analysis and, ultimately, focus of action. As a minimum it should include:

- **A comprehensive view of the drought risk system and drivers of change.** Typically, drought results from hydro-meteorological events, but they are not the only drivers that might be important. Consideration must also be given to episodic pollution events, which may reduce available water supply, and short-term increases in demand, for example the hosting of a major international event. Without considering all the aspects that influence drought risk, strategies can be poorly developed and risks falsely stated. How these drivers respond to changes in climate, socio-economic development, industrial advances, or agricultural practice are important questions. Estimates of the impact of potential changes, using quantitative and qualitative evidence where possible, must be made and taken into account in identifying the perceived risks. Although such initial estimates may be highly uncertain, they can be progressively refined as new evidence and more information is gathered.

- **Actively seek to highlight potential opportunities.** SDRM is an ambitious approach that seeks to manage drought risk in a way that promotes wider benefits to human and freshwater ecosystems efficiently and effectively. The earlier potential win–win opportunities can be identified, the greater the chance of delivering coordinated, multi-functional responses. Opportunities may include, for example, working with natural processes that slows the flow to encourage groundwater recharge and attenuates flood flows or increasing headroom within the supply and demand balance through changes in agricultural practice and community behavior.

DEFINE TIMESCALE AND SPATIAL SCALES OF INTEREST

Timescale is an important consideration in taking a strategic approach to managing drought risk. Some activities have long lead times to implement and, once implemented, have long lives. Other activities have a much shorter lead time, and include actions that can minimize the consequences of a drought as it develops without having a negative impact on recovery or longer-term risks.

This multiple timescale view contrasts conventional practice that has often adopted a timescale and scope that is too short or too narrow to challenge the status quo and promote innovative responses. For example, plans are often within a 20–30 year timescale and are based around an assumed single solution, such as a major new reservoir or transfer scheme, or providing better water management within a single sector, such agriculture. As a result, drought management has tended to focus on addressing immediate issues based on short-term 'fixes' with limited consideration of longer-term sustainability or wider benefits. This short-term view is a particular barrier in promoting more innovative ecosystem-based responses that often require much longer temporal scales to implement and yield tangible results than conventional measures (Renaud *et al.*, 2013).

By setting objectives that cover a long-term (over 100 years) and large scale (over whole catchments, basins or even national and international transboundary basins), the constraints of existing organizational and physical structures can be challenged and innovative approaches developed. Adopting such an approach enables the strategic direction to be set, unencumbered by local or political issues. During and immediately after a drought, it may be necessary to move quickly to aid recovery, for example by allowing short-term over-abstraction. Understanding how these types of short-term measures will be phased out when the drought ends should be a central consideration. Lessons from the US and Spain indicate that after new wells are drilled, farmers will continue to pump ground water unless there regulations are in place to revert to pre-drought practices. It is therefore crucial that short-term actions do not foreclose or undermine the implementation of future, more sustainable, options. To be successful, SDRM must explain how activities will transition from the short-term to the long-term and from small-scale to large-scale.

Adopting a longer-term view is also often at odds with the priorities of decision makers and politicians who are under pressure to show immediate results to protect the public against hazards. SDRM therefore needs to develop a suite of measures that recognize short-term political realities, while continuing to satisfy longer-term needs.

DEFINE GOALS OB ECTIVES AND MEASURES OF SUCCESS OVER SCALES OF INTEREST

An SDRM plan should establish and communicate the agreed goals (i.e. the desired outcomes from the plan), objectives (i.e. the specific targets to be achieved, over both the short- and longer-term) and associated measures of success (i.e. how progress towards achieving the objectives will be determined). The goals, objectives and measures of success may vary for different regions, reflecting different challenges. For example, in predominantly agricultural basins, the focus may be on providing greater flexibility in water provision, reducing demand, the appropriateness of virtual water exports, and securing environmental flows for critical refugia habitats. In urban areas the focus is likely to be on safeguarding individual water needs and priority industrial water use.

When setting goals, objectives or measures of success the focus should be placed on the 'outcomes' rather than 'inputs'. This is a common mistake in drought risk management. For example, by setting an objective in terms of an input, such as enhancing the reservoir storage by a given volume, presupposes that is the best solution. By focusing on outcomes, such as a reduction in risk, the SDRM plan is able to consider a full range of approaches to achieve this. Neither should goals, objectives or measures be based on historical events; future events will be different.

Good SDRM is therefore based on:

- **Compatible goals**: Higher-level water-related and development goals need to be reviewed and refined into the specific contribution that SDRM is seeking by elaborating on national goals or broader water-related objectives.

- **Appropriate objectives:** The way in which goals are translated to specific economic, ecosystem, and social objectives shapes the nature of the plan. Synchronizing multiple objectives and dealing with the evitable conflicts will always be a challenge, but setting out what is desired in an open and transparent way provides the first step towards resolution.
- **Meaningful measures of success:** When entering into a process of trade-offs, predetermined measures of success are useful guides to understanding what may be considered acceptable.

Trade-offs will be inevitability be required in order to develop a preferred solution. In this process not all outcomes will be equal. Some can be considered as 'desired outcomes' (realistic outcomes that could be attain under ideal conditions and can be (partially) traded-off against other outcomes if necessary) and 'satisficing outcomes' (minimum outcomes that are non-negotiable).

Satisficing outcomes

Satisficing outcomes are particularly important for SDRM because they help identify tipping points beyond which impacts may escalate or recovery may become difficult or impossible. Examples of 'satisficing outcomes' for both human and freshwater ecosystems include:

- **Human systems:** Continuing to provide water for drinking and other essential needs is a fundamental during periods of drought. Contingency plans must be in place to meet these needs during droughts of unprecedented duration and severity. Beyond this fundamental requirement, it is useful to identify indicative levels of services that are expected during less severe droughts. Typically, these levels of service will reflect the frequency that progressively more significant water restrictions will be implemented and how long the restrictions may last. For example:
  - *Voluntary water saving:* When the chance of a future drought is raised, media campaigns and other communication actions can be effective in encouraging voluntary water saving. The acceptable frequency of such measures will reflect benefits and costs and must be set out in the SDRM plan. For example, *'Individuals should not be subject to voluntary restrictions more frequently than once every five years.'*
  - *Limited mandatory restrictions:* In the early stages of drought, mandatory restrictions may be needed. The acceptable frequency of such restrictions will reflect the vulnerability of the individuals and economic importance of the organizations or sector affected. Mandatory restrictions (enforceable by law) will typically focus on non-essential water use and should be set out in the SDRM plan. For example, *'Restrictions on non-essential use, such as watering gardens and parks, cleaning cars, etc. should not occur more frequently that once in 10 years, on average.'*
  - *Moderate mandatory restrictions:* As a drought extends, more significant restrictions may be required. The acceptable frequency of more aggressive restrictions, with more significant impacts for individuals and the economy, should also be included.
  - *Extensive mandatory restrictions:* In the most severe droughts, increasingly significant restrictions may be required. Setting out the acceptable frequency and priority of more severe restrictions in a way that is understood and agreed is crucial to ensure the SDRM helps real-time decision making in prolonged droughts.
- **Freshwater ecosystems:** Protecting priority species, habitats and ecosystem services is a fundamental requirement during periods of drought. The satisficing outcomes needed to achieve these priorities will vary, reflecting the natural resources, environmental state of the system, pressures acting on it, importance of the benefits it provides, and inevitable interactions between the human system and freshwater system. However, outcomes are likely to focus around two issues that are critical to maintaining freshwater ecosystem integrity and resilience:
  - *Maintaining the viability of critical refugia:* It is important to identify and maintain freshwater refugia such as deep, shaded pools where species can survive during drought, including habitats that are important for reproduction such as floodplain and upstream habitats.
  - *Maintaining hydrological connectivity and environmental flow:* It is important to ensure the minimum flow required to connect and maintain critical refugia for the survival of freshwater biota. It is also important to ensure the minimum flow to deliver flow-dependent ecosystem services, which are critical for human well-being.

Desired outcomes

A SDRM Plan is likely to include a number of 'desired outcomes' for both human systems and freshwater ecosystems, including:

- reducing the underlying vulnerability to climate variability within the basin reducing water scarcity through a broad range of demand and supply management
- reducing the energy sector's reliance on consumptive water use by diversifying energy production
- seeking opportunities for win–win solutions to drought risk, such as encouraging groundwater recharge to reduce flood and drought risk or enhancing the resilience of both freshwater ecosystems and human systems

- seeking solutions that build adaptive capacity and avoid locking-in to specific solutions that may be expensive to modify in the future.

Setting out what is considered acceptable provides a starting point for discussions. By recognizing that multiple trade-offs are being considered and it may be preferred to offer greater or lesser levels of ecosystem service for better outcomes elsewhere, including directing investment to maximize returns. Further illustrative criteria are summarized in Table 6.1.

Table 6.1. Strategic Drought Risk Management objectives and associated measures of success

Desired outcome	Supporting objective	Measures of success (examples only)	
		Desired outcomes	Satisficing outcomes
Human systems	Increase in preparedness of populations for future droughts	% of water use private homes that is metered % reduction in annual average household water use % of population aware of their risk and what to do in the event of a drought	
	Increase in preparedness of the agricultural sector to drought	Make allocation decisions based on a diverse consideration of water needs and trade-offs Where appropriate, decrease water abstractions required for agriculture during dry season (reducing underlying vulnerability to drought events)	Effectively regulate all abstractions increase in soil moisture retention during dry season on agricultural land % increase in on-farm water storage for use in dry-season % increase farm-sector awareness of risk and what to do as a drought develops
	Increase in of the preparedness of the industrial sector to drought	% increase in efficiency of industrial water use Increase in diversity of sector away from water-intensive industry, including power Increase in awareness of risk as indicated by the number of companies with DRM plans	% reduction in water pollution influencing available water Make allocation decisions based upon a diverse consideration of water needs and trade-offs. Where appropriate decrease water abstractions required for industry during dry season (reducing underlying vulnerability to drought events)
	Ensure human life		Avoid loss of life for droughts an agreed return period drought event Decrease in annual loss of life due to drought and associated famine
	Maintain water supply for domestic purposes	Water supply maintained at an agreed l/day for domestic purposes an agreed and appropriate	Water supply maintained in order to meet basic human needs for all
	Ensure physical and mental health	% reduction in the no. of reported cases of mental-health problems linked to drought	Decrease in no. of people with health problems linked to lack of water
	Maintain income		Decrease in annual loss of jobs and livelihoods due to drought.
	Ensure equity of impacts		Decrease in % of vulnerable facing severe impacts compared to less vulnerable.
	Maintain power for priority needs	Access to cooling water for power generation maintained to ensure an agreed % of usual demand Maintain power supply for priority industrial and agricultural sectors an agreed and quantified %	Maintain power supply for essential domestic and livelihood needs – e.g. cooking, pumping water
Freshwater ecosystems	Protect priority species		Decrease in annual loss of priority species due to drought
	Protect priority habitats	% reduction in the area of priority habitat degraded annually due to drought	
	Maintain environmental flows	% increase in the time environmental flows are met during drought periods	Increase in % of time minimum critical flows for species survival are met during drought periods
	Increase the contribution freshwater ecosystems make to reducing drought risk	Area of new wetlands created to encourage groundwater recharge and provide habitat gain Area of land managed to prevent soil erosion through nature based approaches (e.g. shelter belts)	
	Maintain priority freshwater ecosystem services for economy	% increase in time environmental flows are met in key rivers/wetlands delivering priority ecosystem services Maintain revenue derived from priority freshwater ecosystem services	
	Maintain priority agricultural sectors – i.e. those sectors that provide jobs and food for local populations	Maintain jobs, productivity and revenue derived from agriculture	Decrease % of drought-related unemployment Maintain food production for local consumption
	Maintain priority industrial sectors – i.e. those sectors that provide jobs and key commodities for local populations e.g. power sector	Maintain jobs, productivity and revenue derived from industry	Decrease % of drought-related unemployment. Maintain essential commodity production for local consumption

DESCRIBE DECISION RULES TO BE USED

The way decisions are made should be transparent and widely understood. In developing the rules that govern the decision making process for SDRM, it is important to reflect more than short-term economic efficiency; issues such as fairness and environmental impacts should also be considered, as well as the robustness of the rules, that is how they perform given different futures and their capacity to adapt. The type of strategy that is ultimately developed should reflect these decision rules. If the rules are narrowly constructed the resulting SDRM plan will be equally narrow; if the rules are broadly based to achieve multiple benefits over the long-term and encourage innovation, then the strategy will be broadly based and innovative.

All stakeholders have a role in contributing to the process of agreeing the decision rules and in supporting real-time decisions during a drought event. In particular, this dialogue should include agreement on:

- **Risks of interest and how will these risks will be measured or expressed:** The impacts of a drought are diverse (see Section 1.4). Some strategies may avoid some risks in a way that delivers additional benefits for society, the environment or the economy. The first stage in establishing the basis for decision making is to agree the specific impacts to be considered in the SDRM Plan and how they will be valued and how trade-offs will be made.
- **How will decisions be made during the development of the plan:** Identifying the 'right' actions is rarely straightforward and it is unlikely that sufficient funds will be available to undertake all desirable actions; trade-offs are inevitable. Trade-offs will arise between impacts. For example, by choosing Strategy A over Strategy B it may be possible to minimize damage to biodiversity but may reduce water availability for agricultural or economic use. Trade-offs will also exist in cost profile. For example, Strategy C may have a low initial cost but future modification may be expensive compared to Strategy D.
- **How will decisions be made during drought:** One of the most critical decisions to be made during drought is how limited water resources will be shared among different users. While water allocation plans and sharing rules should provide the basis for sharing water under a range of scenarios, under drought conditions it may necessary to modify the sharing rules. The framework within which these real-time decisions will be made should be set out in the SDRM plan (See Box 19).

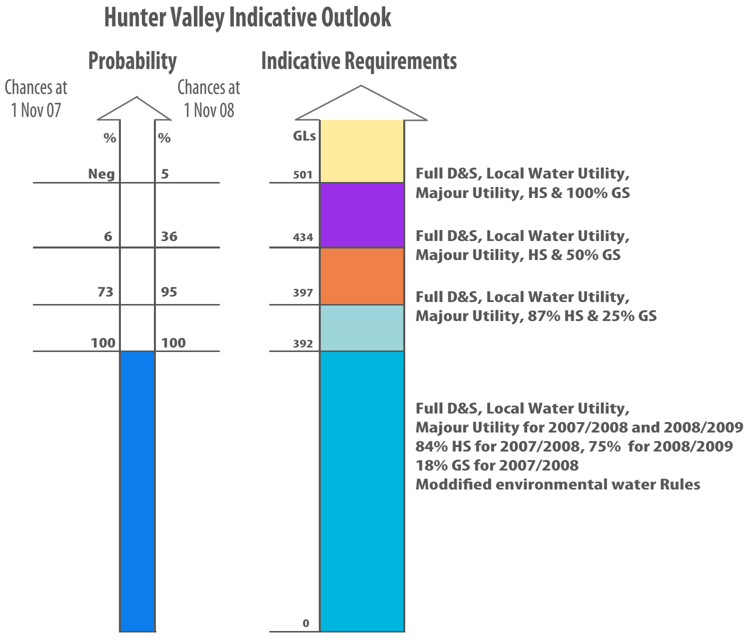
In addition to being clear on goals and objectives, it is equally important to establish the basis for decision making and how conflicts between multiple objectives will be assessed and uncertainties considered.

Box 19: Preplanning of water restrictions rarely provides the full picture (Speed, 2013)

In New South Wales (NSW), Australia water is allocated among different users by catchment-based, statutory water sharing plans. The *Water Management Act 2000* (NSW), s49A allows for the relevant minister to suspend a plan during periods of severe water shortage. Between 2006 and 2010, a number of plans were suspended due to record low inflows. Where plans were suspended, decisions on sharing the available water were made by the NSW Office of Water. These decisions were informed by consultation with 'critical water advisory groups', which were established to advise on the best way to manage limited water. The advisory groups were established to gather advice on allocation and operational issues from local stakeholders, including irrigators, local government and significant industries. Following consultation with these groups, the NSW Office of Water issued periodic communiqués about the water available to different user groups – see figure below.

As the drought deepened, this approach was adapted because the allocation rules in the plans could not be followed due to critical human needs and the complex socio-economic and community factors that arise during periods of water shortage (Harriss, 2010). Suspending the plans also allowed for real-time operational improvements, such as allowing service providers to minimize transmission losses.

The NSW Office of Water has subsequently been considering options for revising existing water sharing plans in light of the lessons from the 2006–2010 drought, so that the plans might better reflect the management actions that were put into place while they were suspended (Harriss, 2010).



Example from communiqué on critical water planning in Hunter Valley (NSW).

The figure indicates the allocation that will be available to different users.

D and S = water for domestic and stock

HS = high security (or high priority) water entitlements

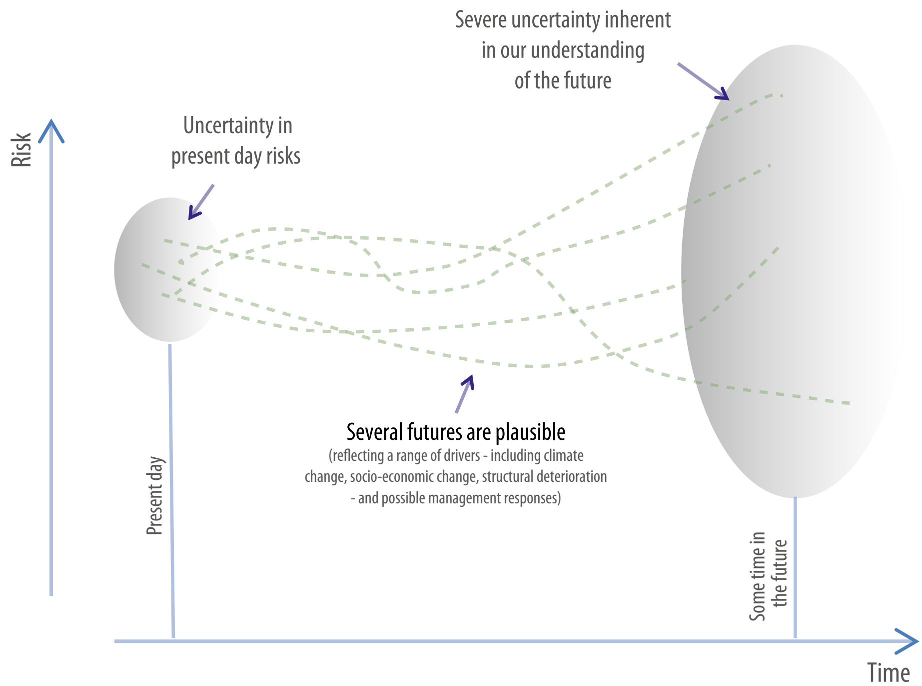
GS = general security water entitlements.

Source: DWE, 2007.

DEALING WITH UNCERTAINTY OVER TIME

Socio-economic and climate conditions will never evolve exactly as projected. In the past, drought managers have typically ignored this uncertainty or implicitly accounted for it through conservatism in the levels of services set. Recognizing uncertainty more explicitly should not prevent decisions from being made. Rather, it is a prerequisite for the strategic and adaptive approach to drought management. Quantifying and acknowledging uncertainty allows drought managers to be better placed to decide how to manage the uncertainty (Figure 6.3).

Figure 6.3. Uncertainty increases with time – including both supply and demand as well as societal preferences (Sayers *et al.*, 2012)



Assuming a worst-case climate change scenario in the development a SDRM plan is likely to be inefficient and lead to unnecessary infrastructure intervention with associated financial costs and potentially negative impacts for the environment. Equally, planning for the most favourable future is likely to a lead to complacency, potentially placing people and property at unacceptable risk. In a changing world it makes sense to adopt solutions that can be modified; adaptive management is much easier in systems that are flexible. Behavioral solutions, reductions in demand, pollution abatement and green infrastructure all provide inherently robust, low-regret aspects of SDRM plans. They also provide a flexible platform for more substantial action if drought risk increases more than expected. These measures should be central to any SDRM plan, with less flexible measures, such as infrastructure solutions, used as supporting measures. Where infrastructure forms part of an SDRM plan, it should be designed to be modified in the future where possible, for example through changes in operational rules or by the addition of further capacity.

Various methods and approaches can capture these advantages within the decision process but all, in some way, reflect the concept of a 'real options' analysis. Real options allow uncertainty and flexibility to be incorporated into decision making. In this context, a real option is an alternative or choice that becomes available when a given decision is taken. For example, designing an activity with the flexibility to upgrade provides an option to deal with more (or less) severe climate change. Specifically, a real option may provide the platform to:

- **expand** an activity (e.g. increase water transfer)
- **contract** an activity (e.g. reduce water use)
- **switch** resources (e.g. towards an alternative supply)
- **phase** gateway and sequential investments (e.g. in response to socio-economic development or to take advantage of new crop options)
- **delay** an activity (e.g. maintaining development free areas to support future pollution free headwater sources or to enhance groundwater recharge)
- **abandon** an activity (e.g. remove temporary measures and water rights more easily).

Further discussion of making the right choice is in Section 6.7.

6.4. Analyze present and future risk

UNDERSTAND HISTORICAL DROUGHTS

Good decision making requires an understanding of how different hydro-climatological conditions lead to different drought hazards and associated impacts. Evidence from meteorological and hydrological records and from historical documents such as agricultural production statistics, water resources management plans and written descriptions of past droughts, and paleoclimatic proxies such as tree rings, pollen and materials within lake sediments, all provide useful contributions to understanding past droughts.

In analysing the historical drought record, emphasis should be placed on identifying drought events that led the system — a water resources system or an agricultural system — to a harmful or unacceptable state. Forensic analysis of past events can help determine how the basin behaves during drought conditions and the nature of the vulnerabilities. For example, the basin may be more vulnerable to short and severe rainfall deficiencies, or to longer but less severe deficiencies. Understanding historical droughts also means understanding drought causation mechanisms. A comprehensive analysis of past drought events can draw attention to the hydro-meteorological processes (e.g. El Niño Southern Oscillation), which cause particular drought conditions and provide a basis for more informative seasonal forecasts and drought risk management strategies.

Care is needed, however. It is highly likely that the climate and socio-economic conditions within any basin have changed significantly over the years. Historical droughts must be viewed in this context.

ANALYZE THE DROUGHT HAZARD

Understanding weather patterns is fundamental to estimating drought hazards. Models aim to reproduce both the spatial or temporal patterns of precipitation with a reasonable replication of the real world. As such droughts hazards are typically assessed through:

i) statistical analysis of direct observations (rainfall, flow record, etc.) or proxy data (such dendrochronology, measuring/counting tree rings, mud varves, ice coring, palynology, pollen analysis)

ii) stochastic weather simulation coupled with physically based concepts such as water balance or soil moisture accounting procedures

iii) downscaling global circulation models (GCMs), either statistically or dynamically.

The severity of a drought cannot be determined based on the consideration of the hazard alone, but also the harm caused. Duration, intensity and spatial coverage are all important. Table 6.2. shows the Standard Precipitation Index (SPI), which is used as a measure of intensity.

Table 6.2. Example of the Standard Precipitation Index intensity scale used in the US

SPI value	Intensity scale
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Source: The National Drought Mitigation Center and the High Plains Regional Climate Center.

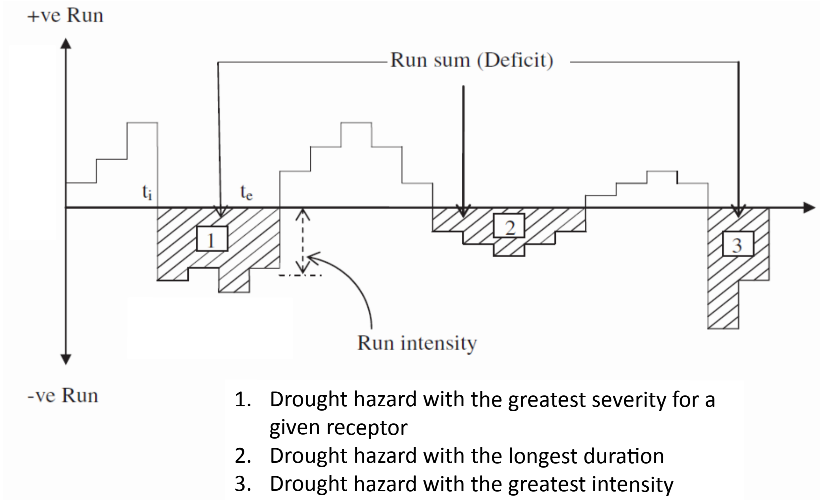
Approaches used to explore duration, intensity and spatial extent include:

- **Regression-based methods:** Regression analyzes have been widely used to relate drought parameters with geomorphic or climatic factors, crop yield factors, and other factors to predict the duration and severity of droughts (e.g. Kumar and Panu, 1997).
- **Runs-based methods:** The notion of runs (Yevjevich, 1972) combines the duration of a drought (run length) and with its intensity (run sum). If linked with an understanding of an impact, the severity of a 'run' can also be determined (Figure 6.4).
- **Group-based methods and synoptic series:** The characteristics of weather conditions that cause the duration of meteorological droughts can be expressed as 'groups'. 'Typical' drought events can be determined using concepts such as pattern recognition (Kumar and Panu, 1994) and neural networks (Shin and Salas, 2000).
- **Statistical or dynamic downscaling from global climate models:** GCMs and regional circulation models (RCMs) are useful for insights into potential future change in climate in response to emission scenarios (Figure 6.5). GCMs and RCMs are deterministic simulations based on different starting parameters to give ensemble outputs, rather than stochastic simulations. Downscaling obtains higher resolution climate or climate change information from relatively coarse-resolution GCMs. Typically, GCMs have a resolution of 150–300 km by 150–300 km and cannot provide information about sub-grid scale features such as topography, which are important in determining regional weather patterns. GCMs cannot be used for catchment-scale hydrometerolgical analysis, because they required downscaling to be regionally meaningful (Box 20). Downscaling attempts to obtain local-scale surface weather data from regional-scale atmospheric

variables provided by GCMs (Figure 6.5). There are two main forms of downscaling techniques (Wilby and Wigley, 1997):

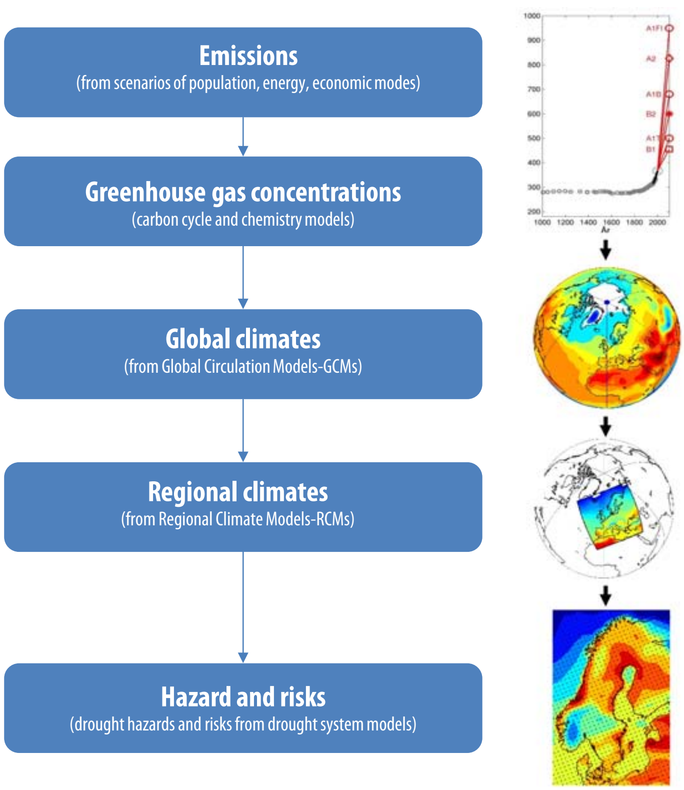
- *Dynamic downscaling:* the output from the GCM drives an RCM with higher spatial resolution that can simulate local conditions in greater detail. Frequency analysis can then be used, but care should be taken with interpreting the results.
- *Statistical downscaling:* a statistical relationship is established from observations between large-scale variables (for example atmospheric moisture), and a local variable of interest (for example rainfall at a particular site). A derived relationship is then used to translate the GCM data to local variables. Typical statistical downscaling methods include regression methods and neural networks, weather pattern-based approaches and stochastic weather generators.

Figure 6.4. Drought characteristics using the run theory for a given threshold level



Source: based on Mishra and Nagarajan, 2011

Figure 6.5. The basic process of using climate models to assess drought hazards and risks



Box 20: Important considerations when using global circulation models and regional climate models

Although GCM and RCMs represent many important interacting physical processes that occur during a drought, they do not represent all of them. Equally, projections vary significantly between GCMs and RCMs for any given emission scenario, and between emission scenarios. Using the outputs from GCMs and RCMs with expert reasoning and analysis of local datasets can provide a useful understanding of potential changes in climate and the effect on atmospheric processes and rainfall. However, it is important to:

Compare real data with the GCM and RCM outputs. The credibility of GCMs and RCMs varies by location. In some instances, features of the physical landscape and orographic processes that control the weather within a particular basin may be less resolved than in others, or simply missed. The GCM and RCM representation should be validated by comparison with observational records for the baseline results to assist with the credibility of projections for future climate extremes.

Consider multiple GCM outputs and climate scenarios. GCMs represent different processes in different ways and no single GCM offers the most reliable projection. It is therefore important to understand the most appropriate models for a region, and use the results from all available models.

Understand the limitations of GCMs. The focus of GCMs to date has been on changes in mean values and the ability of the GCMs to credibly reflect climate extremes is less clear. The detail of storm dynamics and radiative balances with future events is crucial in understanding future extreme rainfall, but this is an area poorly treated in many GCMs.

Source: Sayers *et al.*, (2014b).

ASSESS PRESENT DAY DROUGHT RISKS

Any analysis of drought risks requires:

- an understanding of how drought hazards form and how associated risks are generated
- a drought hazard event set (representing many possible meterological events) to be established and their root causes to be understood, including intensity, duration and spatial extent of a range of potential events
- the exposed receptors to be identified, including receptors exposed directly and indirectly to the drought
- the vulnerability of each receptor and the key factors affecting their vulnerability to be determined, including the agreed value of the potential harm and the potential for autonomous recovery
- an assessment of the potential harm and associated losses, both event and expected annual damages.

The process reflects the understanding that 'risk' is a function of the probability of the drought hazard p_{hazard}, the degree of exposure e and the vulnerability v of the exposed receptors, that is:

$$\text{Risk} = f(p_{hazard}, e, v)$$

In evaluating this relationship, both qualitative and quantitative approaches have a legitimate role:

Qualitative approach: The likelihood and consequences of an adverse event are divided into different levels and the significance of the risk assessed using informed judgement). The result of this type of qualification is typically a risk matrix as shown in Figure 6.6.

Quantitative approach: Because risk is not an observable quantity, it cannot be assessed directly from historical records. Instead a timeseries of statistical hazard events or a synthetic timeseries needs to be combined with knowledge about exposure and vulnerability functions that translate the drought hazard to an estimate of harm. To understand the risk, both the event and expected annual damages are important. To calculate the value of the expected annual damages (EAD) requires an event set of droughts and their associated impacts, or a derived probability distribution of drought hazard events and their associated impacts. A practical approach is to build a damage probability curve based on different return periods of droughts, and the EAD value can be derived from the combination of the probabilities and damages (Figure 6.7). This simplified approach does not lend itself well to consideration of sequenced (uncorrelated) and clustered (correlated) extreme drought hazard events. Appreciating this type of behaviour is important for drought and developing an understanding of how water resources and issues of storage respond to such sequences. Event-based integration provides a more appropriate way of estimating the annual expectation of risk.

ASSESS FUTURE DROUGHT RISKS

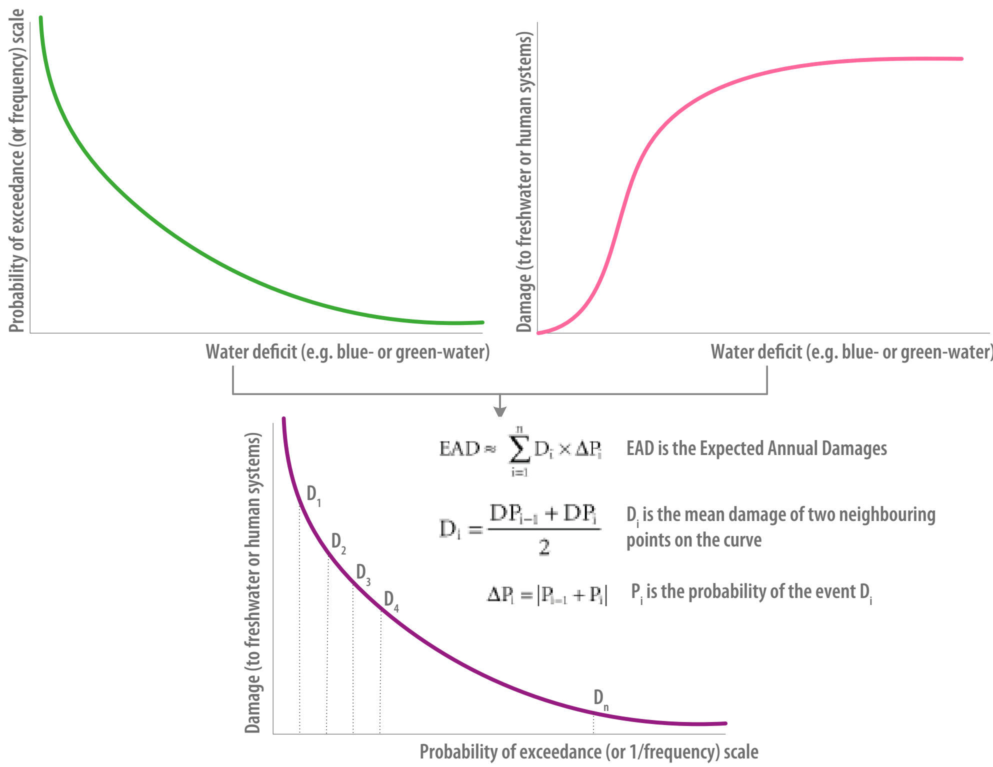
While the present and the past can provide some information about future drought risk, conditions are changing and the past contains only a few realizations of droughts and extremes are rare. Exploring future change, particularly alternative climate, demographic, social and economic futures is central to determining future drought risks and appropriate management options. Currently, the degree of change cannot be precisely determined and any attempt would fail to understand the chaotic and unknowable nature of future changes and interactions that might exist to 'black swans' events, i.e. surprise foreseen events and impacts. However, it is not impossible to provide useful insights for a particular region. Expert, observational and model evidence can be used to construct plausible future scenarios of change in land use and land management practice, together with changes in regional and global climates.

Figure 6.6. A qualitative approach to the assessment of risk

Likelihood of an adverse event \ Scale of impact	Minor	Moderate	Serious	More serious	Most serious
Extremely unlikely	Low	Low	Low	Moderate	High
Highly unlikely	Low	Low	Moderate	High	Very high
Unlikely	Low	Moderate	High	Very high	Very high
Likely	Moderate	High	High	Very high	Very high
Highly likely	High	High	Very high	Very high	Extremely high

Source: GIWP. China

Figure 6.7. The expected annual damages (EAD) can be approximated by summing the area under the curve



By exploring different future scenarios, an understanding of what the future may look like and, importantly, how different strategies play out in those futures, can be developed. Good scenario development is not straightforward and requires expert dialogue supported by quantified evidence. Various methods exist to help develop meaningful future scenarios (see for example www.foresight.gov.uk). Some of the basic rules for developing meaningful scenarios are:

- **Be open to future change.** The future is unlikely to be a simple projection of existing trends. By developing an understanding of the potential drivers that might influence future drought risk, the status quo can be challenged and space given for innovation to emerge.
- **Distinguish autonomous actions from purposeful actions.** Autonomous adaptation (i.e. actions taken by individuals and organizations, without specific policy prompting) and purposeful drought risk management actions must be clearly identifiable. Scenarios must realistic, but ambitious, in their assumptions about the influence drought risk management can exert over broader planning,

policy and behavior. For example, a future where all government policies and the behavior of all citizens and organizations are rational in the context of drought is not likely to be achieved and many decisions are not within the remit of drought risk managers alone to deliver.

- **Be internally consistent and evidence based.** Not all alternative futures are credible. For example, it may be inappropriate to assume a high growth in the demand for hydro-electric power while also assuming low GDP growth. Scenario development should be transparent in its assumptions and applying them consistently to each component of the scenario.
- **Be capable of quantif ed analysis.** At the core of the scenario analysis is a system drought risk model for estimating the severity and consequence of the changing drought hazard, and a cost model for computing the different costs of drought risk management options. To be meaningful, risk analysis must reflect the performance of the whole system of sources, pathways and receptors and how each component of risk is influenced by change. By using a whole system risk model, alongside quantified scenarios of change, alternative strategies can be appraised and used to support expert selection of the preferred approach.

Once developed (and various methods exist to help develop meaningful future scenarios - see for example www.foresight.gov.uk) the concept of multi-futures underpins the appraisal of alternative strategies – as discussed in the next section.

6.5. Develop and appraise alternative management strategies

IDENTIFY INDIVIDUAL MEASURES AND INSTRUMENTS

A strategic approach to drought risk management promotes wider benefits to society and ecosystems by adopting an approach that offers the greatest opportunity for a long-term solution. The early identification of win-win opportunities, including maximization of opportunities for wider benefits significantly improves the chance of delivering a coordinated, multi-functional response to drought.

A wide range of management instruments (i.e. policy, regulatory or communication actions) and measures (i.e. physical actions) all have a legitimate role to:

- **Reduce the chance of a drought occurring (hazard):** By increasing the naturally renewable surplus in the supply versus demand balance within the basin or region, the chance of drought occurring is reduced. Responses may include managing the sources of drought risk to reduce the chance of a meteorological drought or modifying hydrological pathways within a basin to reduce the chance of an associated blue-water drought or green-water drought.
- **Reduce the severity of the associated consequences (exposure and vulnerability):** By developing water sensitive societies, with a reduced dependence on water consumptive industries, and healthy ecosystems (protected environmental flows, connectivity for priority habitats and flow-dependent livelihoods and economic activities). This includes agreeing rational priorities for water to safeguard supplies to the most vulnerable can reduced the severity of the consequences of a drought.

Some actions will do both. For example, actions to safeguard environmental flows affect the way a drought manifests itself in the freshwater ecosystem, while enhancing the health of the freshwater ecosystem during non-drought conditions, improving its resilience to drought. Further details on individual measures and instruments are in Chapter 7.

DEVELOP A PORTFOLIO OF MEASURES AND INSTRUMENTS

A portfolio response to managing drought risk has a number of advantages. In contrast to a single measure approach, redundancy is built in. This redundancy provides confidence that drought risks will be managed as envisaged. For example, a water supply system relying solely on a single reservoir may have a high chance of failing to guarantee supply during periods of drought within its catchment. An appropriately established portfolio response compromising, for example, capture and recycling of wastewater, actions to reduce leakage, the construction of wetlands to promote groundwater recharge, and a flexible and drought-ready system of allocations and entitlements may offer a more robust approach. In China, this more comprehensive portfolio-based approach is starting to emerge (Box 21). The extreme drought conditions experienced in California in 2013–15 also prompted a broader array of measures to be taken across federal government, the Californian state legislature and the Governor's office. These measures included regional reallocations of supply, new regulations and funding support for water re-use, residential water restrictions, groundwater management reforms, and new reporting requirements for leakage. The individual measures and instruments that may form part of this portfolio are discussed in detail in Chapter 7.

EVALUATE ALTERNATIVE STRATEGIES

A structured and transparent evaluation of the long-term performance of alternative strategies enables a preferred approach to SDRM to be identified. Making the 'best' choice relies on assessing the full range of benefits and costs associated with each alternative.

Assessing costs

The cost of implementing a strategy must be considered from a whole life perspective – including the costs associated with developing and implementing the approach, mitigating any adverse impacts, and, if relevant, decommissioning. To enable a valid comparison, all costs must be considered and included, not only those that are easily quantified. For example, valid costs may relate to payment for ecosystem services, such as setting aside land for groundwater recharge or habitat connectivity; new infrastructure for developing and transitioning to planting drought resistant crops; awareness arising programmes; or implementing new regulations to reform, for example, the water allocation and entitlements regime; or governance structures.

Box 21: A portfolio-based response to drought risk in China

Activities to manage drought risk within China are typically classified under five headings:

Space management: The location of natural water resources do not match the economic and social distribution that has developed in China. As a result, Huang-Huai-Hai, Guanzhong-Tianshui and other northern regions have significant water resource issues and now have some of the most water-vulnerable ecosystems in China. Space management refers to actions taken to harmonize the location of socio-economic activity and water resources. This has resulted in inter-regional and inter-basin water transfer projects (such as the south–north water transfer scheme) and (some) modification to the spatial planning process in areas such as Beijing, Tianjin, Hebei, Henan and Shaanxi province.

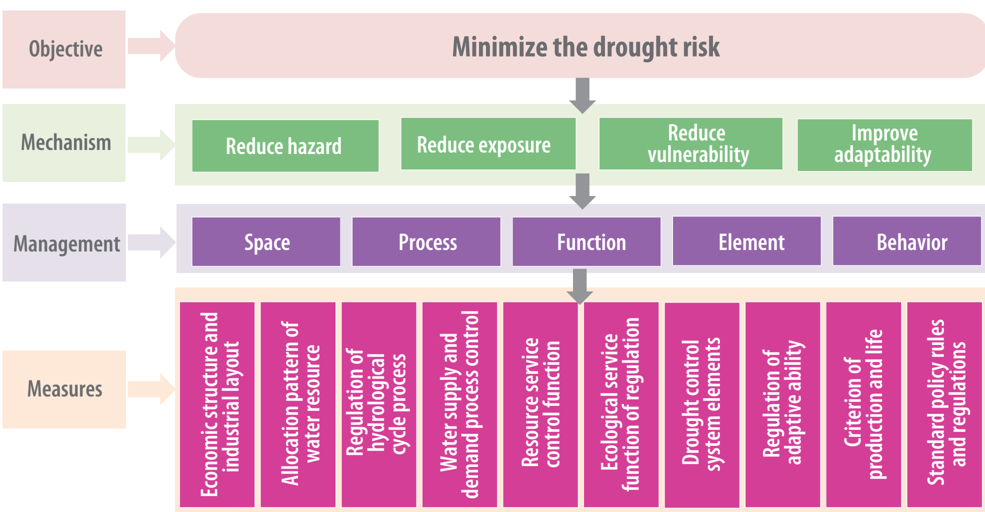
Process management: Process management focuses on providing emergency water supply capacity during a drought. Based on discussion with a range of stakeholders, minimum standards of service are used to guide storage volume needs to provide an adequate emergency water source during moderate, severe and extreme droughts. For example, during extreme drought, sufficient reserve capacity is needed to ensure 30–40 L/person/day for urban residents, and 20–30 L/person/day rural residents, to provide 20–30 m^3/mu for agricultural production of basic food grains and to support main cash crops and key industrial enterprises as far as possible.

Function management: Function management focuses on providing sufficient water during a drought to ensure the impact on society and the ecological environment is in an acceptable range. The Chinese Government has launched a series of studies and construction projects to provide water resource protection areas, soil conservation and aquatic ecosystems restoration projects.

Element management: Element management focuses on the framework of planning and implementing drought management activities. This includes demand management, water-use efficiency, protecting water resources and the ecological environment, optimizing the allocation of water resources, enhancing drought tolerance, developing appropriate reserve capacity and improving monitoring and early warning systems. Element management also includes the process of medium-term planning and setting out the direction and drought management measures for the next 10 years.

Behavior management: Behavior management focuses on changing behavior and promoting a water-sensitive nation. For example, China has developed a series of industry specifications and standards, such as guidelines for the water use during a drought – the 'National Drought Water Quota' – and a system of drought-risk classifications, drought planning guidelines and drought response guidelines.

Measures and instruments of drought management



Source: GIWP

Assessing benefits

Droughts have multiple and diverse impacts (see Section 1.4) and the benefits of taking action can be environmental, economic or social – or all three. Any analysis of risk therefore relies on these wide-ranging impacts being valued in a meaningful, transparent and consistent way. In a traditional cost–benefit analysis (CBA) all benefits are given a monetary value enabling alternative strategies to be easily compared. One criticism of CBA, however, is that it fails to capture the multitude of non-monetizable benefits, particularly those associated with ecosystem services and social well-being. It is not impossible to determine a monetary value for these benefits and Table 6.3 shows the various available techniques. However, allowing a like-for-like comparison with direct financial and economic benefits is difficult. For example, a committee of the US National Academies reported in 2004 that:

> *Benefit–cost analysis should not be used as the lone criterion in deciding whether a proposed approach should be approved. A more appropriate role for benefit–cost analysis is to serve as a primary source of information concerning the benefits and costs of project alternatives, and the groups who gain most from a project. This separation of the role of benefit-cost analysis from its use as a mechanistic decision criterion would reduce the pressure on USA Army Corps analysts to seek a high degree of precision, which does not always reflect a similar degree of accuracy (NRC, 2004).*

Table 6.3. Techniques for evaluating non-monetary ecosystem impacts

Method	Brief description	Advantages/disadvantages
Replacement cost	Calculates the direct cost of replacing or restoration of a damaged freshwater ecosystems	Requires prior agreement on restoration measures; relies on often unavailable or unreliable cost estimates of similar measures; may fail to account for indirect restoration costs, e.g. planning costs, monitoring costs.
Replacement cost multiplier	Calculates cost of restoring an ecosystem plus additional funding for lost values due to damage and uncertainty	As above, but inclusion of contingency funding allows for uncertainties. May be difficult to justify contingency budget to funders though.
Valuing ecosystem services	Evaluates economic benefits of restoring a given ecosystem service using a tradeable substitute, e.g. watershed restoration vs. a water treatment plant to improve water quality	Explicitly recognizes value of ecosystem services, but can be difficult to quantify and may be over-reliant on narrow valuation of use values, ignoring non-use values such as aesthetics.
Contingent valuation	Evaluates people's willingness to pay for a restored ecosystem	Includes non-use values. People may find it difficult to make quantitative estimates of their willingness to pay. There may be discrepancies between what peoples say they would be willing to pay and what they will actually pay when required. Can be expensive to apply.
Travel cost method	Estimates the value that people place on an ecosystem by their willingness to pay and spend time travelling to the ecosystem	Useful where restored ecosystem has amenity or recreational value. Less so if it doesn't.
Hedonic pricing	Estimates the value of a restored ecosystem by evaluating the effect of a restored area on nearby property values	There is substantial evidence that homebuyers will pay a premium for proximity to a healthy ecosystem and desirable environmental amenities. Less useful where housing is not near restored ecosystems.

Source: Adapted from Holl and Howarth, 2000.

There is a growing consensus across risk management that the impacts that can appropriately be converted to monetary values should be used, and where this is not appropriate, the values should remain in native parameters such as the number people without drinking water remains a count of people, or the mean species abundance per hectare. The main strengths of using native parameters is that they do not have inherent uncertainties linked with monetization, allowing greater transparency and understanding of the benefits. Competing interests still need to be weighted through some form of multi-criteria analysis (MCA) (see Box 22). Weighting of competing interests should be developed during non-drought conditions, as doing so during a time of crisis often leads to 'quick win' (and potentially unsustainable in terms of cost) options being prioritized (Box 23).

Box 22: Multi-criteria analysis

Multi-criteria analysis (MCA) decision making processes are based on the assumption that society has competing interests and values across competing stakeholders and that 'monetisation' cannot adequately capture these complex values and interactions for a variety of reasons, ranging from strictly technical issues to ethical premises. MCA consults stakeholders to determine the criteria against which they think impacts should be assessed and agrees indicators for each, including economic, social and environmental impacts. Stakeholders are then asked to rank the criteria according to importance – e.g. fishing communities might be more interested in economic, social, and well-being criteria and less about environmental criteria. Other stakeholders might have a different set of preferences reflected in the analysis. The performance of alternative strategies is then assessed against these indicators and each stakeholder group is ranked to identify their most preferred and least preferred strategy. A process of negotiation then follows to find the most 'acceptable solution' for as many stakeholders as possible by rationalising conflicts and competing interests. It is assumed that only by establishing the maximum possible stakeholder support (and thus 'acceptability'), can an intervention be sustainable in the long run. MCA is most useful in situations where competing interests and non-monetary impacts are important and can be used alongside traditional CBA to help identify strategies with the greatest efficiency, equity or effectiveness.

Source: Adapted from a briefing from the National Economics Forum Brieifing No. 6: Multi-crtieria analysis.

Box 23: Pitfalls of assessing costs and benefits during a time of crisis: The South East Queensland Experience

In South East Queensland, Australia, in response to the Millennium Drought and serious concerns that Brisbane and the wider region would literally run out of water, the state government invested significant funds in a developing the South East Queensland Water Grid. New infrastructure constructed as part of the grid included a desalination plant and a recycled water scheme. This infrastructure cost A$1.2 billion and A$2.6 billion respectively. A subsequent review by the Queensland Audit Office (QAO) found that no robust business case was developed for the desalination plant and that the decision on the capacity of the plant did not benefit from a rigorous CBA, which normally would have been required for such a large investment. A business case was prepared for the recycled water scheme setting out the costs of the scheme, but less rigour was applied to estimating the potential benefits and they were overstated. As such, the volume of water supply required from the plants and the associated costs were not balanced against a realistic assessment of the benefits. The audit also found that while the infrastructure has delivered water security, no other benefits have been realised. Environmental outcomes have not been achieved and no economic outcomes were specified. The QAO found that the decision to build the new infrastructure was an appropriate response to the extreme drought, but that better planning may have avoided the need for such drastic and costly action. It also found that, even during an emergency, the decision to build the new infrastructure should have been supported by a thorough and rigorous assessment of the costs and social, economic, and environmental benefits, in all modes of operation.

Source: QAO, 2013

Understanding tipping points in the assessed impacts and benefits

Tipping points further complicate the assessment of impacts and the benefits of avoiding these impacts. Understanding the tipping points at which significantly greater impacts are incurred or opportunities are lost is a central consideration in understanding the importance of an impact. Capturing non-linear developments, for example the risk of a sudden collapse of fish stocks, is particularly difficult to identify and reflect in the assessment. The first step towards incorporating tipping points within an appraisal is to determine the thresholds at which they occur, such as, for example, the flow below which hydropower generation is no longer economically feasible.

CONSIDER AND RECORD UNCERTAINTIES

Drought risk, as with any other socio-climatic risk, is characterized by the natural variability of the climate both in time (from seasonal to decadal timescales) and space, the response of the hydrological pathways, and the vulnerability of the exposed receptors.

The uncertainty within the climate and hydrological response is often referred to as 'aleatory uncertainty' and is a characteristic of all natural systems and cannot be removed or reduced. Other sources of uncertainty derive from a lack of knowledge, which is often called 'epistemic uncertainty'. These uncertainties emerge from incomplete understanding of natural processes and from the impossibility of forecasting the evolution of socio-economic and climate systems into the future.

To manage uncertainty, it must be first recognized and then explicitly accounted for within the decision making process. This includes identifying the sources of uncertainty, assembling the available evidence on those uncertainties, documenting that evidence for future review, and setting out how a given uncertainty will be accounted for within the decision making process, for example through probabilistic description or scenario analysis or some other approach. This framework is summarized in Figure 6.8.

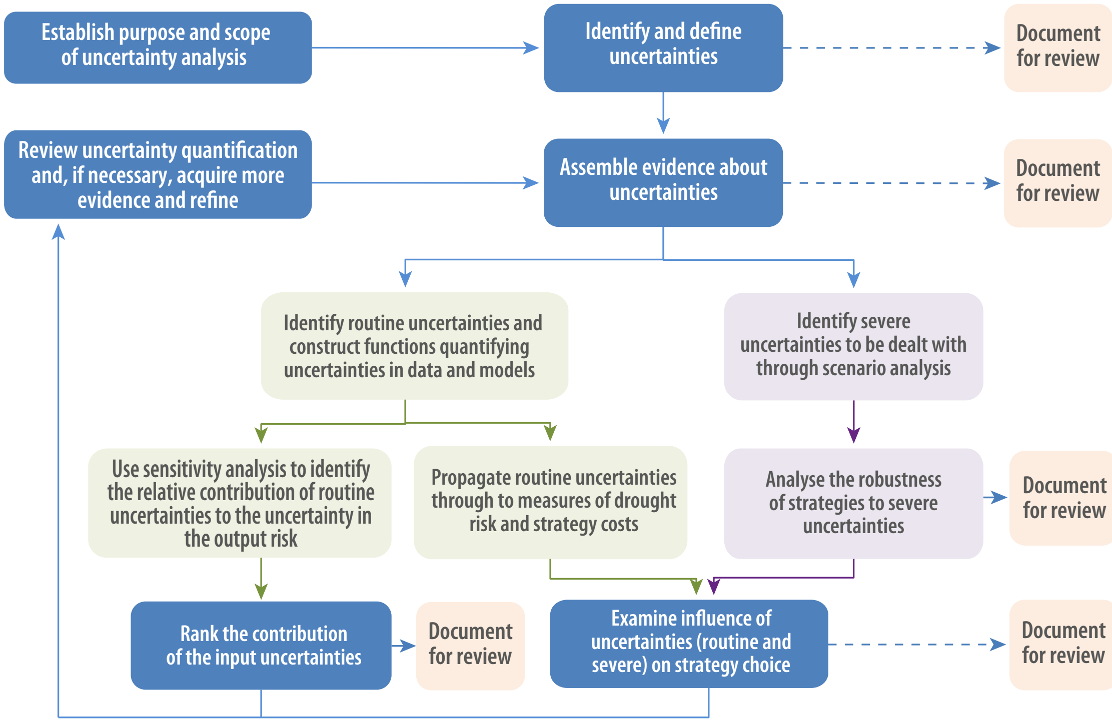
6.6. Make a choice: selecting the right adaptive strategy

Any single strategy is unlikely to achieve all desired outcomes and some trade-offs will inevitably be required, either in the benefits achieved or costs incurred. This section discusses some of the issues than underlie the political (and only in part technical) process that supports identifying the preferred strategy.

Determining what to do given perfect information and objective outcomes is straightforward. However, uncertainty complicates this process. A 'good' choice seeks to ensure that the action taken is better than all others, taking into account important economic, social, environmental issues and uncertainties.

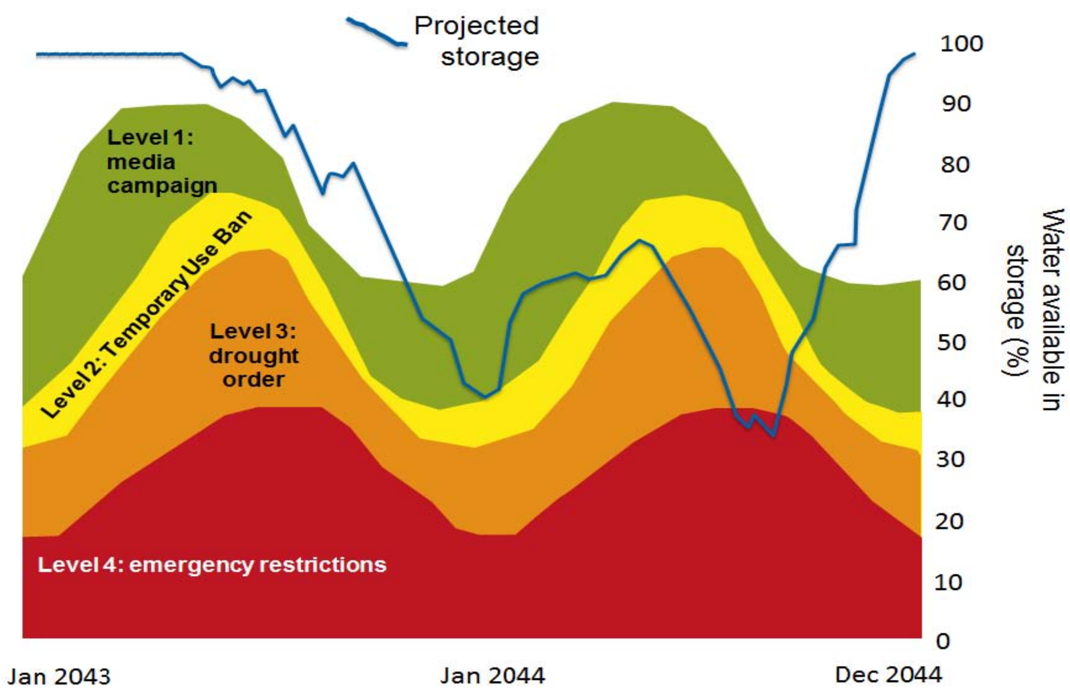
Traditionally in drought risk management, this complex decision process is simplified by setting agreed (acceptable) standards of service for the drought manager to achieve, often described in the context of acceptable restriction frequencies relating to public safety, social equity and environmental impacts. Decision making then focuses on the least-cost approach to achieve these standards, taking into account economic, social and environmental costs. Often, scenario analysis is used to explore the 'what-if' questions. For example, Thames Water, responsible for water supply to London is required to demonstrate Ofwat (the water regulator) how it would achieve four levels of service that represent progressively more significant water restrictions, assuming a hypothetical future drought (Figure 6.9).

Figure 6.8. A framework for explicitly identifying and recording the evidence used to assess uncertainty within drought risk management



Source: Sayers et al., 2012 adapted from Hall and Solmatine, 2008.

Figure 6.9. Thames Water: Demonstrating planned investments avoid unacceptable restrictions in 2040s based a plausible worst case 'what-if' drought



Source: Courtesy Thames Water, UK

Approaches based on pre-determined standards of service can promote continuing current practice and constrain the development of more ambitious and innovative strategies. This is because the merits of 'tried and tested' versus more innovative but unproven water resource options are more easily demonstrated within a narrow set of standards.

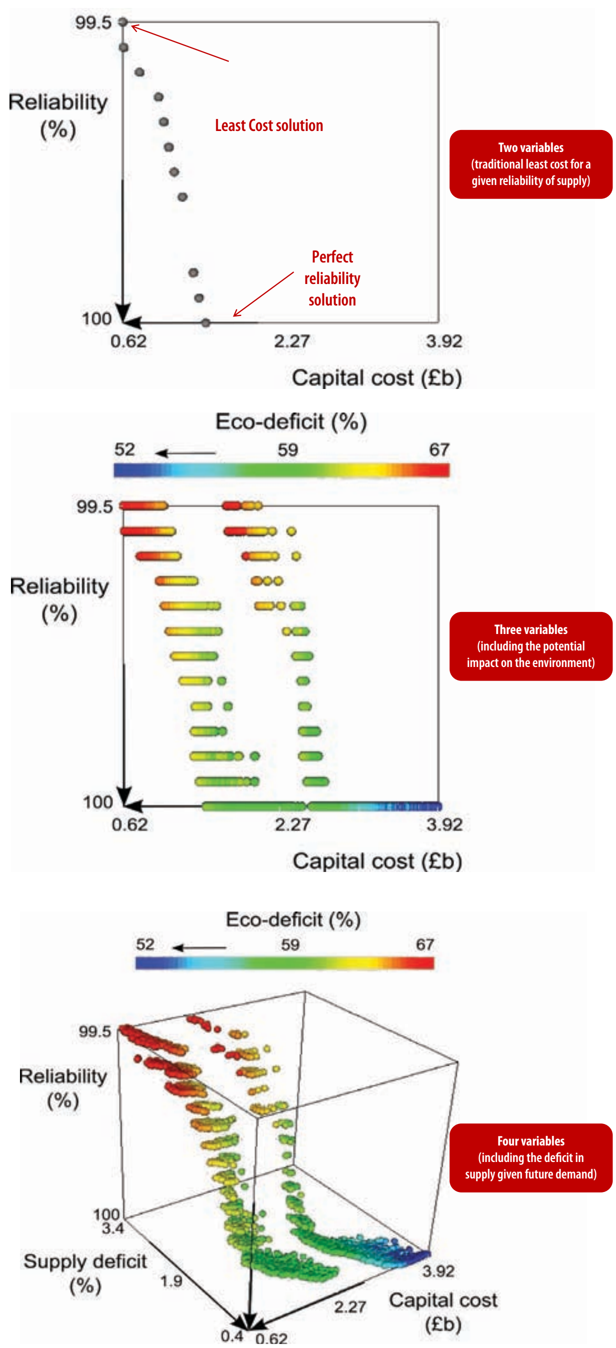
In contrast, a risk-based approach is more open and is fundamentally an approach based on trade-offs. Allied with the concepts of adaptation and robustness, risk-based approaches help decision makers balance ecological, socio-cultural and economic values, understand inherent trade-offs and identify the preferred long-term approach. Adaptation recognizes the opportunity to make progressive decisions as the reality of the future becomes better know and robustness seeks solutions that achieve acceptable outcomes over a range of a scenarios rather than the best possible outcome over a single scenario.

Formal techniques are now maturing that support this more comprehensive approach to decision making, including for example:

- **Multi-criteria approaches:** Extending the traditional MCA to enable trade-offs to be presented as a continuous relationship, enabling the relationship between cost and benefits to be shown and tipping points in either the benefits accrued or the damages incurred to emerge (Figure 6.10).
- **Scenario approaches and robust decision making:** Any given strategy will not necessarily achieve similar outcomes in all futures. Some strategies may achieve the best outcomes given a particular assumption about the future but catastrophically fail if an alternative future materializes. Robust decision making assesses the performance of alternative strategies across a wide range of future scenarios. A 'robust' strategy that performs acceptably well in all plausible futures should be sought (e.g. Sayers *et al.,* 2012).
- **Adaptation pathways:** An adaptive approach recognizes that future decisions will need to modify the actions taken today. The strategy should therefore be conceived as series of decision points rather that single programme of activities. Valuing the adaptive capacity embedded within the strategy is important to ensure future choices are not unnecessarily constrained by previous choices and that alternative actions can be taken with limited additional cost (Brisley *et al.*, 2015).

All of these techniques, and other similar approaches, support making trade-offs in a way that is intuitive while reflecting the reality of an uncertain future and the legitimate and competing interests of stakeholders. These techniques help form a transparent assessment of alternative strategies that supports an open process of negotiation.

Figure 6.10. Exploring trade-off approaches based on multi-criteria analysis

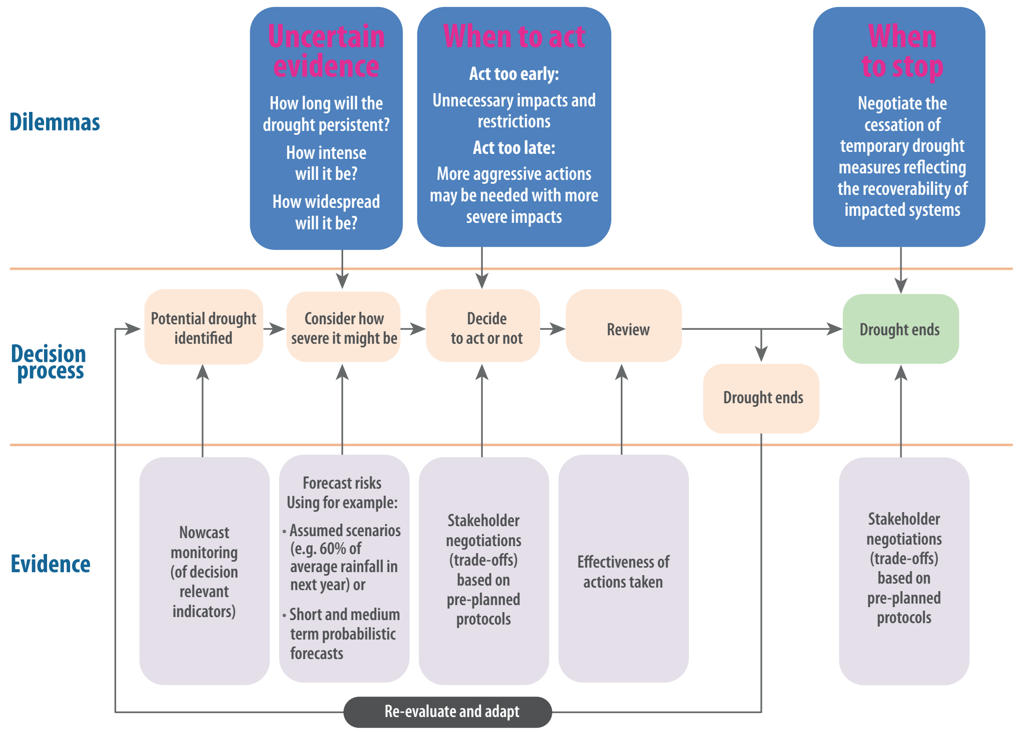


Source: Thames Water, based on research from University College London.

6.7. Act to implement the preferred plan

The greatest opportunity to reduce drought risk is to take strategic actions during non-drought conditions when there is time to develop innovative strategies and implement long lead-time solutions. When a drought is forecast (or directly observed) the decision process changes (Figure 6.11). Decision makers face a series of dilemmas about when to act: act too early and unnecessary impacts and restrictions may result; act too late and more aggressive actions may be needed with more severe impacts. The strategic planning phase during non-drought conditions should provide a framework for these choices, including identifying the stakeholders and the decision making authority. It should also have pre-tested a range of 'what-if' scenarios and evaluated alternative actions. Although the detail of a real drought will inevitably differ from those simulated by the framework, key trade-offs and conflicts should already be known to support more informed choices.

Figure 6.11. Response and recovery: dilemmas, evidence and the decision process



6.8. Engage stakeholders and promote participation

To be successful, any strategy must be shared by those with a legitimate interest in the decisions (Table 6.4). Encouraging stakeholders to participate and empowering them to act during non-drought conditions, during a drought and after a drought is vital. This is not easy and relies on an appropriate engagement processes supported with resources.

If done well, the SDRM planning process provides an opportunity to coordinate actions across a variety of sectors and organizations and, through this collaboration, find efficient approaches to managing drought risks that deliver multiple benefits. In the absence of an SDRM plan, stakeholders may assume they are helpless to reduce drought risk and use this assumption to rationalize their inaction or continue behaviors that have adverse impacts elsewhere, for example continuing to inappropriately or illegally abstract groundwater.

The different needs, challenges, and opportunities associated with stakeholder engagement during different stages of the SDRM planning process, include:

- **During non-drought conditions:** The most significant opportunity to reduce risk is during non-drought conditions, allowing for a more objective approach, and for discussions to occur without the pressures that can exist during the height of drought. Engaging stakeholders who fail to appreciate the risks is difficult; therefore, engaging stakeholders in a meaningful way during non-drought conditions relies on well-articulated and stakeholder-focused communication of the risks and uncertainties.

- **During a drought:** It can be easier to engage stakeholders during drought, when the risk posed by drought is more apparent, and can provide the impetuous for change. Any SDRM measure that, for example, involves restriction of access to natural resources to sections of society such as limits on fishing or water abstraction, should be planned in advance and should be subject to consultation with stakeholders through an open and inclusive process.
- **Post-drought:** Engaging stakeholders after a drought can be particularly successful because the impacts of the drought are fresh in their minds and stakeholders have a greater awareness of the effectiveness of recent actions. Greater opportunities exist at this time for negotiating agreements between the various water-use sectors to avoid or reduce future conflicts.

Table 6.4. Example stakeholders and their potential contribution to SDRM

Stakeholder	Potential contribution to SDRM
National government ministries and agencies with sector policy and planning responsibilities	☒ Provide knowledge and advice on sector policies, plans and related processes. ☒ Identify and publicize priorities related to evidence and knowledge needs. ☒ Facilitate access to data and information. ☒ Encourage integration across sectors, policies and plans at all levels. ☒ Facilitate capacity building around drought issues. ☒ Participate in the development of Drought Risk Management Strategies. ☒ Act on evidence to inform international cooperation and national polices, plans and other water and development related programmes.
Regional governments and agencies	☒ Have similar to national level roles but at the more regional level ☒ Facilitate integration across and within a region
City or village government	☒ Have similar to regional-level roles but at a more local level ☒ Facilitate participation and capacity-building of local community and other stakeholders ☒ Translate the strategic planning process to on the ground actions
Academic institutions	☒ Contribute evidence on the drought hazards, exposure and vulnerability ☒ Provide data and information on drought risks (present and future) ☒ Help build capacity across drought issues.
Farmers and the broader agricultural sectors	☒ Ensure existing irrigation systems are efficient and easily maintained ☒ Install water measurement devices monitor water use ☒ Use conservation practices to increase soil moisture, reduce evaporation, reduce runoff and encourage infiltration ☒ Maintain and establish riparian buffers, filter strips, grassed waterways, and other types of conservation buffers near streams and other sources of water ☒ Raise animals that do not consume large quantities of water ☒ Plant crops that withstand dryness, hold water, and reduce the need for irrigation ☒ Rotate crops in ways that increase the amount of water that enters the soil
Major utility providers (water, energy, transport)	☒ Continue to promote water efficiency messages among customers and volunteer water saving during droughts ☒ Reduce water footprints and support their customers in reducing water use (through, for example, efficient appliances) ☒ Reduce dependence on water consumptive activities
Local community group, individuals and business	☒ Participate in activities to provide local knowledge and information, and drought options and priorities for water ☒ Help facilitate the transfer of knowledge and encourage appropriate behavioral change in their local communities ☒ Act on the evidence of drought risks provided ☒ Provide feedback on the utility of knowledge and evidence provided, and how this could be better
NGOs	☒ Share the results and experience of their own research and programmes ☒ Provide advice and expertise to inform the development and delivery of drought management ☒ Disseminate good practice across the NGO network. ☒ Build the capacity of their constituencies

6.9. Monitor performance, review and adapt

Drought systems are dynamic and SDRM plans need to be adapted in response to changing hazards and risks. A SDRM plan should explicitly recognize this process of review and adaptation and build in a programme of monitoring. As a minimum, a formal process should be established to:

- **Monitor performance of the plan:** Future drought events provide an opportunity to evaluate the performance of the plan and learn lessons. But moving too rapidly to adjust the plan in reaction to a single event (or even during an ongoing drought) can lead to poorly considered responses with potentially negative long-term impacts. A process of continuous monitoring across all aspects of the plan (including the physical actions taken, the influence of policy adjustments though to changing behavior a range of stakeholders) provides the evidence for any necessary adjustment.
- **Review and adapt as necessary:** Review and modification of the plan that should be accepted as a natural part of the continuous adjustment that underlies a strategic approach. This process of review will consider both the evidence gathered through monitoring but also further model- based studies using updated evidence on climate change, growth and any changes in stakeholder preferences that may be relevant.

CHAPTER 7
MEASURES AND INSTRUMENTS

7.1. Introduction

This chapter explores the individual measures and instruments that can form part of a SDRM approach. Measures and instruments can include: (i) modifications to the water allocation and entitlements regime; (ii) developing a supply surplus; (iii) providing a better response to a drought when it occurs and taking action to promote recovery; and (iv) influencing broader policies that promote a sustainable water future and embed resilience to drought.

7.2. Water allocations and entitlements

Water allocations and entitlements are critical in determining what water resources will be available for abstraction and use during periods of drought and how those resources will be shared. The framework of water allocations and entitlements determines how available water resources will be shared, both over the long-term, and at any given point in time, among competing regions, sectors, and individuals. Increasingly, such systems comprise:

- **water allocation plans, which determine the total water available (groundwater and surface water) over the long-term** (e.g. average annual system yield)
- an **entitlement regime, for granting rights to individual water abstractors (such as irrigators and urban water utilities) to take water, for example**, via water abstraction licences
- wa**ter-sharing rules for determining** how the water that is available will be shared among water entitlement holders (Speed *et al.*, 2013).

Water allocation systems are typically designed to deal with natural hydrological variability. The allocation may allow entitlement holders to take more or less water, depending on the flow in the river or the volume in storage. Water allocation systems are not, however, always well placed to respond to the extreme shortages and alternative water sharing mechanisms may be required.

In preparing for future droughts, and responding to drought when it occurs, a central question is 'What is the most appropriate water allocation and entitlement regime to minimize risk?'. The answer needs to address:

- constraints imposed by existing water entitlements and how they affect the capacity of water managers to implement changes to water-sharing rules and water trading
- rules for sharing water during drought and when to suspend 'normal' water sharing rules
- allocation of water for the environment during drought to maintain environmental flows
- arrangements for water trading and its role in supporting water users to manage drought risks
- the price of water during non-drought and drought conditions and incentives for water users to better prepare for and respond appropriately to a drought.

ESTABLISH AN APPROPRIATE WATER ENTITLEMENTS REGIME

Water allocation systems should be underpinned by a suitable water entitlements regime, which is the mechanism for defining the long-term rights of different water abstractors. To support water allocation choices during drought, the water entitlements regime should, as minimum, enable:

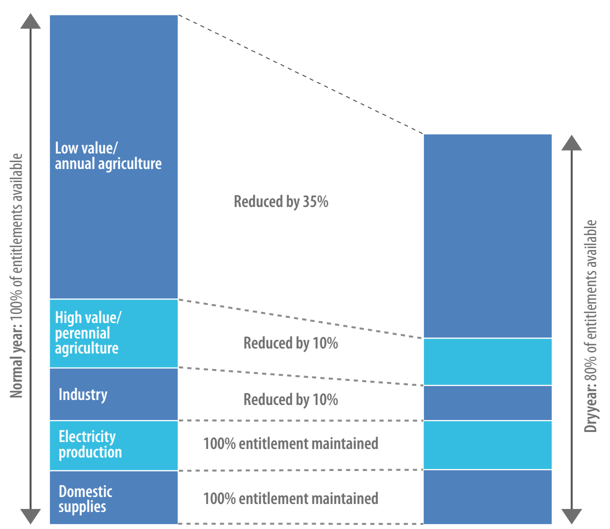
- **Water entitlements to be adjusted** to modify the allocation to reflect the specific demands during a drought.
- **Different priority to be given to different water uses or users:** by including a mechanism for differentiating between categories of water entitlement.
- **Discuss and agree future restrictions with water users** via a transparent means of sharing reduced water among the various water entitlement holders. Approaches will depend on the risk appetite of the water users. For example, irrigators who are growing seasonal crops may be willing to accept a higher risk of water shortages in return for a higher yield from the system and greater availability of water over the long-term, if the benefits of more water outweigh the impact of periodic shortages. In contrast, in a water scheme where the majority of water users grow perennial crops, a more conservative approach to determining the volume available for allocation may be more appropriate, given that a shortfall of water may result in the death of crops that take years to be replaced. These approaches used are discussed further in Box 24.
- **Enable appropriate water trading** for water users to prepare for and respond to drought (see Section 7.2.5). Significant preconditions are required to support sustainable water trading (see Productivity Commission, 2003). Such conditions take time to implement and need to be addressed in the SDRM plan during non-drought conditions and must be in place before a drought.

An ambiguous or inflexible water entitlement regime created challenges during drought in California, US. The pre-drought allocation and entitlement regime contributed to uncertainty over what water users could expect to receive, led to conflict, and limited the scope for water to be allocated and managed strategically (see Box 25).

Box 24: Water allocations and assigning the risk of shortfalls

A common approach to sharing water among water entitlement holders is an 'announced allocation' system. This approach is used in Australia, Brazil and other countries where water supplies are linked to water storage. Announced allocation involves making a periodic announcement, for example annually or monthly, of the water allocated to users, based on an assessment of the available water. The amount of water available to individual entitlement holders is then determined, typically based on their long-term entitlements, along with priorities of different categories of water allocation in some instances. For example, priority uses such as urban water supplies or electricity production may be allocated their full quota before other uses are allocated any water at all (see below).

Adjusting water allocations



Source: Speed *et al.*, 2013

The assessment of annually or seasonally available supplies may be based on actual water in storage, or projected water availability. Furthermore, assessments can be undertaken conservatively or aggressively. Available supplies may be calculated in a way that guarantees all the allocation will be available during the year. A more conservative approach is to allocate based on what is in storage, but over a longer allocation timescale, for example over three years. In that case, annual allocations are set at a level that would guarantee supply at that level for the next three years, even if there were no further inflows during that period. This approach may be appropriate in arid systems with highly variable rainfall, where floods stored during one year may form the basis of supply for several years. Alternatively, water can be allocated on the assumption that further rain will fall during the allocation period, however it is defined. Such an approach will increase the long-term yield of the system, but also increases the risk of a failure of supply.

Approaches can also be adapted to provide individual water users with the capacity to manage their own risk of water shortfalls. One approach is to allow water users to carry over a proportion of their unused annual allocation to the following year. This provides a mechanism for allocation holders to manage their own risk – that is they may increase their reliability of supply, by using less on an annual basis and holding the rest in storage as a contingency.

An alternative approach to sharing available water – termed 'continuous sharing' – is now being applied in some irrigation districts in Australia. It is a water accounting approach that removes annual allocations and carryovers. System capacity is allocated against each allocation holder and updating their available supplies on an ongoing basis, allowing for any usage, further inflows, and system losses. Under such a mechanism, the amount of water available to each water user is accounted for at all times, including during drought. This allows the maximum flexibility to individual water users as to how they manage their share of the 'airspace' with a reservoir or system of reservoirs.

Box 25: California 2010: Entitlements based on prior appropriation and implications for drought management

In California, entitlements to water are managed based on the doctrine of 'prior appropriation' (Tarlock, 2001). Under this system, water rights are granted to the first person to claim the right to divert a certain volume of water from a stream. That right holder then has seniority. Later users can also claim rights to water (provided there is still sufficient left), but will have junior rights.

Available water is allocated amongst rights holders based on this system of 'first in time, first in right', meaning that the owners of rights who have held them for longest are the last to have their allocation reduced in times of shortage, regardless of what the water is used for. In some instances, historical claims to water are not well documented, and the situation is made difficult by the fact that water resources in California are significantly over allocated.

Priority is thus given to the most 'senior' rights holders, despite the fact that those uses may be less productive or of lesser economic or social importance. Rights are jealously guarded, and there has been significant discontent amongst water users about efforts to reduce water supply during periods of drought, including the threat of legal challenges to proposed reductions. Taken as a whole, this has significantly constrained the capacity of water resource managers to respond to the huge challenge presented by the 2010s drought.

California's approach to managing groundwater also presents challenges during drought. Historically, farmers and land owners have had the right to take as much water as they can from aquifers below their land. Given that aquifers are a common pool resource this has the potential to create an incentive for land owners to abstract groundwater before their neighbours do. Groundwater has become a major water source during the drought (2010–), with around 60% of California's water supplies now coming from underground.

SHARE WATER DURING DROUGHT

To be successful during times of drought, water allocation systems should, as a minimum, identify:

- The trigger point at which normal water sharing rules will be suspended and drought rules will apply. Given the significance for water users of suspending normal water sharing arrangements, such trigger points should be as clearly defined as possible and based on objective, verifiable factors, such as water supply levels (see examples from Spain, Melbourne, and the Murray–Darling given in Boxes 26, 27 and 28).
- The responsible agency for making the decision about whether the trigger point has been reached and if it is appropriate to implement restrictions. Typically, this responsibility may be given to a decision making body such as a government agency or a ministerial council or taskforce. The decision making body should include both independent experts and a full range relevant stakeholders to ensure that the decisions made are, as widely as possible, accepted and supported (see Box 29).

An overarching consideration is striking a balance between providing certainty for water users about how water will be managed during drought, with clear allocation rules, and providing flexibility for governments and resource managers to respond in the most appropriate way, recognizing that droughts are extreme events and it can be difficult to predict how a particular drought event will develop. In determining this balance, decision making must reflect:

- **Equitable allocation:** allocating water in a way that is fair and equitable among different regions and user groups.
- **Variation in the signif cance of the risk:** allocating water in way that minimizes the social and economic impacts and takes opportunities to reduce these impacts through other mechanisms such as considering alterative water supplies that may be available to water users.
- **Environmental protection:** maintaining an allocation to the environment that ensures critical flows to connect refugia habitats and limit the impact on priority species or ecosystem services (see Section 7.2.3).

Box 26: Water sharing and inter-basin transfers during drought, Spain

Completed in 1979, the Tagus-Segura Inter-basin Water Transfer allows water to be transferred from the Entrepeñas and Buendía dams, located in the Tagus River basin (in the Castillat La Mancha autonomous region) and the Segura River basin (in the Valencia, Murcia and Almeria regions). The transfer scheme was originally designed to transfer 'excess' water supplies. The 1998 Tagus River Basin Management Plan established rules to share water between the regions and included rules for how water would be shared during drought, based on the volume of water stored in the Entrepeñas and Buendía dams, and with different thresholds set for different months (between 456 and 563 mm^3). The plan provides that:

- under drought conditions, decisions on the amount of water to be transferred is referred to the central government's Council of Ministers
- under drought conditions, irrigators in the Tagus River basin can sell water rights to irrigators in the Segura basin, using the transfer infrastructure
- no transfers are allowed when the volume of water in the dams falls below a defined threshold (240 mm^3).

These arrangements highlight the heightened political sensitivity and strategic considerations attached to water allocation decisions during drought: no defined rules for sharing under drought exist and decisions are not made by the Commission that normally manages the transfer scheme, but are referred to a political body.

Source: Quibell *et al.*, 2013

Box 27: Restricting abstractions under water licences during drought, Melbourne, Australia

Melbourne Water Corporation is a government-owned entity with responsibility for water supply and wastewater management for Melbourne and the surrounding area. It also manages the supporting waterways with approximately 2,000 licensed water users, primarily using water for agricultural, industrial, commercial, stock and domestic purposes.

The 2007 Drought Response Plan, prepared at the height of the Millennium Drought, provides a framework for 'responding to the impacts of drought or low-flow conditions on licence users'. The plan is designed to identify responses in worsening low-flow conditions and to provide a basis for sharing water when flows are insufficient to meet user needs. The plan aims to balance certainty for users with the need for flexibility (Melbourne Water, 2007).

The plan includes three warning levels: low, moderate and high. These warning levels give licensed users with an indication of the risk of restrictions being placed on water abstractions. The warning level is based on a combination of factors, including seven-day average stream-flow conditions, rainfall predictions, and an assessment of the condition of the catchment.

The plan identifies trigger points for restrictions to apply, as well as when the restrictions would be lifted. Triggers are set based on the average daily flow volumes over a seven-day period, with different triggers applying in different catchments and at different times of the year (see below). Where restrictions are implemented, they can affect the amount of water that can be taken, or the time at which it is taken, with different restrictions on water use applying to different sectors and at different times of the year.

Trigger levels for restrictions for licensed users in Little Yarra River, Woori Yallock Creek and Yarra River

Waterway	Location	Site ID	LOW-FLOW PERIOD			HIGH-FLOW PERIOD (Winter-fill)		
			Applicable Dates	RESTRICTION Trigger (ML/day)	RELIEF Trigger (ML/day)	Applicable Dates	RESTRICTION Trigger (ML/day)	RELIEF Trigger (ML/day)
Yarra River Lower (incl. all tributary catchments not listed in Appendix 5)	Chandler Hwy	229143	01 Nov - 30 Apr	300.0	300.0	01 May - 31 Oct	300.0	300.0
Yarra River Upper (incl. all tributary catchments not listed in Appendix 5)	Yarra Glen	229206	01 Nov - 30 Apr	300.0	300.0	01 May - 31 Oct	300.0	300.0
Little Yarra River	Yarra Junction	229214A	01 Nov - 30 Jun	60.0	60.0	01 Jul - 31 Oct	60.0	60.0
Woori Yallock Creek (Excluding Wandin Yallock Ck catchment)	Yellingbo	229679	01 Nov - 30 Jun	45.0	45.0	01 Jul - 31 Oct	120.0	120.0

Source: Melbourne Water (2007) Drought Response Plan, Licensed Water Users. Melbourne, Australia

Box 28: Priority allocation of water during drought, Minnesota, US

In Minnesota, state laws require all water users taking more than 37.85 m^3 (10,000 gallons) per day to hold a water permit. Applicants for water permits must demonstrate measures for improving water-use efficiency and applicants for surface water permits must develop a contingency plan and be able to withstand the impact of not being allowed to abstract water for an undetermined time. Permit holders may be restricted from taking water during low flow to protect water for in-stream uses and higher-priority users. The regulatory system addresses water allocations and abstractions both during normal conditions as well as during drought. Six water use priorities have been established by the state government that, in order of priority, are:

1. domestic water supply
2. uses consuming less than 37.85 m^3 of water per day
3. agricultural irrigation and processing of agricultural products
4. power production
5. other uses
6. non-essential uses (water lawns, washing cars, irrigating golf courses).

During periods of water shortage, water users are progressively suspended from taking water, starting with the lowest priority users (i.e. water for non-essential uses).

Source: Pirie *et al.*, 2004

Box 29: Providing for critical human water needs – Murray–Darling Basin, Australia

In the Murray-Darling Basin, critical human water needs are the highest priority water use for communities who are dependent on the basin's water resources (Water Act 2007, section 86A). The act requires that the basin plan identify the water required to meet critical human water needs, as well as the water required for conveyance purposes. Volumes are set out in the plan for the three Southern Basin States – New South Wales, Victoria, and South Australia. The basin plan identifies water quality and salinity trigger points at which levels the water becomes unsuitable for meeting critical human water needs, as well as the process for monitoring, assessment and risk management associated with ensuring water is available to meet those critical needs.

The volumes required for critical human needs were calculated based on 'basic individual water requirements such as drinking, food preparation and hygiene, water to cover community essentials, such as keeping hospitals, schools, emergency services and other key services operating, water for essential commercial and industrial users, and water to maintain, as far as possible, the fabric of society' (MDBA, 2010).

The basin plan provides for three levels of water sharing arrangements (Tiers 1, 2 and 3) and gives the basin authority the power to put water sharing arrangements into place, subject to assessment of the water available to meet critical needs. For example, the basin authority may declare that Tier 3 water sharing arrangements (the most extreme) enter into effect if there is an extremely high risk that water will not be available to meet critical human water needs in the next 12 months, based on a 'worst case planning water resources assessment'. The sharing arrangements affect the water accounting rules that apply in the Southern Basin States, and determine the amount of water that can be allocated amongst water entitlement holders and otherwise taken by users within each of the states.

Box 30: Approach to securing environmental flows, Australia

In Australia, the different water sharing rules in place under various water laws and allocation plans are generally designed to accommodate variability in climatic and hydrologic conditions and to meet the needs of different water users. Flexibility is built into the plans to accommodate environmental requirements. Water resource plans and dam operational rules in Australia typically set minimum requirements for flows to meet environmental needs.

One of the approaches to providing environmental flows in Australia has been by granting entitlements to the environment that are equivalent to other consumptive entitlements. The water entitlement is treated the same or similar to consumptive water entitlements, and is allocated a volume of water seasonally or annually in accordance with the local water-sharing rules. The water is then available to the environmental water manager to be used to achieve the maximum environmental benefit.

One advantage of this approach is that it protects environmental interests during dry periods: the environmental water entitlement is afforded the same level of priority as other users when the available water is shared. It can also allow for greater flexibility in the way environmental water is used. Rather than being bound by rigid release rules, the environmental water holder can make decisions throughout the year based on the seasonal conditions and water held in storages.

Environmental water holders have been established at both the federal level (the Commonwealth Environmental Water Holder) and the state level (for example, the Victorian Environmental Water Holder). The Commonwealth Environmental Water Holder is a statutory position, created under the *Water Act 2007*. At present, the federal government is purchasing water entitlements from willing sellers using a A$3.1 billion fund to increase the water available to the environment. These entitlements – issued under state water laws – are then held by the Commonwealth Environmental Water Holder and managed to achieve environmental outcomes. As at 30 June 2015, the Commonwealth Environmental Water Holder held water entitlements[1] of approximately 2.3 billion m^3, all in the Murray–Darling Basin.

Water is managed under a framework, prepared by the Commonwealth Environmental Water Holder in consultation with a scientific advisory committee, as well as a range of stakeholders. The framework provides ecological management objectives for different levels of water availability (Commonwealth of Australia, 2013). These objectives are shown in the table below.

	Very Low	Low	Moderate	High	Very High
Environmental outcomes in scope	☒ Avoid critical loss of species, communities and ecosystems ☒ Maintain key refuges ☒ Avoid irretrievable damage or catastrophic events	☒ Support the survival and viability of threatened species and communities ☒ Maintain refuges ☒ Maintain environmental assets and ecosystem functions	☒ Enable growth, reproduction and small-scale recruitment for a diverse range of flora and fauna ☒ Promote low-lying floodplain-river connectivity ☒ Support medium flow river and floodplain functional processes	☒ Enable growth, reproduction and large-scale recruitment for a diverse range of flora and fauna ☒ Promote higher floodplain-river connectivity ☒ Support high flow river and floodplain functional processes	☒ Enable growth, reproduction and large-scale recruitment for a diverse range of flora and fauna ☒ Sustain higher floodplain-river connectivity ☒ Support high flow river and floodplain functional processes
Portfolio management options in scope	☒ Allow drying to occur, where appropriate ☒ Water refuges and sites supporting threatened species and communities ☒ Undertake emergency watering at specific sites of priority assets ☒ Use carryover volumes to maintain critical needs	☒ Allow drying to occur consistent with natural wetting-drying cycles ☒ Water refuges and sites supporting threatened species and communities ☒ Provide low flow and freshes in sites and reaches of priority assets ☒ Use carryover volumes to maintain follow-up watering	☒ Prolong flood/high-flow duration at key sites and reaches of priority assets ☒ Contribute to the full-range of in-channel flows ☒ Use carryover to provide optimal seasonal flow patterns in subsequent years	☒ Increase flood/high-flow duration and extent across priority assets, where feasible ☒ Contribute to the full range of flows incl. over-bank, where feasible ☒ Use carryover to provide optimal seasonal flow patterns in subsequent years	☒ Maintain flood/high-flow duration and extent across priority assets, where feasible ☒ Contribute to the full range of flows incl. over-bank, where feasible ☒ Use carryover to provide reserves for future years

Source: Speed, 2013

PROVIDE ENVIRONMENTAL FLOWS DURING DROUGHT

The need to allocate water for environmental flows is well established (Speed *et al.*, 2013) and the importance of maintaining environmental flows is discussed elsewhere in this book (see for example Sections 1.4 and Chapter 10). To maintain appropriate environmental flows during drought, water allocation systems should be sufficiently flexible to ensure that important freshwater ecosystems and the services they provide are maintained. Mechanisms to do this include:

- **Limit abstractions:** Limiting the water that can be abstracted under water entitlements can help ensure sufficient water flows through the river system.
- **Ensure illegal abstractions are stopped:** Non-entitled abstractions or over-abstractions can be a significant draw on water resources, particularly during drought. Preventing these abstractions can have a significant impact on the available resources and on ensuring sufficient flows remains within the river system.
- **Provide controlled releases from reservoirs:** Flow pulses interspersed with zero flow approaches were used to protect the Loddon River in Victoria, Australia in 2006 when there was insufficient water to sustain base-flow releases. This approach helped to maintain the water quality of refuge pools while saving water to use over the extended dry period (Bond *et al.*, 2008).

6. The Commonwealth's water holdings are registered on state-managed entitlement registers and available in summary form at http://www.environment.gov.au/water/cewo/about-commonwealth-environmental-water accessed 11 August 2015

- **Environmental entitlements:** Allowing water entitlements to be held for environmental purposes and actively managing those entitlements can help to achieve desired ecological outcomes (see Box 30).
- **Adopting a f exible approach to extreme, prolonged, drought:** Different priorities and rules are likely to emerge during extreme and prolonged droughts. For example, drinking water may be threatened or environmental tipping points may emerge. In these cases, the priorities for allocating very limited resources will change. In response, alternative approaches may be required to protect the essential needs of people and freshwater ecosystems during periods of prolonged drought, but the basic principles outline above will remain valid.

WATER TRADING ENTITLEMENTS AND ALLOCATIONS

Water trading allows water users to buy and sell water through one of two types of trades:

- **permanent trades:** where the Water Entitlement itself is sold
- **temporary trades:** where some or all of the water available under an entitlement in a given year is sold and the underlying right, the water entitlement, is retained.

Water markets rely on capping the total volume of water available for abstraction, granting entitlements to individual water abstractors and allowing the voluntary exchange of those entitlements or associated volumes of water (see for example Productivity Commission, 2003).

In the absence of water trading, entitlement holders in fully allocated systems can be limited in their capacity to increase their available water. Equally, entitlement holders may have few incentives to use water efficiently. Water markets can provide greater flexibility and market-based incentives for uses, resulting in water moving to higher-value uses. During times of drought, this allows water to be reallocated in a way that (if done appropriately) minimizes the impacts of the drought. Such approaches reduce or, in the case of a fully open market, remove, the role of government and water resource managers in deciding how limited supplies should be shared, and instead provide capacity for individual users to make their own decisions on how best to manage the situation and the related risks.

This flexibility within the water market enables water users to better:

- prepare for future droughts by, for example, buying additional water entitlements on the permanent water market, increasing the amount of water that they would expect to receive under drought conditions
- respond to drought by, for example, buying water on the temporary market, to meet short-term needs or selling water on the temporary market and using the income to offset losses associated with the reduced water availability.

The establishment of market-based mechanisms, such as water trading, have been used to allow both agricultural and urban water users to manage drought risk and respond to drought conditions in a number of countries, including Spain (Palomo-Hierro *et al.*, 2015), the US (Vargese, 2013), and Australia (see Box 31).

SET APPROPRIATE WATER PRICES

Many water users have little economic incentive to conserve because water is either under-priced or not priced at all. In many countries water metering is being actively promoted but with variable take-up. In other countries many people pay a flat fee for water, regardless of how much they use or the nature of the available resource. Reflecting the full value of water as a market-based commodity includes the costs of treating and delivering water to the point of use and also the full cost of withdrawing water from the environment, such as the impact on downstream ecosystems. Understanding the full cost of water can help promote better behavior towards water use. Implementation of water pricing raises issues of social justice to ensure those that cannot afford to pay continue have appropriate access to water as an essential human need. But with careful consideration, 'putting the right price' on water is likely to be a significant component of future of water resource management and the broader sustainability of water use, which will support resilience to drought.

For water pricing to be an effective means of managing scarcity and reducing drought risk, barriers to data availability and institutional capacity need to be addressed. Availability of hydro-meteorological data is important because it tells water resource managers exactly how scarce water is, which helps set appropriate water allocations and water prices at effective levels. Institutional capacity is critical because one or more organizations will need to have the mandate, resources, technical capability and accountability to set prices, gather tariffs and potentially redeploy fees to support other water resource management measures. Unless there are sufficient data and institutional capacity, water pricing is unlikely to be a realistic option.

Box 31: Using water markets to reduce drought impacts in the Murray–Darling Basin

Consistent with the view of Australia's National Drought Policy that primary producers should be self-reliant, water markets have been used as a key mechanism for irrigators to deal with climate variability, including drought. Water markets allow flexibility for primary producers to manage climate risk. Most obviously, this is through allowing them to buy additional water. This includes buying water on:

- the temporary market to compensate for low water availability under the seasonal water sharing rules

- on the permanent market, including buying 'high priority' entitlements, to reduce the risk of water shortage.

Selling water entitlements can also provide a revenue stream to farmers during drought. The cash injection from temporary trading of water was a significant contributor to farm income in the lower Murray River during the Millennium Drought. One study found that in 2006–07 income from temporary water sales accounted for between 8% and 19% of total cash receipts (Oliver *et al.*, 2009).

In addition, water-trading markets have increased incentives for irrigators to improve water productivity, given the opportunity for farmers to trade and thus profit from any water savings they generate. The benefits of conserving water increased during drought with the resulting increase in temporary water prices. Studies suggest that increasing on-farm water-use efficiency has enabled many irrigators to avoid serious losses in severe drought conditions (Mallawaarachchi and Foster, 2009).

Experience during the Millennium Drought in the lower Murray–Darling Basin – which has Australia's most active water market – suggests that water trading benefited irrigators in all major irrigation industries in the region (NWC, 2010). The benefits for some of the key commodity groups are described below:

- **Rice production**: a lower-value crops, with major decreases in water availability, rice irrigators typically sold their annual water allocations to generate income and reduced or ceased annual rice production.
- **Dairy**: when water prices for temporary water allocations were high (>$300/ML), dairy farmers typically sold their annual allocations to generate income that was used to purchase additional fodder. When prices were lower, some irrigators bought additional water to maintain production and capacity. Permanent sales of water also increased over the period as a means of managing debt and as farmers shifted from perennial to more opportunistic annual pastures.
- **Horticulture**: in a number of regions, wine grape and other horticultural irrigators were major purchasers of water on both the temporary and permanent markets. Without water trading, it is likely that many long-lived horticultural assets would have been lost.

The result has been that even where there has been a significant reduction in total water use for irrigation, the ability to trade water has allowed water to be reallocated to its highest value uses has substantially mitigated the economic impact of low water availability (Mallawaarachchi and Foster, 2009). This conclusion is supported by focus group-based studies, where irrigators have expressed the strong view that water trading allowed them to survive drought years (Bjornlund, 2005).

At a macro-level, the benefits of water trading during drought have been enormous. Economic modelling suggests that water trading reduced the impact of the drought on regional gross domestic product in the Southern Murray Darling from A$11.3 billion to A$7 billion (NWC, 2012).

Given that governments inevitably prioritize water for critical human needs, water trading has been less important for managing urban water supplies than for agriculture. Despite this, trading has helped to secure urban water supplies, particularly in regional centers. For example, at the height of the Millennium Drought, the South Australian Government purchased 217 000 ML of allocations in 2008–09, around half of which was for critical human needs for the state capital, Adelaide. A major study by the National Water Commission concluded that without the ability to trade water, the cost of securing urban water supplies would have been higher.

Where governments have purchased water, it has often been with the goal of reducing the severity of urban water restrictions and providing water to maintain parks, gardens and sporting grounds. In addition, local governments have also bought water entitlements to improve long-term supply in response to the expected reductions in availability, due to climate change, and increased demands due to population growth (NWC, 2011).

7.3. Develop a supply surplus and redundancy

Measures that increase available water supply and reduce demand are central considerations in managing drought risks. However, if measures intended to increase supply–demand surplus allow increased water use during non-drought conditions, there will be little benefit of reducing drought risk.

Reserve capacity (or 'headroom') represents the difference between the water available for use (i.e. the deployable output) and demand (Box 32). Reserve capacity may be created on the supply side, for example enhanced groundwater recharge, increased reservoir capacity or construction of desalination facilities, or on the demand side, for example more efficient water use, changed behaviors and mandatory restrictions. Reserve capacity is an important consideration in preparing for future droughts and is typically developed through four steps:

1. Reduce demand using less water than is naturally renewable: This step includes taking action to better balance demand and supply. Actions may range from reducing demand through to more efficient water use and behavioral change by relocating consumptive industries away from water-scarce areas.
2. Make better use of available supply with more flexible allocation of water: This step can help ensure minimum and priority demands are met, as discussed in section 7.2, and can provide an incentive for better sharing and encouraging those with surplus water entitlements or allocations to trade.
3. Enhance supply by using multiple sources: Expanding the range of supply sources to, for example, groundwater and additional surface water sources can avoid over-exploitation and enable some resources to be identified as reserve capacity and not used during non-drought conditions.

And, if all other options are exhausted:

4. Enhance supply by developing new water sources: Traditionally new water sources have included the construction of additional reservoir capacity or transfers as grey infrastructure. Increasingly, green infrastructure is also seen as a legitimate complementary or alternative action, for example, the development or restoration of wetlands to encourage groundwater recharge. In moving through these steps, various measures become available.

Box 32: Demonstrating a supply–demand balance, Thames basin, UK

Water companies in England must demonstrate that they are able to deliver the water demand in a dry year. To plan for this dry year demand, they must set out the raw water availability during normal conditions and how it may be reduced during a range of different drought conditions, typically based on a variety of historical droughts. Levels of Service is the term used for the amount of water resources available to maintain water supply during drought periods, with a given frequency of demand restrictions or supply interruptions and defined as:

Water available for use = deployable output minus outages plus/minus bulk supply imports/exports into basin (water resources zone)

Deployable output is defined as the output of a commissioned source or group of sources or of a bulk supply for a given level of service as constrained by:

- environment
- abstraction licence, if applicable
- pumping plant and/or well/aquifer properties
- raw water mains and/or aquifers
- transfer and/or output main
- treatment
- water quality.

Outages are temporary reductions in deployable output, which can be caused by factors such as mechanical failure or pollution events. During drought it is clearly important that outages are minimal.

The difference between available water for use and the dry-year demand plus an allowance for planning uncertainties (target headroom) is the supply–demand balance. If the dry year demand plus the target headroom exceed the available water, then there is a shortfall or deficit in the supply–demand balance. The greater the deficit, the greater the risk that demand restrictions will need to be introduced more frequently than the company's stated Levels of Service and, ultimately, the greater the risk to security of supply.

Defining deployable output using historical droughts as a reference has practical advantages but also presents some problems. From a policy perspective, it is useful to be able to explain that water companies will aim to be able to supply water through the worst drought in living memory without serious restrictions on water use. Using a real drought also allows simplified approaches to hydrological modelling; in many places, long-gauged flow records exist, and it is often possible to use these to extend shorter records for adjacent catchments. On the other hand, while droughts tend to exhibit a high degree of spatial coherence, the severity of a given drought varies between different catchments. In practice, this means that the standards to which water companies are planning are not necessarily consistent or objectively communicated.

Hall *et al.*, 2011 argued that within the context of a risk-based approach, Levels of Service can be considered as a target for the maximum annual probability of a shortage of given severity, so an example of a Levels of Service might be 'an annual probability of hosepipe bans no greater than 0.05'. Uncertainty is incorporated via a 'head-room' allowance, which is 'a buffer between supply and demand designed to cater for specified uncertainties' (Environment Agency, 2012). The 'available head-room', in a resource zone is defined as the difference between the water available for use (deployable output including raw-water imports, less raw water exports, less outage) and the dry year annual average unrestricted daily demand.

Source: Sayers, 2013 and Hall *et al.*, 2012

REDUCE DEMAND

Reduce demand during non-drought conditions

In many highly developed basins, the potential for further supply-side management has either been largely exhausted or is no longer politically palatable. In these instances, the only viable means of increasing reserve capacity become reforms to policy and regulation in areas such as water billing, metering, appliance efficiency, water usage and recycling (see Section 7.3.3) and public education. The water savings through these types of measures can be significant, and become increasingly significant under conditions of climate change and population growth (Box 33). Permanent restrictions (typically referred to as permanent water conservation measures) may also have a role to play, for example by mandating certain basic water efficient practices such as restricting daytime use of sprinklers (Chong *et al.*, 2009).

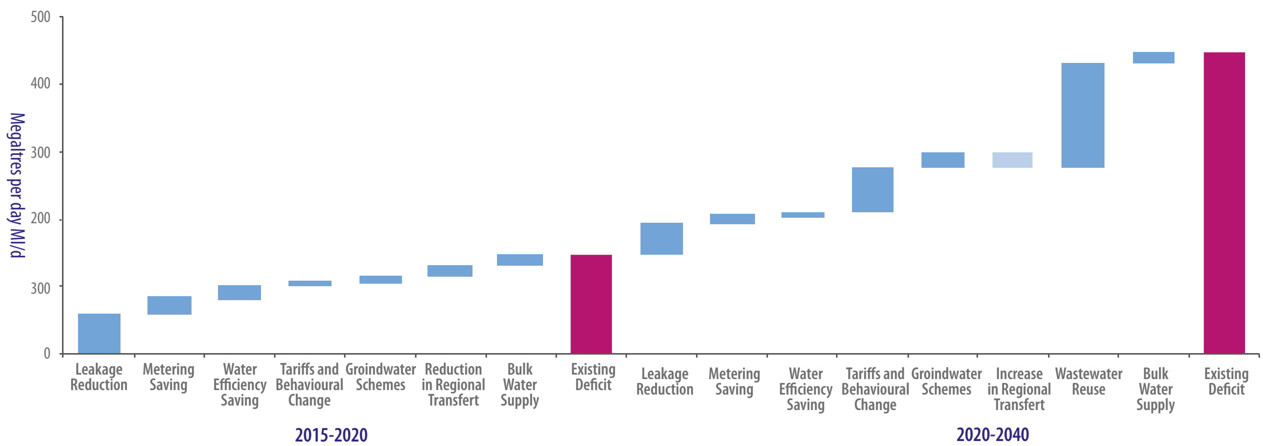
While significant benefits can accrue by increasing reserve capacity through a reduction in demand, there can be a downside. Implementing demand management *during* drought relies on the capacity of water users to reduce their usage. This is more challenging if efficient approaches to water use have already been adopted in response to long-term demand management initiatives –there is less flexibility in the system. Reducing demand may minimize the frequency water users experience water shortages, but when water shortages do occur, there is less scope for implementing demand management measures.

Box 33: Demand management in the Thames basin, UK

The River Thames runs from west to east through southern England before flowing into the English Channel east of London. The Thames basin sustains a population of 15 million, with over 80% of water use in the basin being for domestic and public uses; the remainder is largely used in the agricultural and power sectors. Historic tensions between water for agriculture, industry and domestic uses, and environmental protection continue to be carefully managed in the 21st century, with water quality in the Thames mainstream significantly improved over recent decades through superior point-source pollution management. The Thames basin is drier, on average, than the rest of the United Kingdom and major recent droughts include periods from 1988–1992, 1995–1997, and 2005–2006.[2]

Major pressures on the basin in coming decades include an expanding population, which is estimated to grow by 14% between 2008 and 2026[3] and potential climate change effects – UKCP09 projections indicate a high likelihood of increased flooding and drought conditions.[4] To manage these pressures and maintain certainty of performance, Thames basin managers have indicated that a baseline supply–demand deficit in London of 133 ML/d by 2020 (about 6% of supply) and 414 ML/d by 2040 (about 21% of supply) will need to be overcome.[5] Supply-side measures (new bulk supply, new groundwater schemes, and an increase in regional transfers) account for only a small portion of the total volumetric response to this deficit, reflecting the already highly developed nature of the supply system in the basin. Instead, managers will rely heavily on creating 'new' supply by addressing systemic efficiency measures such as leakage reduction and wastewater reuse and by managing demand and encouraging behavioral change through metering savings, water efficiency savings, and tariffs and behavioral change.

Plan for overcoming supply-demand deficit in London, 2015–2040 (Thames Water)



Source: Thames Water

These measures must, however, be further expanded to allow flexibility in the face of drought. Enforced and encouraged behavior change will play an important role in ensuring that capacity is sufficient not only to meet demand during regular times but also to cope with drought conditions. The Thames Water 2013 Final Drought Plan[6] indicates a heavy reliance on temporary use bans (formerly known as 'hosepipe bans'), prohibiting wasteful uses of water at the household level, and intensive media campaigns to shift individual behaviors. Temporary use bans are only expected to be used for 1-in-20-year droughts while media campaigns are used for more frequently occurring drought conditions.[7]

Demand management and behavioral change strategies require governments to make trade-offs between water use for livelihoods, and environmental and equity objectives. However, there is evidence that such strategies do work in reducing consumption and generating reserve capacity while increasing efficiencies of use. Thames Water projects savings of up to 19.1% over regular conditions in the hottest month of the year, July, under the combined effect of media campaigns and temporary use bans.[8]

Reduce demand during a drought

Reducing demand during drought can make existing supplies go further and delay the need for other potentially more expensive measures.

The most common approach to reducing demand during drought is the introduction of temporary restrictions on water use.[14] Compared with options, such as pricing, temporary restrictions are perceived as an equitable response and often have wide community support. They are also perceived as a cost-effective response, particularly compared with upgrading supply infrastructure (Chong *et al.*, 2009).

7. http://cfpm.org/firma/regions/regThames.htm#past
8. http://www.wwf.org.uk/filelibrary/pdf/thames_vulnerability.pdf
9. http://www.metoffice.gov.uk/services/climate-services/uk/ukcp
10. http://www.thameswater.co.uk/wrmp/Section_9_-_Preferred_Programme.pdf
11. http://www.thameswater.co.uk/tw/common/downloads/aboutus-drought-plan/drought-plan-summary-dec-2013.pdf Accessed May 2016
12. http://www.thameswater.co.uk/about-us/5392.htm Technical Appendices (Part C). Accessed May 2016
13. http://www.thameswater.co.uk/about-us/5392.htm Technical Appendices (Part C). Accessed May 2016

14. Here, restrictions on water use are referring to limiting the way that water supplied, for example as part of reticulated urban water supply, may be used. This differs from limiting the water that may be taken under an abstraction licence. The use of water taken from a reticulated system is in most cases not regulated (as distinct from the granting of water licences to regulate abstractions), with the primary incentive for limiting water use being the application of volumetric water charges.

Water restrictions are often applied as part of a regime where rules are set for different water supply levels so that as water supplies fall, a further level of restriction is triggered, and more restrictive rules start to apply. In the context of residential water usage, restrictions generally apply to discretionary activities, as well as to activities where enforcement is practicable, such as limits on watering gardens, filling of swimming pools, or washing cars. In the case of extreme or prolonged drought, restrictions may result in rationing of water, with households only supplied water for limited periods or to a maximum volume.

In designing a temporary restriction scheme, considerations should include:

- **the cost-effectiveness of different rules,** including the anticipated water savings likely to be accrued under different rules and the associated impact of water users
- **the granularity of the implementation,** including an assessment of the advantages and disadvantages associated with implementing a common approach to restrictions across a catchment or applying location-specific conditions (Chong *et al.*, 2009).

Box 34: Demand management in Southeast Queensland

In Southeast Queensland, Australia, a suite of responses was used over the period of the Millennium Drought (and beyond) in an attempt to significantly curtail water demands. Temporary water restrictions of increasing severity were incrementally imposed, limiting the water use of businesses and households, such as hosepipe bans. A series of permanent efficiency measures were also implemented, including:

- water efficiency management plans, which were mandated for large water-using businesses
- requirements in the building code for improved water use efficiency
- installation of more and better water meters
- expanded use of grey water.

Major efforts also went into community awareness and other programmes aimed at changing individual behavior towards water use.

Taken as a whole, the measures were hugely successful, with residential water consumption falling from over 350 litres per person per day in 2004 to as low as 110 litres at the height of the drought. Many of the measures have remained in force since the end of the drought, and current water supply strategies assume long-term residential water use of between 185 litres and 230 litres per person per day.

ENHANCING SUPPLY

Water re-use and recycling

Additional renewable supply can be created without increasing the total supply to the system by re-using and recycling water. Virtually every industrial and domestic use of water results in substantial volumes of that water being disposed of as wastewater. Many countries recognize wastewater as a resource rather than an inconvenient by-product and it is re-used or recycled various forms. As with other forms of water treatment (e.g. desalination), the feasibility of using water re-use and recycling to generate reserve capacity is largely reliant on the prevailing financing structures, stakeholder attitudes and institutional frameworks. For example, in the absence of regulations requiring recycled water to be purchased by government or private water utilities, it must be priced competitively to encourage utilities to purchase it. Alternatively, the capital cost of constructing recycling facilities must be borne by government knowing that such facilities will only operate in times of water shortage.

Water recycling and re-use is limited by the total water supply available within a given system. However, technological advances and shifting public sentiment combined with increased government attention means that some cities in countries such as Singapore, Australia, Namibia and the US[15] are using treated wastewater as part of their regular supplies. Where the pressures of water scarcity are being felt most, progress has tended to be greatest. With added benefits for the environment by limiting disposal of wastewater, water re-use and recycling is likely to continue to be prominent as urban populations grow and pressures on water supplies intensify. City-level measures to recycle water can be boosted by tying in behavioral change efforts to encourage re-use at the individual household level. Singapore is one of the world leaders in water re-use and recycling, where strictly limited water supplies have been boosted by the development of hi-tech water recycling techniques, including the recycling of wastewater for human consumption and domestic use.

In Singapore, large volumes of water are already imported from Malaysia, so wastewater treatment makes long-term economic and strategic sense (see Box 35). Singapore's extreme water scarcity avoids the problems of non-use that have affected some Spanish desalination plants (Box 40). Together with expanded desalination capacity, water reuse has been shown to dramatically increase the drought resilience of the overall water supply system.[16] Moreover, with extremely limited land resources, increasing reservoir storage in Singapore is not a viable option. In other contexts, however, the costs of technology, maintenance and the large volumes of energy required to run wastewater treatment plants with such high technological capabilities may be prohibitive, incentivising reliance on options that are cheaper and less socially or culturally contentious. Convincing communities to accept treated wastewater for drinking is fraught.[17] Extending this experience globally is gathering pace, but perhaps the political challenges

15. http://www.athirstyplanet.com/be_informed/what_is_water_reuse/who-is-reusing accessed 16 October 2015
16. http://www.pub.gov.sg/Pages/default.aspx accessed 16 October 2015
17. http://www.earthmagazine.org/article/drinking-toilet-water-science-and-psychology-wastewater-recycling accessed 16 October 2015

of implementing recycled water systems are greater than the technical challenges (see Box 36).

Box 35: Water re-use and recycling, Singapore

The state-owned Public Utilities Board in Singapore is a statutory board of the Ministry of the Environment and Water Resources that manages water supply. As part of a national political effort to achieve increased water security, the board initiated a study in 1998. Singapore currently depends on Malaysia for about 40% of its total water supply. The objective of the study was to determine the suitability of using stringently treated wastewater to supplement Singapore's water supply. Since 2001, the project has been formally scaled up and Singapore now has five operational NEWater plants with the ability to supply 30% of national demand. Although a high degree of purity can be achieved through a three-step process of microfiltration, reverse osmosis and disinfection with ultraviolet light, most NEWater produced is used for non-potable applications in manufacturing and air-conditioning. Some water is also blended with reservoir water to supplement regular tap supplies. With estimates suggesting that the non-domestic sector could account for 70% of water use by 2060, the Public Utilities Board plans to expand NEWater capacity to meet 50% of demand by that time.

Source: Information from http://www.pub.gov.sg/

Box 36: Political barriers to implementing potable recycled water: The Australian experience

Potable recycled water provides a water source that can be invaluable during drought. Its use though may be dependent, at least in a democratic setting, on sufficient public support, which in turn depends on sufficient understanding of, and confidence in, what is proposed. The difficulties of generating support are highlighted by recent experiences in Australia.

Toowoomba, a regional town with a population of around 100,000, suffered from severe water shortages as a result of the Millennium Drought. In June 2005, the Toowoomba City Council lodged an application for funding for an advanced water treatment plant to provide potable quality recycled water for the town. The proposal received unanimous support from Toowoomba's nine councillors, as well as the region's state and federal members of parliament.

In the face of significant public opposition to the proposal, a referendum was held. Ultimately, after significant advocacy both by the Council (in favour) and various lobby groups (against), 62% of residents voted against the proposed recycled water scheme and it was abandoned.

Subsequently, in early 2007, the Queensland State Government was developing plans for a number of advanced water treatment facilities to augment the diminishing water supplies for Brisbane and Southeast Queensland. Faced with the prospect of a repeat of the Toowoomba referendum, the Queensland Premier announced that there would be no public vote on the whether to proceed.

Later in 2008, the government announced that treated wastewater would only go into dams when they fall below 40% of capacity. While water levels in dams in Southeast Queensland fell below 14% of capacity at the height of the drought in August 2007, levels have not been below 40% since the recycled water plant came online and thus recycled water has not yet been added to drinking water supplies. The A$2.6 billion recycled water plant has been limited to providing water directly to power stations and a limited number of industrial customers and is operating significantly below capacity (QAO, 2013).

Source: Hurlimann and Dolnicar (2010).

Large-scale and local-scale transfers

Providing the physical infrastructure to move water from an area in surplus to an area in deficit has been used in the management of water resources for a long time. Today, transfer schemes continue to be used, including large-scale, inter-regional transfers, typically focusing on ensuring strategic supplies in water-scarce regions than about drought risk management, and the development of smart water grids that facilitate more localized transfers, typically focusing on ensuring flexibility in times of acute shortage rather than providing permanent transfers. Both of these measures are discussed.

Large-scale inter-basin transfers

In some closed river basins, where demand for water clearly exceeds long-term average water supply, it may be feasible to physically transfer water from one or more nearby river basins to create reserve capacity. Typically, these large-scale inter-regional transfers are focused on ensuring an enhanced supply to water scarce regions rather than reducing drought risk. Inter-basin water transfers are a way of evening out natural spatial variability, shifting water from areas where more water is regularly available, to areas where water demands are comparatively higher or natural water resource availability is lower. Inter-basin transfers increase the scale of water resources management and challenge the context of 'basin management' (Pohlner, 2016). They present political and organisational challenges with trade-offs between users of water in the source region and the destination region, and between the needs of the immediate water environment and human needs further away.

There are numerous examples of inter-basin water transfers. In India, for example, the 'inter-linking rivers strategy' proposes to connect a number of the major rivers in India (Box 37). In China, the Middle Route of China's South–North Water Transfer (see Box 38), which commenced full operations in late 2014, is the largest single inter-basin water transfer scheme in the world and has been largely developed to ensuring strategic supplies to Beijing and the surrounding area. In Australia, north–south water transfers are possible (Ghassemi and White, 2007), but with limited momentum (Box 39). Without implementing broader measures to reduce demand, control pollution and safeguard freshwater ecosystems, inter-basin transfer schemes may have limited impact on reducing drought risks or may even increase them if long-term demand increases in line with the increased supply.

Box 37: Inter-linking rivers strategy, India

The average rainfall in India is about 4,000 billion cubic meters, but most of India's rainfall comes over a four-month period from June to September. The distribution of rainfall is not uniform: the east and north gets most of the rains, while the west and south get less. India also sees years of larger than average monsoons and floods, followed by below-average or late monsoons associated with droughts. This spatial and temporal variance in availability of water creates a demand-supply gap that has been worsening with India's rising population.

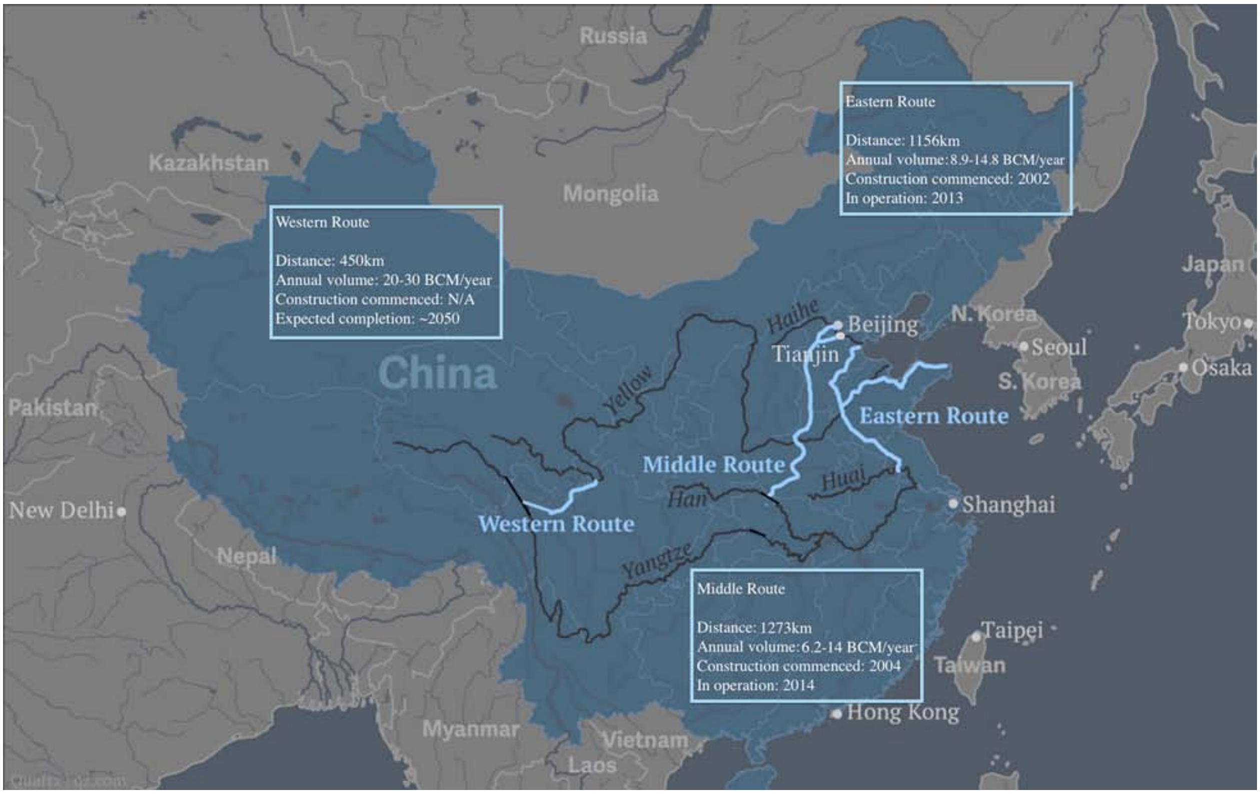
The inter-linking river strategy has been proposed as a means of accommodating this variability. As part of the strategy, rivers of the northern Himalayan region would be connected with the southern penninsular rivers and many of the intrastate rivers. The project is being promoted by India's National Water Development Agency, under the Ministry of Water Resources.

Proponents of the strategy claim it will enable the abundant monsoon waters to be stored and redistributed to more water-scarce areas in times of drought. The project also has potential benefits for transport and rural incomes. There is, however, significant opposition to the strategy due to potentially significant impacts on ecosystems and social displacement impacts associated with engineering on such a scale. The impact the project will have on neighbouring countries, particularly Bangladesh, and the rights these countries have to upstream waters is also unclear.

Box 38: South–North Water Transfer Middle Route project, China

The South–North Water Transfer project (*nan-shui-bei-diao gongcheng* 南水北调工程) was initiated in 2002 and consists of three separate water transfers from the Yangtze River basin to China's arid northern plains, for use by tens of millions of water users in Beijing, Tianjin and Hebei province. The Middle Route commenced operations in late 2014 and is able to transfer 9.5 billion cubic metres/year (nearly five times the annual flow of the River Thames) a distance of almost 1,300 km by gravity from the Danjiangkou reservoir on the Han River to the country's dry north. Construction of the Middle Route project is estimated to have cost the Chinese state about US$34 billion.[18]

South–North Water Transfer proposed routes



Source: GIWP

The Middle Route project aims to help bridge the gap between supply and demand in the north as well as providing reserve capacity for times of drought. The transfer project will operate almost constantly to satisfy existing need and is not simply a 'back up'. However, it may enable Beijing's current 'emergency reserves', on which it has relied every year for at least the past six years, to regain some of their intended emergency use status. These reserves are themselves also reliant on long-distance water transfer as they are mostly situated in central and western Hebei province, which itself frequently short of water, as evidenced by the region's worst drought in 63 years in

18. http://jingji.21cbh.com/2014/6-14/wNMDA2NTFfMTE5OTYwNA.html Accessed June 2014

2014.[19] Additionally, water transfers from the south are intended to reduce unsustainable reliance on groundwater in the north.[20] Managed aquifer recharge in and around Beijing and Tianjin from the transfer scheme could increase reserve capacity in the water resource system as a whole.

However, increasing reserve capacity through inter-basin transfer comes at a cost. Reservoir expansion at Danjiangkou has led to the relocation of about 300,000 residents and has submerged forest and farmland. Direct compensation to these residents has accounted for over 10% of total project costs. Moreover, abstractions of up to a third of annual flows in the Han River for channelling waters north are expected to contribute to water quality reductions downstream of Danjiangkou. As a major infrastructural response, the inter-basin transfer schemes face many of the same trade-offs and challenges as large dams (WCD,2000).

Local-scale smart water grids

So-called 'water grids' enable the physical transfer of water from one location to many others within a single geographical unit (e.g. a nation-state). In the UK, the concept of a smart water grid continues to be developed, to providing flexible transfers between neighbouring water supply companies coupled with inter-basin transfers to move water from the 'wet' north to the 'dry' south. A recent study by the UK Institute of Civil Engineers concluded that construction of a national 'grid' in the UK is feasible, and could be cheaper than building new reservoirs in England's south (ICE, 2012). Water grids also offer the opportunity of improving the combined yield of a number of storages and of spreading supply risk (see Box 39). However, smart grids are not without disadvantages. For example, the proposed UK water grid remains controversial because of potential whole-of-life costs and environmental impacts.

Desalination

Successive technological advances in membrane manufacturing and related areas continue to drive down the cost of desalinated water and some water-scarce regions have grown reliant on desalination as a major contributor to water supply. In Israel, for example, the government aims to have an installed desalination capacity of 750 million m^3/year by 2020, able to supply about one third of projected annual use.[21] However, the negative consequences that may be associated with desalination, compared with additional demand-side measures, need to be considered. The high-energy use of the plants may contribute to greenhouse gas (GHG) emissions and add significant operating costs, depending on technologies used. Hyper-saline discharges can have localized impacts on coastal environment. However, cost is the most significant barrier. Even when the plant is not operational, fixed operating costs can represent a relatively high proportion of total operation costs. For example, the Gold Coast Desalination Plant, in Southeast Queensland, Australia, constructed during the height of the Millenium Drought (2007-2012), cost A$3.8 billion (QAO, 2013), and has not been operated in recent years because of the availability of surface water supplies and the high cost of producing desalinated water. The plant has fixed costs, including repairs, maintenance and fixed energy charges of more than A$11 million per year, which are locked in for the long-term. These costs, combined with a low utilization rate, has resulted in the cost per megalitre of water produced to be far higher than estimated. For example, during 2011–12, operating and maintenance costs were $4,403 per mega litre (QAO, 2013). The Queensland Audit Office's review was critical of the process for deciding to proceed with construction of the plants and found that better planning may have avoided the need for such drastic and costly action.

In other contexts, desalination is viewed as 'reserve capacity', back-up supply for times of drought and shortage. In Spain (see Box 40), the Llobregat plant became fully operational in July 2009 following a period of severe drought, but rarely operated in its first few years and only at full capacity for maintenance and testing. Nevertheless, the reserve capacity remains and can be used if conditions require it.

Additional reservoir capacity

The development of new surface water storage by constructing dams to create reservoirs has long been pursued as a strategy to address water scarcity and drought risks. New reservoir construction remains a primary means to create reserve capacity in many countries.

Few measures better capture the difficult trade-offs that must be considered when creating reserve capacity to smooth the peaks and troughs of natural variability. In developing a reservoir scheme, extensive dialogue is required to identify (i) the potential beneficiaries of enhanced water storage levels and water supply, such as hydropower providers and domestic, industrial and agricultural water uses and recreational users and (ii) those that may be negatively impacted by the dam construction and operation, such as people whose land is inundated or downstream riparian communities who might lose out on disrupted ecosystem services.

19. http://en.ce.cn/main/latest/201408/28/t20140828_3444386.shtml Accessed June 2014
20. http://www.scmp.com/news/china/article/1612035/new-stage-huge-south-north-water-transfer-project-channel-bring-relief Accessed May 2016
21. www.water.gov.il/Hebrew/ProfessionalInfoAndData/2012/07-Israel-Water-Sector-Desalination.pdf – Accessed March, 2014

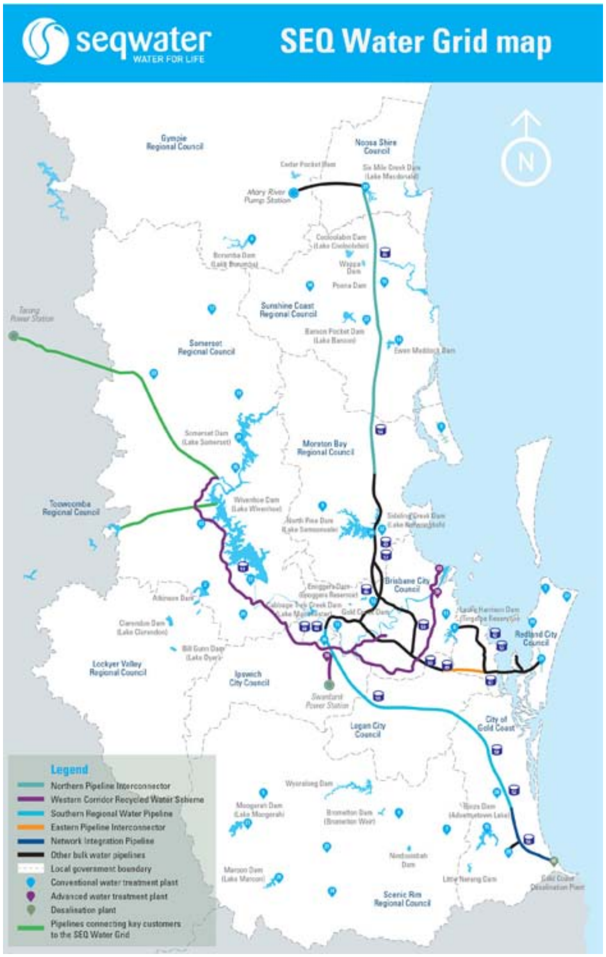
Box 39: The Southeast Queensland Water Grid, Australia

The centrepiece of the Queensland Government's response to the Millennium Drought was the construction of Australia's largest urban water security system – the Southeast Queensland Water Grid. Set up in 2007, the A$7 billion network can carry water to about three million people spread over 21,000 km². The grid was designed to link existing water supplies, increasing the potential yield of storages and spreading supply risk.

The network includes 12 dams for capturing rainfall, as well as a desalination plant and a recycled water plant. While the dams already existed at the time of the Millennium Drought, the Gold Coast Desalination Plant and the Western Corridor Recycle Water Scheme (comprising three advanced water treatment plants) were commissioned during the height of the drought. The desalination and recycled water plants were developed as drought response options. Today, the Gold Coast Desalination Plant is operated in hot standby mode, while the Western Corridor Recycled Water Scheme has been placed in care and maintenance due to the current high water security in the region.

The water treatment plants connected to the dams have been linked through a pipe network, allowing treated water to be moved across the region to where it is needed. The system was designed to provide greater security of water supply in a climate of extremes.

Southeast Queensland Water Grid



Source: Seqwater (personal communication, Liz Kearins, Nov 2015). Image reproduced courtesy of Seqwater.

Box 40: Desalination in Catalonia, Spain

Spain built Europe's first ever desalination plant in 1964 and is now the largest user of desalination technology in the Western world. After protests by environmentalists and farmers derailed earlier plans to meet future water demand through large inter-basin water transfers, Programa AGUA set out plans for 21 new desalination facilities on Spain's Mediterranean coast in 2004.[22] Desalination, it appears, is likely to remain a priority investment for the Spanish Government as it faces an uncertain future under demand shifts and climate change.

The Llobregat desalination plant, just outside of Barcelona, was completed in 2009 following rapid construction during a period of extreme drought. When finished, the desalination plant could supply approximately 20% of metropolitan Barcelona's tap water, as it has a maximum capacity of 200,000 m³ per day. Unlike desalination plants operated at a constant rate to meet baseline needs, the operating criteria for the Llobregat plant are tied to the water levels of the nearby Ter and Llobregat reservoirs. If these reservoirs are over 80% full, daily production is at a designed minimum of 20,000 m³. If they are less than 60% full, production is 180,000 m³ per day, with graduated production between 60% and 80% of dam capacity. Dam levels were below 80% for much of the construction period for the Llobregat plant, but they have very rarely fallen below 80% since the completion of the plant in late 2009 (Sanz *et al.*, 2013).

The Llobregat experience captures the trade-offs required in creating reserve capacity through desalination and has spent much of its life effectively dormant, contributing little to local water supply.

Desalination in Spain highlights the difficulties[23] of determining how much and what type of reserve capacity to build into a water resource system. The Llobregat plant's critics are able to point to the price paid by Catelonian, Spanish, and European taxpayers for a plant that rarely generates freshwater. Balancing the economic scales, in this case by attracting a return on the large investment in Spanish desalination plants, is complicated by natural variability and uncertainty. Yet it remains the unenviable task of policy makers faced with the question, 'How much reserve capacity is enough?' Many would argue that the Spanish investments demonstrate the folly of incorporating *too much* reserve capacity into a local system, excessively trading away drought risk for what may have become an unmanageable financial risk.

The task of deciding how much reserve capacity is enough has become a question of dam management as well as reservoir construction. By building a new dam, storage in a basin may be significantly increased, but that capacity only exists if there is water in the reservoir and it is allocated according to recognized principles. A reservoir that is routinely operated at near-empty provides little or no headroom when drought conditions set in. A reservoir that captures too much of the flow is likely to have significant downstream impacts. Likewise, a large reservoir represents a diminishing source of reserve capacity if sedimentation is uncontrolled or if water quality is not closely monitored. With improved dam management, it is possible that the risks of decreased productivity and livelihood impacts associated with drought hazards may be reduced with no additional physical reserve capacity required. Like demand

22. www.ncbi.nlm.nih.gov/pubmed/16574308 Accessed May 2016
23. http://www.nytimes.com/2013/10/10/business/energy-environment/spains-desalination-ambitions-unravel.html Accessed May 2016

management, this is, in effect, creating additional 'virtual' reserve capacity. Management of significant uncertainties and, where possible, reducing those uncertainties through improved data collection and advanced modelling, plays a crucial role in determining the limits of virtual reserve capacity.

The arguments for and against dam construction are well known, and include governance and political challenges as well as technical issues (WCD, 2000; Moore *et al.*, 2010). An open, transparent, evidenced-based dialogue is critical for resolving these trade-offs and understanding if there is a real need for additional large-scale storage in the context of a more strategic portfolio based approach to managing drought risk.

Large reservoirs are not the only means of providing additional surface storage. For example, in Australia farm-level reservoirs are increasingly used to provide capacity to help mitigate local drought risk. Although such measures can be locally effective, drought impacts on the wider catchment can be exacerbated (Box 41). These spatial interactions highlight the importance of understanding the impact of any action on the whole drought risk system; without this understanding action may reduce risks in one location or one sector while increasing them elsewhere.

Box 41: Dam management at the farm level and the need for careful considerations, Australia

Researchers at the University of South Australia have analyzed the potential for dam management at the farm level to minimize risk.[24] The study highlights that farm-level dam management practices, when aggregated to a catchment level, can exacerbate drought risk and potentially flood risk. The proliferation of small farm dams in unregulated catchments can also deprive local streams of run-off during droughts (Bond, 2008). Hydrological modelling suggests that during drought years, farm dams can capture most of the annual flow in low-rainfall catchments (McMurray, 2006), locking the sections downstream of the dams into permanent drought (Bond, 2008).

MA IMIZE THE USE OF NATURAL INFRASTRUCTURE

Working with natural processes and maximizing the utility of natural infrastructure is increasingly seen as a cost-effective approach to managing water-related risks and other natural hazards in a way that also provides a wide range of ancillary benefits (e.g. UNEP, 2014). In the context of drought, using natural infrastructure, particularly the creation and restoration of wetlands, can support the role of ecosystems in reducing drought risk and building resilience to drought, by:

- **Reducing the drought hazard:** for example, by mitigating climate change through enhanced carbon sequestration and modifying weather events by managing vapour fluxes through to encouraging groundwater recharge through wetland creation and restoration and regulating water flows and quality across a catchment.
- **Reducing the consequences of droughts for human and the freshwater ecosystems:** by improving the health of freshwater ecosystems during non-drought periods and maintaining critical connections and refugia to increase freshwater ecosystem resilience to drought, and to maintain livelihoods and access to food, fuel, shelter and water before, during and after drought events.

Example natural infrastructure measures for supporting drought risk management include:

- modifying weather (afforestation) to reduce meteorological drought hazard
- enhancing aquifer recharge: reducing blue-water drought hazard
  - protecting and restoring natural wetlands to regulate flows, reducing the chance of blue-water drought
  - enhancing natural recharge to bolster groundwater supplies for use during dry periods
- regulating flow and water quality to reduce the blue-water drought hazard
- improving agro-ecosystem practices to reduce the green-water drought hazard.

These and other ecosystem-based measures are discussed in more detail in Chapter 8.

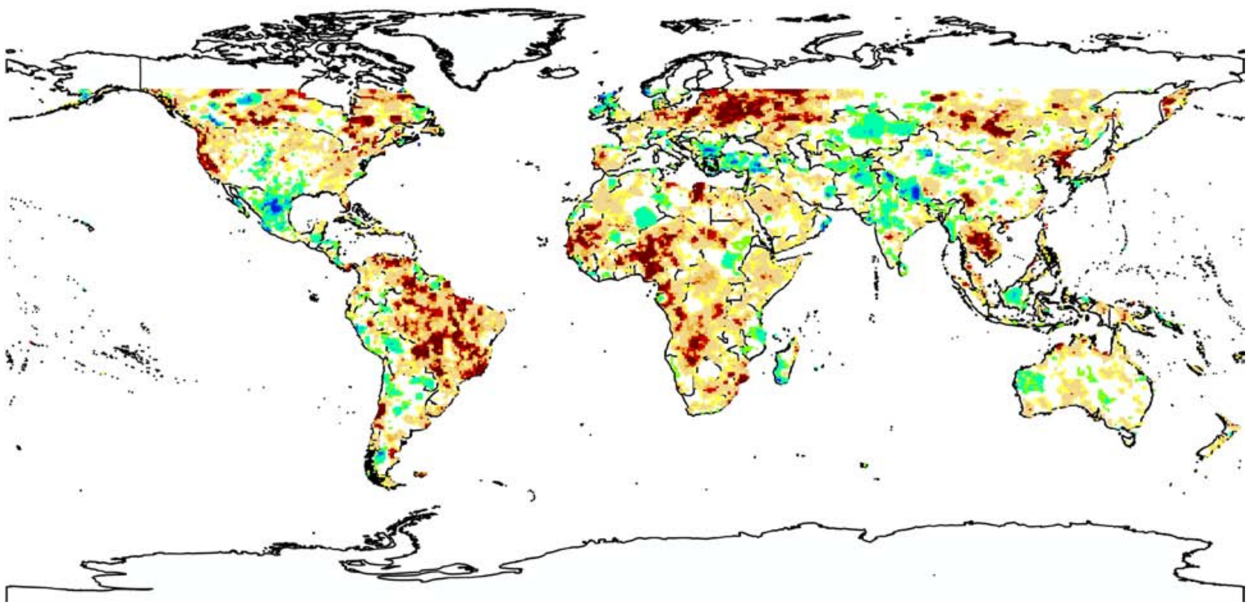
7.4. Enable a better response and faster recovery

In addition to taking actions during non-drought conditions, SDRM develops the capacity to take action that reduces the impact of a drought when it occurs and aids the speed of recovery. This includes raising awareness of a developing drought, reviewing and enacting an emergency plan as set out in an SDRM plan, supporting water users with temporary water supplies, managing the allocation of available water resources in accordance with established rules or principles, trading water allocations (where the mechanism exists), and maintaining critical freshwater connections and pulse base flows to refugia. It also includes continuing to help the human systems and freshwater ecosystems to fully recover, a process that does not stop immediately after the weather breaks. Cessation of water restrictions, financial compensation to farmers, reinstatement of 'normal' abstraction controls and restocking and rehabilitation of habitats are all part of this processes.

The specific measures that are likely to form part of the process of response and recovery are discussed.

24. http://www.globalwaterforum.org/wp-content/uploads/2012/04/Appropriate-small-dam-management-for-minimising-catchment-wide-safety-and-drought-threats-GWF-1212.pdf Accessed May 2016

Figure 7.1. Example output from the Global Integrated Drought Monitoring and Prediction System



Source: University of California, June 2015. The dark brown patches indicate areas of exceptional drought, through to patches of dark blue showing areas of exceptional wetness. Showing the MSDI — Multivariate Standardized Drought Index — as at June 2015 as proposed by Hao and AghaKouchak 2013.

PROVIDE RELIABLE FORECASTS AND WARNINGS

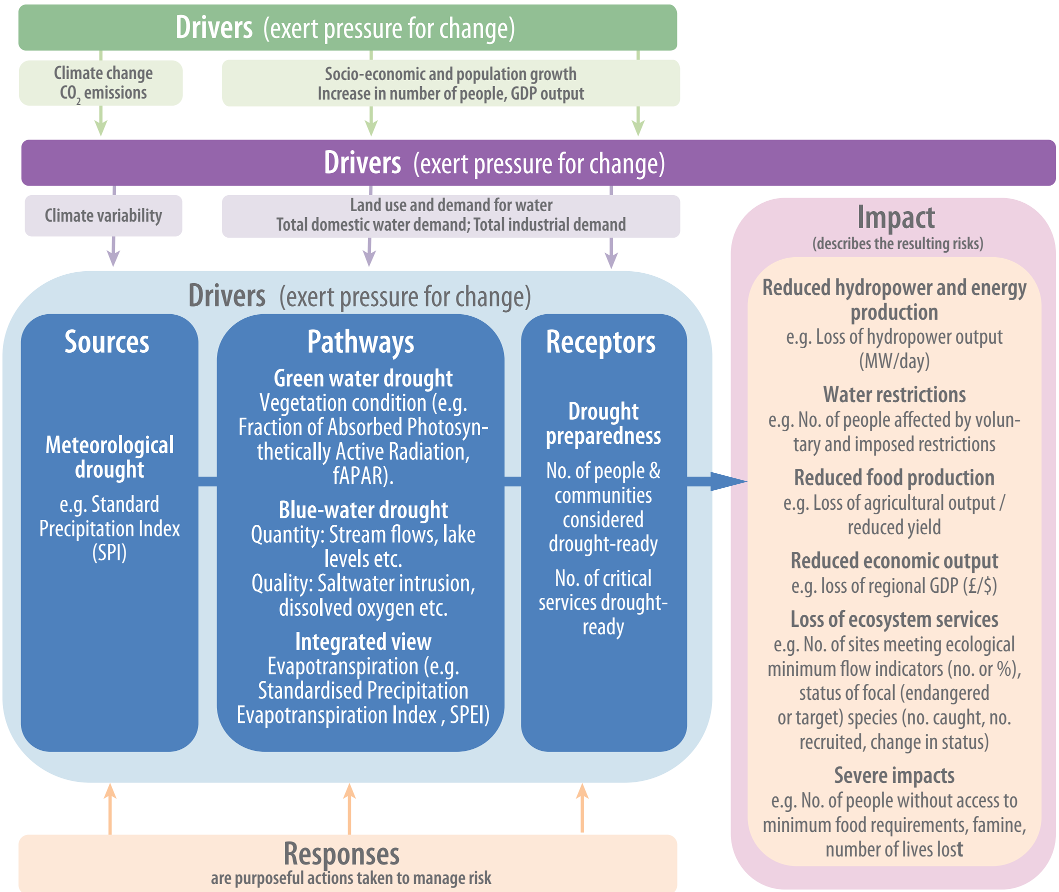
Reliable near-term and seasonal forecasting and associated early warning systems provide critical support to SDRM. In recent years, there have been significant improvements in the assessment and mapping of drought hazard and risks in providing credible nowcasts as well as seasonal and decadal forecasts and long-term scenarios. They help ensure the timely declaration of drought and that action is taken to limit the most significant impacts of drought and underpin well-informed choices. Following the lead of the US Drought Mitigation Center, various drought observatories and forecast centers now operate around the world in, for example, Australia (Box 42) and the European Commission's prototype European Drought Observatory (Box 64). Important advances are being made beyond displaying immediate and very near time conditions towards seasonal forecasts and even longer-term forecasts.

On a short timescale, such as a month or a season, it may soon be possible to indicate the probable timings of the onset and termination of drought based on observations and analysis anywhere in the world. A global system that could monitor upcoming droughts and issue warnings was first proposed at a ministerial summit in South Africa in 2007 by US government researchers at National Oceanic and Atmospheric Administration. Today, the Global Integrated Drought Monitoring and Prediction System (GIDMaPS), developed by the University of California[25] provides present drought conditions and seasonal forecasts based on either the Standardized Precipitation Index (SPI), Standardized Soil Moisture Index (SSI) or Multivariate Standardized Drought Index (MSDI) (Figure 7.1). Further advances in the development of a global capability will, however, require greater cooperation between nations and organizations (see Section 8.3.2).

But to maximize the use for forecasting in decision making, it is not enough to simply forecast the drought hazard (e.g. meteorological drought, blue-water drought or green-water drought). Taking action relies on forecasts being translated into meaningful warnings that enable individuals, communities and business to take appropriate action. This action includes improving the communication of the severity of hazard, such as by drawing comparisons with drought that may have been experienced in the past and moving beyond hazard forecasting to risk forecasting that communicates both the probability and impacts on drinking water, agricultural production, hydropower and the confidence in those forecasts. This communication requires an extension to the traditional drought indices used to express the severity of the droughts. The move towards risk-based approaches requires a more comprehensive monitoring process, although not necessarily more complex monitoring and forecast models of the whole 'drought risk system'. Models need to represent the vulnerability of the receptors in addition to the meteorological sources and hydrological pathways (Figure 7.2).

25. http://drought.eng.uci.edu/ accessed 6 September 2015

Figure 7.2. A range of drought indicators reflecting the 'whole system' are needed to support rational risk based choices



PROTECTING PUBLIC HEALTH

Protecting public health during a drought and helping people to recover their lives quickly is of paramount importance. SDRM has a role in maintaining a number of key elements that are vital to human health (adapted from CDC, 2010):

- **Quantity and quality of potable water:** Drought can impact the quality of both surface water and groundwater sources. Consideration should be given to how treatment systems will cope with the changes in the nature of the treatment that may be needed during a drought. For example, the filtration components in surface water treatment facilities are designed based on historical water quality data and are effective at removing microbiological contaminants from untreated source waters. If source waters have unusually high sediment loads, such as those caused by wildfires, they can easily clog these filters.
- **Food and nutrition:** Although considerations of emergency food supplies are outside this scope of this book SDRM does have a role in ensuring agricultural quality standards are maintained during a drought. For example, as supplies reduce, the quality of water being used for agricultural purposes typically decreases. In the face of extreme drought, farmers may opt to use reclaimed or recycled water (i.e., treated municipal sewage) to irrigate their fields and process the crops they grow. If not closely monitored, this agricultural practice could pose a threat to the safety of the food supply by increasing the likelihood of public exposure to pathogens, like Salmonella and toxin producing E.coli, and other potentially toxic substances.
- **Living conditions:** SDRM has a role in ensuring energy supplies, sanitation and hygiene, recreational activities, as well as mental health (reflecting the stress drought can bring). All of those present particular issues during drought conditions and should be considered in the development of the SDRM. Specific measures will vary to reflect the local setting but these broader risks should be addressed within the SDRM.
- **Disease:** Many types of human diseases that are associated with poor hygiene and poor water quality are also associated with drought, including those that are infectious, chronic, and transmitted by animals and insects (i.e. vector borne and zoonotic). Numerous factors contribute to the increased incidence of these diseases in drought conditions,

ranging from higher concentrations of human pathogens in water to changes in the behavioral patterns of wild animals. Giving consideration to the management of these drought risk pathways can reduce the potential for an escalation in drought impacts.

- **Identifying the most vulnerable:** As with most natural and manmade disasters, drought impacts different people in different ways. The most vulnerable members of the community should be identified in preparation for future droughts (for example the register of 'at-risk individuals' defined within the Pandemic and All Hazards and Preparedness Act (PAHPA), within the US). Groups particularly vulnerable to drought (such as those living in rural or remote areas who depend on water from private wells and small or poorly maintained municipal systems where water quality is more susceptible to environmental changes) should be identified and special measures taken.

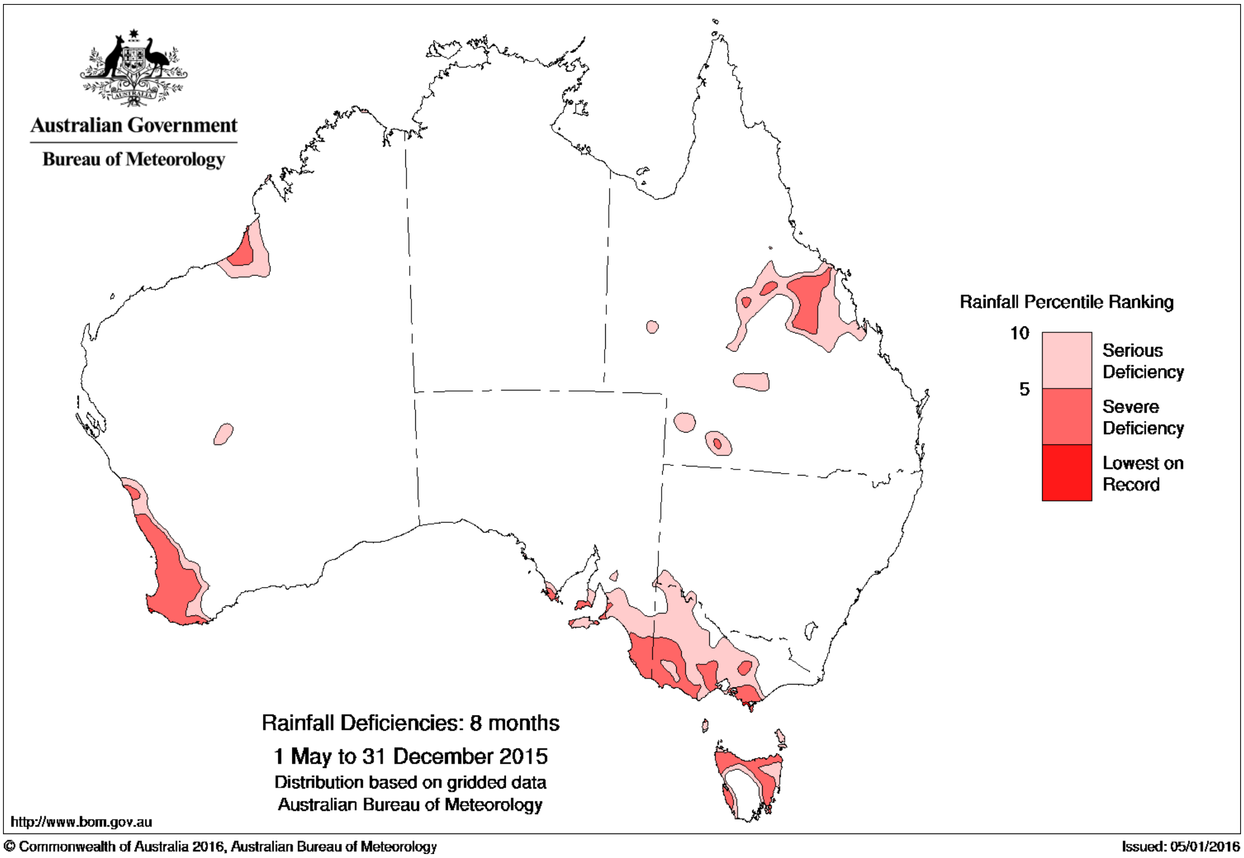
Box 42: Seasonal climate forecasts, Australia

The Bureau of Meteorology, Australia's national weather, climate and water agency, provides a range of observational, meteorological, hydrological and oceanographic services. Since 1965, the bureau's 'drought watch service' has been a key component of national drought management. The bureau provides information to government, businesses and rural communities, as well as synthesising and assessing the available information, helping to identify where action or drought relief may be required (Bureau of Meteorology, n.d.). The bureau provides a consistent basis for both federal and state government actions, including issuing national drought alert, drought declarations, and various responses to drought.

The bureau prepares monthly drought statements that highlight areas that are experiencing rainfall deficiencies, including both long-term and short-term deficiencies. Assessments are derived from a nationwide daily rainfall-measuring network, coupled with an understanding of the relationship between rainfall deficiency and the severity of recorded drought. In addition to analysing rainfall data, the bureau's drought statements also report on soil moisture.

A 'drought watch' is initiated for a region if accumulated rainfall over three successive months is within the lowest 10% on record. A drought watch ceases when 'plentiful' rainfall returns, which is defined as well above average rainfall for one month, or above-average rainfall over a three-month period (BOM, n.d.). In addition, the bureau's Seasonal Climate Outlook Service offers a rainfall and temperature outlook and stream flow forecasts for the coming three months. The outlooks are based on the outputs of a range of international climate models and particularly rely on the NINO3.4 index as the basis for classifying the El Nino-Southern Oscillation conditions (see BOM, n.d.).

Six-month rainfall deficiencies for period 1 May 2015 to 31 October 2015



Source: BOM, n.d., see http://www.bom.gov.au/climate/drought/

PROTECT FRESHWATER ECOSYSTEMS AND SUPPORT THEIR RECOVERY

Maintaining freshwater ecosystem health during non-drought periods is fundamental to achieving fast recovery following a drought event: healthy ecosystems are considered more resilient to extreme weather events and more likely to recover from the impacts of such events than degraded systems (Sudmeier-Rieux and Ash, 2009). Proactive management is needed during non-drought and pre-drought conditions to maintain or restore freshwater ecosystem health and resilience. This involves measures such as maintaining freshwater ecosystem connectivity, protecting priority refugia, maintaining environmental flow and reducing human degradation of the system. These measures are outlined in Section 7.5.2 and discussed in detail in Chapter 8.

ECONOMIC AND FINANCIAL RECOVERY: PROVIDING COMPENSATION

Providing financial compensation and humanitarian aid continues to play a major role in supporting individuals and communities recover quickly from drought. For example, Australian farmers were reimbursed for drought losses in 1992 and major international aid efforts were mobilized in response to the Horn of Africa Drought in 2011. However, care is needed to encourage drought resilience. A review of the US Federal Crop Insurance Programme, a government insurance programme that is meant to protect farmers in times of weather-related devastation, highlighted perverse incentives that may be embedded within compensation mechanism. It was concluded that the Federal Crop Insurance Programme, although intended to alleviate risk for farmers, actually drives the agricultural community toward the use of high-risk farming methods and less resilient land management practices by encouraging a narrow set of farm practices that meet the requirements of the Federal Crop Insurance Programme (NRDC, 2013). Progressive compensation instruments seek to support behavioral change and reward resilience – developing such instruments requires careful consideration of the local pressures and practices.

7.5. Promote a sustainable water future

In the absence of any other consideration it is easy to assume that drought risk can be managed through engineered infrastructure (new reservoirs, transfers, etc.). It is more difficult to manage drought risk in such a way that promotes wider benefits to society and ecosystems; yet it is this latter approach that offers the greatest opportunity for a long-term solution. The early identification of win-win opportunities - including maximization of opportunities for wider benefits through wetlands and groundwater recharge, blue corridors to link refugia and changes in water use behaviors by industry and individuals - dramatically increases the chance of delivering a coordinated multi-functional response to drought.

URBAN PLANNING: DROUGHT-SENSITIVE DEVELOPMENT

In achieving the broader, longer-term goal of transforming society towards a water-sustainable future, SDRM develops closer links with urban planning than conventional DRM to enhance the supply surplus and influence development patterns. SDRM supports initiatives to:

Improve leakage control: For example, in England and Wales in 2010–11, 2,559 Ml/d of water was lost through leakage.[26] Leakage becomes most critical at times of drought and establishing leakage targets to be addressed during non-drought conditions is important for both drought and broader water resources planning. Other actions to develop more flexible supplies or reduce demand will often be secondary to achieving leakage reduction (SMC, 2012).

Deliver more efficient water use for business and industry: Business and industry can play a significant role in facilitating SDRM and reducing drought risk if appropriately regulated and incentivized. For example, in England the water use of businesses can be assessed using five key performance indicators (Defra, 2012). The five areas look beyond simple efficiency:

1. the water a business uses, both supplied and directly abstracted
2. water reuse and efficiency within factories and other facilities
3. water used in supply chains
4. nutrients and organic pollutants released into water sources
5. metal emissions to water.

Minimize water use in new homes (reuse and recycle): SDRM has a role to encourage water-efficient homes and the specific consideration of drought issues within codes, for example for low-water air conditioning systems, low-flush toilets, and grey-water recycling. In many countries, there is a requirement to build new homes to increasingly stringent standards of water efficiency. For example, the Code for Sustainable Homes in England[27] provides minimum standards for home water efficiency. This code should also encourage water-sensitive planting and low-water garden maintenance regimes.

26. http://www.defra.gov.uk/statistics/environment/inland-water/iwfg13-leakage Accessed June 2014
27. http://www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide.pdf Accessed May 2016

Retrofitting to improve water use: Improving the water performance of existing homes is more difficult. SDRM has a role in supporting incentives for water and energy companies to work co-operatively with local authorities to retrofit homes with energy and water-efficiency measures. In England, some schemes have had success, including CERT[28] (the Carbon Emissions Reduction Target), CESP[29] (Community Energy Saving Programme), HEMS (Household and Energy Management Strategy) and the Green Deal.[30]

Encourage behavior change through domestic water metering: In the domestic sector, water metering can have a significant impact on water use. In England, for example, all new houses are metered and more existing houses will be progressively metered. Although primarily a vehicle for managing water resources more generally, water metering has been suggested as a vehicle for monitoring usage and identifying leakage and excess use in times of drought.

FRESHWATER ECOSYSTEMS: PROMOTING DROUGHT RESILIENCE

Many of the Golden Rules for SDRM (set out in Section 5.5) reflect the need to achieve a positive interaction between the freshwater ecosystem and human system to (i) build and maintain the resilience of the freshwater ecosystem by protecting it; and (ii) use freshwater ecosystems to reduce drought risk to society. The first set of measures is a prerequisite to successfully implementing the second set of measures: resilient and healthy freshwater ecosystems are necessary to effectively use freshwater ecosystems as part of drought risk reduction to society.

SDRM recognizes the importance of this interdependence in achieving a sustainable water future. In addition to the natural infrastructure measures discussed in Section 7.3, a more pervasive recognition of freshwater ecosystems within SDRM requires approaches that safeguard and promote freshwater ecosystems. This is discussed in more detail in Chapter 8.

7.6. Summary of measures and instruments

SDRM seeks to develop and use a wide range of measures and instruments to manage drought risk as summarized below.

28. http://www.decc.gov.uk/en/content/cms/funding/funding_ops/cert/cert.aspx Accessed June 2014
29. http://www.decc.gov.uk/en/content/cms/funding/funding_ops/cesp/cesp.aspx
30. http://www.decc.gov.uk/en/content/cms/tackling/green_deal/green_deal.aspx

REDUCE THE CHANCE OF A DROUGHT HAZARD OCCURRING

A wide range of approaches are available to help reduce the chance of a drought occurring. These include, for example:

- **Inf uencing future climate change (meteorological drought):** As a minimum, giving preference to low-carbon solutions. More ambitious drought risk managers will look for solutions that sequestrate carbon such as afforestation and wetland restoration.
- **Inf uencing present-day weather (meteorological drought):** Maintaining native forest or large-scale afforestation may reduce drought risk. Evidence suggests that deforesting large areas of native forest, particularly in tropical regions, modifies rainfall patterns and could increase the severity of drought. Meanwhile, evidence for whether large-scale afforestation can increase rainfall seems inconclusive, suggesting that it is dependent on local meteorological conditions, altitude and also forest type.
- **Inf uencing the hydrological pathways to impact blue-water drought and green-water drought:**
    - *Blue-water drought:* (a) **Increase permanent and temporary supply.** Actions to enhance reserve capacity and regulate flows: Extend recycling and reuse through the basin; develop new permanent supplies; establish temporary supply capacity; encourage aquifer recharge in rural and urban areas to provide additional storage and augment river base flows during dry periods; develop appropriate inter-basin transfers that avoid displacement of drought issues and add to reserve capacity; encourage natural flow regulation and groundwater recharge through the protection of wetlands and native forests; implement landscape-scale modifications such as afforestation to regulate, purify and, in some cases, augment river flows; ensure optimum operation of existing infrastructure to regulate environment flows and pulse releases during drought. (b) **Reduce demand:** Actions that result in real water-use savings in industry, agriculture and society: during non-drought conditions: Promote less water dependent enterprises that keep flow in the river and aquifers; ensure enforcement of water that use regulations to avoid illegal abstractions from rivers and groundwater; establish economic incentives to improve water efficiency in agriculture and industry in a way the expands the water supply surplus and avoids greater use of available water that may reduce resilience to variability in available supply; during drought conditions: agree and, when necessary, implement prioritized restrictions. (c) **Enhance f exibility in supply:** Actions that enable limited water resources to be directed to best effect during a drought. Develop an active process

of water trading (market) and promote appropriate water trades and transfers; prepare to revise restrictions and dam operations in consultation with a wide range of stakeholders as priorities change during a drought.

- *Green-water drought:* (a) **Encourage soil moisture retention:** Use agricultural techniques that reduce the evaporation of soil moisture and reduce soil erosion.

REDUCE THE CONSE UENCES SHOULD A DROUGHT OCCUR

SDRM does not only focus on reducing the chance of drought hazard occurring but also on limiting the consequences when drought does occur. The actions that may be taken, include:

- **Reducing the exposure of receptors:** Use of progressive planning policies that seek to avoid inappropriate development in drought- prone areas. For example, drought-sensitive housing stock should be developed that avoids the need for watering gardens and incorporates water-efficient appliances such as taps and toilets; avoiding unnecessary municipal water demands associated with maintaining of green space of low utility (e.g. roundabouts); avoid placing highly consumptive industries in drought-prone areas.
- **Reducing the vulnerability of exposed receptors:**
  - *During non-drought conditions:* Provide education programmes to raise awareness and encourage voluntary water saving; provide affordable insurance programmes; empower people and industry to act early by providing better forecasting and warning; encourage the use of drought-resilient crops and crops with low water requirements; adopt agricultural water management approaches that maximize the supply surplus during non-drought conditions; adopt water sensitive urban planning and use of drought tolerant species; encourage healthy freshwater ecosystems that deliver key services by implementing environmental flows and reducing pollution and over-exploitation of water resources; integrate drought management with food and water resource security through food stockpiling and reciprocal agreements.
  - *During and post-drought conditions:* Provide financial aid to those impacted; lift temporary restrictions and take action to aid the recovery of impacted habitats and species.
- **Inf uencing demographic change:** Consider influencing population growth and migration to avoid unsustainable growth in drought-prone regions.

CHAPTER 8
SAFEGUARDING AND ENHANCING FRESHWATER ECOSYSTEMS

8.1. Introduction

This chapter explores the relationship between SDRM and protecting and using ecosystems, particularly freshwater ecosystems. It explains how human systems and freshwater ecosystems need to be considered together within SDRM, and how healthy ecosystems can contribute to reducing drought risk. This chapter also outlines guiding principles and measures for integrating ecosystem-based approaches into a broader portfolio of SDRM measures.

8.2. Understanding freshwater ecosystems: structure and processes

An ecosystem is a dynamic and complex living community, which includes microorganisms, plants, animals, and their non-living environment interacting as a functional unit in a given area (MEA, 2005). Ecosystems can be described at a range of scales from micro – such as a pond or garden – through to the entire globe. Some, but not all, definitions argue that humans are an intrinsic part of most ecosystems and that an ecosystem is an integrated socio-ecological system. There are profound connections between ecosystems and human society. However, for the purposes of this book, a distinction is made between the socio-economic aspects of human systems and the natural structure, processes and biodiversity within ecosystems.

A variety of different ecosystems exist within a river basin, including forests, grasslands, high mountains and so on. Some ecosystems might be relatively unaffected by humans; others might be heavily modified by agriculture, urbanization or other activities. The variety and health of basin-scale ecosystems will impact on the way water flows through the basin, the quality of water in rivers and on other aspects of specific freshwater ecosystem functions and services.

Freshwater ecosystems include the river channel and the water within it, the floodplains, lakes, aquifers and upstream catchments that influence the river, as well as the plants and animals that live in and around those systems. Freshwater ecosystems depend on physical features such as water quantity, water quality and timing of flow. Many of the threats to freshwater ecosystems involve activities that alter these fundamental physical characteristics of the basin, including physical barriers to flow, water extraction, filling or draining of shallow wetland habitats, and pollution of waterways with toxic substances and excessive nutrients. Freshwater ecosystems are complex, and the way humans manage them has implications for drought risk management.

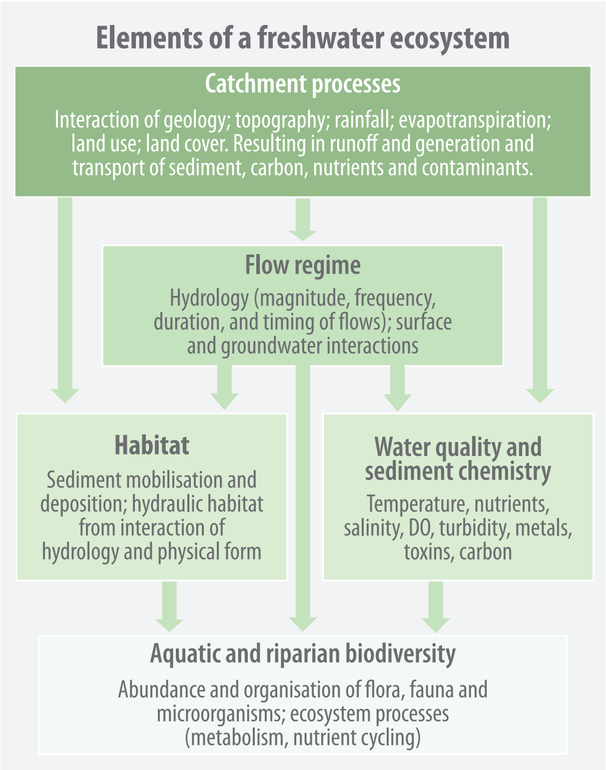
ELEMENTS OF A FRESHWATER ECOSYSTEM

At the basin scale, rivers are usually the central features of freshwater ecosystems. While basin characteristics vary, all river basins support common physical, chemical, and biological processes (the ecosystem functions of the basin) and are made up of a common set of physical and biological components (the ecosystem structure of the basin). This book considers these in terms of five distinct, but related, elements (Speed *et al.*, 2016).

1. **Catchment processes** drive the major inputs into a river. The interaction between the hydrological cycle and the topography, geology and vegetation within a basin, along with land-use practices, all influence catchment-scale processes. These processes include infiltration and runoff of water, and the generation of sediment, carbon, nutrients and other chemicals and their movement via the river system. Catchment processes determine the composition and timing of the water, energy, and materials that enter the river channel.
2. **Flow regime** is primarily a product of the catchment runoff that collects within the river corridor, as well as surface, groundwater and hyporheic interactions. The flow regime describes the magnitude, timing, frequency and duration of flows in the river basin.
3. **Habitats** are created across the river corridor by the flow regime driving the geomorphic processes that shape the physical structure of the river system: rif es, ponds, floodplains, hyporheic zones, riparian zones, and the river channel itself. The interaction of the physical structure of a river ecosystem and the flow regime also create the pattern of hydraulic habitat and influence connectivity – that is, the extent to which water, biota, sediment, and other materials can move up and down the river channel (longitudinal connectivity) and move between the river channel and the flood plain (lateral connectivity).
4. **Water quality** in-stream is primarily a consequence of the inputs from the upstream catchment and the riparian zone, the nature of flow regime, the physical structure (including the soil properties) of the river itself, and its interactions with the hyporheic zone. Together, these elements determine the physical and chemical characteristics of stream flow, including sediment chemistry, water temperature, and levels of nutrients and toxins.
5. **Aquatic and riparian biodiversity** within a river system depend on, and develop in response to, the flow regime, the water quality, and the available habitat, as well as the species pool available for colonization. These factors shape the abundance, diversity, and composition of plants, animals, and microorganisms within a river ecosystem.

These five elements of freshwater ecosystems and the relationships between them are shown in Figure 8.1, which highlights a hierarchy of drivers and responses. Some responses are also drivers of other processes. These elements enable freshwater ecosystems to perform their critical functions and provide a range of goods and services that people need. While Figure 8.1 shows the primary direction of influence between different processes and components, influences can also occur in the other direction. For example, aquatic and riparian biodiversity are significantly influenced by catchment processes, flow regime, available habitat, and water quality, but aquatic and riparian biodiversity can also influence those same elements. Similarly, riparian vegetation can trap sediment and organic matter and prevent it entering the river channel, affecting both habitat and water quality, or it can influence water temperature as a result of shading.

Figure 8.1. Key elements of the freshwater ecosystem



Source: Adapted from Speed et al., 2016

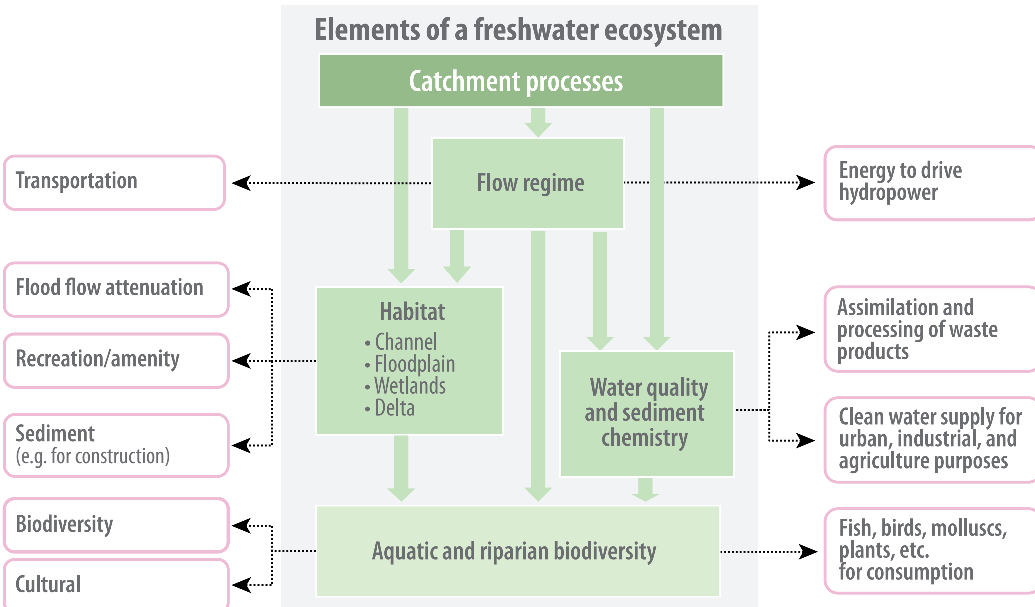
SERVICES PROVIDED BY FRESHWATER ECOSYSTEMS

Freshwater ecosystems provide a range of services (Figure 8.2). To deliver these services, freshwater ecosystems depend on water quantity, water quality and timing of flow. Changes to any one of those elements – the catchment, the hydrology, or the physical form – may impact the drought (and flood) response of the river basin. Threats to freshwater ecosystems alter these physical characteristics, for example barriers to flow, water extraction, filling or draining shallow wetland habitats, and pollution of waterways. Providing drinking water depends on the flow regime within the basin – volume, timing and reliability. The capacity of the basin to transport and store water, and to attenuate the impacts of drought (and flood) on human society, depends on the nature of the catchment (which will influence runoff), the flow regime (which will dictate the timing, frequency, and size of river flows), and its physical form (geology, topography etc.).

PATHWAYS BETWEEN FRESHWATER ECOSYSTEMS AND HUMAN SYSTEMS

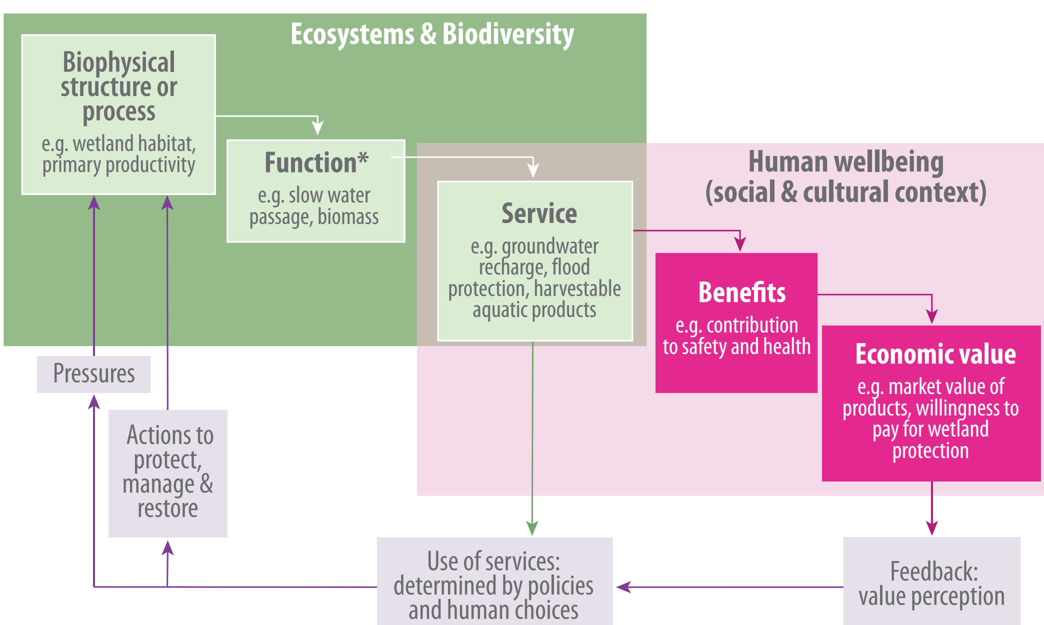
Figure 8.3 shows the pathway between freshwater ecosystem services and human well-being developed through a global initiative on The Economics of Ecosystems and Biodiversity (TEEB, 2010b). It illustrates how the human system has an impact on freshwater ecosystems through using ecosystem services and through decisions made about the management of ecosystems.

Figure 8.2. Examples of ecosystem services provided by freshwater systems



Note: *Although different services are shown linked to components of the freshwater ecosystem, a particular service may be dependent on multiple aspects of the ecosystem. For example, river transportation is dependent on the channel form (i.e. habitat) and the flow regime.*
Source: Speed et al., 2016

Figure 8.3. The pathway from freshwater ecosystems and biodiversity to human well-being



**Function is the subset of biophysical structure or process providing the service.*
Source: based on TEEB, 2010b

VALUING ECOSYSTEM SERVICES

The Millennium Ecosystem Assessment (MEA) estimated that, globally, approximately 60% of all ecosystem services, and up to 70% of regulating services, are being degraded or used unsustainably (MEA, 2005). Failure to account for the real contribution of ecosystem services to human well-being is thought to be a significant factor in the continuing loss and degradation of these service (TEEB, 2010). Researchers and natural resource managers are trying to value ecosystem services to help make the case for safeguarding or restoring ecosystems.

Valuing the services an ecosystem provides is not the same as putting a price on the ecosystem itself. Valuation can provide monetary or non-monetary quantification of the services an ecosystem provides to allow the benefits of safeguarding or restoring ecosystems to be compared with other natural resource management options. For example, monetary valuation of retaining water in the Murray–Darling River in Australia helped demonstrate the economic benefits of maintaining a healthy river ecosystem compared to abstracting water from the river for irrigation. It was estimated that recovering 2,800 GL of water for the environment would reduce the gross value of irrigated agricultural production by A$542 million annually; but that the additional river flow would provide enhanced ecosystem services (worth between A$3 billion and A$8 billion linked to floodplain vegetation, water-bird breeding and native fish stocks (CSIRO, 2012).

Over the many years, economists have developed a number of methods for quantifying costs and benefits of ecosystem management and restoration, including replacement costs calculation, contingent valuation and hedonic pricing as summarized in Table 6.3. These techniques have advantages and disadvantages and obtaining definitive data is often challenging. Nevertheless, approaches are becoming increasingly sophisticated as experience is gained across the water resource management, ecosystem conservation and economics communities (e.g. Brouwer, 2015). Today, various tools are emerging that support the estimation of the economic values of specific ecosystem services, such as the InVEST tool.[31]

In the context of SDRM, valuing freshwater ecosystem services can help rational decision making around how rivers, lakes, wetlands or aquifers are protected during drought, and how they should be managed to help mitigate drought risk. Valuation has the potential to help decision makers address the full range of trade-offs between SDRM approaches.

31. http://www.naturalcapitalproject.org/invest/ Accessed 9 November 2015.

8.3. Drought impacts on freshwater ecosystems

Ecosystems have evolved over millennia to cope with naturally occurring droughts. However, the onset of climate change means there is likely to be significant changes in the frequency, duration and severity of drought. Some ecosystems might be unable to adapt to such changes. Many ecosystems are under increasing pressure from other factors such as pollution, over-abstraction or invasive species, which also reduces their resilience to drought and leads to combined impacts that can irreversibly damage ecosystem services or biodiversity.

Drought can impact the health of ecosystems either directly or indirectly. Direct impacts arise from the nature of green-water droughts or blue-water droughts and are mostly caused by a lack of water or increased temperatures. Indirect impacts largely stem from the way water resource managers attempt to manage the risks and impacts of drought on human society.

DIRECT IMPACTS OF DROUGHT ON FRESHWATER ECOSYSTEM HEALTH

Drought manifests itself in freshwater ecosystems predominantly through changes in water temperature, volume and flow, which can then have knock-on effects to water quality, freshwater ecosystem function and ultimately on freshwater ecosystem services and biodiversity. Most studies of drought impacts report on relatively short temporal and spatial scales (Humphries and Baldwin, 2003). A limited number of studies have been undertaken on the effects of supra-seasonal drought on the ecology of freshwater ecosystems (Lake, 2003; Bond, Lake, and Arthington, 2008). However, prolonged droughts are likely to cause progressive loss of freshwater habitat, declines in water quality and continuing depletion of food resources. These impacts can trigger biotic responses such as changes in population densities, species richness, life-history schedules, species composition, patterns of abundance, type and strength of biotic interactions, food resources, and trophic structures (Lake, 2003). Table 8.1 summarizes how drought hazards can manifest in hydrological changes in flow and connectivity and shows the resulting impacts on freshwater ecosystems, water quality and ultimately freshwater biota.

Table 8.1. Summary of the impacts of drought on freshwater ecosystems

	Hydrological disturbance	Freshwater ecosystem change	Water-quality response	Biotic response
↓ Increasing severity of drought	Lower river flows and water levels in standing water; reduction in the hydraulic heterogeneity of flow.	Reduced habitat available for most freshwater biota, exposing marginal areas.	Reduction to the diluting capacity of the ecosystem: wastes and toxic materials are not diluted and exported, leading to intensification of pollution and increased algal blooms.	Decline in fauna strongly dependent on flow, such as rif e-dwelling insects and other invertebrates such as mussels.
	Loss of lateral connectivity, breaking contact between stream and riparian zone. Extended period during which floodplains are not inundated.	Loss of floodplain and riparian habitat.	Decrease in organic matter inputs from riparian zone. Less riparian shading leading to higher water temperatures.	Lack of floodplain inundation depletes invertebrate egg bank on floodplain, so micro-invertebrate 'boom' on next inundation is greatly diminished.
	Threshold for cessation of flow reached and longitudinal connectivity lost. Streams become a series of fragmented pools. Shallow sections, such as rif es and runs, are the first to disappear while deep shaded areas persist for longer.	Normal transport of nutrients, biota, detritus and organic matter downstream is inhibited, which creates pools with distinctive lentic environments. Detritus composition is inhibited because particulate organic matter is retained in dry channels. Decreases in inputs of dissolved organic carbon and nutrients means production declines. This may lead to autotrophic production being favored over heterotrophic production. But isolated pools may become temporary hotspots of production – particularly in pools with nutrient-rich hyporheic upwellings or unshaded pools with high accumulations of particulate organic matter.	As water flow and volumes decrease, water temperatures may start to rise. This leads to reductions in dissolved oxygen. Accumulations of organic matter and sediments occur in pools. Nutrients and conductivity may also increase. This leads to increased levels of dissolved organic matter and low dissolved oxygen levels. In unshaded pools, the build-up of nutrients, high temperatures and solar radiation can precipitate blooms of algae, leading to reductions in dissolved oxygen concentration.	Biota becomes trapped and concentrated in pools. Some pools may persist as refugia, while others may dry up, killing their inhabitants. Competition and predatation by fish and lentic newcomers may intensify in pools. Freshwater biota may be depleted by terrestrial predators. Levels of parasitism and disease, notably of fish, may rise in pools. Changing population parameters and interactions between and among species can have reproductive consequences well after drought. High temperatures and depleted oxygen levels severely threaten biota.

Source: Based primarily on information from Bond, Lake, and Arthington, 2008; Lake, 2003; Humphries and Baldwin, 2003; Boulton, 2003.

INDIRECT IMPACTS OF DROUGHT ON FRESHWATER ECOSYSTEM HEALTH

During periods of drought, conflict between the needs of ecosystems and people can be at their most acute. Mounting a compelling case for water to be set aside for the natural environment can be difficult, particularly when the impact on a business or community is readily apparent. In some instances, the indirect impacts on ecosystems that arise from prioritizing water for immediate human use might be considered an acceptable trade-off. However, in many cases the degradation of ecosystem services caused by indirect impacts may not be considered at during non-drought conditions. In the absence of a strategic planning process, some decisions can have perverse outcomes and exacerbate drought impacts on freshwater ecosystems and prolong recovery periods. Such measures include:

- Halting dam releases or increasing water storage for domestic and economic use, which can lead to rapid reduction in downstream river flows.
- Reducing water abstraction for ef uent treatment or dilution, which can lead to declines in surface water quality (Andersen *et al.*, 2004 and Aravinthan, 2005).
- Transfers from other basins as an emergency source of supply, which can lead to increased water scarcity in the source basin and potentially introducing non-native species and pathogens to the drought basin.

Similarly, measures implemented during non-drought conditions that are based on a narrow consideration of potential impacts can also exacerbate the vulnerability of the system as a whole. For example, a proliferation of small dams in unregulated catchments in Australia, partly intended to increase farm-scale resilience, has meant that streams have been deprived of run-off during droughts. Hydrological modelling suggests that during drought years, farm dams can capture most of the annual flow in low-rainfall catchments, locking river sections downstream of the dams in more permanent and more severe drought (Bond *et al.*, 2008).

CASCADING AND ESCALATING IMPACTS THROUGH COUPLED SYSTEMS

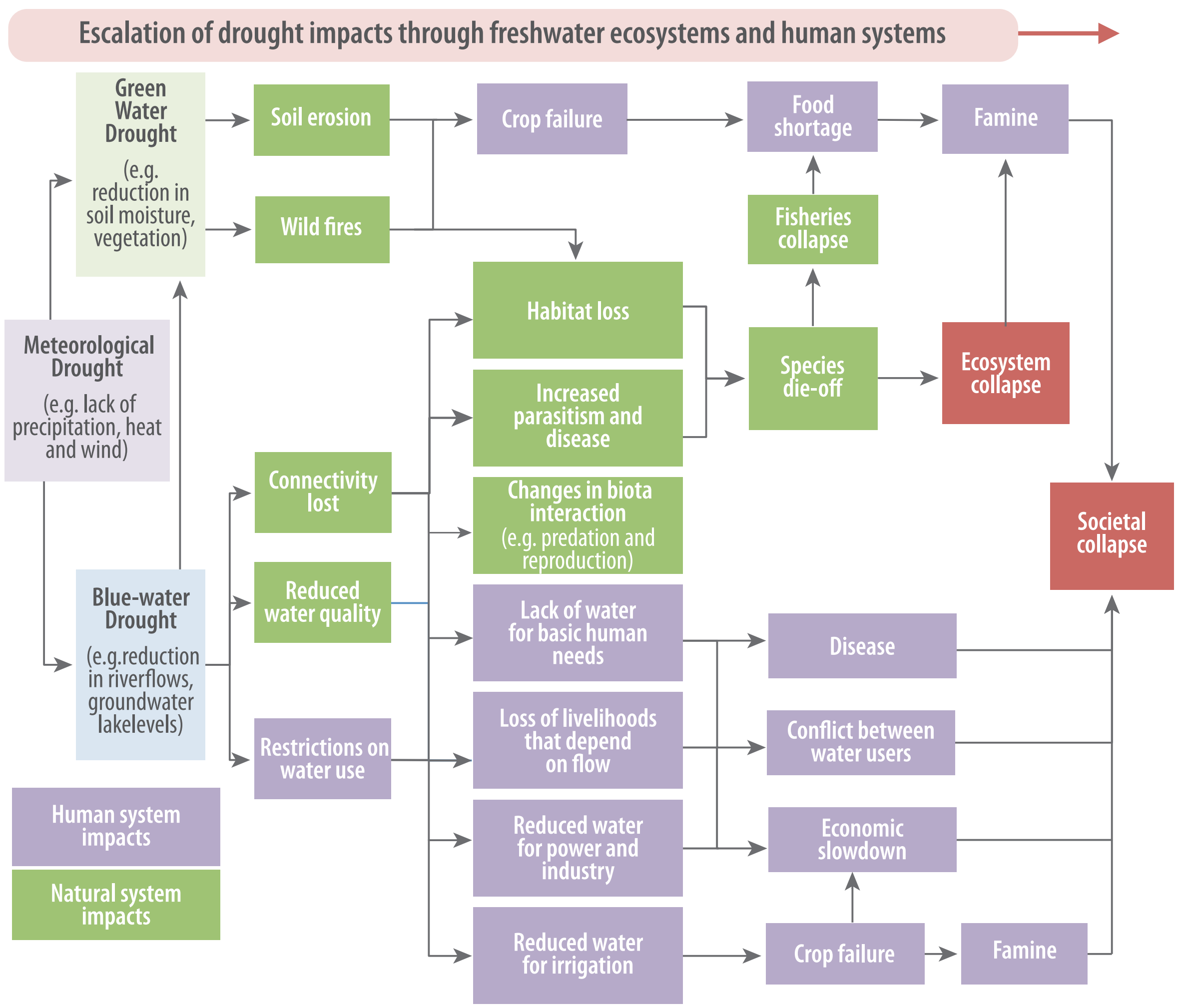
The connected and dynamic nature of freshwater ecosystems means that drought impacts on one part of the ecosystem can cascade downstream and escalate the impact of the drought (Figure 8.4). For example, a meteorological drought in an upper basin area may result in reduced infiltration to groundwater and reduced stream flow. The resulting blue-water drought downstream might then restrict hydrological and habitat connectivity and reduce the ability of the river to dilute pollutants. Further downstream, there may be knock-on impacts to drinking water supplies and fisheries, affecting the local economy.

The escalation of impacts will be different in each river basin, but will generally fall in the following categories:

- **Loss of livelihoods:** Degradation of freshwater ecosystems can lead to loss of ecosystem products and services on which livelihoods depend, e.g. fisheries, water for commercial irrigation or river flows for tourist activities such as rafting and boating.
- **Economic slow-down:** Power generation that depends on water for cooling or river flow (for hydropower) might decline; agriculture that depends on river flow or soil moisture can suffer; industrial output that depends on water for processing or cooling might diminish.
- Acute food and water shortages for basic human needs: As rivers and lakes dry up, household water supplies might diminish and subsistence crops can fail.

During prolonged drought, the combination of effects can drive ecosystem collapse or major societal change, particularly if policies are not in place to help communities replace the lost ecosystem services. This change can include increased conflict between users, political unrest, and in extreme cases famine that can potentially lead to migration. For instance, some researchers have concluded that the crisis in Syria is partly a result of a lack of water supply (i.e. a provisioning service) resulting from drought, which intensified competition over diminishing fertile land and water and played a direct role in the deterioration of Syria's economic conditions and political unrest (Gleick, 2014).

Figure 8.4. Drought impacts can escalate as drought persists



INHERENT RESISTANCE AND RECOVERABILITY TRAITS OF FRESHWATER ECOSYSTEMS

Evidence suggests that biota in some freshwater ecosystems appear well adapted to the predictable hazard of reduced rainfall and ensuing loss of soil moisture (Boulton, 2003; Magalhaes *et al.*, 2007). Indeed, low-flow periods are believed to be a major force in maintaining biodiversity (Everard, 1996). They enable the successful recruitment of some species (Humphries *et al.*, 1999) such as certain floodplain plants; purge invasive species that are less well adapted to the local setting (Lake, 2003; MEA, 2005); and can also benefit predators by concentrating prey into limited areas. Freshwater biota that are subject to regular periods of dryness have evolved traits that allow them to survive, recover and recolonize effectively under drought conditions (Bond *et al.*, 2008). These traits include:

- Resistance traits enable species to persist during a dry period either by possessing desiccation-resistant life history stages or by using remnant habitats that offer less harsh conditions in an otherwise dry environment.
- Recovery traits such as mechanisms for widespread and rapid dispersal amongst suitable habitat patches enable species to recolonize and recruit more effectively after the dry period breaks (Bond *et al.*, 2008; Lake, 2003). Species that possess these traits include fish, aquatic birds and mobile invertebrates.

These adaptations do not, however, mean that when a drought breaks freshwater ecosystems and biodiversity will simply bounce back to their pre-drought condition (Bond *et al.*, 2008). This may be true for seasonal dry periods (Humphries and Baldwin, 2003), but the longer and more severe the drought, the longer recovery will take, with possible local species extinctions (Lake, 2008).

Moreover, prolonged drought might lead to tipping points or crossing thresholds that result in abrupt, non-linear shifts in ecosystem functions and structures. For example, changes to ecosystem functions might be gradual while stream flow declines during a drought; but if the stream dries completely the loss of hydrological connectivity causes abrupt loss of a specific habitat, alteration of conditions in pools downstream, and fragmentation of the river ecosystem (Humphries and Baldwin, 2003). When such thresholds are crossed, impacts on freshwater biota and ecosystem services may be disproportionately severe (Boulton, 2003) and reversing the changes can be difficult (Wentworth, 2011).

In addition, human-induced environmental change is believed to compromise the resilience of plants and animals to extreme events such as drought (Staudinger *et al.*, 2013). For instance, evidence points to an increasing frequency, intensity and duration of abrupt ecological change that is due, at least in part, to anthropogenic climate change (Falkenmark and Rockström, 2008). Loss of biodiversity as a result of pollution, over-abstraction or loss of habitat connectivity also appears to be critical in determining ecosystem resilience (Wentworth, 2011).

8.4. Reducing drought risk through an ecosystem approach

Increasingly, it is recognized that healthy ecosystems, including freshwater ecosystems, can play a role in managing drought (and flood) hazards. This includes using natural infrastructure to:

- **Reduce the chance of drought:** For example, protecting large areas of native forests in upper basin areas helps to maintain rainfall and reduce the chance of meteorological drought. It also protect wetlands and forests to regulate river flows and maintain or enhance water quality to reduce the chance of a blue-water drought. Innovative eco-agricultural approaches can also help to retain soil moisture and reduce the chance of a green-water drought.
- **Reduce the consequences of drought on society:** For example, maintaining and restoring riparian vegetation and sub-surface wetlands acts as a barrier against dry soil erosion, sandstorms and wild fire propagation.
- **Sustain basic human needs such as food and water:** For example, supporting functioning freshwater ecosystems creates a food 'safety net' by providing alternative food sources such as fish and drought-resistant plants when crops fail (Campbell *et al.*, 2009; PEDRR, 2010). Natural water sources can also supply water for domestic use where conventional supply systems have failed.

Any degradation of freshwater ecosystems that reduces their ability to provide these services will have knock-on effects on human systems. When developing SDRM measures, considering trade-offs and including analysis of measures is important to:

- safeguard freshwater ecosystems from drought because they hold important habitats and biodiversity and they provide ecosystem services that are critical for human development objectives
- work with natural processes to reduce drought risk for human systems because they are important for socio-ecological resilience.

SDRM advocates building on ecosystem approaches, developing across all sectors of hazard management (Box 43). Table 8.2 summarizes the measures for ecosystem-based SDRM. The table is organized according to the relevant ecosystem elements (**catchment processes**, **f ow regime**, **water quality**, **habitat** and **biodiversity)** and are discussed in turn.

Box 43: Ecosystem approach to disaster risk reduction

The 'ecosystem approach' has been advocated by the UN Convention for Biodiversity (CBD). The CBD describes the ecosystem approach as 'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way'. The approach recognizes the importance of ecosystems to society and puts people and their natural resource-use practices at the center of decision making (Sudmeier-Rieux *et al.*, 2006).

The ecosystem approach underpins the allied concepts of ecosystems-based disaster risk reduction (eco-DRR) and ecosystems-based adaptation (EBA). These concepts focus on using biodiversity and ecosystem services to reduce risk to natural disasters and adapt to a changing climate.

The emphasis of eco-DRR (Renaud, Sudmeier-Rieux, and Estrella, 2013) is on planning and building capacity for disaster response and recovery. Many disasters are caused by natural hazards that happen suddenly and are difficult to prevent, such as tsunamis, earthquakes, landslides and, to some extent, floods. In contrast, meteorological drought emerges slowly and its impacts on freshwater ecosystems and human systems can, in theory, be mitigated even as it unfolds. According to eco-DRR principles, ecosystem-based DRM should focus on approaches to both reduce the chance of a drought occurring and minimize vulnerability.

EBA concepts (CBD, 2009) can also provide some useful insights for ecosystems and SDRM. Climate adaptation includes preparing for, coping with, or adjusting to climatic changes and their associated impacts (Stein *et al.*, 2013). Climate adaptation is therefore a form of risk management and a means of reducing vulnerability of both natural and human systems. Climate adaptation science is continually developing and a growing number of adaptation planning tools are emerging to help practitioners apply adaptation principles to natural resource and conservation decision making (Staudinger *et al.*, 2013). For example, the US National Wildlife Federation has published a guide on *Climate-Smart Conservation: Putting Adaptation Principles into Practice* (Stein *et al.*, 2014) and WWF has published the 'Flowing Forward' guidelines on climate change, water resources and freshwater conservation (Le Quesne *et al.*, 2010b).

The ecosystem approach offers potential cost-effectiveness benefits, avoidance of costly and controversial built infrastructure, and can provide multiple benefits. However, there are also uncertainties relating to the non-linear response of ecosystems to environmental change, a lack of robust evidence of effectiveness of eco-DRR and EBA at large scales, and the longer temporal scale that may be required to yield some DRR benefits.

Table 8.2. Example ecosystem-based measures that form part of SDRM

Freshwater ecosystem element		Non-drought conditions	During drought	After drought
Freshwater ecosystem element	Catchment processes	Analyze and map critical areas for biodiversity and/or provision of ecosystem services, especially run-off/recharge. Protect critical areas, and prioritize measures for them in an SDRM plan. Improve landscape permeability (e.g. agro-forestry, rotational grazing, restore small water bodies).	Implement SDRM measures for critical areas set out in the plan. Maintain protection to key areas for water resource generation. Maintain landscape permeability measures.	Review and adapt protection of critical areas and measures in an SDRM plan.
	Flow regime	Map priority areas for environmental flows (e.g. hydropower dams, major inland fisheries, reaches prone to sedimentation or eutrophication, tributaries/wetlands of high conservation value, water holes, and species refugia). Prioritize environmental flows for these areas in water allocation plans.	Maintain environmental flows for priority areas (e.g. through infrastructure operation and/or modified water abstraction).	Maintain temporary abstraction restrictions and storage operation rules until river flows return to optimal levels. Pro-actively restore ecosystems that are close to or have passed tipping points.
	Water quality	Reduce/eliminate water pollution (e.g. through progressively tighter effluent discharge permits, improved farming practice, enhanced spatial planning). Maintain environmental flows.	Temporary restrictions on some types of discharge where river flow is low. Allow some types of effluent discharge, which might support maintenance of environmental flow without disproportionate damage to ecosystem. Maintain environmental flows to priority areas which are sensitive to pollution, e.g. for drinking water abstraction, species refugia.	Revert to normal effluent discharge regime once river flows return to optimal levels. Maintain temporary abstraction restrictions and storage operation rules until river flows return to optimal levels.
	Habitat	Identify and where necessary protect networks of priority refugia through an SDRM plan (e.g. headwaters, springs, pools and backwaters).	Safeguard environmental flows to and between refugia and limit pollution. Maintain riparian vegetation and prevent removal of fallen trees in priority refugia/protected areas to keep water temperature within a suitable range and create micro-habitats. Prevent conversion of dry streambeds or dehydrated wetlands into farm land. Restrict fishing and livestock access to water in priority refugia/protected areas.	Maintain temporary abstraction restrictions and storage operation rules until river flows return to optimal levels. Pro-actively restore ecosystems that are close to or have passed tipping points. Revert to normal effluent discharge regime when river flows return to optimal levels.
	Biodiversity	Implement all measures outlined above. Research and plan for potential last resort, ex-situ conservation measures (e.g. translocation, captive breeding, seed banks).	Implement careful ex-situ conservation, e.g. through translocation, captive breeding, seed banks.	All measures outlined above. Reintroduce captive bred or translocated species providing habitat has returned to normal conditions.

MANAGING CATCHMENT PROCESSES

The most important measures for safeguarding catchment processes that contribute to SDRM involve understanding the hydro-ecological regime of the catchment. This understanding includes mapping key areas for runoff and recharge that can maximize water resource availability during drought. It also requires research and understanding of the implications for water resource availability of different land-uses – including forests and wetlands – across the catchment. Improved planning and management of the wider catchment or basin is fundamental for adaptation strategies to ensure connectivity between specific habitats (Campbell *et al.*, 2009; Staudinger *et al.*, 2013; West *et al.*, 2009). Knowing where rivers receive water from, or lose water to, informs proposals to protect or restore key catchment areas. This type of analysis can be undertaken at the national scale as well as within river basins, as has happened in Mexico through the Water Reserves initiative (see section 9.5). Equally, understanding how land-use change affects the regional climate is important, especially at the national scale and in large river basins.

The aim should be to produce an integrated catchment-wide spatial configuration, including protected areas, which maximizes natural rainfall generation and enhances aquifer recharge infiltration.

Maximizing natural rainfall generation by protecting or planting to maintain or increase rainfall can have a meaningful impact on reducing meteorological drought hazard. Evidence suggests that deforesting large areas of native forest, particularly in tropical regions can modify rainfall patterns and increase the severity of drought (see, for example, Sheil and Murdiyarso (2009). Evidence about large-scale afforestation increasing rainfall and therefore reducing drought risk seems inconclusive (for example Abiodun *et al.*, 2013). Local meteorological conditions, altitude and forest type are also influential factors. Reforestation of native vegetation is being explored in some regions, for example in Brazil, to combat desertification and mitigate the effects of drought (Ministry of the Environment, Brazil, 2004).

As the environmental and social impacts of large dams and reservoirs have become increasingly well understood, interest in the potential capacity of subsurface storage and enhancing aquifer recharge infiltration has grown. Despite this increasing desire to utilize natural infrastructure responses, there is limited practical experience of large-scale implementation.

The hypothetical benefits of enhanced aquifer recharge over large dams include reduced losses to evaporation, reduced greenhouse gas emissions, comparative ease of maintaining high water quality (although this varies case by case), and alleviation of pressures on arable and forested land. Impacts and advantages of managed aquifer recharge vary according to the technique used. Techniques include spreading methods, including infiltration ponds and irrigation; induced bank infiltration; well and borehole recharge; in-channel modifications, including construction of check dams; and runoff harvesting. In many regions where groundwater is subject to over-extraction and water tables are falling, enhancing aquifer recharge could also decrease the incidence of saltwater intrusion into coastal aquifers and slow rates of land subsidence. Working with natural infrastructure is increasingly seen as a means of enhancing recharge.

There is evidence that wetlands can help regulate flows in dryland regions (Falkenmark and Rockström, 2008) by augmenting low flows in rivers and recharging groundwater. However, understanding the local hydrology is critical because these systems are highly complex and localized, and in some circumstance wetlands can have the opposite effect (e.g. Bullock and Acreman, 2003).

Enhancing natural recharge can bolster groundwater supplies for use during dry periods. Techniques include in-stream recharge, establishing artificial wetlands in areas of favourable recharge to deep aquifers, and constructing recharge dams. For example, during the 2004–2007 drought in eastern Spain, groundwater recharge was used in the Juncar River basin to augment water supplies during the driest periods (Sayers *et al.*, 2014c).

It is also important to avoid excessive consumptive water use by non-native upstream vegetation.

To be successful, aquifer recharge schemes require careful oversight and planning to ensure the degree of recharge is sufficient to be useful in drought. While potentially promising for the future, with evidence emerging of success at a local scale (Box 44), more analysis of large-scale pilot programmes is needed before aquifer recharge is taken up widely.

Box 44: Managed aquifer recharge in Rajasthan, India

The crisis affecting groundwater storage across many of the world's irrigated agricultural zones shows that control of groundwater withdrawals presents great difficulties for water managers.

Managed aquifer recharge (MAR) schemes, especially small-scale community schemes, have been implemented across many of the world's arid and semi-arid regions. Analysis of these schemes is often limited due to a lack of data. One important exception is in India, where construction of community MAR schemes is part of national and state water policy. An early and well-documented Indian case study was in the Arvari River catchment.[32] In 1985, the Arvari catchment was highly degraded, resulting in mass migration. An NGO, Tarun Bharat Sangh, responded to water scarcity in the catchment by constructing crescent-shaped earthen dams designed to slow runoff during intense storms and increase recharge of the local aquifer. The scheme has now expanded to 70 villages in the region and thousands of earthen dams have been built. Over time, the water table has risen and perennial flow in the Arvari River has been observed since 1995.

The Arvari catchment case study is also interesting for its democratic approach to water management, where decisions about the operation of the dam system and other water-related matters are made by the Arvari River Parliament, a stakeholder platform in which village representatives agree on water management approaches. Given that this approach to MAR – relying on check dams to slow runoff – requires collaboration of local landholders on dam siting and controlled withdrawals from the aquifer during dry periods, there is a clear need for management institutions to have local buy-in and and for measures to be enforced in a transparent manner. Creating and maintaining such institutions presents one of the key challenges associated with using MAR as a tool for building reserve capacity.

As well as ensuring protection of critical parts of the catchment, studies have also suggested measures that increase the permeability of the landscape can help species resilience

32. Data from http://unesdoc.unesco.org/images/0014/001438/143819e.pdf Accessed May 2016.

(Franklin and Lindenmayer, 2009; Campbell *et al.*, 2009). This includes practices that 'soften' land use such as lower-intensity farming, agro-forestry, rotational grazing and restoration of small water bodies (Staudinger *et al.*, 2013; Campbell *et al.*, 2009).

MANAGING THE FLOW REGIME

Maintaining connectivity between important refugia by ensuring sufficient water flows is critical for resilience of biodiversity and continued ecosystem services. Measures that focus on understanding, prioritizing, safeguarding and restoring flows should be a key feature of any ecosystem-based SDRM approach.

Before drought occurs, and in line with mapping catchment processes, priority reaches for maintenance of flows should be defined. These priority reaches can include hydropower dams, major inland fisheries, river reaches that are prone to sedimentation or eutrophication, tributaries or wetlands of high conservation value, water holes and refugia for IUCN Red List species. Environmental flows for these areas should be prioritized within water allocation plans, along with options for delivering flows during different stages of drought. As the drought unfolds, allocation plans and rules will need to be adapted to take account of emerging critical water requirements. Monitoring ecosystem response to the management of flows during drought is therefore important (see Chapter 7 for further discussion on water allocations and entitlements).

Delivering environmental flows to critical parts of the ecosystem before, during and after drought requires either appropriate abstraction patterns and rules or appropriate operation of infrastructure:

1. **Appropriate abstraction patterns and rules.** In river systems where there is no option for flow releases, abstraction patterns and rules can be modified so that certain reaches continue to receive preferential environmental flows. This could be achieved by limiting abstraction to certain times of day, limiting the volume of water abstracted, suspending particular abstraction licenses, or trading water licences between users (Bond *et al.*, 2008; Speed *et al.*, 2013).
2. **Appropriate infrastructure operation.** Under normal conditions, barriers to flow such as dams and sluices should be operated to release the required environmental flow to retain ecosystem functions and ensure ecosystem services are maintained. Water allocation planning should ensure that water for environmental flows is held in storage to be released throughout dry periods. However, in severe drought where storage volumes fall to critically low levels, such that the desired environmental flows cannot be delivered, short-term mitigation strategies will be necessary (Bond *et al.*, 2008). Releasing even a small amount of flow continuously is important to retain hydrological connectivity, which is critical for several freshwater ecosystem functions. Where even this amount of release is not possible, one solution is to introduce periods of zero flow interspersed with provision of small pulses of 'contingency flow' held in storage. For instance, during Australia's Millennium Drought, periods of zero flow were introduced to maintain water quality in refuge pools in the Loddon River, Victoria, interspersed with pulses of flow (Loddon River Environmental Flows Scientific Panel, 2006). These pulses should be carefully quantified so they deliver sufficient flow to protect refugia habitats and their biota. These contingency flows also need to be carefully timed to coincide with critical times for freshwater ecosystem survival, for example during spawning periods or times of seedling recruitment. A modest amount of flow at the right time could be sufficient to protect individual species or habitats until the drought breaks. The success requires an understanding of how flow regimes support ecological functions, as well as knowledge of the life history patterns and recruitment strategies of important species.

Environmental flows can be the first sacrifice during drought. Where this happens, it is crucial to reinstate them as soon as possible after the drought breaks. Temporary abstraction restrictions and storage operation rules may need to be kept in place until water reserves and river flows return to usual levels. Groundwater replenishment, through facilitated or artificial recharge via constructed wetlands or sand dams, should also be prioritized in catchments where groundwater contributes to surface flows. Replenishing groundwater will ensure sustained augmentation of river base flows over a significant time period. After drought, freshwater ecosystems have a lowered resilience and, in some cases, will need pro-active restoration, especially where tipping points have been approached or passed. Restoration actions should focus on priority habitats and species, and on restoring critical ecosystem functions that provide services for livelihoods and human well-being and for key economic sectors such as energy generation.

MANAGING WATER UALITY

Given that the resilience of ecosystems to drought is affected by the extent and intensity of other pressures, including pressures on water quality, it is important to try to reduce pollution before, during and after drought.

In many parts of the world, concern about the aesthetic, environmental and health impacts of water pollution have prompted increasingly strict rules on point source pollution, such as the 1972 Clean Water Act in the US and the Urban Waste Water Treatment Directive in the European Union. These regulatory tools will help to improve drought resilience. SDRM plans should encourage further implementation of regulatory tools, as well as measures to tackle more challenging issues of diffuse pollution, especially from farming, such as promoting improvements to land management to reduce run-off of sediment, nutrients and pesticides or by promoting water sensitive urban design and spatial planning to reduce run-off from roads.

When blue-water drought takes hold, low flows can mean that concentrations of pollutants in rivers increase. Tipping points could occur in the form of algal blooms affecting drinking water supplies, water-based recreational activities, and levels of toxicity that could irreparably damage aquatic species populations. Tighter temporary restrictions on ef uent discharge or land use around rivers and other water sources may be required.

On the other hand, there might be instances when ef uent discharge is the only flow in the ecosystem. As long as pollutant concentrations are within safe limits and will not cause irreversible harm to biodiversity or ecosystem services, including to human health, above normal limits of discharge may be temporarily allowed. It is important to revert to normal discharge permissions as soon as possible after drought breaks and river flows return.

MANAGING HABITATS AND REFUGIA

Habitats that provide species refugia play a particularly important role in enhancing ecosystems in areas that are subject to natural or human disturbance (Hermoso, 2013). In a freshwater ecosystem, refugia are areas that experience relatively small changes in temperature and hydrology during drought. At a river basin level, a diverse range of refugia will increase resilience due to likely differences in environmental sensitivity among different species or species assemblages. Protecting a variety of potential habitats within an ecosystem increases options for a greater range of vulnerable species under changing conditions, increasing their resilience (Combes, 2003). Identifying and maintaining a diverse range of critical refugia and ensuring they are properly protected should be a key component of drought risk planning.

Thermal refugia are important for drought resilience because they maintain temperatures within a range suitable for species to survive and reproduce. They are often found in river headwaters or where cooler, oxygen-rich groundwater enters the system. Headwaters and groundwater commonly dictate flow regimes and water quality further downstream, especially in small and medium-sized rivers. So these areas may need to be protected as a priority (Combes, 2003). Habitats that are the last to dry out, such as deep pools and side channels, or backwaters that serve as spawning grounds and provide migration corridors to important floodplain areas, are also likely to be priorities for protection.

Protected areas are important tools for increasing connectivity and also ensuring that priority habitats, such as those containing drought refugia, are properly safeguarded (Hermoso, 2013). Protected areas also have an important role to play in limiting human-induced pressures that increase drought risk to ecosystems. In drylands, for example, protected areas reduce stresses from grazing on land, allowing vegetation to regenerate and soils to stabilize and slow desert formation. In climate change adaptation literature, extending and or strengthening protected area networks is emphasized as one of the fundamental options for ecosystem adaptation to climate change (Campbell *et al.*, 2009). Planning and expanding coherent networks of protected areas can be a key component of building socio-ecological resilience. To maximize freshwater ecosystem resilience, protected areas should be planned to retain longitudinal, lateral and vertical connectivity to facilitate the movement of freshwater species. New planning approaches are being developed to identify and prioritize refugia and designate protected areas. These approaches are increasingly taking account of the importance of the flow regime and connectivity (Nel *et al.*, 2011; Abel *et al.*, 2007; Linke *et al.*, 2011).

Measures that address catchment processes, flow regime and water quality should be designed in part to protect priority refugia. Other actions can also help protect priority refugia:

- maintaining riparian vegetation and preventing removal of fallen trees in priority refugia to keep water temperature within a suitable range and create micro-habitats
- preventing conversion of dry streambeds or dehydrated wetlands into farm land
- restricting fishing and livestock access to water during drought (adapted from Bond *et al.*, 2008).

MANAGING A UATIC AND RIPARIAN BIODIVERSITY

Specific approaches may be important to prevent the loss of certain species populations, particularly once drought hits. Different species respond to droughts in different ways: some are tolerant to the changes; others physically move as their habitat becomes unsuitable, dispersing autonomously. Other species are unable to do either and are likely to suffer heavy losses under drought conditions unless there is intervention. Human interventions to assist species in drought conditions can be based on either in-situ or ex-situ conservation. In-situ conservation measures aim to increase the resilience of existing species in their current locations. Measures relate to catchment processes, flow regime, water quality and habitat (Campbell *et al.*, 2009). Where in-situ conservation measures, it may be necessary to implement targeted population management strategies.

One common ex-situ technique is species translocation, that is moving species from sites that are becoming unsuitable to other sites where conditions are thought to be more favourable for their continued existence (Campbell *et al.*, 2009). Translocation is an option where the rate of habitat fragmentation prevents the ability of species to move naturally (Gleick *et al.*, 2009). Tested translocation techniques are available for many vertebrate species and some invertebrates. However, translocations can be controversial (Campbell *et al.*, 2009) and negative consequence can arise. For instance, the species could become invasive in the habitat to which it is moved (Campbell *et al.*, 2009). There is also potential to compromise natural community-scale genetic structures and to transfer diseases among isolated populations (Bond *et al.*,2008). There is also a risk that translocations may fail, potentially resulting in extinctions; this is a particular concern for species with small, isolated populations. The characteristics of both the species at risk and the potential translocation sites should be carefully considered (Hunter, 2007). The advantages and disadvantages of translocation need to be carefully assessed to minimize species loss and facilitate natural population spread (Campbell *et al.*, 2009). Frameworks for developing policies and making informed decisions for managed translocation have been developed (Staudinger *et al.*, 2013).

Other ex-situ conservation measures, such as seed banking and captive breeding may be necessary for species whose ranges or populations are dramatically reduced by drought. Reviews of captive breeding indicate that it is a resource demanding and technically difficult activity and should be a last resort particularly given the low rates of success reported and the fact that it shifts attention away from in situ preservation of habitats (Campbell *et al.*, 2009). In addition, removal of all individuals into captivity would cause species to go extinct in the wild, with potentially severe consequences for ecosystem functions and services. Ecosystems might become so altered that subsequent re-introduction of that same species back into the wild becomes unfeasible (Campbell *et al.*, 2009).

MANAGING AGRO-ECOSYSTEM PRACTICES

Agro-ecosystem practices that reduce the evaporation of soil moisture can be useful to SRDM. Agro-ecosystem practices include agro-forestry, shadow crops, mulching and vegetation banks. Shelter belts of native vegetation can also act as barriers against dry soil erosion, sandstorms and wild fire (Campbell *et al.*, 2009; Krysanova *et al.*, 2008), reducing the severity of drought consequences. In Burkino Faso and Niger, careful management of protective vegetation has reversed land degradation and conserved soil moisture, reducing the chance and impact of drought and ensuring food supply for communities in marginal drylands. Over three decades these techniques have been replicated by hundreds and thousands of farmers, significantly increasing local resilience to droughts (PEDRR, 2010; Reij *et al.*, 2009). Planning at a landscape scale must be undertaken in conjunction with farm-scale measures: the capacity of agricultural systems to withstand drought is dependent on ecosystem spatial configuration, and functions and services at the catchment scale (Falkenmark and Rockström, 2008).

8.5. Guiding principles in promoting and protecting freshwater ecosystems

SDRM should safeguard healthy ecosystems during non-drought periods as well as maintaining critical functions during drought. Understanding, valuing and optimizing ecosystem services should be a central component of SDRM planning. Many of the Golden Rules of SDRM (Section 5.5) reflect this component of planning: setting multiple goals, implementing a portfolio of measures and assessing whole-system behavior. Underlying these Golden Rules are more specific principles that support ecosystem-based SDRM measures and build on the wider concept of an ecosystem-approach.

CLARIFYING THE PURPOSE OF ECOSYSTEM MANAGEMENT WITHIN STRATEGIC DROUGHT RISK MANAGEMENT

Clarifying why ecosystems are considered in SDRM decisions is important. At a broad level, the purpose will often be to maximize the potential contribution of ecosystems to society. More specifically, this can be expressed as one or more of the following three objectives:

- **Protecting priority freshwater species and habitats** such as endangered species or habitats included on the

IUCN Red Lists[33] or protecting species or habitats of national importance.

- **Safeguarding critical ecosystem functions and services** including those that supply long-term benefits, such as sediment flow to low-lying deltas, and short-term services such as seasonal fisheries and flow for hydropower.
- **Optimising the contribution freshwater ecosystems make in reducing drought risk** as discussed in 10.3.3.

Understanding how any individual ecosystem-based SDRM measure (see section 10.4) is likely to contribute to one or more of these objectives is an important step.

UNDERSTANDING LINKS BETWEEN ECOSYSTEMS WATER RESOURCES AND HUMAN SYSTEMS

Well-managed freshwater ecosystems can positively affect the human system. Although the relationship can be complex and is context-specific (Box 45), healthy ecosystems provide services that may reduce drought risk to humans. For example, restoration of wetlands can increase groundwater recharge, decreasing the chance of a blue-water drought. Well-managed agro-ecosystems often reduce moisture loss reducing the consequences of green-water droughts such as wind-blown soil loss.

Conversely, developing the resilience of human systems through, for instance, increasing efficiency of consumptive water use can also positively affect ecosystem resilience. Diversifying industry away from water-consumptive sectors or conserving soil moisture to reduce agricultural water use can reduce abstraction from rivers and aquifers, helping to maintain environmental flows and freshwater ecosystem health.

Conversely, developing the resilience of human systems through, for instance, increasing efficiency of consumptive water use can have positive feedback effects on ecosystem resilience. Diversifying industry away from heavily water consumptive sectors or conserving soil moisture to reduce abstraction for agricultural water use can help to reduce abstraction from rivers and aquifers, thus helping to maintain environmental flows and freshwater ecosystem health.

SDRM plans should recognize these interdependencies and capitalize on the potential for the positive impacts and mutually beneficial outcomes (Figure 4.6).

33. http://www.iucnredlist.org/ Accessed May 2016

Box 45: Links between forest and wetland cover, water resources and drought

Recent science has begun to illustrate the complex relationship between forest and wetland cover and water resource flows. This relationship is variable and context-specific. Overall, the impact of forest cover on a meteorological drought depends on local climatic conditions, altitude, topography and forest type. Wetlands can also either help reduce drought risk by assisting groundwater recharge or exacerbate risk through increased evapotranspiration, depending on the biophysical situation.

Recent research has demonstrated that large-scale transpiration and condensation processes from tropical forests, or 'biotic pumps', can generate 'aerial rivers', which transport humidity to the interiors of continents (Makarieva and Gorshkov, 2007; Sheil and Murdiyarso, 2009; Spracklen *et al.*, 2012). In Latin America this phenomenon delivers rainfall to south-eastern Brazil (Arraut *et al.*, 2012) and there is speculation that deforestation of the Amazon is at least partly responsible for the 2014–2015 drought in that region (Verchot, 2015). Within river basins, some types of native forests have also been shown to help maintain and regulate water flows (Dudley and Stolton, 2003), support water resource recharge and purification and, therefore, safeguarding drinking water supply for some of the world's major cities (World Bank, 2010). Evidence suggests that deforestation can reduce or alter seasonality of rainfall (Butt *et al.*, 2011), decrease river flow (Bruijnzeel, 2004; Stickler *et al.*, 2013) and amplify the magnitude of droughts (Bagley *et al.*, 2014). Even localized forest loss might push some sub-regions into a permanently drier climate regime, increasing the vulnerability of societies to drought conditions (Sheil and Murdiyarso, 2009; Mahli *et al.*, 2007).

However, in some circumstances deforestation at a local scale might increase river flows, as a result of lower evapo-transpiration from the crops and pasture that replace former forests. This is due to the reduced height of vegetation, less complex canopy, shallower rooting depth and lower leaf area index (Calder, 1998; Giambelluca, 2002). It follows that, in some instances, afforestation might actually increase evapotranspiration and reduce run-off (Jackson *et al.*, 2005) and intensify water shortages (Farley *et al.*, 2005). This seems to be particularly true in tropical countries, where evapotranspiration from trees can exceed infiltration rates (Scott *et al.*, 2005). Perverse impacts on water resources have been observed from tree planting initiatives that aim to sequester carbon as a means of climate change mitigation (Pittock *et al.*, 2013); and afforestation in West Africa has caused both positive and negative impacts on water resources in the Sahel, depending on the location of the afforestation (Abiodun *et al.*, 2013).

Large-scale wetlands are thought to have modifying impacts on extreme weather events (Dadson *et al.*, 2013). For example, the seasonal Niger Inland Delta in Mali forces water vapour into the atmosphere that impacts atmospheric circulation, resulting in convective storms and increasing rainfall relative to surrounding areas. Wetlands can also augment low flows in rivers and recharge groundwater through the slow release and infiltration of water, helping to reduce the probability of a blue-water drought. The Hadejia–Nguru floodplain wetlands in semi-arid north-eastern Nigeria recharges a shallow groundwater aquifer that local farmers rely on for dry season irrigation (Goes, 1999). The outflow from the aquifer also provides a significant contribution to the rural water supply in the surrounding uplands. In Australia, reed swamps in the Kiewa Valley, Victoria are key discharge areas, releasing significant base flows downstream, even though flows into the swamps are negligible (Raisin *et al.*, 1999).

In other circumstances, wetlands can act as a barrier to recharge and can reduce flows downstream (Bullock and Acreman, 2003). For example, analysis of the influence of headwater wetlands or 'dambos' in Zambia on river flows suggests that these wetlands might actually reduce low flows (Bullock, 1992) as a consequence of high evaporation rates.

BUILDING SOCIO-ECOLOGICAL RESILIENCE

Healthy ecosystems are more resilient to extreme weather events than degraded systems (Sudmeier-Rieux and Ash, 2009), ensuring quicker recovery of ecosystem services after drought. Assessments show that where ecological resilience is high, natural systems are better equipped to respond to and recover from climate-related changes in meteorological extremes, freshwater runoff, harvest pressures, and other potential stressors (Staudinger *et al.*, 2013), and are therefore better able to provide ecosystem services. Maintaining and restoring ecosystem function is central to enhancing resilience.

Socio-ecological resilience should help to increase the capacity of ecosystems, and linked human systems, to cope with changing conditions; 'growth and efficiency alone can often lead ecological systems, businesses and societies into fragile rigidities, exposing them to turbulent transformations under the pressure from unavoidable fluctuations and surprises (e.g. dry spells and droughts)' (Falkenmark and Rockström, 2008).

Managing ecosystems for resilience is an emerging field and there is relatively little scientific evidence on the effectiveness of different strategies; much information is still based on ecological reasoning (Heller and Zavaleta, 2009) and draws on existing conservation planning tools (Chester e*t al.*, 2012). However, pro-active management of multiple non-drought pressures on freshwater ecosystems is likely to enhance their resilience to drought. Robust monitoring, evaluation and adaptive management of the effectiveness of different approaches will be particularly important for ecosystem-based SDRM.

MAINTAINING CONNECTIVITY IN FRESHWATER ECOSYSTEMS

Maintaining or restoring connectivity in freshwater ecosystems is critical to ensure downstream water supplies, safeguard fisheries and for other critical ecosystem services such as sediment transport and navigation. Connectivity is particularly important for biodiversity to provide species access to cooler thermal refugia and migration to more suitable habitats, if required (Combes, 2003). Climate adaptation studies have also emphasized the importance of ensuring functional connectivity between habitats for facilitating species adaptation (Campbell, *et al.*, 2009).

Connectivity in freshwater ecosystems can be longitudinal (upstream–downstream), latitudinal (main channel to side channels and floodplain wetlands) and vertical (connectivity with groundwater). Connectivity in freshwater ecosystems requires maintaining water flows through rivers, lakes and wetlands. Safeguarding freshwater ecosystem resilience to drought should focus on ensuring sufficient environmental flows so that key ecosystem functions and services are maintained. Environmental flows describe the quantity, timing and quality of water flows to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems (Brisbane Declaration, 2007).

UNDERSTAND TIPPING POINTS

Safeguarding the resilience of freshwater ecosystems to drought requires tipping points to be identified, beyond which irreversible harm may occur. Crossing these thresholds should be avoided. Recognizing these tipping points also helps assess the role of an ecosystem in reducing drought risk (PEDRR, 2010). A significant challenge for drought managers is the limited understanding of how ecosystems respond to environmental change (Tylianakis *et al.*, 2008) and combinations of stress. It is however clear that by reducing multiple anthropogenic pressures on ecosystems and by enhancing biodiversity resilience is improved (Wentworth, 2011).

UNDERSTAND COSTS AND BENEFITS OF ECOSYSTEM-BASED STRATEGIC DROUGHT RISK MANAGEMENT

Maintaining and restoring ecosystems functions and services can be a cost-effective way to reduce drought risk (PEDRR, 2010; Campbell e*t al.*, 2009; Dalton e*t al.*, 2013; Sudmeier-Rieux and Ash, 2009; World Bank, 2010; UNEP, 2014; Krysanova e*t al.*, 2008). In particular, ecosystem approaches might lower restoration and maintenance costs compared with grey infrastructure (Russi, *et al.*, 2013) and can provide multiple benefits beyond SDRM.

As with all water resource management efforts, it is important to gather and analyze data, including quantified metrics of costs and benefits, to assess the effectiveness and value for money of ecosystem-based SDRM measures. Historically, ecosystem management practitioners have gathered and published insufficient monitoring data on ecosystem-based initiatives. Data should be gathered on carefully targeted metrics to fully understand the effectiveness and efficiency of ecosystem-based SDRM measures.

IMPORTANCE OF ENGAGING STAKEHOLDERS IN PROMOTING SOCIO-ECOLOGICAL RESILIENCE

To increase the uptake of ecosystem-based responses that promote socio-ecological resilience a change in attitude is need to foster confidence in the ability of ecosystems to reduce risk. Working closely with stakeholders to build and effectively communicate the evidence base is crucial in this process. Lessons on the costs and benefits to different stakeholders of specific ecosystem-based measures need to be conveyed. Stakeholders should have a role in assigning credible values to ecosystem services and helping decision makers develop robust economic arguments for protecting and restoring freshwater ecosystems (Shepherd, 2008). Data on the role, benefits and costs of ecosystem approaches compared to conventional grey infrastructure solutions is also needed. Without this information, implementation of measures can be problematic. For instance, during the Californian drought of 2010–, some stakeholders complained about water allocations for the environment due to a lack of understanding of the potential benefits, including benefits to society. Stakeholders across the water sector have an important contribution to make, both during non-drought and during drought conditions.

CHAPTER 9
ENABLING ENVIRONMENT AND IMPLEMENTATION

9.1. Introduction

The successful implementation of SDRM requires coordination and cooperation between all those with an interest in water-related issues. Coordination and cooperation is required to develop more innovative strategies and to ensure their implementation (Box 46). This chapter explores a range of issues that can either enable the successful implementation of SDRM or act as a barrier:

- **Policy and supporting systems** set the 'direction of travel' and define the overarching objectives and principles for managing drought risks, as well as helping to maintain momentum in building drought resilience over the long-term. Regulatory controls and other planning measures are included in these support systems.
- **Institutional arrangements** establish the mandate and accountability for a broadly based approach to drought management and coordinate between institutions.
- **Behavior of other water-related sectors** influences drought risk management. It can be significantly influenced by the water use of other sectors. SDRM seeks to influence the behavior of these sectors and encourage innovation to reduce consumptive use and improve water quality.
- **Stakeholder involvement and risk awareness** helps to ensure different views are considered as part of the planning process and to ultimately strengthen political support at all levels.
- **Funding and incentives** help to ensure financial resources are available to support implementation.
- **Science and research** provide a basis for rational decision making, as well assessing compliance and impact through monitoring to support adaptive management

The following discussion explores these issues in more detail.

Box 46: Drought and India's 2012 National Water Policy

India's National Water Policy (2012) recognizes water is a scarce resource that is fundamental to life, livelihood, food security and sustainable development. It also sets out the challenges in India for water-related natural disasters (floods and drought), water quality, and equity in availability, access and distribution. The policy acknowledges impending challenges related to climate change. Importantly, it also acknowledges that water resources management and associated governance has been inadequate to date.

The policy recommends developing a water framework law as an umbrella statement of the general principles governing how legislative and/or executive (or devolved) powers are exercised by the federal government, the states and local authorities.

In managing drought, the policy states that emphasis should be on:

- drought preparedness, with coping mechanisms as an option
- rehabilitation of natural drainage systems
- land, soil, energy and water management with scientific inputs from local, research and scientific institutions to evolve agricultural strategies and improve soil and water productivity to manage droughts
- community involvement in preparing an action plan for dealing with drought situations.

One of the other biggest weaknesses of the National Water Policy is that it does not discuss environmental flow allocations, although ecosystem water needs are acknowledged. This becomes an important issue during the onset of drought or lean seasons when competition for scarce resources is severe.

However, in the absence of an implementation framework, these measures remain only on paper.

Source: Khurana and Babu, 2013

9.2. Policy and supporting systems

Drought cuts across many policy considerations (Figure 4.5). Without accounting for risks of drought within these wide-ranging policies, the mandate for taking strategic action to manage them is limited and political momentum is difficult, if not impossible, to maintain.

In the majority of cases where policies do refer to drought, they tend to focus on the response phase (emergency supplies, economic support), rather than addressing underlying water resource management issues. This is perhaps one reason why many governments tend to focus on drought too late and fail to respond until a drought occurs. To progress towards more proactive, strategic management of drought risks, a more ambitious approach to drought policy is also needed.

Irrespective of how drought policy is configured, whether it is a standalone policy or embedded within broader polices, it should explicitly encourage strategies that build resilience of the freshwater ecosystem and human systems to droughts at a local, community level as well as at regional and national levels by undertaking three broad actions:

1. Prioritizing actions that create flexibility in water resources and improve the supply–demand surplus at a basin scale – this includes developing policies that:

- **Eliminate perverse incentives:** Existing drought policies and practices that include perverse incentives that may be exacerbating the effects of drought should be identified and eliminated. For example, during the California drought (2010–), the Bureau of Reclamation continued to fund groundwater pumping in overused aquifers as part of its drought response programme. While these actions provide short-term relief to farmers, they hindered progress towards long-term, sustainable water use and drought resilience by increasing conflicts between groundwater and surfacewater users.[34]
- **Reduce consumptive water use and pollution:** Sensitivity to variability in supply is best provided by establishing a long-term, supply–demand surplus, through, for example, encouraging water saving and protecting water quality, which also supports healthy freshwater ecosystems that promote resilience to drought.
- **Promote voluntary collaboration between stakeholders:** All levels of government, stakeholder organizations and individuals should be encouraged to participate in managing drought risks. Voluntary collaboration should include providing incentives that reward behaviors to contribute to the supply–demand surplus by reducing water use, recycling water and reducing pollution. Policies should also require emergency relief plans at all levels of government.
- **Modernize dam operations to manage f ood risk and boost water supply**: Many dams have the capacity for water supply and flood risk management. Dam operators should be required to ensure their operation rules take advantage of modern seasonal drought forecasting capabilities and demonstrate that water supply and in-stream flow benefits have been maximised. They could also be encouraged to take action to restore floodplain function and maintain or enhance groundwater recharge opportunities.

2. Prioritizing the restoration of the natural hydrological functioning and associated ecosystem services to increase water supply–demand surplus and to promote drought resilience - this includes developing policies that:

- **Protect priority ecosystem services, habitats and species during a drought:** Priority freshwater ecosystem services and habitats and species should be identified within policies to ensure environmental flows are maintained during drought to safeguard critical connectivity and refugia during non-drought.
- **Restore the natural hydrological functions and safeguard critical ecosystem services during non-drought periods:** Incentivising and, where necessary, mandating that hydrological functions are restored and protected, especially in headwaters of a basin, is important so that natural forests, wetland, meadow, and floodplain systems can accumulate and retain snowpack, absorb high flows and slowly release water over time.[35]

3. Adopting a long-term, evidenced-based approach to building drought resilience across all relevant sectors - this includes developing policies that:

- **Promote drought sensitive development:** Many countries have planning policies that are sensitive to floods, earthquakes and other hazards and often state that any development cannot increase the level of associated risk. Drought risks, and the contribution additional development makes to an increased level of risk, are seldom included in planning considerations. Taking account of the long-term implications of development, particularly water-consumptive industries, on drought risk within planning policy is needed to avoid exacerbating future risks.

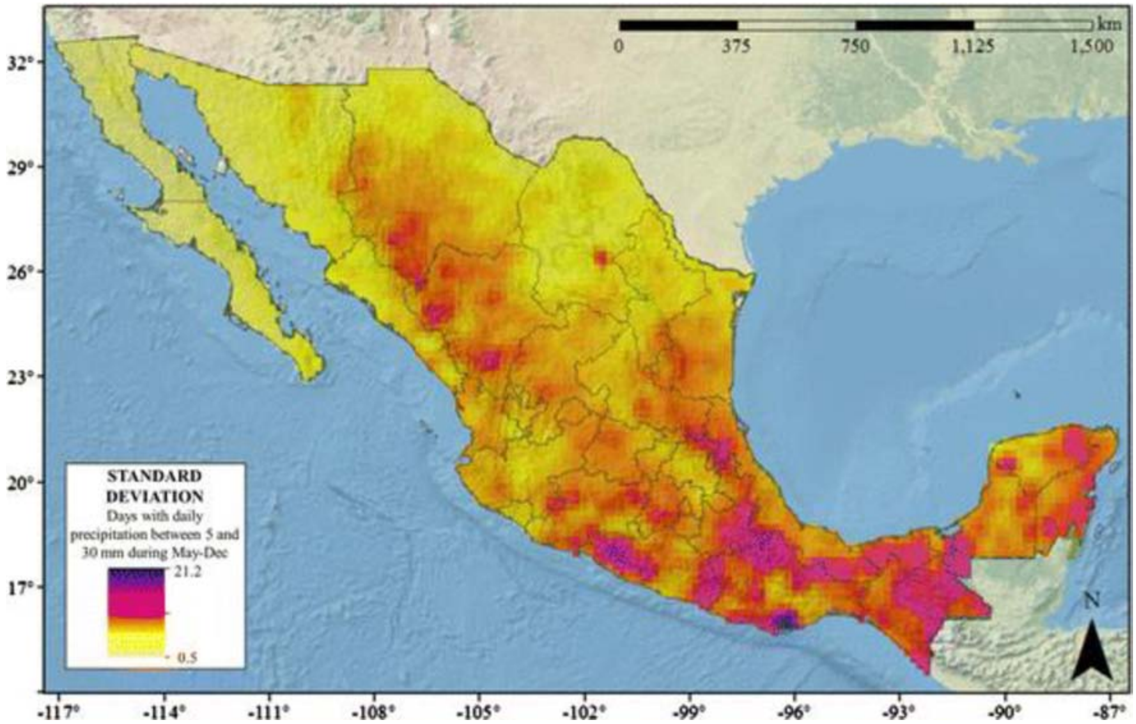
34. http://www.circleofblue.org/waternews/wp-content/uploads/2015/08/Drought-recommendations-8.12.15-FINAL.pdf accessed 2 November 2015

35. This approach can build on international best practice such as the Western Watershed Enhancement Partnership between the US Bureau of Reclamation and the US Forest Service and partnerships with non-federal entities like the US Forest Service's 'Forest to Faucet' partnership with Denver Water http://www.denverwater.org/SupplyPlanning/WaterSupply/PartnershipUSFS/ accessed 2 Nov 2015

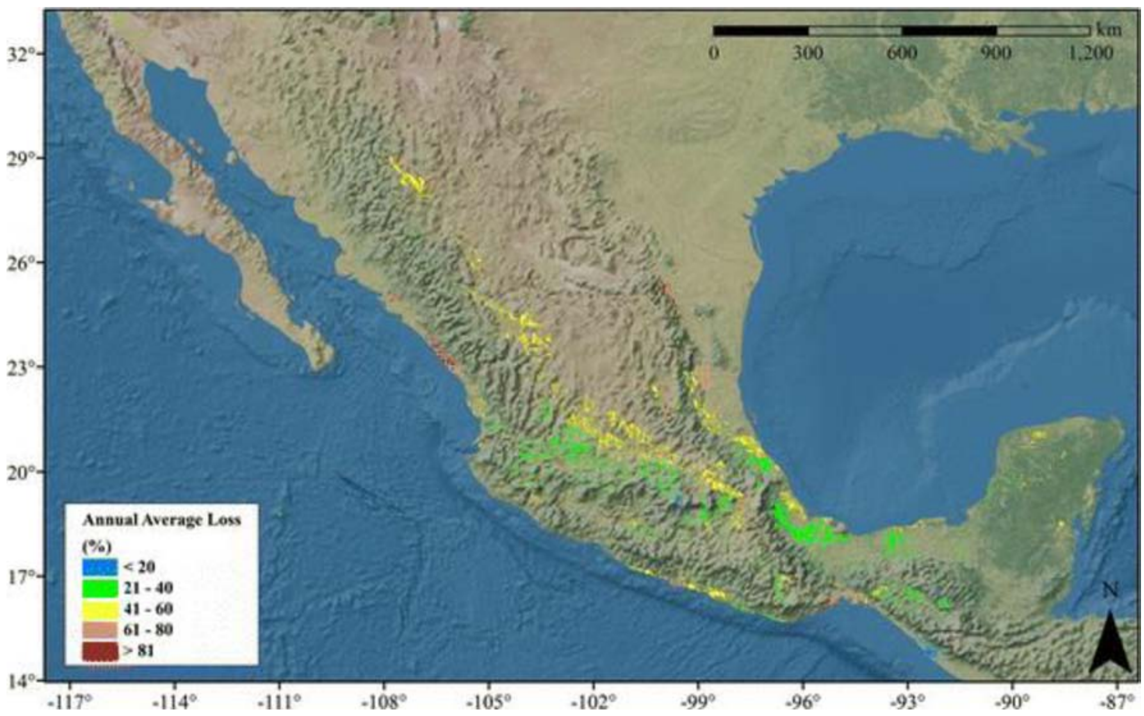
Box 47: Probabilistic assessment of agricultural drought risk assessment, Mexico

Using a probabilistic approach, Quijano *et al.*, (2015) assessed the economic impact of drought on rain-fed agriculture in Mexico. The risk was expressed in different economic terms to support appropriate risk financing schemes and other risk transfer instruments. A mapped example of the evidence is provided below. These maps show the assessment of drought on maize across Mexico.

Standard deviation of the number of days with daily precipitation between 5 mm and 30 mm during May–December (based on daily precipitation grids 1979–2008)



Distribution of the annual average loss for maize under rain-fed conditions



Source: Quijano *et al.*, 2015

- **Encourage a long-term view and the need to adapt:** Provide incentives that encourage stakeholders to take a long-term view of future drought risks such as, for example, subsidized insurances or preferential priority for grants. Adaptive capacity can be formally recognized within national funding rules (as in HM Treasury (2009)) for example precautionary guidance for the influence of climate change can be offered. As various droughts have demonstrated the worst time to respond to a drought is in the midst of one. At that point, there are few, if any, good options available to avoid the worst impacts of drought, and combined with enflamed passions and politics, reaching consensus on solutions is nearly impossible.
- **Evidence-based and under continuous review:** Good drought policy is based on evidence of present and future risks across a wide range of impacts (see Box 47). Developing this evidence requires investment in local, national, regional and global observation networks and forecast and warning delivery systems. Modelling approaches also need to be capable of exploring future risks and how they may change under a range of climate change and socio-economic scenarios and alternative drought risk management strategies, for example, as developed by UK Climate Change Committee.[36]
- **Make drought risk management plans and review f ndings readily available:** Data should be readily available to the public, including through regular reports that describe the results of national and local SDRM efforts. These reports should outline the investment in drought risk management include a quantified description of benefits for water supply–demand, ecosystem function, and the benefits to other sectors.

The principal recommendations emerging from the California Drought (2010 ongoing) echo many of these points (Box 48).

Box 48: Principles and recommendations for improving water resource resilience in the California Drought (2010 ongoing)

Proactive drought policies that encourage a move towards long-term drought resilience have emerged as a central theme during the California drought (2010 ongoing). In an open letter to the Committee on Energy and Natural Resources of the US Senate and others (August to October 2015), a coalition of conversation organizations, Circle of Blue, highlighted the need for federal polices to prioritize environmental flows to ensure the nation will be less likely to reach a crisis point in future droughts. Four principles and associated actions were set out in the letter.

Principle 1: Federal programmes should prioritize actions that reduce the risk of water shortages, create flexibility in water management, and improve the reliability of water systems on a basin scale.

- Eliminate perverse incentives – ensuring drought actions do no harm and avoid perverse incentives that may be exacerbating drought risks.
- Coordinate programmes across drought-affected watersheds to promote voluntary partnerships with irrigators.
- Use agriculture easements to manage water demand – including funding for voluntary transactions and rewarding drought resilient behave.
- Coordinate conservation programmes – to both improve the efficiency of and flexibility in agricultural water use while promoting ecological health.
- Promote voluntary water transfer strategies – to create flexibility and promote conservation across a basin.
- Modernize dam operations to manage flood risk and boost water supply.

Principle 2: Federal programmes should prioritize restoring hydrologic function and ecosystem services as a cost-effective means of increasing water supply and drought resilience.

- Extend and enhance the WaterSMART (grants) Programme – recognizing grants as a powerful tool for conserving water.
- Study the use of hydropower revenues for conservation projects.
- Restore and protect hydrologic function on federal lands
- Stack benefits across multiple sectors – ensuring those drought management actions with strong environmental benefits are prioritized.

Principle 3: Federal programmes should incentivize and support intact watershed processes.

- Prioritize and incentivize intact watershed (governance) processes – prioritizing government funding to basins with a track record of partnership and successful implementation.
- Use the Basin Study Programme and the Cooperative Watershed Management Act to promote intact watershed (governance) processes.
- Develop partnerships to improve data collection.

Principle 4: Federal programmes should be more accessible to and lower transaction costs for state, local, tribal and non-governmental entities.

- Study the unintended consequences of restrictive eligibility requirements.
- Designate a single point of contact in major river basins for federal drought resilience programmes.
- Clarify the tax treatment of appropriate water rights.
- Review federal programmes for increased coordination opportunities
- Publish the results of federal drought resilience programmes.

WaterSMART: http://www.greentechmedia.com/articles/read/watersmart-raises-7m-amid-ongoing-california-drought

Source:http://www.circleofblue.org/waternews/wp-content/uploads/2015/08/Drought-recommendations-8.12.15-FINAL.pdf accessed 2 November 2015

9.3. Institutional arrangements and legal framework

Institutions and the associated legal frameworks are an important aspect of a drought-resilient society, to provide the capacity to manage and adapt to disturbances. By linking the human systems and freshwater ecosystem, they shape the relationship between people and their environments. For example, institutions and legislation can establish water rights, determine how resources are used and by whom, and organise the way data and information is used for a drought management regime. Institutional arrangements underpin resilience by influencing the ability to mobilize and use resources, how

36. https://www.theccc.org.uk/2015/10/29/preparing-for-uk-water-extremes-flooding-and-drought/ accessed 2 November 2015

problems are framed, and the extent to which governance structures are responsive, flexible, and support knowledge-sharing and learning. SDRM therefore requires the support of an institutional framework with the capacity to plan for the long-term, take the necessary actions and, where necessary, adapt.

To date, drought planning been dominated by engineering and technological solutions to secure water supplies and reduce the impacts of drought on water users. The institutional framework to support this approach primarily requires codes and standards used by water engineers to secure supply, water allocation rules, and water pricing regimes. This framework supports the goal of securing access to water within a given level of reliability, for specified users and defined *a priori*. As a result, these frameworks often promote the status quo, relying on tried and tested infrastructure and management solutions to resolve expected problems and immediate threats at a local scale; capability is also provided for managing more significant, broader-scale droughts (Box 49). In contrast, SDRM seeks to promote longer-term and system-wide solutions that, in turn, require an institutional framework that enables resilience-promoting strategies. Some of the most important aspects of an institutional framework to support SDRM are discussed in the following section.

Box 49: Crisis in the Carolinas: the 1998–2002 drought highlighted an inadequate institutional framework

Beginning in 1998, many areas in the Carolinas experienced several years of below-normal precipitation. Deficits over the four-year period were among the largest ever recorded, and the cumulative deficit resulted in severe hydrologic impacts, including critically low streamflows, groundwater levels, and reservoir storage. The most severe water supply impacts occurred when river and reservoir levels reached critical lows in summer 2002. At least 60 community water systems across the two states were vulnerable to running out of water if the drought continued. On the Yadkin–Pee Dee River, rapidly declining water supplies required emergency meetings between dam operators, state agencies and water users to manage the limited resource.

The Carolinas were in crisis mode in 2002. Water managers and decision makers were ill-prepared for an unprecedented, severe and long-lasting drought. Management activity was largely reactive, driven by impending water shortage emergencies. As one interviewee recalled, 'One day we had water in the river, and the next day, it was like somebody cut the faucet off. We were really scrambling at the time, when we saw it starting to drop like that'. At the local level, 'everyone was doing their own thing'. For those water systems or communities faced with water shortage emergencies, response was described as 'off the cuff' and 'shoot from the hip'. With limited authority or previous experience with such a severe event, state-level response was also reactive. There was little or no knowledge of water stakeholders' needs (including basic contact information), minimal expertise with drought monitoring, and underdeveloped channels of communication.

While the crisis conditions were partly attributable to the severity of the drought, they were also a legacy of the institutional components that underpinned drought management throughout the 20th century. The prevailing assumption that the Carolinas were 'so well-watered that we would never have that [drought] problem' guided the region's overarching approach to water resources management and drought planning. Consequently, local water systems made most drought-planning decisions. Their decisions were primarily based on knowledge about the local water supplies and demands and historical hydrological and climatological data. While this local-level approach was adequate to prevent and mitigate impacts during previous drought, this drought's spatial and temporal extent taxed the region's capacity to cope with a 'drought of record.' Furthermore, the lack of formal drought plans also contributed to a reactive, crisis-oriented response. Few municipalities had up-to-date response plans 'because it just never, nothing ever close to what occurred in that drought, had occurred before.' Although a drought in the 1980s had triggered the adoption of local response plans in South Carolina, by the late 1990s, the systems were 'out of practice' in terms of implementing those plans. The existing state-level drought plans provided only a skeletal structure for state and local response. The federally licensed hydropower projects in the Catawba–Wateree and Yadkin–Pee Dee did not have drought contingency plans or other formal rules to guide management decisions during the drought. In short, the 1998–2002 drought exposed the limits of the prevailing strategies and practices to manage and prepare for drought risks. The drought also highlighted how increased demand on water supplies and a lack of coordination and communication among decision makers could contribute to the vulnerability of water resources and users in the Carolinas at a regional level.

Source: Lackstrom, 2015

STRATEGIC DECISION MAKING ARRANGEMENTS

Where institutions are diverse and not well integrated, institutional interactions can create disconnects between levels and across different management regimes and can constraint adaptation. Actions implemented at one scale, even successfully, may have adverse effects at other temporal or spatial scales. Such disconnects across scales can hinder local-level capacity to adapt and undermine the ability of existing institutions to support collaboration. In the context of drought, clear vertical linkages have been shown to help cooperation, coordination, and the capacity to address drought. For example, in North and South Carolina, state-level guidance, financial or technical resources, and mandates have been shown to support local-level drought planning and capacity building (Lackstorm, 2015). Achieving horizontal integration (between sectoral interests) is equally important in promoting integrated multiple actions.

Achieving this effectively requires a lead authority with the strategic overview of all drought issues. This does not imply a single organization has responsibility for taking all drought management actions, but that strategic decision making is improved if a single organization has the mandate to:

- supervise and coordinate drought policy development across all levels of government
- ensure basin-level management plans appropriately consider drought issues
- ensure SDRM plans are developed and updated as appropriate
- ensure drought monitoring programmes are maintained and advanced as necessary

- ensure early warning system are in place and appropriately accurate
- ensure drought risks are understood and communicated
- facilitate access to funding for drought management activities
- undertake post-drought review and lessons learnt studies
- ensure cooperation on drought issues at the trans-basin level
- develop and support research, science, and educational programmes
- establish the process for real-time decision making when a drought is forecast, including maintaining a register of the stakeholders to be engaged in the process of decisions making
- provide evidence-based advice to political decision makers on the trade offs between water users and appropriate water allocations and restrictions during drought and in the longer-term management of drought risks.
- facilitate a participatory approach to the choices made (and the inevitable trade-offs) and an open decision process.

The role of an organization with strategic oversight helps to implement water resources management policies and projects under complex and dynamic conditions. It provides the governance structure in which policy and strategies are developed and measures implemented. However, what happens in practice is ultimately a result of the interactions of people, both individuals and organizations or groups. Strategic oversight guides the stakeholders through the specific socio-cultural, political, economic and environmental circumstances in which they operate to manage drought risk over the long-term (Table 9.1). In basins where drought risks are managed successfully it is likely that: (i) organizations are trusted and have established relationships within the river basin and more broadly; (ii) individual stakeholders within the basin are committed to achieving mutual benefits; and (iii) actions taken to manage drought risk are implemented in a timely manner.

REAL-TIME DECISION MAKING ARRANGEMENTS

Effective, real-time decision making relies on a reliable and credible forecast and well-described roles and responsibilities for declaring drought onset and cessation and implementing restrictions or other emergency actions. The declaration of drought is partly subjective and highly political. Drought forecasts can also be unreliable and may be unlikely to be acted on in a timely way. Without a clear decision process in place, the degree of subjectivity and the influence of politics can undermine good, risk-based decision making. Although decisions to declare drought and to implement measures are best taken by those who are likely to experience the impacts, the need for global scale cooperation and support is being recognized with influential organizations calling for a global capability in providing an early warning systems for drought (Pozzi *et al.*, 2013).

Table 9.1. Governance questions: Effective strategic oversight enables key questions to answered

Governance dimension	Main descriptive questions
Levels and scales	☒ Which administrative levels are involved and how? ☒ Which hydrological scales are considered and in what way? ☒ To what extent do they depend on each other or are able to act productively on their own? ☒ Have any of these changed over time or are likely to change in the foreseeable future?
Actors and networks	☒ Which actors are involved in the process? ☒ To what extent do they have network relationships also outside of the case under study? ☒ What are their roles? ☒ Which actors are only involved as affected by or beneficiaries of the measures taken? ☒ What are the conflicts between these stakeholders? ☒ What forms of dialogue between them? ☒ Are there actors with a mediating role? ☒ Have any of these changed over time or are likely to change in the foreseeable future?
Problem perspectives and goal ambitions	☒ Which various angles does the debate of public and stakeholders take towards the problem at hand? ☒ What levels of possible disturbance are current policies designed to cope with? ☒ What levels of disturbance of normal water use are deemed acceptable by different stakeholders? ☒ What goals are stipulated in the relevant policy white papers and political statements? ☒ Have any of these changed over time or are likely to change in the foreseeable future?
Strategies and instruments	☒ Which policy instruments and measures are used to modify the problem situation? ☒ To what extent do they reflect a certain strategy of influence (regulative, incentive, communicative, technical etc.)? ☒ Have any of these changed over time or are likely to change in the foreseeable future?
Responsibilities and resources	☒ Which organizations have responsibility for what tasks under the relevant policies and customs? ☒ What legal authorities and other resources are given to them for this purpose or do they possess inherently? ☒ What transparencies are demanded and monitored regarding their use? ☒ Is there sufficient knowledge on the water system available? ☒ Have any of these changed over time or are likely to change in the foreseeable future?

Source: from Bressers et al., 2015

Typically, some form of drought committee or task force will have the role of decision maker (or statutory adviser to an institution that is mandated to act, Figure 9.1).

Plans change in the face of real events. Critically, the decision making body, which is typically a specifically convened drought committee, should include representatives of all stakeholders with a legitimate interest in the outcomes of the decisions taken, as trade-offs and choices will have to be made. As a minimum, this is likely to include representatives from:

- national government departments and agencies with the authority to make policy decisions (e.g. ministries responsible for environment, water, agriculture, energy, tourism, and industry etc.)
- local decision making authorities with on-the-ground knowledge and the power to take operational decisions
- local groups and technical specialists with specific expertise and perspectives to offer, including:
  - community groups
  - professional institutions, environmental agencies, hydrometeorology service
  - non-governmental organizations (NGOs)
  - universities and research institutions
  - industry representatives (energy sector, tourism sector; farmers; water companies).

This group will have specific responsibilities for:

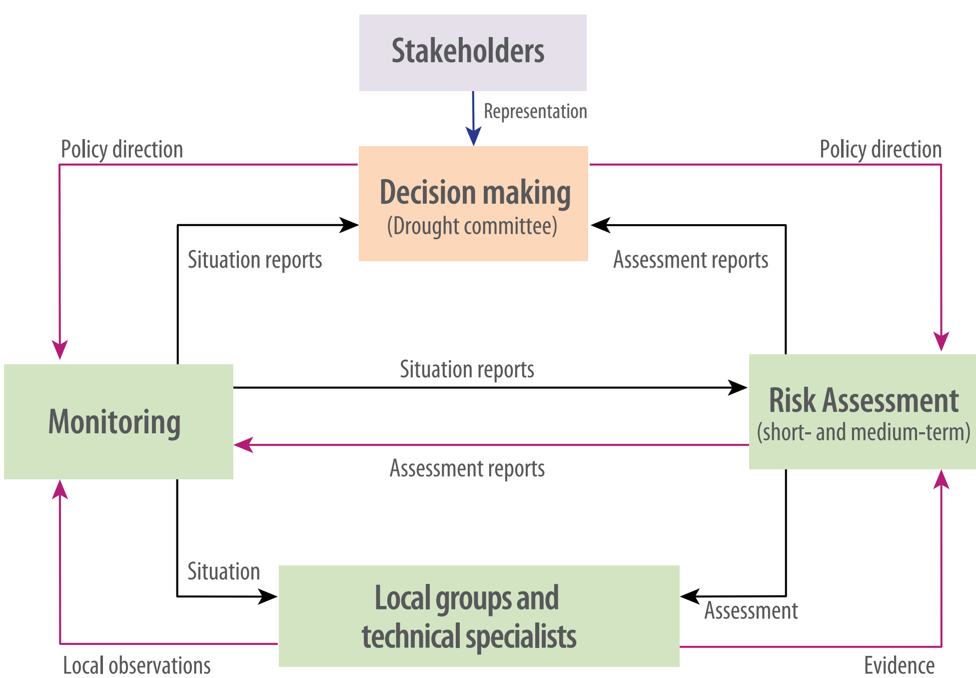
- determining how and when to declare the onset and cessation of drought, although the formal declaration, and authority for associated emergency measures, is likely to require political approval as the severity of drought escalates (see Box 50)
- overseeing the implementation of pre-determined plans and determining response actions and water allocation priorities based on evidence from the risk assessment and monitoring activities
- identifying and accessing all forms of assistance from the various levels of government during severe drought
- maintaining a pre-agreed SDRM plan under review and making adjustments in light of evidence and circumstances
- disseminating drought information
- determining the severity of the drought ex-post to support timely compensation payments where appropriate
- reviewing lessons learnt and making recommendations for future improvements.

The **monitoring** activities should support the SDRM decision making through:

- providing global, regional and local data on the severity and spatial variation in blue-water drought and green-water drought indicators, with data-quality statements
- synthesizing local observations into meaningful indicators
- ground truthing and assessing the credibility of the risk assessment processes.

The risk assessment process provides insights into short- and medium-term risks, often using a combination of weather forecasts and pre-agreed medium term scenarios of precipitation. The risk assessment is used with local evidence to identify the most significant risks and the most likely effectiveness of alternative actions.

Figure 9.1. Organizational arrangements for real-time decision making

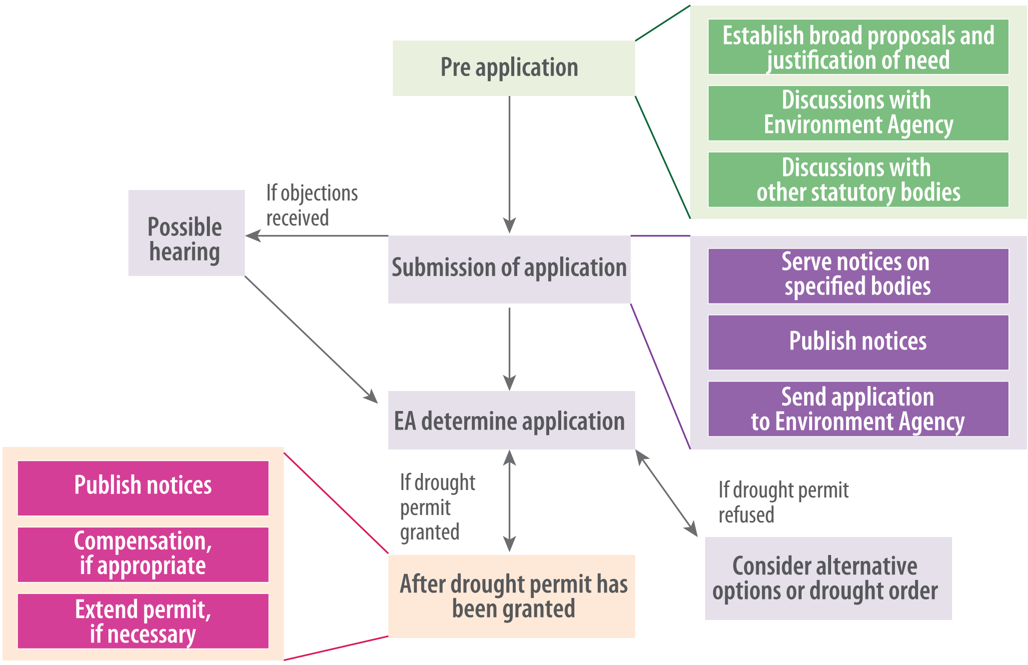


Box 50: Drought permits, ordinary drought orders and emergency drought orders, England

In an escalating drought, privatized water companies in England may have to apply to the Environment Agency, the government agency with strategic oversight of water issues, for a drought permit or apply to the Secretary of State for Environment, Food and Rural Affairs for a drought order. Drought permits enable companies to take water from new sources, or to alter restrictions on existing abstractions. Drought orders can go further and restrict the non-essential use of water. To obtain a drought permits, the Environment Agency must be satisfied that 'a serious deficiency of supplies of water in any area exists or is threatened' and that the reason for the deficiency is 'an exceptional shortage of rain'. For drought orders, the Secretary of State must be satisfied that either 'a serious deficiency of supplies of water in any area, exists or is threatened' or 'such a deficiency in the flow or level of water in any inland waterway to pose a serious threat to any flora or fauna which are dependent on those waters, exists or is threatened' and that the reason for the deficiency is 'an exceptional shortage of rain'. For emergency drought orders, the Secretary of State must be satisfied both that, 'by reason of an exceptional shortage of rain, a serious deficiency of supplies of water in any area exists or is threatened' and that 'the deficiency is such as to be likely to impair the economic or social well-being of persons in the area'.

Drought permits and drought orders are only valid for specified periods and may be renewed only for limited periods. Water companies are expected to take mitigation measures to reduce the effect of drought permits or drought orders on the environment.

Process for applying for a drought permit



Information needed to support a drought permit or order application

Information required	Reasoning and comments
Details of the drought management actions a company has already taken	We are unlikely to grant drought permits or support drought order applications unless a company has already implemented all reasonable demand-side actions.
An environmental assessment to show the likely impact on the environment.	This will allow companies to prioritize sites for additional abstractions where any environmental impact would be least damaging and prepare in advance the information needed for the environmental report which supports an application.
Details of monitoring and mitigation requirements in the environmental monitoring plan.	Adequate data collection is needed so companies can assess the impacts from the implementation of the drought management action and a sites recovery post implementation. Companies must also provide details of likely mitigation or compensation needed against serious impacts on the environment as a result of implementation of drought management actions. The environmental monitoring plan and environmental assessment need to be reviewed regularly to ensure they are updated as planned surveys are completed.

Sources: Defra, 2011; Environment Agency, 2010

Box 51: Co-ordinating drought responses, California (2010 ongoing)

The California Drought Contingency Plan (DCP) outlines the roles and responsibilities of agencies and organizations that may be involved in drought management. The Interagency Drought Task Force was established following the 2008 and 2009 Drought Proclamations and Executive Orders. The Task Force is chaired by the Department of Water Resources serving as the primary coordinator of the state's drought effort, including the preparation of the DCP. The DCP was developed in consultation with the California Water Plan Steering Committee, representing 21 state government agencies with jurisdictions over different aspects of water resources and receiving input from its Advisory Committee.

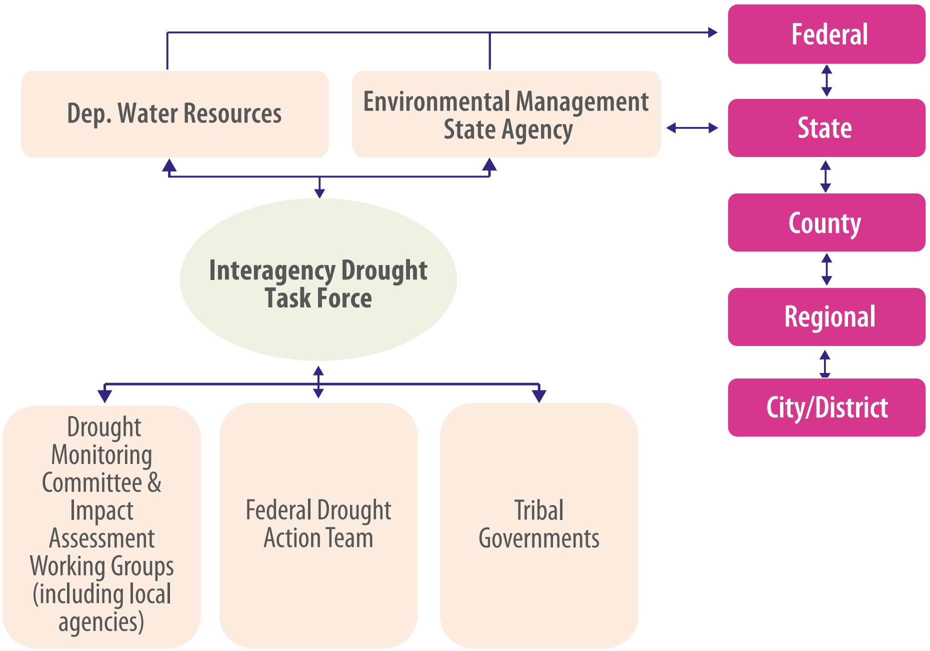
The Task Force gives policy direction to the Drought Monitoring Committee and the Impact Assessment Work Groups. The Committee and Work Groups develop situation reports and impact assessment reports for the Task Force. The Task Force ensures accurate and timely distribution of water supply data and drought forecasts to water managers and the public.

The Task Force is responsible for mitigation and response actions. Under the DCP, an emergency drought response is implemented in accordance with the Standardized Emergency Management System for multi-agency and multi-jurisdictional responses to emergencies in California. The Task Force is supported by the California Emergency Management Agency on emergency response and recovery. The Task Force coordinates with federal, local, and tribal agencies and other stakeholders on drought management and response efforts. A general communication and coordination structure (see figure below) is proposed for agency planning and drought response.

The primary roles of the Drought Monitoring Committee and the Impact Assessment Work Groups are monitoring of water supply and drought, and assessing drought impacts on various regions and sectors. This information is used for impact assessment. Assessment reports are disseminated to the Task Force and agencies, and are posted on the DWR Drought website.

The Impact Assessment Work Groups assess impacts on vulnerable regions, sectors, and groups throughout the state. Members include local agency representatives such as county emergency managers and water agency officials, and other stakeholders who work with the state to assess or respond to drought impacts. The Impact Assessment Work Groups assist the Drought Monitoring Committee and provide regional input on impending or current drought. These work groups assess drought impacts and help develop appropriate response and mitigation strategies.

General drought communication and coordination structure



Source: Based on the California Drought Contingency Plan, 2010. http://www.water.ca.gov/waterconditions/docs/Final_CA_Drought_Contingency_Plan-11-18-2010a.pdf accessed November 2015

ENGAGEMENT AND PARTICIPATION OF STAKEHOLDERS

Local communities

Local communities have a central role to play managing their risk to future drought and should be encouraged to participate in the development of SDRM plans and their implementation. All members of the community, particularly the most vulnerable to drought, should be encouraged to contribute:

- to the SDRM planning process, to express opinions about desirable improvements, and to set goals and prioritize objectives
- to lead the development of a community drought plan
- to their understanding of past droughts and how they have been affected and how they would likely be affected them in the future
- local observations to the formal monitoring systems and to develop confidence in drought forecasts
- a set of actions that they will take to reduce drought risk in the long-term and in response to drought when it occurs
- to the education of others within the community about water, drought, and the community's drought plan.

The important role communities play in developing drought resilience is increasingly being recognized. In the US, for example, the concept of 'drought-ready communities' forms an integral part of the drought planning process (Box 52).

Box 52: Community plans: Developing drought-ready communities the US

In the US, following a series of droughts from 2000 onwards, authorities have focused on building 'drought-ready communities' (Svoboda *et al.*, 2011). The process of developing drought-ready communities is seen as delivering important outcomes:

- a better understanding of past droughts and their impacts on the community
- support for, and implementation of, better local monitoring systems
- better communication about drought conditions and impacts
- improved knowledge of what actions to take to prepare for and in response to a drought.

The benefits of taking community action include:

- increased awareness of water, climate and drought issues
- reduced impacts during the next drought
- reduced stress during the next drought
- reduced impact on freshwater ecosystems during the next drought.

Drought-ready communities are not the same as drought-proof communities, but any drought monitoring, communication, and response plan developed by and for the drought-ready community may help reduce the impact of any drought.

Source: University of Nebraska. www.drought.unl.edu/portals/0/docs/DRC_Guide.pdf accessed March 2014

Professional bodies and the expert community

Professional bodies play an important role in shaping the policy debate around drought risk management and developing best practice. They are well placed to provide an independent view on future challenges, the role of regulation, education and training, and provide authoritative contributions to specific technical issues. In the UK, for example, the Institution of Civil Engineers (ICE) and the Chartered Institute for Water and Environment Management (CIWEM) are actively involved and use their position to highlight issues at the highest levels of government (Box 53).

Box 53: A contribution to the debate on managing drought in the UK

In 2012, the Institution of Civil Engineers (ICE) and the Chartered Institute for Water and Environment Management (CIWEM) set out a joint Policy Position Statement on the causes of drought in the UK and how the UK could better plan for drought. The paper, backed by an influential membership, challenged the drought risk management community in England and Wales to:

- Continue comprehensive drought planning by all those with an interest in the water environment — water companies, government bodies and regulators, other abstractors and businesses that rely on water. Plans should be updated as circumstances dictate, even during drought if planned actions turn out not to be the most sensible solution, or as a new option comes to light.
- Provide clear information to the public and other water users explaining drought is natural and cannot be avoided, but that people can help to manage its effects.
- Ensure that ways people and businesses can save water in drought is clearly communicated.
- Minimize conflict and encourage effective management by encouraging good communication between all those involved in drought management.
- Consider restrictions on water use for non-essential purposes, appropriate to the level of drought severity, early in a drought, to reduce demand.
- See temporary water use bans as an important drought management tool, and not as a failure of water resource management. Water companies should not be financially penalized for appropriate use of these restrictions. However, water companies should take into account the significant cost of such restrictions on some users.
- Recognize the importance of water to farming and business in drought legislation and management.
- Consider the need for a 'drought monitoring system', similar to that which exists in the US, to complement and enhance the European Drought Alert System, to improve preparedness and response to droughts.
- Encourage imaginative mitigation of the adverse impact of drought measures (such as additional abstraction) so that the effect on the environment is reduced as far as possible.
- Support further scientific research on delivering improvements in seasonal forecasting, soil moisture monitoring systems and developing climate services, together with better mechanisms to ensure rapid uptake of this science into drought management and public information systems.
- Support further research into long-term drought forecasting methods; the way that catchments and the environment respond during drought, and recover after drought; and the impact of climate change on future droughts.

Source: http://ciwem.org/knowledge-networks/panels/water-resources/managing-drought-in-the-uk.aspx accessed March 2014

Non-governmental organizations

Non-governmental organizations (NGOs) and civil society lobbying organizations have important roles to play in shaping an SDRM plan. This role includes working with community-based organizations and cooperatives to implement some initiatives, as well as supporting innovative demonstration and pilot projects and facilitating communication between various stakeholders. NGOs also have a powerful voice as an advocate and for taking a longer-term view to protect freshwater ecosystems, both critical issues in the successful delivery of SDRM. Challenging governments to do better, and presenting research to support their case are all legitimate contributions for NGOs to make in improving SDRM.

9.4. Behavior of other water-related sectors

AGRICULTURAL PRACTICE

Agriculture dominates water use in the majority of countries around the world. Influencing agricultural practice can have a significant impact on drought risks for both the human system and freshwater ecosystems. SDRM has a role to play in influencing agricultural policy, through national and international agreements and subsidies that shape agricultural practice, and through compensation and insurance arrangements to ensure drought-positive behavior is encouraged and that perverse behaviors that heighten drought risks are avoided.

SDRM also has a role to work more directly with farming communities and to develop best-practice guidance, supported by policy. Encouraging on-the-ground changes to farming practices that promote good soil health, appropriate selection of cropping, efficient irrigation and flexible water sharing (Box 54). These measures can be helpful for reducing vulnerability to green-water drought, and they may also reduce reliance on irrigation, helping to reduce the impacts of blue-water drought. Some practical examples of farming methods to help reduce drought risk include:

- **No-till farming methods:** Planting directly onto the stubble of last year's crops helps retain soil moisture, reduces reliance on future rainfall and reduces drought vulnerability. According to US Department of Agriculture data, farmers who used no-till methods on corn in 2010 were 30% less likely to receive payment from the Federal Crop Insurance Programme than conventional farmers (NRDC, 2013), suggesting they were less likely to suffer drought impacts.
- **Cover cropping:** Cover-cropped fields have also been shown to build healthier soil. These crops are not grown for market but to protect and enhance soil health. Planting a mix of cover crops, such as winter wheat and hairy vetch, increases soil nutrients and water retention, and prepares the soil for the next planting rather than depleting it. A recent USDA survey found that the benefit was most pronounced in areas hardest hit by drought (Mellon, 2013).
- **Pasture rotation:** Daily pasture rotation improves soil moisture absorption and retention and can help pasture to be drought resistant, reduce the severity of drought, and provide a basis for a faster recovery after drought ends.
- **Alternative cropping:** Alternative cropping can promote an approach that uses water appropriately in the context of the water resource, for example planting low water-consumptive crops, such as replacing rice with wheat in some areas.
- **Conservation agriculture:** Practices such as agro-forestry, shadow cropping, mulching, terracing, and reduced tilling conserves soil moisture and reduces irrigation demand.
- **Irrigation water savings:** Practicing efficient water-application techniques can reduce abstraction requirements for crops. Care is needed to develop a surplus in the allocation. Using the water 'saved' through more efficient techniques to grow more crops on the same farm – even with greater efficiency – can exacerbate vulnerability to drought as cumulative evapotranspiration increases and return flows to original water sources, and to downstream water users, is reduced.
- **Small-scale rainwater harvesting:** Can reduce irrigation demand, if it is not used in a way that exacerbates vulnerability as well.

Box 54: Changed agricultural practice to increase productivity during drought in Australia

Australia's Millennium Drought resulted in water allocations for irrigation in the Murray–Darling Basin falling from more than 12,000 GL before the drought in 2000–01, to a low of 4,094 GL in 2008–09. Overall, there was a 67% decline in water use from 2000–01 to 2008–09 in the basin. At the same time, the gross value of irrigated agriculture fell by only 20%, adjusted for price trends. This implies that agricultural productivity more than doubled over the period, even as farmers were experiencing severe drought. Studies suggest that irrigators used a range of strategies to adapt to drought. Evidence suggests there were five main interacting adaptions:

- changes in crop mix: overall, there was a decline in rice and cotton, and an increase in cereal crops
- substitution of purchased feed for irrigated pasture in dairy production:
- irrigation efficiency improvements: irrigation application rates fell in the dairy industry from 4.2/ML/ha to 3.5 ML/ha, and fell by around 10% for all agricultural sectors in New South Wales
- irrigated crop yield improvements: crop yield per unit of water increased in the cotton, dairy, cereals, meat and grape sectors, although there were a range of factors that may have contributed to this increase
- flexible water trades of allocations and entitlements.

Source: Kirby *et al.*, 2014

SPATIAL PLANNING

Spatial planning has a significant role in determining long-term consumption patterns. In most instances, the impact of planning choices on water consumption and associated drought risk is unintended. Encouraging planners to consider drought, and presenting them with useable information about drought risks, is a legitimate component of SDRM (Box 55).

Appropriately influencing building codes provides a pathway for SDRM to reduce consumptive water use. Building codes influence the use of water-conserving devices and the water footprint of new buildings and may also encourage retro-fitting. Landscaping codes can also influence water use, particularly in areas where water-consumptive vegetation is inappropriate for the local climate. For example, incorporating large gardens in town planning may require summer watering. Encouraging consideration of more compact residential development, although it would not eliminate water use for lawns, can reduce it.

Extending the consideration of drought to the planning and approval of industrial development and has had little attention to date. However, the spatial misalignment of supply and demand that many countries experience and the significant additional operating costs of this implies that drought should be considered alongside other hazards (such as floods) in planning policy.

Box 55: Water sensitive spatial land use planning and development choices in the UK

Currently, drought is not mentioned in planning legislation in the UK, unlike flooding, which has been considered in planning policies for many years. There is some consideration of water supply, although usually for consultation with the water supply companies and the incorporation of water-efficient technologies. Planning authorities are being encouraged to work closely with the water supply companies and the Environment Agency on the timing and numbers of new households in areas of greatest growth to secure water supplies. These considerations are usually addressed through local development plans prepared by local authorities on a regional basis, rather than for individual planning applications. However, local planning authorities are also encouraged to consider water resource and drought issues when:

- large developments are proposed that are not identified in local plans and require significant quantities of water
- a local plan requires enhanced water efficiency in new developments as part of a strategy to manage water demand locally and help deliver new development.

Building regulations stipulate some water-efficiency requirements for newly built domestic properties and the Code for Sustainable Homes has a water efficiency element, although implementation is dependent on the local authority. For example, the Greater London Authority requires rainwater harvesting in new developments; however, other authorities do not.

Sources: Based upon (i) POST note 419 – Water resource resilience, 2012 www.parliament.uk/briefing-papers/POST-PN-419.pdf accessed November 2015 and (ii) UK National Planning Policy Framework, 2012 www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf accessed November 2015

DAM RE OPERATION

Dams, in particular larger dams, often fulfill hydropower, water supply and flood risk management functions. In many cases, the operating rules used to manage the water resource have not been updated since construction, may not take full advantage of modern, short, and seasonal forecasting technologies, and rely on predefined rules tied to specific calendar dates rather than present or forecast hydrologic conditions and demand. This sometimes results in lost opportunities to capture water and may unnecessarily reduce the environmental reserve to satisfy environmental flow requirements if drought materializes or extends. When combined with voluntary actions to restore floodplain function and maintain or enhance groundwater recharge opportunities, modernizing dam operation rules can yield significant water supply and in-stream flow benefits (US Nature Conservancy, 2015). SDRM planners should engage dam owners and operates to ensure operating rules reflect modern risk-based practices and use modern forecast abilities.

9.5. Risk communication and awareness

EDUCATIONAL PROGRAMMES

Implementation of drought risk strategies requires the cooperation of the public in the execution of many of the measures, especially behavioral change and abstraction reforms. Government leaders and the public are unlikely to support drought risk management if they do not believe there is a risk. Immediately following a major drought event, there is typically considerable discussion of the need for action to reduce future risk, but very rapidly, as conditions return to near normal, support for taking action often wanes. Educational programmes to raise awareness of both the short- and long-term water supply issues across the global, national, regional and community scales are therefore crucial in developing an understanding of how to respond to drought when it occurs and to ensure longer-term drought planning continues during non-drought years.

Educational programmes can promote learning that:

- Develops a greater awareness of the drivers of drought risk and links to sustainability
- Encourages people to engage with the development of the SDRM and the underlying rationale for the choices made
- Increases sharing of expertise and alternative perspectives.

The development of age-appropriate educational materials for use in schools, in training community leaders, and for professional training (supported by online resources) is important for this (Box 56).

Box 56: Educational programmes highlight drought issues in US schools

The U.S drought Portal provides information on water conservation, efficiency, and demand management and is a clearinghouse of links to information about drought and water conservation. One part of the site provides resources for school educational programmes. 'Drought for Kids' from the National Drought Mitigation Center gives an overview of drought – the science, the impacts, and what people can do to prepare for drought and provides a collection of links to resources for teachers. The Delaware River Basin Commission offers 'Drought for Kids' information that describes drought, gives conservation tips, the effects of drought on plants and wildlife, with links to games and other resources.

WaterWiser also provides more advanced educational materials. For example, a training module is available for weather forecasters and anyone wishing to gain fuller understanding of the US definitions of drought, measures of drought severity, indicators and monitoring of drought, drought impacts, and drought predictions.

The Digital Library of Earth Science Education encourages people to do their own research, and maintains the searchable Digital Water Education Library.

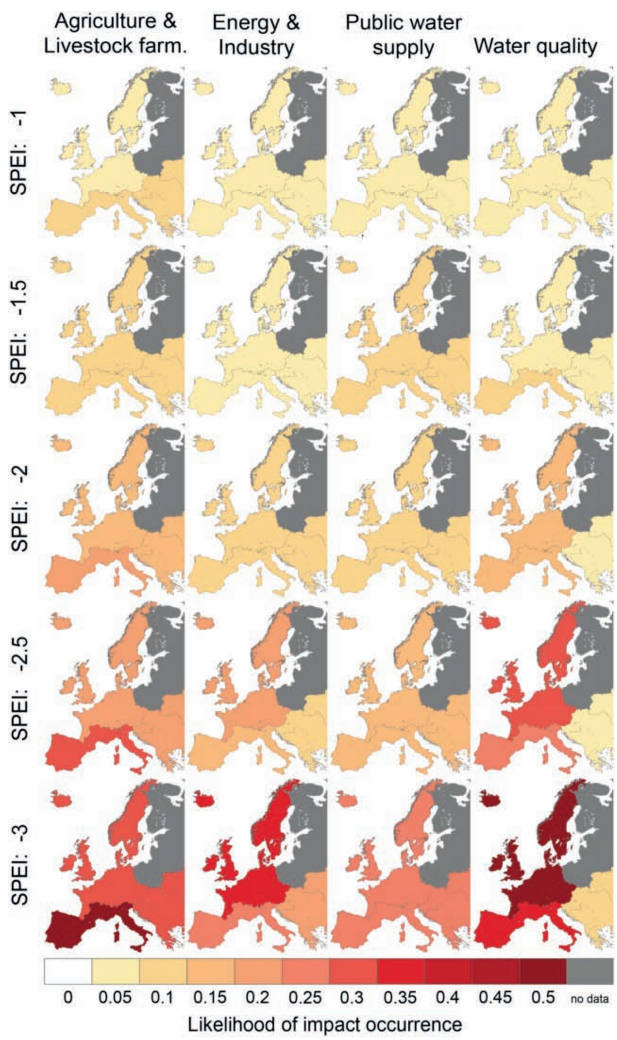
Links and sources:
US Drought Portal: https://www.drought.gov/drought/content/resources/education accessed 5 November 2015
Drought for Kids http://drought.unl.edu/DroughtforKids.aspx Accessed May 2016
Digital Library of Earth Science Education http://www.dlese.org/library/index.jsp Accessed May 2016

MAPPING DROUGHT RISKS AND DROUGHT ZONATION

To be successful, SDRM requires stakeholders to be aware of and to understand the risks, the spatial and temporal coherence of risks, and how risks might change in the future (Box 57). Without a wide appreciation and acceptance of risks, effective action can be slow to implement. One important vehicle in developing this understanding is the ready access to credible drought hazard and drought risk maps that are:

- **Clear on their purpose and the decisions they support:** The most effective maps have a clear purpose and role in decision making. This role may be for general communication of drought risks for public awareness raising; for national-scale planning; for the zonation of development areas (Box 58); for transboundary negotiation understanding the spatial and temporal coherence of widespread drought; or for identifying risk hot spots to support investment. Being clear on the specific purpose of the mapping activity is an important first step towards ensuring that maps are useful and useable.
- **Clear on what is mapped:** As introduced in Chapter 3, drought risk is a combination of the probability of drought hazard occurring and the associated exposure and vulnerability. Any drought risk mapping should be clear on these aspects and how they have been combined. To date, most published resources classify drought risk as a combination of a hazard index and a vulnerability index, where the vulnerability index is a combination of subjectively weighted vulnerability factors (for example Sreedhar *et al.*, 2013) without really understanding the impacts of the drought risk. A recent study (Blauhut *et al.*, 2015) uses a statistical assessment of past drought impacts to develop damage functions – past drought impacts are used as a proxy for category-specific vulnerabilities without subjective weighting procedures. This approach enabled the regional likelihood of drought impacts for given severity of hazard to be mapped (Figure 9.2).

Figure 9.2. Drought risk map for Europe: The likelihood of impact category for five different hazard levels defined using the Standardized Precipitation Evapotranspiration Index (SPEI)



Source: Blauhut et al., 2015

- **Honest about limitations of the evidence:** Communicating risk is complex. Policy-makers often demand precise information about droughts and fail to recognize the uncertainties that exist. The public at large expect to use water as they wish, and expect others to provide that water. Political leaders, who wish to remain popular, are often reluctant to dissuade users from this view. Mapping a range of risk metrics together with clear statements on the associated confidence in these estimates provides vital support to this dialogue.
- **Based on a process of ongoing improvement using all available expertise and resources:** Maps should be updated to take account of evidence from a range of ongoing, in-situ and remote observations, including sharing information across regions and national boundaries, and local observations by community groups and other local stakeholders.
- **Clear about the distinction between real time and long-term average risk:** Both real-time (short-term forecasts) and average annual expectation maps have a role to play. Real-time status reports, based on local evidence, and forecast reports, based on forecast data and local knowledge, can communicate an understanding of how drought risks are likely to change. Given the potential for drought to be driven by large-scale climate, regional and even global cooperation is important.

Box 57: Providing access to information on drought to help promote community resilience: US national drought mitigation and monitoring resources

The National Drought Mitigation Center's website (drought.unl.edu) has been compared to an online textbook for drought planning. It includes an overview of key concepts related to drought planning and an extensive collection of state and local drought plans and resources.

The National Drought Mitigation Center has worked closely with the National Integrated Drought Information System on the US Drought Portal (drought.gov) as well as delivering workshops and webinars for stakeholders, planners, and scientists; holding a national drought forum; and establishing early-warning systems for regional drought.

The US Drought Monitor (droughtmonitor.unl.edu) is a national collaborative effort to synthesize multiple indices and impacts and produce a weekly map of drought conditions across the country.

The newly completed Drought Risk Atlas (droughtatlas.unl.edu) has historic drought comparisons using climate station data. The Drought Management Database (drought.unl.edu/drought management/Home.aspx), also recently launched, is a growing collection of planning strategies. These projects are ongoing and part of the National Drought Mitigation Center's mission to disseminate information to help reduce societal vulnerability to drought.

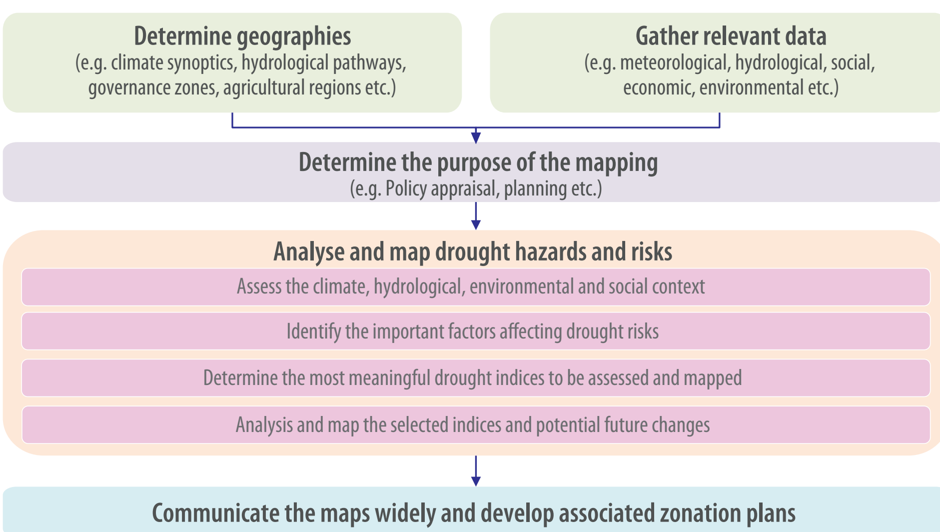
Planners and stakeholders are encouraged to use and add to the Drought Impact Reporter (droughtreporter.unl.edu), which has a collaborative mapping component. Additional local observations or summary reports in the Drought Impact Reporter contribute to a better understanding of drought impacts across socioeconomic and environmental systems and help create a permanent record of impacts for both local and general use.

Source: Schwab, 2013

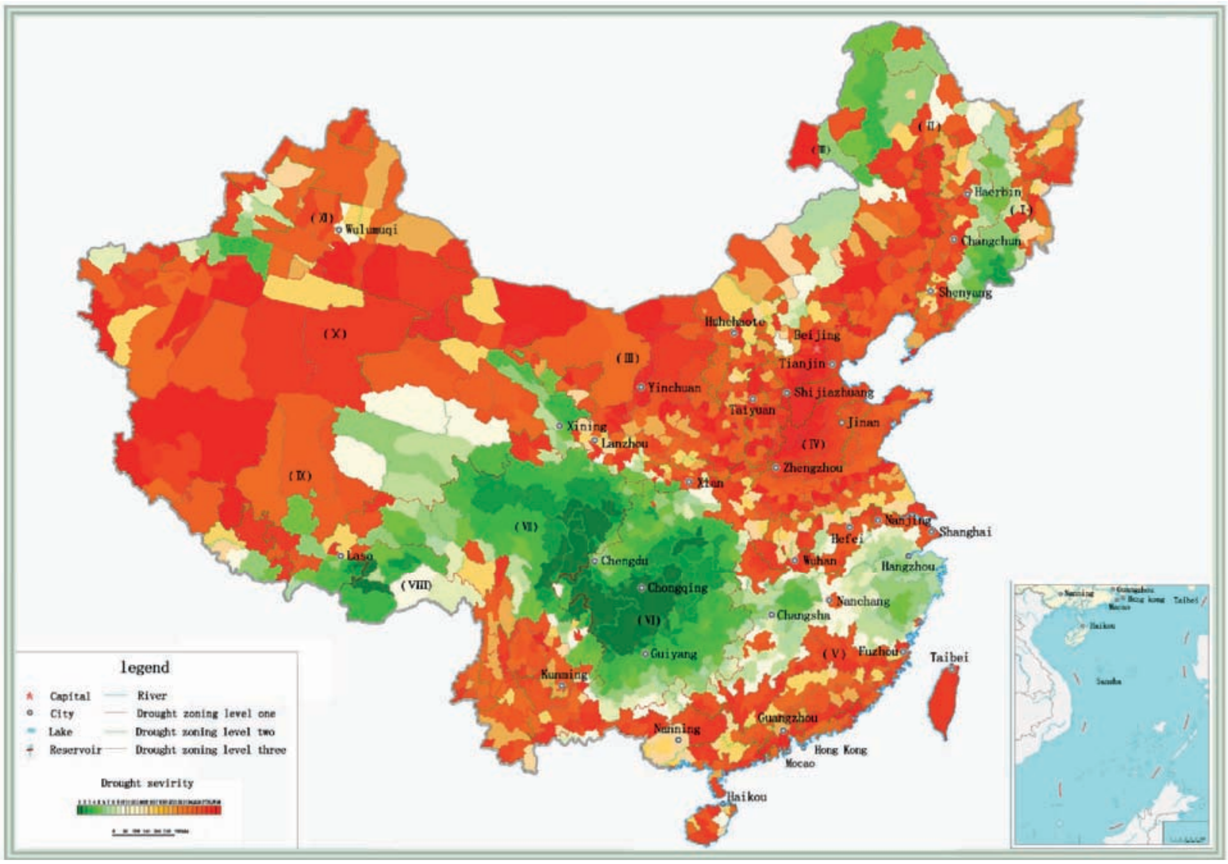
Box 58: Developing drought-risk maps and zonation planning: an example from China

Drought-risk mapping and the zonation of drought hazards and risks has been the subject of significant research in China in recent years. This work, led by the General Institute of Water Resources and Hydropower Planning and Design (GIWP) and the Ministry of Water Resources, is being used to inform national policies around drought management. To develop the maps, the GIWP have gathered data gathering and undertaken numerical analysis to develop a series of zonation maps.

The basic process of drought zonation being followed by the General Institute of Water Resources and Hydropower Planning and Design and the Ministry of Water, China



The regional zonation by the severity of the severity of the drought hazard, China



Source: Research undertaken by the GIWP, China

ENCOURAGING BEHAVIOR CHANGE: NEGATIVE AND POSITIVE CAMPAIGNS

Encouraging drought-sensitive behavior through the public 'shaming' of individuals and organizations considered to be wasting water is an increasing feature of drought events. Recent droughts have seen an escalation in the use of social media to shame excessive users and highlight leaks. In California, for example, it is common for residents to share pictures and videos of neighbours wasting water, using the 'Drought Shame app' and via other social media platforms. By November 2015, which was four years into the drought, state authorities encouraged the shaming process and launched a website (www.savewater.ca.gov) to which residents could send details and photos of water waste. Local water agencies or municipalities followed up on select reports with warnings or, in some cases, fines. Although there is no clear evidence on the effectiveness of drought shaming in terms of water savings, it can clearly engage the public and raise awareness of drought issues.

Positive campaigns are also useful to raise awareness. During the San Francisco drought of 1976–77, the city turned water rations into a challenge, an adventure even, to find out just how little water they could use. Radio advertisements urged them to 'shower with a friend'. Similar tactics continue to be used today. During the California drought (2010 ongoing) the public have been, in part, challenged to make saving water into a game. However, the vast majority of communications reinforce the serious nature of water conservation.

Communication should seek to encourage individuals and communities to actively participate in reducing the water-related risks they face. To do this effectively is difficult and requires communication to connect with audiences and focus on specific issues that motivate (and enable) regional and local governments, organizations and community leaders to act.

9.6. Funding and incentives

Economic instruments and financial measures can be powerful in supporting the delivery of SDRM. These instruments and measures can include payments for ecosystem services, polluter pays systems, appropriate water pricing frameworks (discussed in 7.2.5), compensation payments or grants and better coordination of limited available funds.

PAYMENTS FOR ECOSYSTEM SERVICES

In most countries, some form of payment for water use is usual. Payments typically include an allowance for a certain standard of service being provided in drought conditions. Additional payment systems may be required when specific water users require a higher standard of service for reliability or quality water supply, even during drought conditions. Additional payments can be made by these water users to water-supply utilities. But additional payments could also be made to other groups that safeguard water-related ecosystem services to reduce drought risk. For example, Payment for Ecosystem Service (PES) schemes have emerged over recent decade. Often stimulated by civil society, these schemes transfer payments from 'buyers' of ecosystem services (mostly downstream businesses or municipalities) to 'sellers' (usually upstream land managers or farmers). PES schemes involve payments to the managers of land or other natural resources in exchange for specified ecosystem services, or actions anticipated to deliver these services, over-and-above what would otherwise be provided. Well-designed PES schemes can be an effective way help maintain or enhance these ecosystem services by, for example, entering into agreements with individuals, communities, businesses or governments.

To be effective the design of the PES scheme should include:

- **Voluntary entry:** stakeholders enter into PES agreements on a voluntary basis.
- **Benef ciary pays:** payments are made by the beneficiaries of ecosystem services – individuals, communities and businesses or governments acting on behalf of various parties.
- **Direct payment:** payments are made directly to ecosystem service providers. In practice, this is often via an intermediary or broker.
- **Additionality:** payments are made for actions over-and-above those that land or resource managers would generally be expected to undertake. Precisely what constitutes 'additionality' will vary from case-to-case, but the actions paid for must go beyond regulatory compliance.
- **Conditionality:** payments are dependent on the delivery of ecosystem service benefits. In practice, payments are more often based on the implementation of management practices that the contracting parties agree are likely to create these benefits.
- **Ensuring permanence:** management interventions paid for by beneficiaries should not be readily reversible, and therefore, provide continued service provision.
- **Avoiding leakage:** securing an ecosystem service in one location should not lead to the loss or degradation of ecosystem services elsewhere (Smith *et al.*, 2013).

POLLUTER PAYS

Many countries have existing, albeit imperfect, mechanisms for imposing fines or charging for permits for industries or individuals who pollute or over-abstract water resources. These schemes vary: in some countries funds are returned to the local or central government exchequer; in others, they may be ring-fenced for environmental projects that, to some extent, offset damage to ecosystems or treat pollution. Depending on the arrangements, polluter fines might be used for drought risk reduction measures in the river basin where the polluting or damaging activity occurred. It must be recognized that not all degradation, or 'pollution', can be compensated for financially. Therefore, this principle should be applied in the context of other instruments to ensure long-term damage is avoided.

In the US, for example, although hydropower is an important source of renewable energy and a critical component of the nation's energy portfolio, it has significant negative impacts on fish, including blocking fish passage and altering flow, temperature, and sediment regimes. To promote sustainable hydropower facilities, The Nature Conservancy has suggested that additional conservation efforts should be funded from hydropower revenues and licensing fees. The suggestion is that this funding should be used to support conservation efforts within the basin from which the revenue is generated to restore hydrological or ecosystem functions. This suggestion follows the example of the Columbia Basin Water Transactions Programme, which restores and protects in-stream flows above hydropower facilities to the benefit of power production and endangered salmon, steelhead, and native trout populations.

Compensation, grants and tax incentives are all legitimate tools for changing behavior to deliver water-saving outcomes:

- **Compensation:** Compensation can take a variety of forms and may be linked with PES schemes. An example of compensation includes rewarding landowners who change their agricultural practices to reduce the demand for irrigation water and support the strategic management of floodplains and groundwater recharge. Or, for example, replacing financial support for groundwater pumping in over-tapped aquifers with payments for short-term water transfers among users to reduce drought impacts without increasing basin-wide water scarcity.
- **Grants:** Grants can be a powerful way of changing behavior. In the US, for example, the Bureau of Reclamation provides grants for water reclamation and water reuse projects under the Department of the Interior's WaterSMART initiative. WaterSMART focuses on improving water conservation,

sustainability and helping water resource managers make sound decisions about water use. It is recognized as a powerful tool for conserving water through collaborative local projects, with 80 grants issued in 2013/14 saving an estimated 200 million m^3 of water per year. WaterSMART have also established two rebate programmes to encourage Californians to replace inefficient toilets and grass lawns with more water-efficient alternatives. The so-called 'turf and toilet' programme is expected to provide rebates of US$30 million to replace more than 10 million square-feet of lawn and upgrade more than 60,000 water-wasting toilets.[37]

- **Tax incentives to encourage exchange of water entitlements:** In many countries, tax deductions are one of the main financial incentives for charitable contributions or donations of real property. In the US it has been suggested that giving water rights to a state should be entitled to a federal tax deduction (US Nature Conservancy, 2015). Lack of a tax incentive is considered one of the primary obstacles to water rights donations by landowners. Such incentives may, in some instances, encourage landowners to donate all or a portion of their water rights to federal and state water resource managers, which would enable more effective drought risk management strategies to be developed.

COORDINATE FUNDING PROGRAMMES

Drought management is typically paid for by government or quasi-government organizations funded through general taxation. This makes sense because there are often broad social or economic benefits to society depending on the way drought risk is managed. However, opportunities often exist to streamline the multiple sources of government funding to support better water resource outcomes. Ensuring that all relevant funding sources are prioritized, to the extent possible, to reduce drought risk, create flexibility in water management and improve the reliability of water provision on a basin scale is an important precursor to maximizing the benefits of investment. In particular, this includes coordination with stakeholders across the water sector to coordinate all funding sources available for drought risk management, conservation, water-related infrastructure and, in coastal areas, salinity control.

Enabling both private sector and public funding sources to be combined and coordinated can also bring additional funding for drought-related issues. For example, in California, federal agencies have been asked to review all cost-sharing (private/public) programmes to determine whether eligibility requirements are limiting participation in drought-resilience efforts. Some non-government organizations that could bring matching funds to projects are prohibited from applying for some grants.

9.7. Science and research

Droughts are complex, large-scale phenomena involving numerous interacting climate processes and various land-atmosphere feedbacks. They impact human systems and freshwater ecosystems in a variety of ways. Although progress has been made, these phenomena and interactions are still not well understood, which makes it difficult to adequately characterize, monitor, forecast and manage drought. Improving our scientific understanding will be central to improving SDRM in the longer term. This will include advancing science to enhance the understanding of the: (i) drought hazard, including climate drivers and the processes that lead to meteorological, blue-water drought and green-water drought; (ii) associated environmental and socio-economic impacts; and (iii) vulnerabilities, risks and policy responses.

37. http://www.water.ca.gov/waterconditions/ accessed November 2015

PART C

SUPPORTING EVIDENCE: INTERNATIONAL CASE STUDIES

CHAPTER 10
CASE STUDIES OF EXISTING AND EMERGING PRACTICE

10.1. Introduction

International approaches to drought management vary in response to particular challenges faced, the underlying scarcity of water and climate variability, as well as the political and institutional context and cultural traditions. To support the development of this book, the approaches adopted in six regions were reviewed (Table 10.1). These unpublished studies were used to inform the earlier chapters and are briefly summarized in this chapter. The context within which drought management takes place in each country or region is summarized in Table 10.2.

10.2. Europe: England and Spain

OVERVIEW

Northern Europe is often considered as having adequate water resources; however, an imbalance in the long-term water demand and the available water resources is no longer uncommon. As a result, when drought episodes have occurred their impacts have been acutely felt, particularly in southern European countries (such as Spain) and the south-east of England. In 2003, for example, Europe experienced a severe drought, resulting in about €10 billion in economic losses (EC, 2007a). The drop in water levels affected the stability of dykes; interrupted navigation on the Danube, Elbe and Rhine Rivers; and slowed energy production with hydroelectric dams in Spain operating well below capacity and nuclear power plants in France struggling to find river water to cool their reactors. A combination of crop failure, forest fires and loss of income from tourism, travellers were discouraged by water restrictions and record temperatures, exacerbated economic impacts. A significant number of deaths were also attributed to the associated heat wave. The event was the first of a series of droughts over the coming five years.

POLICY CONTE T

At a European level the primary legislation on water is provided through the Water Framework Directive (WFD, 2000). Under the WFD, member states must demonstrate that, with some exceptions, all water bodies meet good ecological status, and they must maintain a cycle of river basin management planning to act as primary mechanism for organizing action to achieve or maintain good ecological status. The WFD also commits member states to ensuring no deterioration in the ecological status of water bodies. The WFD sets out what member states must achieve without dictating the means of achieving that result. A summary of this policy and legislative framework is in Box 59.

To support the process of implementation, in the context of water, the European Commission has provided the Strategy for Water Scarcity and Drought (WSandD) that reflects the European Blueprint for Water (EC, 2007a). The Blueprint for Water sets out the requirements to support sustainable water resources:

- pricing water correctly
- improving drought risk management
- fostering water-efficient technologies and practices
- creating a water-saving culture
- allocating water and water-related funding efficiently
- considering additional water supply infrastructure
- improving knowledge and data collection.

The roles and responsibilities in Spain and the legal framework in England are summarized in Boxes 60 and 61 respectively.

Table 10.1. Case study reviews: Locations and authors[38]

Case/region	Lead author
Europe providing an overview of European policy with a more detailed focus on England and Spain	Paul Sayers (Sayers, 2013) with valuable contributions and advice from: • Chris Lambert (Thames Water) • WWF-Spain • Guido Schmidt.
Middle East and North Africa (MENA) with a focus on Morocco and Syria	Guy Jobbins and Hammou Laamrani (Jobbins and Laamrani, 2013)
North America (US)	Wen Lei, with subsequent contributions from Don Whilite (Wen, 2013)
Asia (China)	General Institute of Water and Hydropower (GIWP) Planning Team led by Professor Li Yuanyuan and Professor Li Jianqiang.
Asia (India)	Indira Khurana and Suresh Babu (Khurana and Babu, 2014)
Australia with a focus on the Murray–Darling, Victoria	Robert Speed (Speed, 2013)
Latin America with a focus on Mexico and Brazil	José Antonio Rodríguez Tirado (Mexico) (Tirado, 2013) Mario Mendiondo (Brazil) (Mendiondo, 2013)

Table 10.2. Context of the case studies

Region	Europe	Middle East and North Africa Region (Morocco and Syria)	North America	Latin America (Brazil and Mexico)	Australia	Asia (China)	Asia (India)
Policy drivers	At a European level, the policy drivers are provided by the Water Framework Directive (focusing on achieving good ecological status for water bodies) and the Strategy for Water Scarcity at an EU level, together with associated national policy and legislation.	State-centered planning. Prevention of mass rural migration for social and political reasons.	Absences of national policies as drought planning activities are conducted by state, regional, local, and tribal governments.	An absence of drought-related national policies, although recent droughts have supported developments in this area.	Water-related aspects of drought responses captured as part of a broader water reform agenda (e.g. under the 2004 National Water Initiative), which was part of national macro-economic reforms, as well as in response to over-allocation and environmental concerns.	National Drought Relief Regulations 2009 have a focus on guaranteeing domestic water supply, coordinating the use of water for production and for ecosystems and promoting sustainable development.	Disaster Management (DM) Act 2005, with a focus on providing better planning and mitigation, including for drought. Several programmes are being implemented to address drought, but results are not commensurate with the funding.
Institutional set up	Within each member state, a lead competent authority must be identified for each river basin. Delivery responsibilities are through various local authorities and regulated water companies. A combination of institutions provide information on drought risks.	A complex and emergent set of national institutional arrangements with fragmented institutions and multiplicity of actors. Predominance of the role of local authorities in assessing impact and decision making in assistance allocation in both countries.	National drought monitoring (NIDIS) and mitigation services (NDMC), state drought plans and authorities.	A complex mix of multiple federal ministries and agencies, regional and basin agencies and more local councils.	Local government lead on urban water supply. State government leads on water resources management.	Ministry of Water Resources takes a lead in developing water-related policies and guidance. Multiple other national level ministries have a role in delivering water-related policies. Responsibility of implementation is typically devolved to provincial, county and city-level governments.	National Disaster Management Authority at the federal level, similar authorities at the state and district levels. For drought, the Ministry of Agriculture is a nodal agency for inter-sectoral coordination. Community-level initiatives of water harvesting and drought proofing.
Social and environmental dimensions	Competition between ecosystems and industrial and human demands is increasing and there is a growing social expectations for both reliable water supply and ecosystem health.	Inequalities between regions in access to state services. Focus on rural areas, although urban poor are also impacted.	Competition between ecosystems and industrial and human demands is increasing and there is a growing social expectation for both reliable water supply and ecosystem health.	Cooperation among institutions, engagement of stakeholders and the awareness of drought risks, particularly to ecosystems are all significant challenges.	Over-allocation of water resources leading to water-security issues for irrigators and significant environmental degradation. Recent droughts with severe impact on major urban centres for the first time.	Serious tensions between water for economic uses and for ecosystems due to rapid development and population increase. Climate change and land-use change leading to an increase in extreme weather events, including more frequent and intense droughts.	The significant divide by rural and city economics, the focus on economic growth has heightened perceived conflicts between different sectors of society and between ecosystems and human needs. Outcomes appear to significantly disadvantage the rural poor.
Overarching issues	The relative water consumption varies across member states. In Spain, agricultural demand dominates; in England, domestic and industrial demand are dominant. The regulated nature of the water utility industry tends to limit innovation as the focus is on short-term goals with clear economic returns. The need for a long-term, risk-based, approach is widely recognized.	There is limited expertise in institutional and policy dimensions and no coherent vision. There is also a predominant agriculture focus and limited innovation in off-farm responses. Political engagement is intermittent and crisis driven.	The lack of a National Drought Policy (with preparedness and mitigation at its core) means few states are appropriately preparing for drought. Recent droughts (particularly in California) have highlighted the lack of a coherent water resource plan capable of managing drought risks sustainably.	There is a long history of focusing on reactive efforts directed to provide water and food and to minimize economic impact once drought is declared. Infrastructure solutions have tended to dominant the longer-term water resource planning process.	There has been a move away from drought as a natural disaster to recognizing drought as natural part of climatic cycle and encouraging individual responsibility for planning and preparing for drought. National competition reforms have introduced water markets across most basins as means of driving increased productivity and efficiency.	There is a lack of co-ordination among multiple management authorities and a lack of system design and implementation from basic research, planning, response, to evaluation of drought response.	Significant ongoing conflicts between water users are heightened during droughts.

38. The review of drought approaches in Syria was compiled before the onset of the civil war, which has had profound impacts of people in the region.

Box 59: The policy and legislative framework of the European Union

The EU operates through a system of supra-national independent institutions and intergovernmental negotiated decisions by the member states. Institutions of the EU include the European Commission, the European Council, the Court of Justice of the European Union, the European Central Bank, the Court of Auditors, and the European Parliament. The European Parliament is elected every five years by EU citizens.

The EU sets out requirements of member states through various instruments, including:

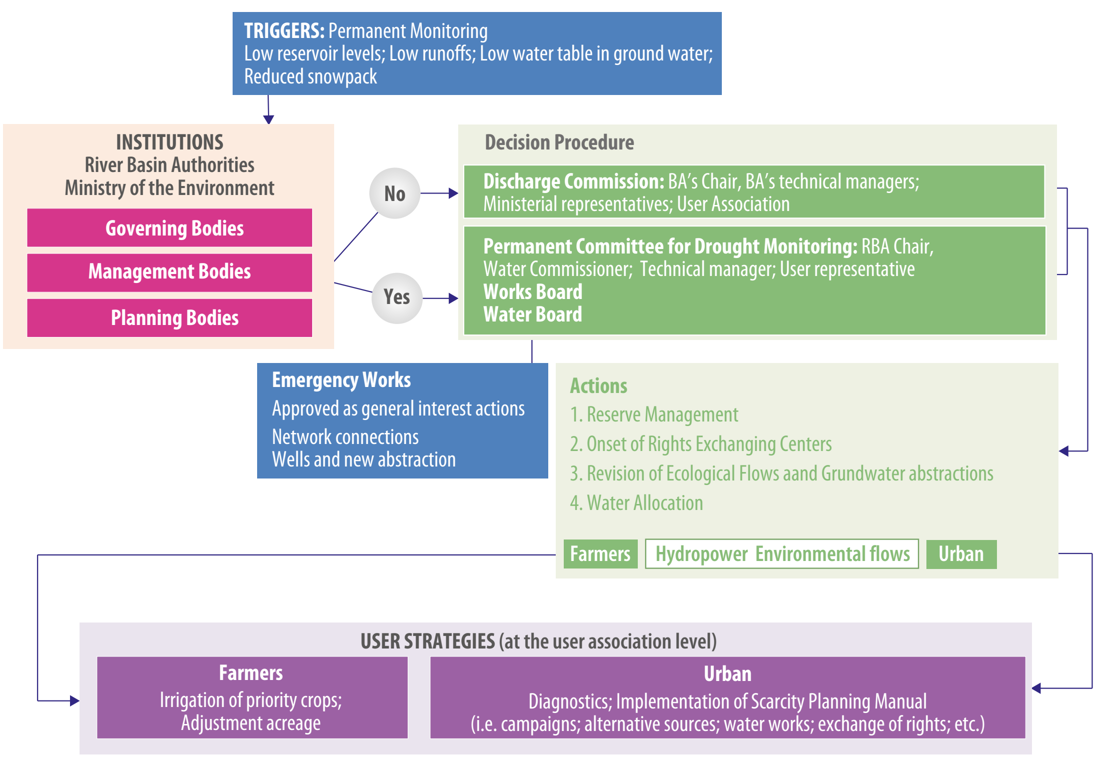
- European Policy: Sets the broad aim to be achieved. For example, the main overall objective of EU water policy is to ensure access to good-quality water in sufficient quantity for all Europeans, and to ensure the quality status of all water bodies across Europe. Policies are often published as discussion documents, such as expert reports and communications. For example, the water policy is supported by three primary documents that do not have any legal status:
  - The Blueprint Communication (European Union, 2012)
  - The 4th Implementation Report on the Water Framework Directive - River Basin Management Plans (European Union, 2015)
  - A review of the Strategy on Water Scarcity and Droughts (European Commission, 2012).
- European Regulations: Must be implemented by member states with little room for interpretation.
- European Directives: A directive is a legislative act of the European Union that requires member states to achieve a particular result without dictating the means of achieving that result. For example, the Flood Risk Management Directive requires individual member states to undertake a flood risk assessment and development flood risk management plans for areas at significant risk. Currently, there is no specific directive on drought.
- European Decisions: Typically require an individual, organization or company to take action in a prescribed way.
- Subsidiarity Principle: The principle of subsidiarity states that a matter should be handled by the smallest, lowest, or least centralized authority capable of addressing that matter effectively. According to this principle, the EU may only act (i.e. make laws) where action of individual countries is insufficient.
- Member state: An individual sovereign nation within the EU. Member States are free to develop the detail of legislation, regulations and processes to meet the requirements of a directive.

Box 60: Water management roles and responsibilities in Spain

Water management planning responsibilities are divided between the Central Government, Regional Governments and River Basin Authorities (RBAs) in Spain. The operational management and delivery of the planning often falls to the local authorities. The Central Government (through the Ministry of Environment) provides the national policy lead. Regional Governments then manage the river basins that lie wholly within their region and RBAs manage the trans-regional rivers.

RBAs were first established in 1927 and manage the majority of water resources within Spain. Although the RBAs are established by the Ministry of Environment they function autonomously from the national government. The competent water authority (either the RBA or the regional administration) takes the lead in both managing water scarcity and drought planning. Their actions are guided by the National Hydrological Plan, set out by the ministry, and compliance with relevant EC directives. The interactions between the component water authority, the ministry and other stakeholders in discharging their responsibilities during a drought are set out in the figures below.

Institutions and their roles and responsibilities during a drought



Source: Garrote et al., undated.

Before the Water Framework Directive (WFD) was implemented, the RBAs took their lead from the National Hydrological Plan to develop specific basin plans. However, the WFD advocates a 'bottom-up' process starting at the RBA level. RBAs represent the highest administrative body to manage and control water resources. RBA are also responsible for constructing water infrastructure using a combination of their own financial resources and national contributions. Regional and political interests therefore lead to an ongoing process of renegotiation over river basin boundaries. This can involve both the aggregation of smaller rivers into large basins and, more often, the disaggregation of large basins in several small river basins to enable responsibility to be transferred to the regional governments (as seen in the former Júcar and Norte River Basin Districts).

Box 61: Legal framework for water management in England

The relevant legislation in England includes a number of water-specific Acts and supporting legislation.

The Water Industry Act 1991 and Water Industry Act 1999 deal with issues associated with water and sewerage companies and licensed water suppliers as well as regulation by The Department for Environment, Food and Rural Affairs (Defra, the lead water ministry), the Office for Water Services (Ofwat, the economic regulator of the privatized water utility sector), the Drinking Water Inspectorate (DWI) and the Consumer Council for Water (CCWater).

The Water Resources Act 1991 as amended by the Water Act 2003 regulates of water resources management and water quality standards by the Environment Agency (the statutory environmental regulator of the water utility sector). The Act allows for three legislative ways for dealing with drought situations: drought permits, ordinary drought orders and emergency drought orders. Under the Water Act 2003 there is also a statutory requirement for water companies to prepare, maintain and publish drought plans. Drought plans cover the range of actions necessary to deal with various drought situations. They set out how a water company will continue to meet its duties to supply water during drought periods with as little recourse as possible to drought permits or drought orders.

The Flood and Water Management Act 2010 seeks to improve the process for temporary bans on water use during droughts; introduce mandatory standards and automatic adoption by water and sewerage companies of sewers connected to the public sewerage system; and make more robust arrangements for the approval, adoption and maintenance of sustainable urban drainage.

The Climate Change Act (2008) requires water companies, the Environment Agency and industry in general to set out their approach to adapting to climate change.

Supporting environmental legislation: There are numerous other aspects of environmental legislation that impact water resource management and actions taken during drought. In particular, an assessment of the expected environmental effects must be submitted alongside any application for a drought permit or drought order. The environmental assessment should include as minimum (i) the likely changes in flow/level regime due to implementing the proposed drought permit or order; (ii) the ecosystem features that are sensitive to these changes; (iii) the likely impacts on sensitive ecosystem features; (iv) mitigation that may be required to prevent or reduce impacts on sensitive ecosystem features; (v) in-drought and post-drought monitoring requirements.

Where the proposal for a drought response measure is likely to damage an important habitat site, or where it cannot be proven there will be no adverse effect, the applicant must demonstrate that all other possible options (or alternative solutions) for public water supply have been identified and used before the Environment Agency or Defra will approve the application. The more environmentally damaging the impact on the water environment is, the more stringent the measures need to be to reduce demands on water resources.

PROGRESS IN DROUGHT RISK MANAGEMENT PLANNING

Water resource planning in the context of drought is expected to form part of national, basin and local decision making (EC, 2007b). At a member state level, the focus is on policy, legal and institutional aspects, as well as insurance to mitigate extreme drought effects.

At a basin level, Article 13.5 of the WFD notes that when appropriate, a drought management plan (DMP) should be developed as part of a broader river basin management plan. Although not an obligation, the main objectives of the DMP (when developed) are to:

- guarantee water availability in sufficient quantities to meet essential human needs to ensure a population's health and life
- avoid or minimize negative drought impacts on the status of water bodies, especially on environmental flows and quantitative status for groundwater
- minimize negative effects on economic activities, according to the priority given to established uses in the river basin management plans, in the linked plans and strategies (e.g. land-use planning).

At a local level, the focus moves to implementing the DMP and the tactical response needed to meet essential public water supply and raise awareness of the actions individuals and organizations must take. Guidelines for the development of a DMP are also provided by the European Commission (EC, 2007b) and include setting out:

- indicators and thresholds of action to be used (Box 62)
- measures to be implemented as the severity of the drought deepens
- organisational framework to deal with drought and subsequent revision and updating of the existing drought management plan
- how 'prolonged droughts' will be managed – Article 4.6 of the WFD allows for 'temporary deterioration' of the associated water bodies, but the DMP must include a clear prioritization of water use and the impact of emergency restrictions.

Box 62: Trigger points in Spain's Drought Management Plans

In 2007, Spain approved Drought Management Plans (DMP) (Planes Especiales de Sequía) for all river basins, in compliance with the 2001 Water Law. For the first time, the plans established a standard for adapting water allocation to periods of extreme low water availability. The plans operate by setting different threshold levels (normal, pre-alert, alert and emergency) depending on the resources available in each system within the basin at each point in time. Each level triggers different actions starting with public awareness campaigns and rising progressively through efficiency measures, sale of water permits and finally to imposed restrictions. The goal of each action is to avoid reaching the next level and, ultimately, to avoid imposing severe use restrictions. Although there are a number of weak aspects to the legislation (e.g. lack of environmental thresholds, use of different management systems: river basin versus water management area, definition of the economic compensations), Spanish DMPs have been used to design an EU Guidance on DMP and increase the robustness of the system of prior allocation.

The indicative contents for a DMP are also set out as follows:

- general basin characterization under drought conditions
- the river basin's experience on historical droughts
- characterization of droughts within the basin
- drought warning system implementation
- programme of measures for preventing and mitigating droughts linked to indicators systems
- update and follow-up of the DMP
- public supply specific plans
- prolonged drought management.

The degree DMP have been implemented varies across member states varies. In England, for example, national, regional and water company-specific plans have been developed. These plans largely focus on agreeing actions that will be taken as a drought event deepens, including (i) prioritizing water restrictions; (ii) water transfers; and (iii) water trading. In England, where the water companies are privately owned, the DMPs also often used to support any case made to the water regulator (e.g. Ofwat) to invest in increasing reserve capacity through infrastructure solutions as well as decreasing demand.

Many member states within Europe share river basins and transboundary agreements on water sharing during drought are common, but continue to be debated (see Box 63).

Box 63: Transboundary agreements during drought: Spain and Portugal and the Albufeira Agreement

Spain shares five major water courses with Portugal (the Miño, Limia, Duero, Tajo and Guadiana rivers) and shares some smaller river basins with France. Water management of the transboundary rivers with France are addressed with a simple administrative agreement. Management of the transboundary rivers with Portugal (Figure below) is coordinated through historical treaties (reflecting the importance of the rivers and volumes involved). The first treaty was established in 1864 and bilateral treaties and agreements have continued to evolve since with the latest, the Albufeira agreement, signed in 1998.

Under the Albufeira agreement, river flows are guaranteed on a 3 monthly basis and in some cases minimum weekly river flows are established in order to preserve environmental flows. Spain is, however, exempt from achieving these targets during periods of drought. In this case 'drought' is declared when the precipitation in the previous 6 months is around 60-70% lower than the reference period. During these periods water resources in 'bordering areas' must be used for mutual benefit, without adversely impacting one country more than the other whilst avoiding environmental damage downstream. Water control structures within the river network also need to be agreed by both parties (it is unclear how far upstream and downstream this requirement persists).

Map of trans-boundary river basins in Spain and Portugal

PROGRESS IN DROUGHT FORECASTING AND WARNING

The need for improved early warning of drought has also been a central feature of drought management in Europe. Many Member States operate some form of drought forecasting service including the UK and Spain. The European Commission has also established a prototype European Drought Observatory (EDO) (see Box 64).

Box 64: The European Drought Observatory (EDO)

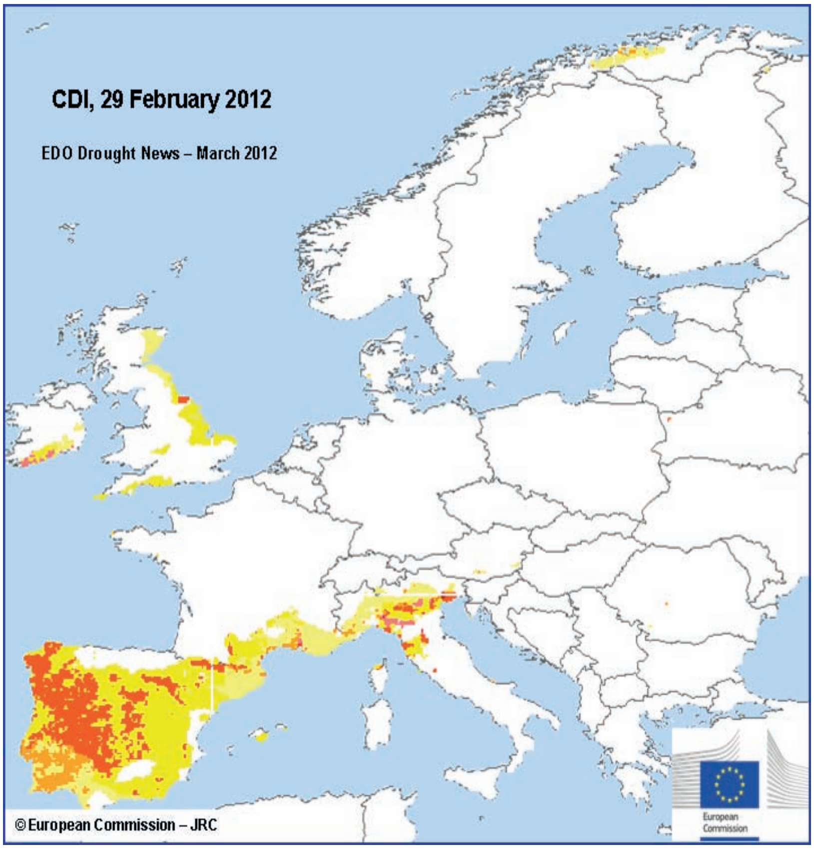
The European Drought Observatory (EDO) provides continuous monitoring of drought indicators across Europe and displays them via a map server. The indicators cover the entire European continent and are presented as absolute values and as a deviation from the expected long-term average. The EDO covers hydrological drought indicators and is starting to link with more detailed regional and local services, such as the Water Information System.

Those indicators provided through the EDO include:

- **Precipitation** (Monthly Standardized Precipitation Index for different aggregation periods)
- **Soil Moisture** (Daily soil moisture, Daily soil moisture anomaly, Forecasted soil moisture anomaly, Forecasted soil moisture trend)
- **Vegetation status** (Normalized Difference Water Index 10-day daily composites, Fraction of Absorbed Photosynthetically-Active Radiation (fAPAR) 10-day composites, fAPAR anomalies 10-day composites).
- **Combined Drought Indicator (CDI),** based on SPI, soil moisture and fAPAR is also provided and used to present one of three levels of drought alert at a pan European scale:
  - *Watch:* when a relevant precipitation shortage is observed
  - *Warning:* when this precipitation translates into a soil moisture anomaly
  - *Alert:* when these two conditions are accompanied by an anomaly in the vegetation condition.

In theory, a monthly Drought Report is published and covers each of these indicators. However, the EDO remains a prototype system. As such, the updating of the monthly reports is sporadic. An example from the March 2012 report is given below.

Combined drought indicator from 29 February 2012



Note: The three colours represent three types of alert messages: (1) yellow (watch) significant precipitation deficit, (2) orange (warning) precipitation deficit leads to a soil moisture deficit, and (3) red (alert) rainfall and soil moisture deficit are accompanied by a reduction of the photosynthetic activity of the vegetation cover (fAPAR). The figure is based on a combination of the SPI-1, SPI-3 and SPI-12 from February 2012, soil moisture anomalies from 11–20 February 2012, and fAPAR anomalies from 21–February 2012.

LESSONS LEARNT AND LIVE ISSUES

Drought planning is typically seen as part of the continuum of water resources planning. Long-term water supply plans allow for occasional drought. Drought plans set out the actions that will be taken to manage water supplies and environmental impacts during a drought. In Europe, this process is generally controlled by government (either as a regulator or operator) and delivered through a combination of public and private sector entities. Some of the common lessons and attributes of current practice that have emerged over recent years together with the live issues and challenges are discussed.

Lessons learnt

Across Europe, the approach to drought management, and more broadly water scarcity management, is being reformed. This includes reviewing the adequacy of traditional approaches of demand and supply management, taking a critical review of historical abstraction agreements and encouraging water trading. A number of importance lessons underpin this ongoing change.

The importance of legislation and drought planning: DMPs are considered essential for managing water resources and droughts and to help make the right decisions at the right time. Legislation at a European scale is being proposed that will mandate that DMPs must be developed. At a national scale, many member states already require them. During drought episodes, exceptional measures are often needed including the use of temporary supplies (for example strategic drought wells or transfer conduits) and water restrictions. DMPs are seen as central to this process.

The need for better monitoring, forecasting and definition of thresholds for action: At a pan-European and member state scale, the importance of good and relevant information on drought risk is well recognized and the identifying and monitoring droughts is becoming increasingly sophisticated. For example, in Spain a national indicator system has been developed to indicate one of four levels of drought alert. Each level is associated with actions identified in the relevant DMP.

Temporary supplies remain a legitimate part of a drought response: New supplies alone are unlikely to support a secure water future. Nonetheless, extraordinary measures to increase supply during drought remain a common, and legitimate, response. In Spain for example, additional 'droughts wells' and increased abstraction for existing sources are both used to increase supply. In England, desalination is used within the Thames Basin. Water transfers, new surface reservoirs, aquifer recharge, and desalination are all explored as part of a broader portfolio response to combat drought.

Financing of water management: There is an increasing focus on the user-pays principle. The user-pays principle typically includes payment through direct metering, but also selling abstraction licences as a way of managing imbalances during periods of drought. Drought situations have also seen increased levels of exemptions allowing some water users (e.g. agricultural) to reduce their share of cost recovery.

Live issues and emerging challenges

Moving from crisis management to strategic drought planning: Traditionally, drought management within Europe has been reactive. Droughts have been considered emergencies and managed through a process of crisis management, rather than based on developing a more comprehensive, longer-term, approach. Drought management plans represent an important step forwards to achieve this more strategic response that sets out a dynamic framework of actions to prepare for, and effectively respond to, drought events.

A lack of evidence on the real costs and impacts: There is a significant lack of objective evidence of how drought influences all aspects of the Drivers-Pressures-States-Impact-Response (DPSIR) model. Cost estimations are made roughly, based on news and lobby groups (for example farming organizations in Spain claiming for total losses). There is equally limited scientific understanding on the ecological and social impacts of water scarcity and drought.

Abuse of emergency powers: Many countries allow water providers to take actions to increase sources of supply and increase storage infrastructure to accommodate droughts. The abuse of these measures has been frequently criticized, with developers taking the opportunity to fund long-term infrastructure projects and justify cost-recovery exemptions for water users during periods of drought. There is a growing concern among the public and environmental groups that drought orders and other emergency measures are being abused to meet rising demands for water. Rivers and their wildlife are threatened by water companies taking too much water, while failing to implement basic water conservation measures. Environmental reports to assess impacts of drought orders are inadequate or developed with limited opportunity for review and consultation. Environmental assessments must be prepared for drought orders well in advance of them actually having to be used to allow consultation much earlier in the process.

Providing relevant information as the foundation for effective drought policies and plans: Drought indicators and risk maps promote effective networking and coordination between competent authorities in water management at different levels as well as the public and are a prerequisite to developing appropriate policies to reduce vulnerability and increase resilience to drought.

Developing better risk-based indicators of drought: New risk-based metrics are yet to emerge in any structured way and various organizations are looking to establish risk metrics both to guide actions during drought episodes and to alleviate future drought risks. Improving the usefulness of **indicators** and better forecasting is ongoing.

Developing institutional capacity to better manage drought: When working towards a long-term drought management strategy, Europe will need to continue to develop the institutional capacity to (i) plan for drought – including assessing the frequency, severity and localization of droughts and their various impacts on crops, livestock, the environment and communities; and (ii) manage droughts when they occur.

Managing illegal abstractions and over allocations: Illegal and unmonitored abstractions are a significant issue in some countries, such as Spain. Reducing the over-allocation of resources also presents a significant challenge in many countries, such as England. Controlling such abstractions during periods of droughts is a difficult political and social challenge but central to the better management of drought.

Developing an efficient and effective market for water (water trading): For water supply to remain sustainable, it is generally accepted that the economic efficiency of existing allocations will have to increase. It is generally considered that water trading could be increased as a legitimate response to water scarcity and drought management. Safeguards to avoid inappropriate trades and the frameworks around trading are being discussed.

Maintaining ecosystem health: Drought is recognized as a serious threat to ecosystem goods and services. Across Europe, droughts typically coincide with higher temperatures, a combination that can significantly impact ecosystems. Major impacts include decreased river run-off and water oxygen levels, and the intensification of cross-sectoral water competition, often resulting in a low priority given to ecosystem water needs. There is also some evidence for increased risk of pest outbreaks, due to an increase of drought-induced vulnerability of plants and a temperature-driven expansion of pest species. More extreme and prolonged droughts can alter species ranges of forest trees, alter forest communities, affect primary production, and may facilitate the invasion of alien species. Ensuring drought management planning processes recognize these wider impacts, and that they build in ecosystem management and ecological restoration as part of these plans, as well as looking for opportunities to optimise ecosystem functions and services as part of the drought risk management strategy, is an important and difficult challenge.

Adapting to future change: Increasingly, the need to adapt to climate and other future change is featuring within the water resource and drought plans

10.3. Middle East and Northern Africa: Syria and Morocco

OVERVIEW

Sixteen of the 22 countries of the MENA region are severely water stressed receiving less than 1,000 m³ of annual renewable water resources per capita (World Bank, 2007). Twelve of these countries have annual renewable water resources of less than 500 m³ per capita, placing them in conditions of absolute water stress (Falkenmark 1986; FAO, 2012).

The region's geography is complex. Deserts and mountains lie close to humid coastal areas, and hugely fertile river valleys cross arid rangelands. The overwhelming proportion of the area is arid or semi-arid, and rainfall is highly variable from year to year and place to place (Eshel *et al.*, 2000). In general, precipitation is higher in coastal and mountain areas and declines inland, and surface and groundwater resources are scarce (Cullen *et al.*, 2002). With most precipitation falling in winter months, water supplies are generally lowest during the hot summer months when demand for water is highest. These factors worsen the situation of general water scarcity, and vulnerability to the impacts of drought makes it the region's most significant natural disaster (Erian, 2011).

Drought has been the major determinant of crop yields and economies in the region, and may have been a key driver of patterns of human land-use and occupation throughout history (Kaniewski *et al.*, 2012). Climate change and repeated droughts are known to have had profound social and political impacts in ancient Mesopotamia and Egypt, and the medieval Middle East (Touchan *et al.*, 2007; Ellenblum, 2012; Kaniewski *et al.*, 2012).

After around 500 years of reduced drought frequency, recent decades have seen increases in drought frequency and severity in the Arab region (Chbouki *et al.*, 1995; Touchan *et al.*, 2007; Touchan *et al.*, 2008). Inland countries such as Jordan and Syria have experienced temperature warming and precipitation decline, with droughts increasing in severity, magnitude and duration (Al-Qinna *et al.*, 2011). Most notably, an area covering Syria, northern Iraq and Iran experienced an intense and prolonged drought from 2006–10, leading to large agricultural losses and displacing hundreds of thousands of people. This was only slightly drier than the drought of 1998–2000 (Trigo *et al.*, 2010).

Between 2000 and 2010, 75% of the Arab region's land area was affected by drought for two or more years, with 38% affected for three or more consecutive years (Erian, 2011). Droughts could occur at different times in the winter rainy season (Göbel and De Pauw, 2010). These events exposed 156 million people to moderate or high levels of drought stress, most seriously in northeast Syria, southern Sudan, the northern areas of Tunisia, Algeria and Morocco, northeast Somalia, northeast Iraq, and the northeast of Saudi Arabia (Erian, 2011). Some studies indicate that the shift in recent decades to dryer conditions with more frequent and severe drought may be associated with global climate change (e.g. Weiß *et al.*, 2007; Al-Qinna *et al.*, 2011; Touchan *et al.*, 2011), although considerable uncertainty remains about this relationship (e.g. Hemming *et al.*, 2010).

In response to this increased frequency and severity of drought, international and regional efforts have been mobilized since the 1990s to promote and support implementation of drought risk management approaches. Key institutions involved have been the Food and Agriculture Organization of the United Nations (FAO), the National Drought Monitoring Center of the United States of America (NDMC), the International Center for Agricultural Research in the Dry Areas (ICARDA), and the Arab Center for Study of the Arid Zones and Dry Areas (ACSAD).

However, these initiatives have been mostly focused on the exposure and management of rangelands and pastoralist communities, the group most vulnerable to drought risk in the region. With a few notable exceptions, water authorities have been much more focused on the increasing problem of general water scarcity rather than specific vulnerabilities to variability in water supply caused by drought.

A more detailed discussion of the drought issues in two of the countries within the MENA region, Syria and Morocco, is presented below.

POLICY CONTE T

An increase in drought events has placed considerable stress on water resource systems. These systems already faced considerable pressures. With typically 80% or more of water resources allocated to agriculture, few water sources remain to be mobilised and with rapid growth in urban demand, the majority of water resource systems in the region have little resilience to significant drought impacts.

Emphasis has shifted to approaches based on improved governance, integrated water resources management, and water demand management. However, these approaches require challenging reforms of institutions and the development of new management and technical capacities. Concerned by the increasing frequency of drought, Morocco has attempted to integrate drought risk reduction approaches within its reforms of the water and agriculture sectors. In contrast, in Syria the process of reform in the water sector did not directly address issues related to drought management.

Both reform processes face considerable institutional barriers, complicated by difficult situations arising from acute water scarcity.

Morocco

The Moroccan process of reform is not complete, and is highly complex, but is showing signs of progress (Jobbins and Laamrani, 2013). The 1995 Water Law established the framework for integrated water resources management in Morocco. Key reforms included the creation of 8 sub-national River Basin Agencies (RBAs), and the privatisation and metering of urban water supply. The law also established new instruments for authorities to respond to drought and other water scarcity emergencies. These included provisions for confining water supply to domestic, urban, and industrial uses, restricting water withdrawals, prohibiting the planting of certain crops, and rationing water supplies to cities. Several articles referred to the strategic value of groundwater in droughts, with provisions for restricting the digging of wells other than those for domestic supply, and requisitioning water from irrigation zones for domestic supply.

Drought management was also incorporated in three key policies published in 2009 - the national strategies for water, agriculture (Plan Maroc Vert) and climate change. The reduction of vulnerability to natural hazards and climate change was one of six strategic actions areas in the National Water Strategy. It called for a national drought management strategy, and for drought plans at the basin level to establish definitions and indicators of drought, proactive measures to diversify water sources, and contingency plans. At the time of writing, a National Water Plan was being developed to operationalize this strategy. The Plan Maroc Vert includes objectives for water conservation, drought resilience, and mainstreaming adaptation and resilience to climate change and variability, including drought periods, in agricultural and water planning.

Despite this progress, at the time of writing the National Drought Management Plan had not been published. Instead, drought management policy and procedure appeared to be evolving through working relationships and committees coordinated by key stakeholders.

Syria

In Syria the pace of reform was overtaken by the development of a prolonged and widespread drought that exceeded coping mechanisms, with severe humanitarian and security consequences (Jobbins and Laamrani, 2013). The Ministry of Water Resources, created by Decree 44 of 2012, absorbed the functions of the former Ministry of Irrigation and assumed supervision of water supply institutions at provincial levels. Other key institutions involved in water resources management are the Ministry of Environment, responsible for water quality monitoring and pollution abatement, and the Ministry of Agriculture, responsible for improving water use efficiency in irrigation.

The Water Law 31 of 2005 provided the principal legal basis for water management. However, it provided no provisions explicitly for managing drought. Article 23 stated that the emergency provision of drinking water was the only exception to the requirement for a permit to dig a well to be obtained in advance.

Law 17 of 1986 created directorates for each water basin. Prime Ministerial Resolution 629 of 2007 further decentralizing decisions, ordering the creation of a commission for each water basin. Water basin commissions are responsible for planning for water shortages in their respective basins, but at the time of writing it was not clear whether any commissions had developed water resource management plans, or whether they had addressed drought risk in any way.

Similarly, the 10th Five-Year Plan (2006–10) and National Water Strategy (2003) prioritized water as a crucial sector, discussed increasing water scarcity and identified the need for an integrated water resources management plan. However, neither document focused on drought and variability in water supply as an explicit issue requiring specific measures in water policy or management.

The National Drought Strategy was developed under the Ministry of Agriculture through FAO-funded technical assistance in 2005 and approved in 2009. It focused on reducing vulnerability to drought, minimizing socio-economic drought impacts, and facilitating post-drought recovery (Ministry of Agriculture and Agrarian Reform, 2012). It was a major departure from prevailing agricultural and water policy because it was based on the principle that drought is a regular environmental feature rather than an aberration. It stressed regular monitoring of climatic, agricultural, hydrological and socio-economic indicators, and linking these indicators to pre-prepared contingency plans, with priority for state interventions given to the most vulnerable population groups.

The strategy focused on managing agricultural drought, particularly in the rangelands. It proposed establishing a National Drought Steering Committee under the office of the Prime Minister, with responsibility for all drought management and planning, including resource allocation and policy-making. The National Drought Steering Committee coordinates inputs from different ministries, including water, and oversees a National Drought Task Force. The National Drought Task Force, chaired by the Deputy Minister of Agriculture, has technical representation from relevant ministries, institutes and agencies. The National Drought Task Force's key role is to prepare and review contingency plans, eligibility for drought relief and recovery, and proposals for reducing vulnerability from the household to the national level. In 2011, a National Fund for Drought Mitigation was established to provide financial sustainability for implementation of drought policy in the agricultural sector. Measures supported include compensation for farmers, funding of an early warning system, and regular monitoring and evaluation, with a budget of 1.35 billion Syrian Pounds (US$19 million) in 2012 (Ministry of Agriculture and Agrarian Reform, 2012).

PROGRESS IN DROUGHT RISK MANAGEMENT PLANNING

Morocco

Morocco has responded to a series of severe drought crises, and associated economic impacts, with a reform process encompassing law, institutions, policies, research, and practice. This reform is characterized by an attempt to mainstream drought risk management in different aspects of national development planning. Establishing an institutional framework for integrated water resource management, including engaging with the private and civil society sectors has been successful. Major watersheds are now managed by semi-autonomous river basin agencies, which plan allocations, collect user fees, and are active in drought management. There is also increased cooperation between authorities, civil society organizations, and water users (Abdul Malak and Fons-Esteve, 2011). However, equity between different water users remains a significant issue, particularly in the context of inter-basin water transfers.

Agriculture remains a key plank of the national economy, but faces increased competition from urban demand and other economic sectors. Economic diversification, (e.g. through tourism) and large investments in water infrastructure have reduced drought sensitivity. In rural areas, drought resilience has been supported by the provision of drinking water network coverage and expansion of irrigated agriculture. However, in the future the largest gains are likely to be made through gains in water efficiency and governance.

Syria

Capacities, institutions and procedures for drought planning and management in Syria were unprepared for the crisis of 2006-10. Anecdotal accounts point to recent efforts by policy makers and officials to reform policies and develop the required capacities. However, in the context of the on-going security crisis it is highly questionable as to whether substantial progress can be made.

Syria also has significant transboundary challenges and also stalled due to the ongoing crisis (Box 65).

Box 65: The transboundary challenge in Syria

Twelve international rivers flow through Syria, the most significant being the Euphrates, Orontes, and Tigris Rivers. Treaties for shared usage have been negotiated with Iraq, Turkey, Lebanon and Jordan. Given the general water scarcity in the region, there is a significant overlap in negotiations between aspects of water resources management, regional politics, and security (Daoudy, 2009). Agreements over the Euphrates with Iraq and Turkey and the Orontes with Lebanon both contain clauses regarding minimum quotas in times of scarcity and percentage shares at other times. However, the different terms of guarantees, coupled with weak monitoring and compliance mechanisms, leaves Syria at a disadvantage in drought years.

In negotiations over dam construction on the Euphrates, Turkey agreed to release an average of 900 m^3 per second and a minimum of 500 m^3 per second to Syria, and to meet any deficits from its own storage reserves; meaning a guaranteed minimum allowance for Syria of 6,623 million m^3 per year (Mourad and Berndtsson, 2011; Elvan, 2012). A similar agreement allows Syria use of a minimum of 1,250 million m^3 per year from the Tigris. However, Turkey has not always met these obligations when facing its own water scarcity challenges. During the drought of 1999–2001 flows fell to around 450 m^3 per second (Zawahri, 2008; Daoudy, 2009). In 2009, at the height of the crucial 2007–10 drought, the Syrian government complained it had received only 400 m^3 per second from Turkey for the previous eleven months (TerraDaily, 2009). Despite irregular meetings of a joint technical committee to oversee water sharing, Syria and Iraq were unable to extract more than promises from Turkey during the drought period.

An agreement with Lebanon over the Orontes River favours Syria in wet years, but favours Lebanon in drought years. Under this treaty, Lebanon can keep 80 million m^3 per year or 20% of flow, whichever is greater, and is required to discharge the rest into Syria (Mourad and Berndtsson, 2011).

As water scarcity becomes more urgent for all these countries, pressure will increase on existing treaties – particularly over the issues of minimum quotas during drought years, and remaining plans for construction of storage dams.

Source: Jobbins and Laamrani, 2013

PROGRESS IN DROUGHT FORECASTING AND WARNING

Across the region, the development of early warning systems has been hampered by the weakness of the relationship between precipitation and ENSO signals (Wilhite *et al.*, 2000) and by a lack of institutional capacity. Some progress has been made, but significant challenges also remain

Morocco

Meteorological drought is tracked by the National Meteorology Office, which monitors rainfall and uses models to produce seasonal forecasts for dissemination to ministries. The National Meteorology Office has benefited from cooperation with international universities and organizations in the development of seasonal forecasts based on meteorological data from Moroccan weather stations. In addition to weekly and seasonal forecasts, key indicators are the observed total number of dry days in the season and departure from normal conditions, usually expressed as a Standardised Precipitation Index.

Hydrological drought stress is monitored through measurements of streamflow, reservoir storage levels, groundwater levels, and the extent of snowpack. This data is regularly compared against scenarios for drinking water supply and the allocation of water to different sectors, triggering response measures when appropriate.

The Ministry of Agriculture monitors agricultural drought stress in each province by tracking harvests. Similarly, livestock drought stress is monitored using indicators of feed supply and cost, conditions of water points, herd health and rangeland condition reported weekly. However, in practice, resource shortfalls and out-dated information management systems limit the implementation of these monitoring systems. Regional and provincial authorities also play an important role in terms of relaying concerns and observations of farmers to more central levels.

Syria

Water monitoring systems in Syria are underdeveloped, even along the major rivers. There is no routine system for sharing data with riparian countries, or using remote sensing to monitor rainfall upstream in transboundary rivers. Attempts to develop a drought early warning system for Syria were hampered by a lack of historical data sufficient to generate drought indices (Wilhite *et al.*, 2000). However, between 2004 and 2006 FAO supported the development of a drought monitoring system based on the Standardised Precipitation Index, and monthly drought bulletins were issued starting in 2005 (FAO and NDMC, 2008). After the end of the project in 2006, the system broke down due to a lack of financial support, but it appeared to have been reactivated following the establishment of the National Fund for Drought Mitigation (Ministry of State for Environmental Affairs, 2010; Ministry of Agriculture and Agrarian Reform, 2012).

LESSONS LEARNT AND LIVE ISSUES

An increase in drought events across the MENA region has placed considerable stress on water resource systems that were already under pressure. With typically at least 80% of water resources allocated to agriculture, few new sources remaining to be mobilized, and rapid growth in urban demand, the majority of water resource systems in the region have little resilience to significant drought impacts in terms of supply-demand surplus.

In more recent years, there has been a shift in emphasis towards trying to improve water governance and reduce demand.

However, existing institutional capacity is low and reform has been slow. For example, concerned by the increasing frequency of drought, Morocco has attempted to integrate drought risk reduction approaches within its reforms of the water and agriculture sectors but these have, as yet, had limited impact of promoting resilience to drought although is showing signs of progress. In contrast, in Syria (prior to the civil war) the process of reform in the water sector largely failed to address drought-related issues and the pace of reform was overtaken by the development of a prolonged and widespread drought that exceeded coping mechanisms, with severe humanitarian and security consequences.

The difficulty in implementing reform is in part due to the limited technical and governance capabilities at a local level, despite relatively strong skills at a national level. As a result, any reform process faces considerable institutional barriers, complicated by difficult situations arising from a severe underlying water scarcity.

More specifically, the live issues in Morocco and Syria, are summarized here.

Morocco

Morocco has made significant strides towards the integration of risk management approaches at a policy and institutional level, although the impacts of these on the ground have yet to be fully realized. The focus on institutional and legal reform raises expectations of sustainability, but strengthening capacity and resilience will take time, and Morocco remains highly vulnerable to a multi-year drought.

Syria

Syria faces a number of pressing challenges for improving drought planning and management in water resources management. These include weaknesses in data and analytical capabilities and institutional fragmentation. However, the most critical issues relate to unsustainable water demand in agriculture and improved risk management of dependency on transboundary sources of water. Droughts affecting Syria are commonly regional, also affecting its neighbours. When Syria is dry and needs water most, Turkey has shown its willingness to limit flows in the Euphrates and Tigris to meet its own water scarcity challenges.

Many policies have incentivized maladaptation to drought risk in Syria. Examples include subsidies for unsustainable livestock management, perverse incentives encouraging unsustainable wheat cultivation, and the poor performance of irrigation systems in which 50–60% losses are the norm (Salman and Mualla, 2003). However, the root of many of these issues was a lack of awareness in the 1970s that variability in water supply would increase so rapidly in the near future.

Whatever Syria's political future, and internal security is currently the greatest concern, these issues will need to be addressed urgently. A move to integrated water resource management approaches has been seen in some areas, such as decentralization to water basin committees and institution of committees for transboundary water management. However, extensive institutional, legal and political reform would be necessary to mainstream drought risk management approaches to an extent that had appreciable impacts on water security.

10.4. North America: United States of America

OVERVIEW

Although, the US is relatively well endowed with water resources (with 21% of world's and 84% of North America's surface freshwater is held in the Great Lakes) there is an uneven distribution of freshwater supply and demand and drought is an ever-present risk. The US Federal Emergency Management Agency has estimated that the annual average costs and losses of drought in the US range from $6 billion to $8 billion. The observed and reconstructed records have all shown that the US has regularly experienced severe and long-lasting droughts from the western states to the more humid east and Mississippi Valley. The National Drought Mitigation Center analysis of data collated by National Climate Data Center and National Oceanic and Atmospheric Administration has shown that since 1895, approximately 15% of the US has been affected by drought in any given year. Droughts of the 1930s, 1950s, and 1999 to the present were particularly severe and long, affecting vast areas. For example, the 1930s drought is widely considered to be the 'drought of record' for the nation. At its peak spatial extent in 1934, 65% of the contiguous US was affected by severe to extreme drought conditions (Wilhite and Vanyarkho, 2000).

POLICY CONTE T

Historically, efforts to anticipate and plan for drought events have been limited in the US. Although drought impacts can be significant (e.g. the 1930s Dust Bowl drought, the 1950s Southwest drought), the US federal government still did not have a comprehensive national drought policy with preparedness at its core by the end of 2012. Governments at different levels and society have typically waited for a drought to reach extreme stages and then quickly organized a crisis management response. Once the rain comes and the drought has passed, the tendency is to return to 'business as usual' without taking the time to review response efforts or suggest ways to improve future planning and response activities. This traditional crisis-based management approach is often referred to as the hydro-illogical cycle, following an illustration that first appeared in the draft document of Planning for Drought: A Process for State Government prepared by Wilhite (1989). An article by Wilhite (2011) appealed again to the federal government to develop and implement a national drought policy in an effort to breaking the hydro-illogical cycle.

Lessons learnt from past drought events have had some influence on drought planning and management practices. For example, the 1930s drought led to unprecedented government relief efforts, and resulted in the creation of long-term, proactive programmes to reduce future vulnerability to drought. Some of these programmes included water conservation practices, increasing irrigation areas, enlarging farm sizes, increasing crop diversity, establishing federal crop insurance, removing some of the most sensitive agricultural lands from production, constructing new or enlarged reservoirs, improving domestic water systems, changing farm policies and developing new aid programmes. The Soil Conservation Service – now the Natural Resources Conservation Service – began to stress soil conservation measures and launched demonstration projects to show the benefits of practices such as terracing and contouring. These conservation measures later helped many farmers to reduce or prevent damages from the 1950s drought.

The *Congressional Research Service Report on Drought in the United States: Causes and Issues for Congress*, was released in August 2012, and concluded that 'while numerous federal programmes address different aspects of drought, the federal government does not have a comprehensive national drought policy with preparedness at its core' (Folger *et al.*, 2012). Although not a particularly new insight (as early as 2000, the National Drought Policy Commission (NDPC, 2000) had noted the patchwork nature of drought programmes) the formal recognition of the need for better coordination was an important step. However, although the federal government plays a lead role in responding to drought crises, no single federal agency leads or coordinates drought-planning programmes.

PROGRESS IN DROUGHT RISK MANAGEMENT PLANNING

Although a national drought policy does not exist in the US, good practice for drought management planning has been set out in the '10-step drought planning process' (Wilhite *et al.*, 1989; 2005b):

- Step 1: Appoint a drought task force or committee
- Step 2: State the purpose and objectives of the drought mitigation plan
- Step 3: Seek stakeholder participation and resolve conflicts
- Step 4: Inventorize resources and identify groups at risk
- Step 5: Establish and write the drought mitigation plan
- Step 6: Identify research needs and fill institutional gaps
- Step 7: Integrate science and policy
- Step 8: Publicize the drought mitigation plan and build awareness and consensus
- Step 9: Develop education programmes
- Step 10: Evaluate and revise drought mitigation plans.

Despite this widely publicized guidance, the absence of a national policy has led to variations in the nature of the plans developed by each state. The majority of plans continue to be crisis-based with only a few focusing on preparedness or risk mitigation in the long-term (Figure 10.1).

The following points compare the differences in the plans from different states. This information is based on data from the USA National Resources Defense Council:[39]

- **California's** plan[40] includes measures that focus on ensuring adequate water availability during times of drought. The California Drought Contingency Plan, released by the Department of Water Resources in 2010, recognizes the need for a proactive approach to managing drought risk but includes few significant preparedness measures. Nested within this plan are a number of city-level plans. For example, the city of Berkeley's strategy includes a city-focused vulnerability assessment that will include assessing water resources; and Los Angeles has a measure to prepare for increased drought conditions. The 2010s drought has highlighted the importance of implementing this plan and, perhaps, the need for review and adaptation (Box 66).
- **New Hampshire's** plan[41] identifies drought as a health-related threat due to climate change but does not include specific measures to address this threat. The city of Keene's strategy includes a measure to increase Keene's water storage capabilities in the face of drought.
- **Oregon's** plan[42] includes measures to improve capacity to provide technical assistance, and incentives to increase storage capacity during times of drought.
- **Washington's** plan[43] includes measures that focus on ensuring adequate drinking water resources and fire protection in areas likely to be affected by drought and improving drought-forecasting capability. King County's strategy includes a measure to develop emergency response protocols for events like droughts.

39. http://www.nrdc.org/health/climate/drought.asp accessed 27 October 2014
40. http://www.nrdc.org/health/climate/ca.asp - ap_drought accessed 27 October 2014
41. http://www.nrdc.org/health/climate/nh.asp#ap_drought accessed 27 October 2014
42. http://www.nrdc.org/health/climate/nh.asp#ap_drought accessed 27 October 2014
43. http://www.nrdc.org/health/climate/wa.asp#ap_drought accessed 27 October 2014

Box 66: Lessons learnt: Reducing water use and increasing reuse during the California Drought (2010 ongoing)

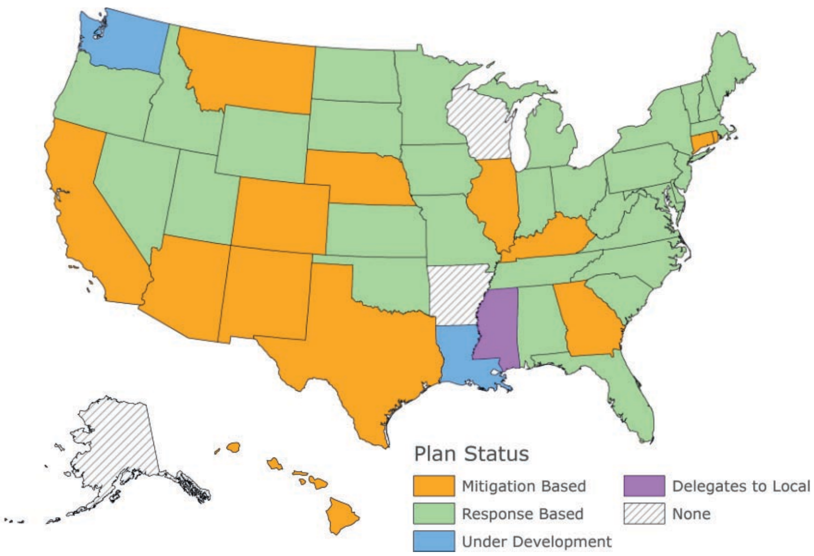
On 30 April 2014, the California Department of Water Resources (DWR) released a report with analysis of 5,400 groundwater wells across the state signalling historic declines in water levels. Groundwater provides approximately 60% of California's water supply in a dry year (40% in an average year). In many areas of the San Joaquin Valley, groundwater levels are more than 100 feet (30 m) below previous historical lows.

There is tremendous opportunity to expand water reuse in California. In most urban areas, water is used once, treated, and disposed of as waste. Urban water suppliers currently source 3% of their water from reclaimed sources and drought managers are now actively considering how to increase the recycling of urban water to relieve pressure on virgin sources. Two-thirds of the reuse potential is in coastal areas where wastewater is discharged into the ocean or into rivers that drain directly into the ocean. In these areas, expanding water reuse may provide water supply and water quality benefits. The Pacific Institute estimates that 0.9 million to 1.1 million acre-feet per year could be reused in coastal areas. The remainder of the reuse potential (0.3 million to 0.7 million acre-feet per year) is in inland areas (Pacific Institute, 2014).

In parallel, suppliers were mandated by Executive Order in April 2015 to reduce water usage by an average 25% - a significant component of this could be delivered through reuse (for example 12% of Spain's waste water is treated and reused). At the forefront of efforts to deliver this reduction have been the 372 urban water suppliers across the state. Sacramento region was one of the most successful in reducing water use, cutting average daily use by 20% between 2013–2015. Further south, water use was higher, and associated reductions less (analysis completed for the *New York Times*, 2015).

Source:
http://cl.s6.exct.net/?qs=ead654ddc9225a9f09453772bb5513a9b878bf6834382a8eda5c50035aa5b9ac accessed 18 June 2015
'Wastewater wonders'. *Jerusalem Post*. Retrieved 18 June 2015
http://pacinst.org/wp-content/uploads/sites/21/2014/06/ca-water-reuse.pdfaccessed 4 September 2015
http://www.nytimes.com/interactive/2015/04/01/us/water-use-in-california.html?_r=0 accessed 1 September 2015

Figure 10.1. Status of state drought plans as of 2015[40]



PROGRESS IN FORECASTING AND WARNING

Since 1999 a weekly assessment of drought conditions for the entire US has been published. This weekly map is a snapshot of drought conditions and their severity, produced jointly by the National Oceanic and Atmospheric Administration, the US Department of Agriculture, and the National Drought Mitigation Center at the University of Nebraska-Lincoln. At the end of each month, the Climate Prediction Center of the USA National Weather Service also issues a long-term seasonal drought outlook assessment for the next three months. The drought outlook is based on the current conditions, as illustrated by the US Drought Monitor, and then projects the future outlook for drought across the country. This outlook is based on a three-month forecast overlaid with current drought conditions.

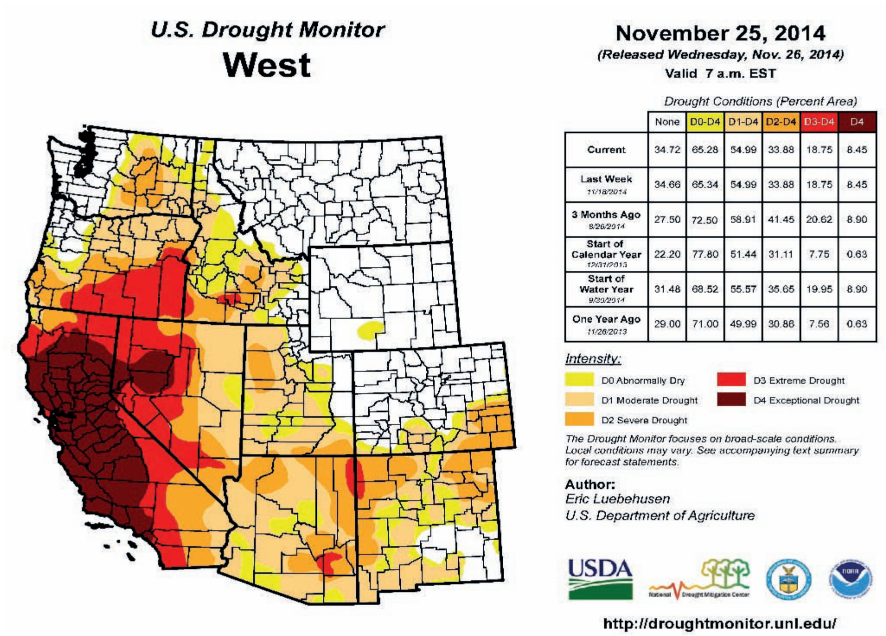
The maps are based on measurements of climatic, hydrologic and soil conditions as well as reported impacts and observations from around 350 contributors across the country. These contributors provide a 'ground-truth' of drought severity from a local perspective. These data are reviewed by partner organizations and best judgment is used to reconcile any differences and ensure the maps are credible. Based on this

44. http://drought.unl.edu/Planning/DroughtPlans/StateDroughtPlans.aspx accessed November 2015

analysis, the severity of the drought conditions is summarized according to a five-category scale (Figure 2.6).

The resulting 'drought map' is used by local decision makers and by the media to inform discussions around drought and, in appropriate circumstances, allocate drought relief (Figure 10.2). For example, the US Department of Agriculture's Farm Service Agency used the US Drought Monitor to distribute an estimated $1.64 billion from 2008 to 2011 through the Livestock Forage Disaster Program; $50 million in 2007 through the Livestock Assistance Grant Program; and additional funds through the Non-Fat Dry Milk Programme in 2003 and 2004. The Internal Revenue Service also uses the US Drought Monitor to determine the replacement period for livestock sold because of drought. In recent years, the US Department of Agriculture has streamlined their process for disaster declarations, making declarations nearly automatic for a county shown to be in 'severe drought' on the US Drought Monitor for eight consecutive weeks.

Figure 10.2. Example for of the weekly US Drought Monitor map for California for November 2014



LESSONS LEARNT AND LIVE ISSUES

Lessons learnt

The traditional crisis-based drought management approach, the hydro-illogical cycle, has proved to be ineffective, poorly coordinated, and untimely, and has done little to reduce the risks associated with drought (Wilhite, 2011). The adoption of the proactive, risk-based approach to drought planning and management is becoming more popular and mainstream in the US.

Proactive drought planning should contain three main components: 1) drought monitoring, early warning and prediction; 2) risk and impact assessments; and 3) mitigation and response measures, with well-defined linkages between them. These components should be outlined in an effective national drought strategy or policy.

The 10-step drought mitigation planning process provides a practical approach to proactive drought planning and management, which may be applicable to other nations who are trying to adopt a more risk-based drought planning approach. The applicability and effectiveness of the 10-step planning process is demonstrated through the introduction of the California Drought Contingency Plan released in 2010.

Live issues and emerging challenges

The US Government has been facing an intense amount of pressure from persistent and emerging water-related challenges. However, many key water laws and policies are outdated, or not effectively or equitably enforced. For example, Folger *et al.*, (2012) concluded that 'the federal government does not have a comprehensive national drought policy with preparedness at its core' and this was a key barrier to progress.

Although many drought-related issues might be local or regional, and should be resolved at the local and state levels, the federal government must play a key role in developing and implementing a national drought policy. As stated in *Preparing for Drought in the 21st Century* (NDCP, 2000) the NDCP believes that 'national drought policy should use the resources of the federal government to support but not supplant nor interfere with state, tribal, regional, local, and individual efforts to reduce drought impacts'. The NCDP recommend that the guiding principles of national drought policy should be:

- favor preparedness over insurance, insurance over relief, and incentives over regulation
- set research priorities based on the potential of the research results to reduce drought impacts
- coordinate the delivery of federal services through cooperation and collaboration with non-federal entities.

The lack of a national policy still remains an outstanding issue. At present, drought planning activities are still conducted by state, regional, local, and tribal governments. Responsibilities are often not adequately fulfilled by the diverse federal, regional, local and tribal agencies responsible for different aspects of water management and regulation.

Assuming that state governments and others begin to move from emergency response toward preparedness and mitigation planning and adaptive and integrated management, the formation of a national drought policy and the improvement of science and technology is likely to become even more critical in effective drought management.

10.5. Asia: China

OVERVIEW

China is home to nearly 20% of the world's population, but has access to only 5% of the world's freshwater resources and 7% of the world's arable land area. As a result, drought is a major threat and since 2000 drought-related losses have accounted for more than 1% of GDP. On average, over 25 million people face drinking water shortages and much of China's vast territory frequently experiences drought conditions.

The vulnerability to drought is underpinned by significant water scarcity issues. The mean annual water shortage in China is 49.4 billion m^3 with significant overexploitation of groundwater (by 19.7 billion m^3 annually) and failure to deliver environment-flows (e-flows) by 12.3 billion m^3 annually.

The long-term over-exploitation of water resources in some areas has led to severe degradation of freshwater ecosystems. The measured flow of the rivers in Northern China shows a sharp decline, with many now benefiting from only 20–40% of their natural discharge, and some reaches permanently dry. After several decades of groundwater over-exploitation, the total groundwater overdraft area is nearly 190,000 km^2, mainly in the northern regions, and more than 400 shallow and deep overdraft zones have formed, resulting in over 90,000 km^2 of territory being affected by land subsidence, over 1,500 km^2 by surface saltwater intrusion and 1,160 km^2 by groundwater saltwater intrusion.

The drought challenge is compounded by China's (i) topography, which descends from the Tibetan Plateau in the west, with an elevation of generally above 4,000 m, to the regions north and east of the Qinghai-Tibet Plateau with an elevation of 1000 ~ 2000 m, and finally to the coastal delta areas and (ii) the complex monsoon climate, with humid regions in the southeast, transitioning northwards through semi-humid, semi-arid and, in the north of China, arid zones. As a result, there is an uneven spatial and temporal distribution of water resources. In terms of temporal distribution, 60% ~ 80% of annual precipitation in most regions occurs during the flood season (Figure 3.3). This exacerbates the difficulties providing stable water supplies for industry and urban living, while also serving the agricultural irrigation demand that tends to peak in the dry season.

There is also a mismatch between economic and social development centers and water resources. Northern China accounts for 64% of the country's total land area, 46% of the population, 60% of the arable land, and 45% of the GDP, but only with 19% of the total water resources. The serious imbalance between the spatial and temporal distribution of water resources and economic and social development underpins major infrastructure investment, including the South–North Water Transfer Scheme (Box 38).

POLICY CONTE T

Water resource planning in China takes place in the context of the so-called 'three red lines' for water resources management. The three red lines policy was promulgated by China's Communist Party Central Committee and State Council in 2010 to establish clear and binding limits on water use, efficiency and quality:

- **Water resources development and utilisation:** Limit total national water consumption to less than 700 billion m^3 per year.
- **Water efficiency:** Water efficiency reaches the equivalent of international good practice e.g. irrigation use efficiency increasing to 60% by 2030.
- **Pollution limits:** Limit total amount of pollution discharged to ensure adequate water quality.

To support these policy objectives, *The Water Law of the People's Republic of China* and the *Drought Control Regulations of the People's Republic of China* set out the approach to managing droughts:

1. **The Water Law of the People's Republic of China** specifies the principles for using water resources and the requirements for water resources allocation, conservation and use. The law sets out the current approach to water rights and requires the preparation of a trans-administrative

regional water allocation plan and a plan for emergency water provision during drought. The law notes the need to:

- meet domestic water consumption of urban and rural residents and take into account agricultural, industrial, environmental and shipping needs
- consider water in spatial planning decisions, including restrictions on the construction of industrial, agricultural and service projects with large water consumption in water scarce areas.

2. **The Drought Control Regulations of the People's Republic of China** support the Water Law and set out roles and responsibilities for establishing drought control and relief contingency plans. These plans should include different emergency measures in response to droughts at different levels (including water quotas see Table 10.3) and associated legal responsibilities. These regulations refer to a drought disaster as 'an event that causes inadequate water supply and hazards to living, production and ecological conditions due to reduced precipitation and shortage of water supply from water projects'.

Table 10.3. Water supply quotas for security objects corresponding to different drought levels according to the Drought Control Regulations

	Objective	Moderate Drought	Severe Drought	Extremely Severe Drought
Living	Urban residents' basic drinking water	Normal water consumption quota	Normal water consumption quota	30-40 L/ person-day
	Basic drinking water consumption of rural residents	Normal water consumption quota	20-30 L/person/day	20-30 L/ person-day
Industry	Water consumption of key departments, units and enterprises in cities and towns	Normal water consumption quota	Reducing water consumption quota according to the actual conditions	Basic water consumption
Agriculture	Water for the critical period of crop growth	20-40 m^3/mu (irrigation areas) 20-30 m^3/mu (non-irrigation areas)	20-30 m^3/mu (basic food grain crop fields)	20-30 m^3/mu (basic food grain crop fields)
Ecology	Basic ecological water consumption of the core ecological areas of the national key natural ecological protection zones	Water quantity for maintaining ecological balance	Out of consideration	Out of consideration

The severity of the drought is classified into four categories: slight, moderate, severe and extremely severe. *In the event of a slight or moderate drought*, actions include: (i) initiating emergency water sources (including new wells); (ii) establishing temporary pumping stations, excavating water transmission channels or temporarily intercepting water in rivers and canals and ditches; (iii) using recycled water, brackish water, sea water and other unconventional water sources and artificial rainfall; and (iv) organising the movement of water to areas suffering from shortages for drinking water for people and livestock. *In the event of a severe or extremely severe drought* actions include: (i) restricting or suspending water supply to industries with high water consumption; (ii) restricting or suspending the discharge of industrial waste water; (iii) reducing agricultural water supply; and, ultimately (iv) restricting drinking water supply for urban residents.

Organizational structure for drought planning and response

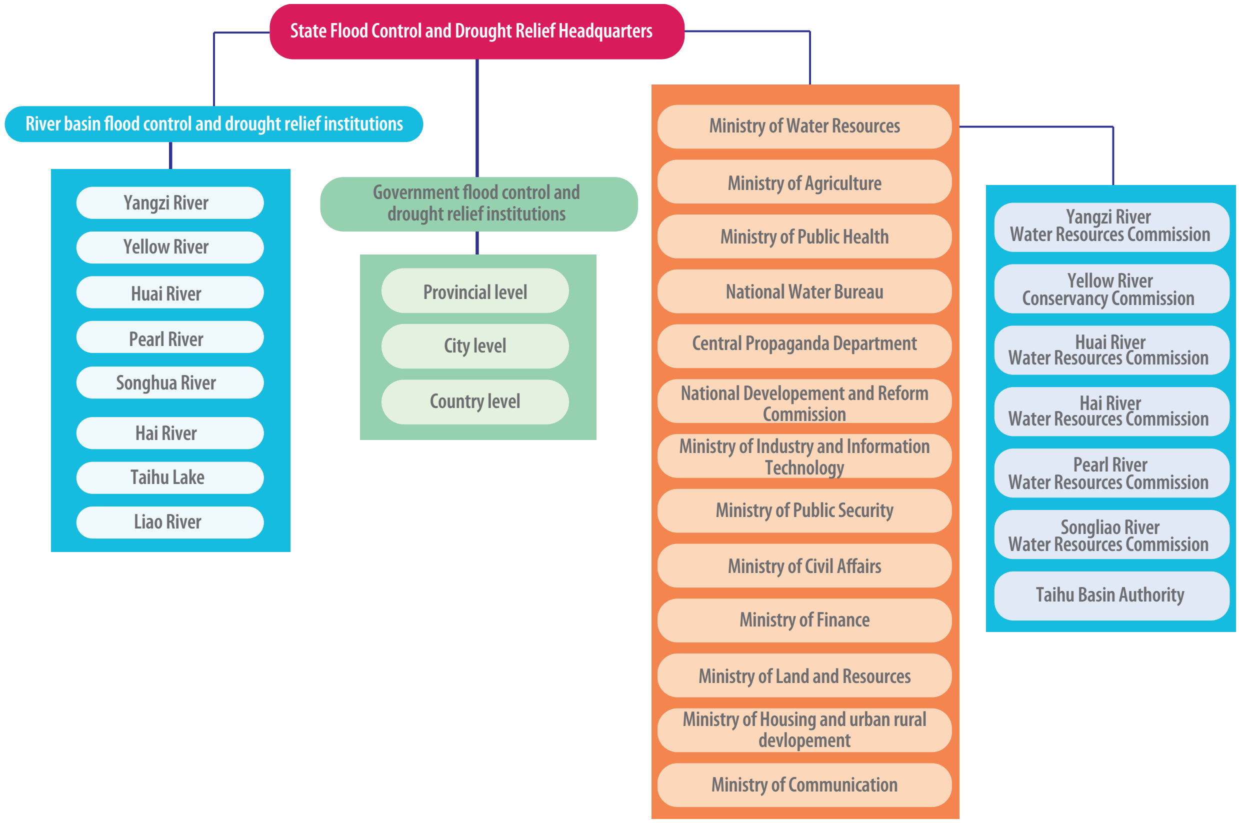
China has a top-down drought relief organization and command system. At the national level, the State Flood Control and Drought Relief Headquarters are responsible for organizing and leading the country's drought relief work. At the basin level, the seven major river basins are responsible for drought relief within the areas under their jurisdiction and support local governments at all levels (see Figure 10.3). Various ministries and commissions also contribute (see Table 10.4).

Table 10.4. Responsibilities of the ministries

Ministry	Responsibility
Ministry of Water Resources	Take charge of drought relief, including organizing, coordinating, supervising and directing the work of drought relief, as well as water allocation and water projects construction
Ministry of Agriculture	Promote and apply drought-tolerant crop varieties, guide and adjust agricultural planting structure in arid regions
Ministry of Public Health	Prevent and control disease, offer medical care
National Weather Bureau	Monitor and forecast weather, carry out artificial precipitation
Central Propaganda Department	Release drought control information
National Development and Reform Commission	Take charge of approval of drought plan, supervise arrangements of drought control facilities
Ministry of Industry and Information Technology	Help dispatch of drought supplies
Ministry of Public Security	Keep social order, ensure public security
Ministry of Civil Affairs	Overseas delivery of drought relief funds and materials, organize donations, ensure basic living needs of drought affected areas
Ministry of Finance	Overseas funding and supervise the usage
Ministry of Land and Resources	Help investigate and exploit ground water sources
Ministry of Housing and Urban-rural Development	Take charge of water supply management for drought cities
Ministry of Communications	Take charge of transport and communications of drought-relief supplies and equipment

Source: GIWP, 2013

Figure 10.3. The flood and drought control and relief organizational system of China



Source: GIWP, 2013

PROGRESS IN DROUGHT RISK MANAGEMENT PLANNING

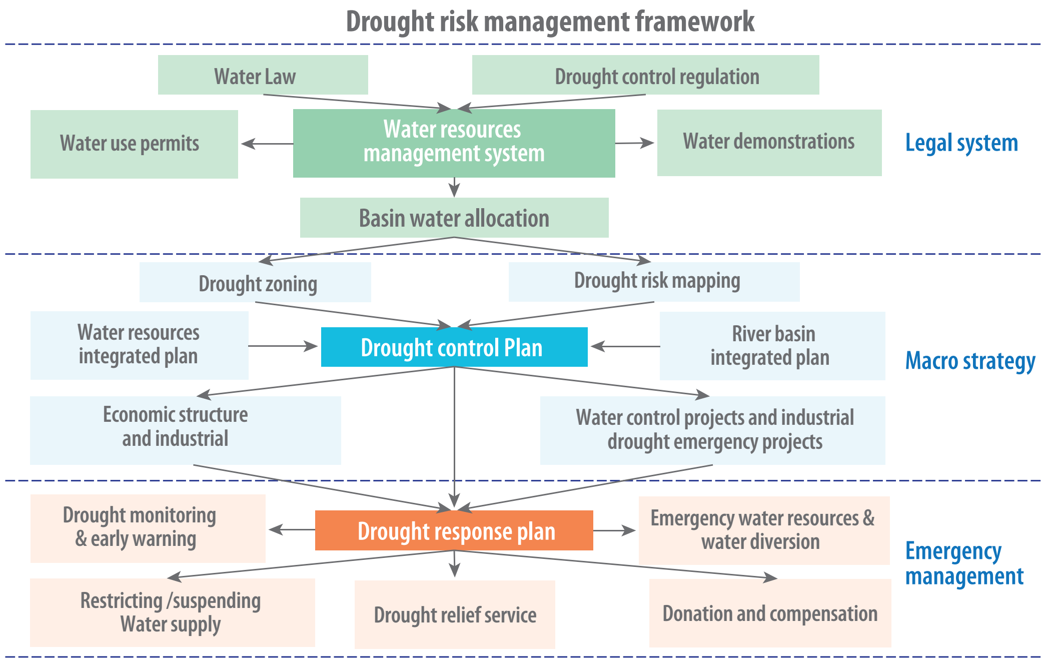
Following the foundation of People's Republic of China (PRC) in 1949, significant water infrastructure was developed. Largely, this infrastructure focused on controlling floods and providing water resources and hydropower. In more recent years, China has formulated basin plans for the seven major river basins that seek to take a broader perspective on protecting drinking water safety, protecting and restoring the functions of water bodies and improving the quality of water and ecological environment conditions. Drought management, however, has been mainly based on emergency management that focuses on temporary measures to address immediate and local problems. These measures have often had limited effects. In response, provincial-level, city-level and county-level drought response plans are all currently in preparation to improve the way emergency responses are delivered.

The move towards a more pro-active approach to drought management is starting and a revised framework for drought management that includes planning and emergency management is being proposed by the General Institution of Water Resources and Hydropower Planning (GIWP, the lead planning agency within the Ministry of Water Resources) (Figure 10.4). The emerging framework incorporates a macro-scale strategic planning process to underpin emergency response and the national laws. This is seen as the core decision making level for drought planning and for adjusting development plans and other related plans based on drought zoning maps.

Supporting risk analysis and drought-resistance assessments

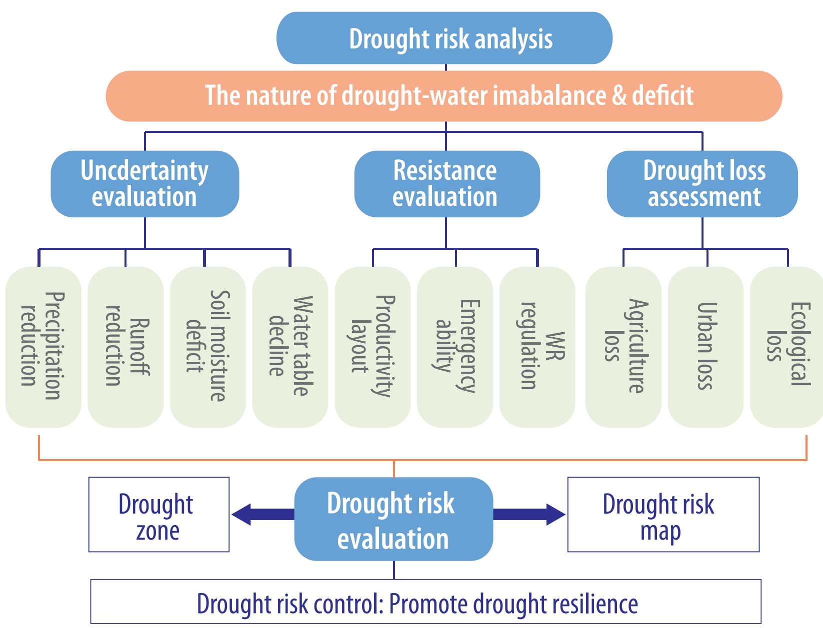
Significant effort is currently being devoted to undertaking supporting analysis of potential drought hazards and future conditions of vulnerability to determine future risks to people, ecosystems and economies. The process is summarized in Figure 10.5.

Figure 10.4. Drought planning and management framework in China



Source: GIWP, 2013

Figure 10.5. Block diagram of drought risk analysis



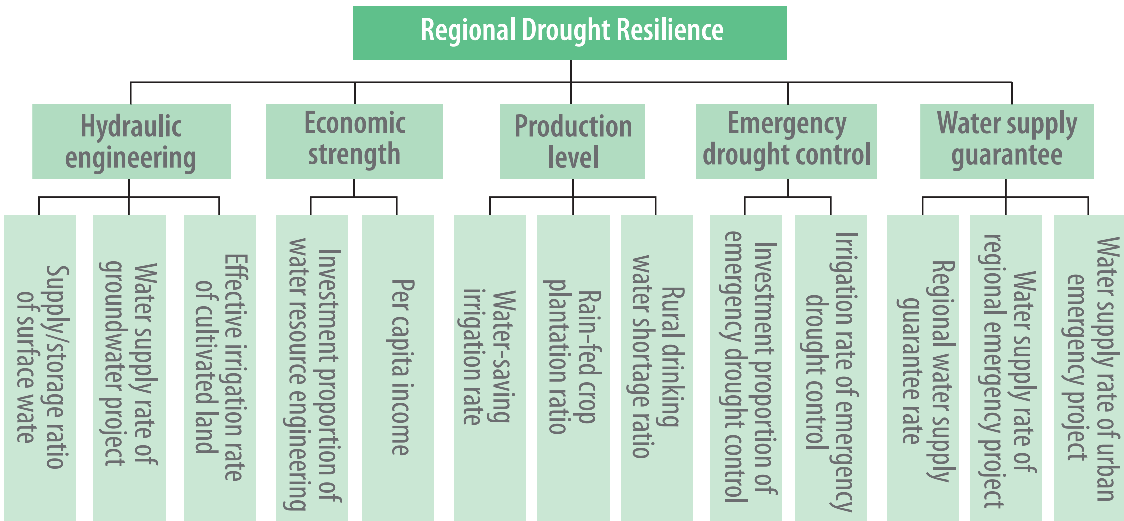
Source: GIWP, 2013

In assessing drought resistance, a regional drought resistance evaluation index system has been developed based on considerations of agriculture, regional and urban water supply systems, regional economic strength and production levels – as summarized in Table 10.5 and Figure 10.6.

Table 10.5. Example of the Urban Drought Resistance Evaluation Index

Objective layer	Criteria layer	Index layer
Urban drought resistance	Water supply system	Drought days at water source
		Urban water deficiency ratio (%)
	Economic strength	Per capita disposable income of residents (ten thousand Yuan/person)
	Water use level	Water consumption per ten thousand Yuan GDP (m3/ten thousand Yuan)
		Repeat utilization factor of industrial water (%)
		Reclaimed water utilization rate (%)
	Emergency drought control and management	Urban emergency water supply ratio (%)
		Leak rate of urban water supply network (%)

Figure 10.6. Regional Drought Resistance Evaluation Index system chart



Source: GIWP, 2013

PROGRESS IN DROUGHT FORECASTING AND WARNING

China has a marked continental monsoon climate. Rainfall and heat appear in the same season, and it is hot and rainy in summer and cold and dry in winter. As the timing, intensity and impact of monsoons and typhoons vary in different years, the spatial and temporal rainfall distribution has great inter-annual and intra-annual changes. The drought forecasting and warning processes in China continue to mature. In particular, a wide range of drought indices are being developed to express the severity of potential and past droughts. These are briefly introduced below.

Meteorological drought hazard – severity indices

A composite index (CI) is calculated using the Standardized Precipitation Index (both 30-day and 90-day) and the Relative Moisture Index (30-day). The CI is used to reflect short- and long-term precipitation anomalies, and short-term moisture deficit (affecting crops).

Blue-water drought hazard and green-water drought hazard – severity indices

China uses multiple indices to represent the severity of a drought. Each index has a threshold value associated with each of the four drought classifications. These indices include:

- Agricultural drought evaluation index: based on relative soil moisture, precipitation anomalies, standardized precipitation index, Palmer Drought Severity Index, irrigation water deficiency ratio, consecutive days without rain, days without water.
- Pasture drought evaluation index: based on precipitation anomalies and consecutive days without rain.
- Urban drought evaluation indices: including consideration of the 'water deficiency ratio', the 'ratio of urban daily water deficit to urban normal daily supply water volume', 'river water level change rate' and the 'groundwater level change rate'.

Drought-impact indices (economic and agricultural production)

China is exploring indices to evaluate the impact of a drought and associated losses. Each index has a threshold value associated with each of the four drought classifications. These indices include:

- Grain loss caused by drought.
- Grain loss rate caused by drought (the ratio of the amount of grain loss caused by drought to total grain output in the same year).
- Human and animal drinking water shortage index (absolute): maximum population suffering from drinking water shortage caused by drought.
- Human and animal drinking water shortage index (relative): the ratio of maximum value to total population in the evaluated region.
- Pasture drought loss evaluation index: meadow loss rate caused by drought.
- Urban drought loss index (absolute and ratio): loss of GDP.

Drought impact indices (environment)

China is exploring indices to evaluate the impact of a drought on the environment. Each index has a threshold value associated with each of the four drought classifications. These indices include:

- Percentage of wetland loss caused by drought.
- Relative drawdown of groundwater level: the difference between regional groundwater levels and average drawdown in previous five years.

LESSONS LEARNT AND LIVE ISSUES

China is in a critical period of development. Maintaining a stable and growing economy, safeguarding and improving people's livelihoods, promoting agricultural modernization and coordinated regional development, while making a positive response to climate change and other environmental issues is a significant challenge. China's drought management is shifting from crisis management to risk management. The Chinese Government has funded significant research focused on drought issues. Within the Ministry of Water, GIWP has a stated ambition to:

- At the macro level, carry out research on the situation of water resources as well as the mechanisms, laws and adaptation strategies for drought management in response to the interactive impact of global climate change and human activities.
- At the practical application level, carry out drought zoning; conduct further research on drought frequency, quantitative assessment of drought resistance, drought loss simulation and other theories based on the drought characteristics of different regions; propose a technical system for drought risk assessment; and, propose pilot demonstration areas.
- At the technical standard level, gradually establish the technical standards for drought classification, monitoring, early warning, relief and other aspects.

Some of the underlying challenges in China include:

- **Improving forecasting and warning:** it is expected that a nationwide drought monitoring network will gradually be formed in China, which covers surface water, groundwater, soil moisture content, water quality and other hydrometric stations as well as meteorology, remote sensing monitoring and agricultural condition monitoring stations. Achieving this will be an important step forwards.
- **Building capacity and awareness:** drought management capacity building remains poor. Drought monitoring and early warning systems are still weak.
- **Improving the process of allocation:** improving water resource allocation at the national, river basin and regional levels is a prerequisite to managing drought better.
- **Funding drought management actions in poorer regions:** funds for drought management activities – from the construction of emergency wells, to efficient projects and ecosystems approaches – in poor regions is difficult to find as these are mostly invested in by the local governments. Overcoming such inequities will be important going forward.
- **Considering water trading:** China is exploring water rights trading to optimize water resource allocation. There are parts of China piloting water resource allocation through trading; the results of these studies may be important for drought management going forward.

10.6. Asia: India

OVERVIEW

Although India has significant water supplies, increasing demand, pollution and climate change are all conspiring to place increased stress on resources. By 2030, water demand in India will grow to almost 1.5 trillion m^3, driven by domestic demand for rice, wheat and sugar for a growing population (estimated to increase from increase from 1.2 billion in 2010 to 1.6 billion in 2030), a large proportion of which is moving toward a middle-class diet. Against this demand, India's current water supply is approximately 740 billion m^3. As a result, most of India's river basins could face severe deficit by 2030 unless concerted action is taken, with some of the most populous basins – including the Ganga, the Krishna, and the Indian portion of the Indus – facing the biggest absolute gap (McKinsey, 2009).

The Indian subcontinent experiences two monsoons: the southwest or summer monsoon (in June–September, accounting for 70–80% of the annual rainfall over major parts of South Asia); and the northeast or the winter monsoon. The variability in these processes and spatial focus means around 70% of the country (or 340 million hectares) is prone to drought, across arid, semi-arid and sub-humid areas. Drought-prone areas are often already water stressed areas, and host a large population of India's poor.

Most of India's very poor (officially defined as those subsisting on less than 75% of the official poverty line or having an expenditure capacity of Rs 8 or US$1.25 per day) inhabit the drought-prone areas. Around 134 million people, dependent on agriculture, reside in chronic drought prone areas (Mahapatra *et al.*, 2010) and hence the link between water scarcity, drought and poverty is pronounced.

On average, drought af icts these areas every third year, with a severe drought every eight to nine years (Box 67). The Belgium-based Center for Research on the Epidemiology of Disasters estimates that droughts have affected nearly 1,061 million people and killed 4.25 million people in India during 1900–2006 (Mahapatra e*t al.*, 2010).

Box 67: Maharashtra drought, 2013: A near miss highlights the risk

In early 2013, the state of Maharashtra faced one of the worst droughts in recent memory. Almost 20% of the state was affected: 11,801 villages across 15 districts were declared as drought affected. Access to drinking water was restricted in around 2,000 villages and 5,000 smaller habitations. Some of the villages were facing drought for the second consecutive year. In March, 1,454 towns and 4,100 villages were supplied with 1,850 tankers of water.

By early 2013, the Marathwada region had only 9% of the total water reserve capacity remaining as compared to 30% in 2012 with groundwater critically depleted in 195 of the 1531 watersheds and 73 already 'over exploited'.[46] In the Ahmednagar district, lack of water for irrigation destroyed cotton, wheat, grape and sweet lime plantations, and sugarcane production.

With the prospect of a continuing drought (and the potential for almost 30 million people to be affected) an Empowered Group of Ministers on drought headed by the Agriculture Minister approved Rs 12.07 billion (US$0.185 billion) of relief for Maharashtra. Other measures announced included:

- 25% of the budgetary fund allocation in 2013 for long-term water conservation measures and drought-relief schemes
- Government-funded emergency shelters to provide water for animals at no cost
- Implementation of schemes worth Rs 227 billion (USD 3.47 billion) for agriculture, irrigation and water conservation.

In June 2013, the drought broke as the monsoon arrived on time in Maharashtra. As of 13 June, the state had received 36.6% of the average rainfall for June and of the 355 talukas (a subdivision of a district) in the state, 177 received 100% rainfall for the period. With the timely rain, pre-sowing operations started with full capacity.[47]

POLICY CONTE T

Historically, droughts in India have led to famine and loss of life on a colossal scale. The 1947 drought affected much of India with disastrous consequences. It did, however, prompt the process of moving away from largely relief-based approaches to address drought to more proactive planning; although it was many years later before the Government of India passed the Disaster Management (DM) Act in 2005, prompted by a growing concern over the frequency and magnitude of natural disasters. The 2005 DM Act provided a focus on planning and mitigation and the mandate for the National Disaster Management Authority (NDMA) and National Institute of Disaster Management at the national level and similar authorities at the state and district levels to implement actions to improve preparedness, quick response, relief, recovery, mitigation and forecasting systems. NDMA is the peak body for disaster management in the country, set up 'to build a safe and disaster-resilient India by developing a holistic, proactive, multi-disaster and technology-driven strategy for DM through collective efforts of all government agencies and non-governmental organizations'.[47]

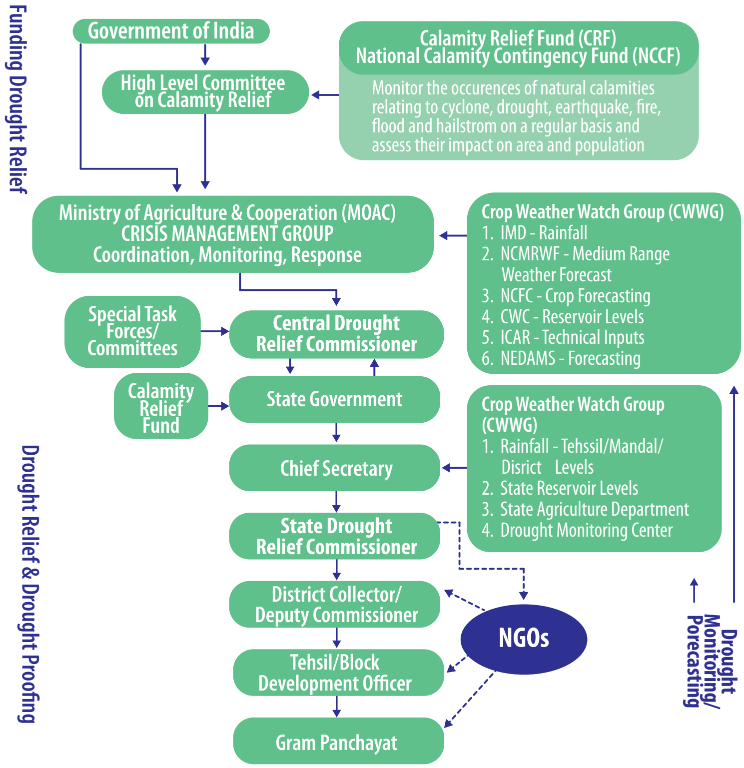
PROGRESS IN DROUGHT RISK MANAGEMENT PLANNING

The current approach to drought management is largely focused on drought as a disaster. Planning is therefore largely concerned with the response, developing the necessary monitoring to support early warning and forecasting and responding to those forecasts. The institutional arrangements reflect this focus and recognize the need for responsiveness at different levels. In the case of India, these levels are the central, state, district levels and panchayat/village levels (Figure 10.7).

45. http://www.ibtl.in/news/exclusive/2079/maharashtra-drought-2013/ accessed November 2015
46. http://nidm.gov.in/PDF/DU/2013/June/13-06-13.pdf accessed November 2015

47. http://ndma.gov.in/ndma/index.html accessed November 2015

Figure 10.7. Institutional framework for drought management



Source: Department of Agricultural and Cooperation 2009

There are, however, significant efforts to move towards a more proactive, long-term, management of droughts in some areas. For example, the National Water Policy 2012[48] recognized water is a scarce resource that is fundamental for sustainable development and that India faces significant water-related natural disasters (flood and drought), and challenges for the equitable availability of water at an appropriate quality and quantity. It acknowledged that climate change and development add to these pressures. Importantly, it also acknowledged that water resources management and associated governance had been inadequate. The policy recommended a long-term approach to the management of droughts that focuses on:

- drought preparedness with coping mechanisms as an option
- rehabilitation of natural drainage systems
- community involvement in preparing an action plan for dealing with drought situations
- land, soil, energy and water management with scientific inputs from local, research and scientific institutions to evolve different agricultural strategies and improve soil and water productivity to manage droughts. Integrated farming systems and non-agricultural developments may also be considered for livelihood support and poverty alleviation.

A significant omission, however, is that the National Water Policy failed to mention environmental water allocations, although ecosystem water needs were acknowledged. To date, the desire for a more rounded approach to managing droughts has yet to translate to implementation.

Progress is being made a local community level. For example, the Andhra Pradesh (AP) Farmer Managed Groundwater Systems (APFAMGS) project was implemented in seven drought-prone districts of AP state. The goal of the project was to enable farmers to manage their groundwater systems better and adopt more sustainable agricultural options. APFAMGS was designed to stimulate farmers' innovation in the assessment and analysis of groundwater, and optimize water-based livelihoods. The project resulted in over 9,000 farmers residing in 638 habitations voluntarily taking steps to reduce groundwater pumping.[49]

In collaboration with the World Bank, the AP State Government also launched the Andhra Pradesh Drought Adaptation initiative (APDAI) for deepening integration of climate considerations with local action, by packaging drought adaptation measures into existing institutional frameworks. The overall objective was to enhance the drought-adaptation capacity of affected communities and reduce their vulnerability towards drought risks (Table 10.6).

48. http://mowr.gov.in/writereaddata/linkimages/DraftNWP2012_English9353289094.pdf accessed November 2015

49. http://www.mdws.gov.in/sites/upload_files/ddws/files/pdfs/Towards%20Drinking%20Water%20Security.pdf accessed November 2015

Table 10.6. Andhra Pradesh Drought Adaptation Initiative: activities and their relevance to drought

	Activity	Relevance to drought
1	Diversified farming systems	Saves crops during short and long, dry spells Provides additional fodder, fuel and food Reduces the risk of total failure of the production system due to prolonged drought and continuous years of drought
2	System of rice intensification	Reduces risk of crop loss due to water scarcity and higher input costs
3	Plough bullock	Timely sowing reduces the crop failure due to pest and disease attack by 30–50 %
4	Seed bank	Helps in timely sowing and minimizes crop failure due to non-availability of seed
5	Nursery	Generates employment Plants help in protection of soil from wind erosion; assured income during drought years
6	Livestock vaccination	Protection of animals from exposure to contagious diseases and epidemics (due to low resistance) during drought
7	Fodder bank	Prevents distress sale of animals due to fodder scarcity Availability of additional fodder during drought for preserving nutrition
8	Backyard poultry	Provides employment and subsidiary income to cope with lack of agricultural income during drought
9	Chick Rearing Center	Creates livelihood/employment opportunities during drought
10	Breed improvement in sheep	Promotes breeds that can survive on meagre vegetation and resistance to diseases
11	Ram-lamb rearing	Making available locally suitable breeding rams would lead to propagation of drought resistant progeny and reduction risk among sheep rearers
12	Groundwater management	Promotes water saving Ensures critical irrigation during drought Prevents overexploitation of ground water
13	Common land development	Provides income generating activities, inputs to agriculture/home, environmental services and safety nets for people in drought years
14	Leased land development	Reduces the risks and vulnerabilities of the women belonging to the poor, landless and women headed households
15	Goat rearers common interest group	Provides support to sustain goat population, which is an important resource to cope during drought

Source: Modified by Khurana and Babu (2013).

PROGRESS IN DROUGHT FORECASTING AND WARNING

Various institutes contribute to India's monitoring and early warning services, including the India Meteorological Department (IMD), Agricultural Meteorology Division, the Drought Research Unit of IMD and the National Center for Medium Range Weather Forecasting (DAC, 2009). The IMD has the lead responsibility for drought monitoring and forecasting functions at a federal level and prepares aridity maps weekly. It also compiles weekly rainfall summaries, giving figures of precipitation at the district level. The National Remote Sensing Center (NRSC) in Hyderabad also contributes remote-sensed data.

Before the onset of the monsoon, an inter-ministerial group headed by the Agriculture Secretary is formed to review and monitor rainfall. This group meets weekly in the monsoon season. Based on the forecast arrival dates for the monsoons and expected rainfall deviations from normal, the potential for a drought is determined. The declaration of a drought signifies the beginning of government response to a drought situation. The Government of India sends a monitoring team only after a drought is declared and a memorandum is sent by the state governments to assess the requirements for relief and release assistance (anon., 2009). Theoretically, given that most of India receives rain from the South West monsoon between June and September, drought should be declared in October. By then, the total rainfall received is known, a final picture of crops sown is available and the water levels in the reservoirs are known. However, politics is often blamed for a delay in the declaration of drought (Khurana and Babu, 2013).

Once a drought is declared, the planning and implementation of drought relief and response measures are initiated. Measures include: (a) contingency crop planning; (b) support to farmers in the form of agriculture input, energy and extension support; (c) relief employment; (d) detailed water resource estimation and water supply restrictions; (e) food provision; (f) relief through tax waivers and concessions; (g) cattle camps and fodder supply; and (h) support to maintain health and hygiene.

LESSONS LEARNT AND LIVE ISSUES

Despite efforts to promote a more broadly based strategy for managing drought, significant infrastructure solutions remain the focus. For example, the interlinking rivers strategy seeks to link India's rivers by a network of reservoirs and canals. In September 2015, the Godavari and Krishna rivers – the second and the fourth longest rivers in the country – were linked via a canal in Andhra Pradesh. The project was completed at a cost of Rs1,300x10^7 (US$196 million). A second scheme, the Ken-Betwa river project – estimated to cost Rs11,676 x10^7 (US$1.7 billion) – is currently under development, with completion likely by December 2015. The impact of such major schemes on drought risk is unclear and significant controversy exists around their development and continued implementation, particularly the impact on the environment and landscape.[50] These developments follow on from decisions first envisioned in 1982, and actively taken up by the Bharatiya Janata Party Government under Prime Minister Atal Bihari Vajpayee in 2002. Moving forwards with a more rounded, sustainable approach to water and drought management that works with natural processes and considers the linkage between freshwater ecosystems and the well-being of human systems is therefore a key challenge.

A number of significant barriers continues to prevent this aspiration from becoming a reality, (Kuhrana and Babu, 2013):

- putting in place effective institutional mechanisms, backed by a legal framework, for the creation of an enabling regulatory environment for water
- promoting a culture of prevention of drought through efficient water management and conservation
- understanding that the people are the most important stakeholders and their understanding and involvement is key
- encouraging mitigation-measures based on state-of-the-art technology and environmental sustainability
- developing contemporary forecasting and early warning systems backed by responsive and fail-safe communications and information technology support
- promoting effective partnerships with the media for awareness generation and capacity building
- establishing mechanisms for recovery from drought to bring back the community to a better and safer level than the pre-disaster stage
- strengthening implementation of the commitment to move from disaster response towards preparedness
- reducing delays in drought declaration (the time lag between the declaration of drought and the relief package needs to be curtailed)
- improving weather forecasting and its communication to communities who will be affected
- prioritizing water allocation during drought to drinking water, followed by environmental flows and subsistence agriculture
- promoting economic growth in drought prone areas in consonance with the water availability
- committing to a policy backed implementation plan and financial and human resources.

50. http://qz.com/504127/why-indias-168-billion-river-linking-project-is-a-disaster-in-waiting/ accessed November 2011

10.7. Australia

OVERVIEW

Droughts are a frequent and recurrent feature of the Australian climate and, as the driest inhabited continent, more than 80% of the country receives average annual rainfall of less than 600 mm. In addition, Australia experiences high annual rainfall variability, particularly across the arid interior, and climate variability is considered one of the greatest sources of risk for Australian agriculture (Kimura and Antón, 2011). Records suggest that some part of Australia experiences severe drought about once in every 18 years, with intervals between severe droughts varying from 4 to 38 years (BoM, 2011).

The combination of arid conditions, highly variable annual rainfall, and an economy that was historically dominated by agricultural and pastoral activities has meant that Australians, and particularly Australian farmers, have a long history of dealing with drought. Australia has experienced significant droughts throughout the past 150 years. Notably, however, impacts are described in terms of the consequences for agricultural and pastoral production, which is the lens through which drought has historically been viewed. In many ways, it has only been in recent years that Australia's urban centers have been significantly affected by drought, most notably during the Millennium Drought, a severe, widespread, and prolonged drought running from 2001–2009.

POLICY CONTE T

Australia's drought policy has evolved significantly over the past century. Early government efforts focused on 'drought proofing' through the construction of infrastructure, primarily dams, and the development of irrigation. Policy later shifted to providing direct financial assistance to farmers during periods of extreme hardship. During this period, droughts were considered a type of natural disaster, with government intervening to support primary producers and others that were suffering from the impacts (Productivity Commission, 2009).

This approach changed significantly with the introduction of the 1992 National Drought Policy (NDP). The NDP represented a move away a crisis management approach to drought towards a climate risk-based one. The emphasis in the NDP was one of self-reliance, recognizing that droughts are a natural part of the landscape, and accordingly something Australians (and most notably farmers) should plan and prepare for. The NDP remains in place, although it has evolved over time as a result of a series of reviews.

The NDP was underpinned by three principles:

1. Primary producers and other sections of rural Australia should adopt self-reliant approaches to managing climatic variability.
2. Australia's agricultural and environmental resource base should be maintained and protected during periods of extreme climatic stress.
3. Agricultural and rural industries should recover as early as possible from drought, consistent with long-term sustainable levels (DAFF, 1992).

The NDP is supported by a range of government programmes aimed at increasing the capacity of farmers and rural communities to deal with dry periods. These include tax incentives for farmers to save money from good years for use in low-income years, support for whole-of-farm planning and financial planning to address drought, education and training, and research into systems for improving drought forecasting and mechanisms for responding to drought at the farm level.

Despite the emphasis on self-reliance, the NDP still provided for direct government support to farmers and rural communities under 'Exceptional Circumstances'. Exceptional Circumstances declarations are made by the federal government, based on submissions from state or territory governments. Previously, where an Exceptional Circumstances declaration was made, farmers within the declared area were eligible to apply for income support and interest rate subsidies. Interest rate subsidies were removed as of 30 June 2012 (DAFF, n.d.).

Drought payments cost the federal government A$100 million per year for the 1992–1999 period (DoEandH, 2001b). This increased significantly during the Millennium Drought, with the federal government paying A$4.5 billion in drought assistance during between 2001 and April 2012 (DAFF, 2012a).

PROGRESS IN DROUGHT RISK MANAGEMENT PLANNING

Approaches to water resources management in Australia have also evolved over time as a result of drought. The major water reforms that commenced in the early 1990s followed a period of significant drought across much of Queensland and New South Wales. This was coupled with problems resulting from over-allocation of water resources (especially in the Murray–Darling Basin) and associated environmental issues, the most high-profile being the occurrence of an algal bloom stretching more than 1000 km along the Darling River. While there were many factors that drove Australia's water reforms, it is likely that water shortages, including periods of drought, contributed to the new goal of better planning for water allocation and allowing more flexibility for water users by way of water trading.

The Millennium Drought was widely regarded as the worst drought on record for south-eastern Australia, and it highlighted many of the benefits of the new water management framework. Water trading in particular came to the fore, providing flexibility for irrigators and other water users, allowing water to be bought by those that needed it most, providing a source of income for those that sold water, and generally reducing economic impacts from water scarcity. At the same time, the severity of the drought highlighted many of the shortcomings of existing plans and systems. Many urban centers, including Australia's largest cities, were exposed to the effects of drought in a way they had not been before, severe water restrictions were imposed, and there was serious concern that some cities could literally run out of water.

The Millennium Drought led to a range of changes to the way water is managed. The federal government responded to the drought with a 'National Plan for Water Security', released by Prime Minister Howard in January 2007 at the height of the drought. The plan was accompanied by a commitment of A$10 billion in funding over ten years to improve water management, with a focus on the irrigation sector, particularly in the Murray–Darling Basin. The plan included proposals for modernizing irrigation through infrastructure upgrades and improved operations, addressing over-allocation in the Murray–Darling, including through a programme to buy back water entitlements, and investment in better water information (DPMC, 2007).

The Millennium Drought also triggered a range for responses to address urban water shortages. These responses included the development of more climate-independent water supplies (such as desalination), more rigorous water supply and water security planning, institutional reforms to clarify responsibilities for water supply, and changes to the way water service providers defined reliability of supply and levels of service. While these responses have left Australia's cities with what are now far more secure water supplies, it has also created a legacy of high-cost infrastructure that water users will be paying for decades to come.

In some regions, the end of the drought has given rise to a further raft of institutional and other changes, in part to improve on reforms that were implemented in great haste at a time of crisis.

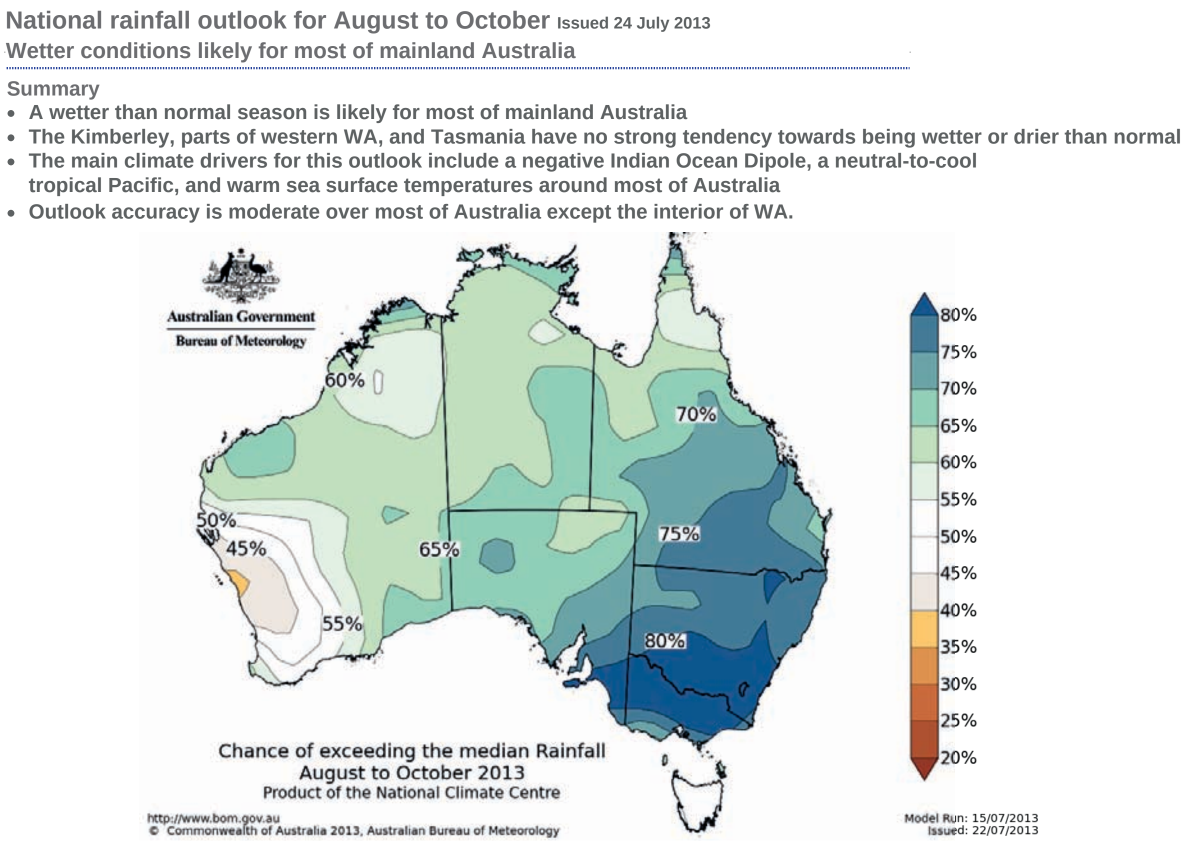
PROGRESS IN DROUGHT FORECASTING AND WARNING

There is a range of different organizations that monitor and report on drought, and each uses indicator systems that are relevant to their particular purpose. These include:

- the Bureau of Meteorology, which uses meteorological indicators (primarily rainfall) and is focused on 'meteorological drought'

- the federal agriculture department, which uses are range of indicators and is focused on 'socio-economic drought' (notably impacts on primary producers)
- state and local water agencies, which use indicators related to water storage levels and stream flow, as well as rainfall forecasts. These agencies are focused on 'hydrological drought' and its relevance to making water management decisions.

Figure 10.8. Example of national rainfall outlook issues by Australian Bureau of Meteorology



Source: Australian Bureau of Meterology, 2013

A focus on the Bureau of Meteorology

The Bureau of Meteorology, Australia's national weather, climate and water agency, provides a range of observational, meteorological, hydrological and oceanographic services. Since 1965, the bureau's 'drought watch service' has been a key component of national drought management. The bureau provides:

- information to government, business and rural communities, as well as synthesizing and assessing the available information, helping to identify where action or drought relief may be required
- a consistent basis for both federal and state government actions, including the issuing of national drought alert, drought declarations, and various responses to drought
- monthly drought statements that highlight areas that are experiencing rainfall deficiencies, including both long-term and short-term deficiencies. The bureau's assessments are derived from a nationwide daily rainfall measuring network, coupled with an understanding of the relationship between rainfall deficiency and the severity of recorded drought. In addition to analyzing rainfall data, the bureau's drought statements also report on soil moisture
- a 'drought watch' for a region if accumulated rainfall over three successive months is within the lowest 10% on record. A drought watch ceases when 'plentiful' rainfall returns, which is defined as well above average rainfall for one month, or above-average rainfall over a three-month period.

The bureau also provides a range of forecasting services. The bureau's Seasonal Climate Outlook Service offers a rainfall and temperature outlook and stream-flow forecasts for the coming three months. An example of the national rainfall outlook is shown in Figure 10.8. The outlooks are based on the outputs of a range of international climate models and particularly rely on the NINO3.4 index as the basis for classifying the El Niño-Southern Oscillation conditions[51].

Since 2007, the bureau has also had specific responsibilities related to water resources. These responsibilities include collecting, holding, managing, interpreting and disseminating Australia's water information; providing regular reports on the status of Australia's water resources and patterns of usage of those resources; providing regular forecasts on the future availability of Australia's water resources; and compiling and maintaining water accounts for Australia, including the 'National Water Account' (Water Act 2007, ss120–135).

While the primary drought indices used by the bureau relate to rainfall, a broader set of criteria have been used by the Department of Agriculture, Fisheries, and Forestry in administering Exceptional Circumstances assessments. The original framework for assessment of Exceptional Circumstances was based on six criteria (DAFF, 2012b):

- meteorological conditions
- agronomic and stock conditions
- water supplies
- environmental impacts
- farm income levels
- scale of the event.

To be declared an 'Exceptional Circumstances event', the event should only occur on average once every 20 to 25 years and have an impact on income for a prolonged period, typically greater than 12 months. In practice, however, the criteria used, the extreme dry conditions experienced in much of Australia over the past two decades, and challenges with determining when a drought has 'ended' have resulted in some areas being drought declared for 14 out of 17 years (Productivity Commission, 2009).

LESSONS LEARNT AND LIVE ISSUES

More than a century of managing regular and severe droughts has resulted in a range of lessons about preparing for, and responding to, drought. The Millennium Drought in particular provided a major test of the significant water reforms commenced during the 1990s and highlighted strengths and weaknesses in approaches to water resources management. It has also led to a range of further reforms to improve water security, particularly in urban centers. The most significant of these lessons are described below.

Def ning reliability of supply: water supply planning should set clear objectives around the reliability of supply. Historically, water supply planning aimed for urban water reliability of around 99%. However, what was poorly articulated was the impact on water users during that 1% of years when the full quota was not available. This has led to an emphasis on better defined 'levels of service', which articulate in greater detail the acceptable frequency and severity of restrictions. Water supply plans are in turn required to ensure sufficient water security to meet those objectives.

Institutional issues: responsibilities for water supply planning need to be explicit. In particular, overlapping responsibilities can result in a lack of accountability.

Water restrictions: water restrictions have proved to be an effective measure for reducing demand during periods of drought. It is important though to recognize the different role of temporary restrictions versus permanent restrictions. Temporary restrictions can delay the time at which the available water is consumed to such a point that an alternative supply is required. The temptation can exist to make temporary measures permanent to reduce long-term demand. However, where this occurs, temporary restrictions are no longer available as a means for managing the supply-demand balance during drought (Chong *et al.*, 2009).

Furthermore, water restrictions need to be implemented with an understanding of the impact of any restrictions on water users, including the financial impact. This is necessary to allow for comparisons with the cost of supply augmentation and generally to understand the likely willingness to pay for new infrastructure to avoid or reduce restrictions (Neal and Moran, n.d.).

Use of climate-resilient infrastructure: many Australian cities have looked to improve water security through the construction of climate resilient infrastructure. While such measures have undoubtedly resulted in more secure water supplies, this has come at a very high cost, particularly where new infrastructure has been built in haste in response to emergency conditions.

In Queensland, the desalination plant and the recycled water treatment plant were both constructed during the height of the drought costing a combined A$3.8 billion to construct (QAO, 2013). A recent review has been critical of the process for deciding to proceed with construction of the plants and found that better planning may have avoided the need for such drastic and costly action. The review also found that what could and should have been done better, even in a time of emergency, was to have a thorough and rigorous assessment of all costs and of the social, economic and environmental benefits, in all likely modes of operation (QAO, 2013).

51. http://www.bom.gov.au/climate/ahead/about-ENSO-outlooks.shtml Accessed 8 May 2016

Water trading: water trading has clearly helped individual irrigators manage and respond to drought. It is relevant to note that the benefits that come from water markets generally depend on there being differences in the demands for water amongst different user (Appels *et al.*, 2004). The benefits of water trading in helping farmers manage the impacts of ongoing drought in the lower Murray basin were to a significant degree dependent on the presence of a range of different water user groups – rice growers, horticulturists, dairy farmers – each with different demands and financial drivers (NWC, 2011). Water trading is less likely to be useful in addressing climate variability and drought in a region dominated by a single commodity.

However, the use of water markets as a drought management tool should occur within a regulatory framework that seeks to achieve equitable social outcomes, acknowledging the inherent social value of water to communities and the food security value of water to the nation (Neal and Moran, n.d.).

Environment: human disturbances, particularly the abstraction of water from river systems, have made freshwater ecosystems more vulnerable to the impacts of drought. When managing water resources during drought, it is important that the needs of ecosystems are recognized. The focus should be on identifying, prioritizing, and protecting key refugia. Most importantly, water resource managers should recognize – and aim to avoid – thresholds beyond which irreversible environmental harm may occur.

10.8. Latin America: Mexico and Brazil

OVERVIEW

Latin America is well endowed with water resources, and vast and diverse freshwater ecosystems. There are, however, extreme variations in water availability. For example, both the federal and state governments in Brazil have been tackling drought problems in the north-east of the country for decades. The so-called drought polygon extends from northern Bahia to the coast between Natal and São Luís and receives about 375–750 mm of precipitation a year compared to elsewhere in Brazil, which typically receives 1,000–1,800 mm/pa.

Mexico also routinely experiences drought that cause serious damage across large parts of the country mainly due to reduced, or a complete absence of, precipitation in the months of the rainy season,[52] which is typically May–September. Central and northern Mexico are the areas most affected, with significant impacts to agriculture and hydroelectric power generation as well as people. It has been estimated that droughts and floods from 2000–2010 have caused about 5,000 deaths, affected 13 million people and caused economic losses of about US$25 billion.[53] The main water use is in the agricultural sector (76.9%); domestic and urban use (14.1%); industries that take water directly from rivers or aquifers (4.0%); and 5.0% for thermoelectric plants.[54]

POLICY CONTE T

Brazil

Brazil began to focus on mitigating droughts after a particularly harsh event from 1877–79. In 1886, under a monarchy with a strong central government, the construction of the first reservoir, or *açude* (the Portuguese word for dam), represented the start of the institutional design for building infrastructure to address droughts. From the end of the 20th century to the beginning of the 21st century, a period of management and control was initiated after the reform of the Federal Constitution in 1988, which created a national system of water management and defined criteria for granting water use rights. The installment of a National Policy of Water Resources was particularly, as well as the creation of the National System of Water Resource Management and the National Water Agency (ANA) as an implementing and coordinating institution of the National System. ANA belongs above all to the Federal Government, yet it has duties that transcend the federal domain. According to the Constitution, water is a limited natural resource and an inalienable public good that belongs either to the federal or the state government. ANA and the councils and committees of the Water Resource Management System and basin agencies are the organizations entitled to award federal and state water use permits or *outorga*. Grants ensure the user has effective access to water, as well as to perform quantitative and qualitative control of the resource during periods of drought (Guitierrez *et al.*, 2014).

Mexico

In Mexico, the National Water Law (SEMARNAT, 2012) refers to droughts in a number of ways. It sets out water entitlements and requires water allocations during drought conditions to be

52. http://www.conagua.gob.mx Accessed July 2014
53. http://pnd.gob.mx Accessed July 2014
54. http://www.conagua.gob.mx Accessed July 2014

determined through subsequent water plans and programmes. The law also allows for temporal cession of water from users to the National Water Commission (CONAGUA), the federal authority in charge of the management and preservation of surface waters and aquifers in the country[55] with a key role in drought planning and management. The titles of concession are recorded in the Public Registry of Water Rights, REPDA.[56]

According to the Law on National Waters of Mexico, the water uses are prioritized as follows:[57]

1. domestic
2. urban
3. livestock
4. farming
5. environmental use or ecological preservation
6. electricity generation for public purposes
7. industrial
8. aquaculture
9. electricity generation for private purposes
10. cleaning of fields
11. use for tourism, recreation and therapeutic purposes
12. multiple uses
13. others.

This prioritization may be changed within a state, subject to consultation, but the Law on National Waters states that domestic and urban uses are always prioritized over any other use.

PROGRESS IN DROUGHT RISK MANAGEMENT PLANNING

Brazil

The Brazilian Water Authority (Agencia Nacional de Águas (ANA)) has lead responsibility for drought planning and management. ANA has promoted mega-transfers and dam building programmes as a primary response to droughts in addition to efficient and allocation measures. In part this reflects the significant development pressures and the difficulties of implementing more diverse responses.

As with many nations, Brazil has historically addressed water scarcity during times of shortage and droughts through emergency response and large water infrastructure works projects (Malgalhães and Martins, 2011). Despite decades of infrastructure and technical fixes to water management, which have helped to buffer against water shortages and have facilitated considerable economic growth throughout Brazil, significant impacts from water shortages have persisted. There have been recent efforts to shift Brazil away from reactionary drought response and sole dependence in the long-term on infrastructure solutions to mitigate drought impacts (e.g. through improved monitoring, decentralization and democratization of water resources management, etc.), and there is a growing interest in improving coordination and institutionalizing these elements into a coherent drought policy, both at the national and sub-national levels (Malgalhães and Martins, 2011).

The recent drought (2010–2013) in the northeast of Brazil has had devastating impacts on agricultural, livestock, and industries. It has also caused a lack of drinking water in residential wells, and left dams and streams completely dry. By April 2013, some 880,000 rural farmers had received federal assistance through social support programmes. This drought again created a discussion within the country about drought policy and management. In the past, this conversation has waxed and waned with respect to the hydro-illogical cycle, with only incremental progress being made to foster more proactive risk-based drought preparedness approaches (Guitierrez *et al.*, 2014).

Mexico

In Mexico, the twenty-six basin councils (Figure 10.9), and associated basin commissions and basin committees that deal with smaller basins and very specific issues, have a role in understanding the specific water related problems and putting in place water management and drought management strategies. In general, these strategies focus on:

- improving permanent monitoring of rainfall and climatic conditions and at a national scale the development of a strong cooperation with Canada and the US to monitor drought occurrence and evolution in the three countries
- reducing the assigned volumes of water, mainly for farming activities and hydroelectric power generation
- implementing federal programmes that provide economic resources to states, municipalities, irrigation districts and irrigation units to improve the use of clean water and the reuse of treated wastewater, so volumes required by different users are diminished
- accessing additional federal support from a specific emergency fund to carry out emergency measures, such as: clean water supply through portable treatment plants, implementation of health monitoring and protection measures, emergency well drilling and operation, and rehabilitation and renovation of hydraulic infrastructure.

55. www.diputados.gob.mx Accessed July 2014
56. www.conagua.gob.mx Accessed July 2014
57. www.diputados.gob.mx Accessed July 2014

Figure 10.9. Map of the 26 basin councils covering the country in Mexico

Following a widespread drought 2011–2012, CONAGUA announced the preparation of the National Drought Management Programme (PRONACOSE) to set out guidelines for the preparation of drought plans and provide a national summary of the projects and programmes being undertaken in the Basins. The development of the PRONACOSE is led by an inter-ministerial group chaired by the Presidency of Mexico, with CONAGUA acting as a technical secretariat, and has the goal of increasing resilience against drought. It also brings together cross–government stakeholders including the Ministries of Economy; Agriculture, Livestock, Rural Development, Fisheries and Food; Education; Energy; Health; National Defense; Social Development; Tourism; the Interior; and the National Forest Commission. CONAGUA also coordinates programmes for the modernization of irrigation to reduce water consumption while increasing farmers' income, the improvement of wastewater treatment plants and the enhanced use of treated wastewaters. The cost of such programmes is cost shared with farmers, states and municipalities.[58] Under this scheme, from 2009–2011, about US$592 million dollars have been invested to improve the efficiency in water supply and US$1,902 million have been invested to build and improve the performance of wastewater treatment plants and to increase the use of treated wastewater.[59]

The resulting National Drought Management Programme for the period 2013–2018 has a comprehensive and participative approach in several ways (Federman *et al.*, 2014):

- It includes both preventing and mitigating drought through, respectively: estimating needed resources, defining actions and organizing stakeholders; and reducing impacts on people, goods, infrastructure, activities, as well as on the environment.
- It enhances forecasting, early warning and data dissemination, which includes both: (i) periodically collecting and analyzing hydrometric and climatic data and information on level reservoirs and that of drought location or its levels or degrees of intensity; and (ii) spreading drought information to guide actions.
- It promotes coordination of governments from the federal, state and municipal levels (for joint programmes and resources) and water users' involvement by including training for understanding monitoring information and the options for user cooperation in water demand reduction actions and an efficient water use.
- It supports a drought plan for each of the 26 basin councils and drought plans for major water users. The first implies that authorities and users within their respective basin council design and later implement their plan based on local features. The plans for major water users look for specific actions for them (major water utilities, irrigation districts or industrial facilities).
- The local implementation also implies that water users and authorities in the basin council will define triggers to implement agreed actions based on official drought evolution information. Also they should agree on a range of voluntary measures, which are expected to bring major water economies as well as mandatory measures.

58. http://www.dof.gob.mx/ Accessed July 2014
59. http://www.conagua.gob.mx Accessed July 2014

CONAGUA has also worked with WWF and Fundación Gonzalo Río Arronte I.A.P. to conduct a scoping study that identifies potential water reserves throughout Mexico. These water reserves are defined as watersheds with favourable conditions – high biological richness and high conservation values, availability of water and low pressure from existing water users – for ensuring ecological flows as stated under the National Water Law. The study identified 189 basins where water reserves could be established, nominated to be the main target of the National Water Reserves Programme. The goals of the programme are: i) establish a national system of water reserves; ii) demonstrate that water reserves ensure a healthy functioning of the water cycle, as well as the environmental services they provide; and iii) build capacity in the implementation of environmental-flows backed by official national guidelines throughout the country. The benefits of these water reserves include:

- Defining sustainable limits on water availability, which supports the principle of saving water and managing demand, reducing risk of water scarcity and drought.
- Guaranteeing the connectivity of the entire basin and support to conserve ecosystems and ecosystem services such as storing, conducting and supplying water, improving water quality, and protection from extreme events.
- Introducing integrated planning and management of both subterranean and surface water, especially in regions with little surface water, such as in the north of the country.
- Preserving or controlled release of peak flows to prevent the sedimentation of river channels, invasion of riverbeds by non-native species, and as a consequence, diminishing the impacts of extreme events on ecosystems.
- Reinforcing the strategy for the conservation of the nation's most important ecosystems and their environmental benefits, including 97 Natural Protected Areas, 55 Ramsar sites, and 78,500 km^2 of river basins.

PROGRESS IN DROUGHT FORECASTING AND WARNING

Brazil

Brazil has a variety of climates, ranging from tropical in the center-north to temperate in the south, and from humid at the north part of the Amazon region to semi-arid sertão region in greater part of north-eastern Brazil. The positive ENSO phase, known as El Niño, is normally related to droughts in the northern part of the country, including the Amazon Rain Forest and the semi-arid Northeast, within which the State of Ceará is located. The negative ENSO phase (La Niña) normally intensifies the drought spells in southern Brazil.

Drought monitoring and early warning is supported by an array of various Ministries and agencies, including those focused upon: (i) weather and climate forecasting such as National Institute for Amazonian Research, the Center for Weather Forecasting and Climate Studies, the National Center of Monitoring and Early Warning on Natural Disasters; and (ii) data gathering and monitoring such as ANA that captures water data from a hydrometeorological network, and Ministry of Agriculture, Livestock and Supply on agricultural data.

Based on the information provided, the federal government recognizes one of two special states that can be declared by an affected region during a drought event:

- **A Situation of Emergency** (less severe): an abnormal situation provoked by disasters that cause damages and losses, which are grave enough for the local government to be partially unable to respond.
- **A State of Public Calamity** (more severe): is an abnormal situation provoked by disasters that cause damages and losses, which are grave enough for the local government to be substantially unable to respond.

Guidelines note that the declaration of either situation or state should last for as short as a time as possible (to re-establish normality) and also only include the areas affected by the drought declaration. Despite this well laid out policy, there is not a systematic procedure for how to make the declarations for the municipalities and what necessarily distinguishes between public calamity and emergency. The decision relies on whether or not there is local capacity to support municipal response action on the environmental, economic, and social impacts of the disaster (Guitierrez *et al.*, 2014).

Mexico

Mexico uses the North America Drought Monitor (NADM) to evaluate the evolution and geographical influence of droughts in the country. The NADM is a cooperative effort between drought experts in Canada, Mexico and the United States to monitor drought across the continent on an ongoing basis. The NADM is based on the highly successful U.S. Drought Monitor (USDM), and is being developed to provide an ongoing assessment of drought throughout all three countries with drought maps produced monthly through a process that synthesizes multiple indices, outlooks and local impacts, into an assessment that best represents current drought conditions. The final outcome of each Drought Monitor is a consensus of federal, state and academic scientists. Major US participants in the NADM programme include NOAA's National Climatic Data Center, NOAA's Climate Prediction Center, the US Department of Agriculture, the US National Drought Mitigation Center, Agriculture and Agrifood Canada, the Meteorological Service of Canada, and the National Meteorological Service of Mexico (SMN, a department of CONAGUA).

Through the North America Drought Monitor (NADM), Mexico classifies droughts in five types based on the potential for damage:

- **Usually dry** (D0): there are not important consequences due to the lack of rain and humidity; it is a phase that usually comes at the beginning or at the end of a drought.
- **Moderate** (D1): some minor consequences to crops due to the lack of rain and humidity; high risk of fires and low levels in small rivers and dams. Voluntary restrictions on water use may be encouraged.
- **Severe** (D2): very likely loss of crops, very high risk of fires and water scarcity is common, so different activities are affected by the reduction of the water levels in dams and water bodies, so some mitigation measures are put into practice, such as restrictions in the production of certain crops. Restrictions on water use must be put out into practice.
- **Extreme** (D3): loss of crops, extreme risk of fires and generalized water scarcity, so there are serious problems due to low levels of water in dams and water bodies. Generalized restrictions on water use are imposed and CONAGUA and other federal agencies implement actions to protect population health and economic activities.
- **Exceptional** (D4): important generalized losses of crops, extremely low levels of water in dams and water bodies, extreme risk of fires, so emergency actions are put into practice to protect population health and economic activities.

LESSONS LEARNT AND LIVE ISSUES

Brazil

Large portions of Brazil's Northeast have experienced an intense and prolonged drought for the majority of 2010–2013. This drought, along with other droughts that have hit the south in recent years, has sparked a new round of discussions to improve drought policy and management at the federal and state levels. There are short-term and long-term gaps and opportunities to improve drought management (summarized by Guitierrez *et al.*, 2014) include:

- **Integrating drought monitoring and forecasting data and technical capacity:** Brazil has significant scientific and technical knowledge and expertise in meteorological, climatological, agricultural, and hydrological monitoring and forecasting. However, these capabilities are not always well integrated.
- **Introducing climate change projections into impact assessments:** Current planning is largely based on an understanding of historical climate extremes. Incorporating climate change projections into models would support planning and management for future drought preparedness and climate resilience.
- **Clarifying and integrating institutional responsibilities:** There appear to be overlapping drought related duties and responsibilities between Ministry of National Integration (MI) (e.g. drought coordination and response through the Emergency National Force on Drought, as well as the drought policy discussion within the work group), Ministry of Environment (MMA) (e.g. desertification and adaptation to climate change) and Civil House of the Presidency (e.g. Integrated Committee during droughts), with limited coordination between the various efforts.
- **Taking advantage of droughts to change practice:** Proactive, risk-based approaches do not develop overnight. The focus that the 2011–13 drought has placed on drought issues and the need to do things better provides an opportunity to introduce change.

Mexico

Historically, Mexico has focused on monitoring and reacting to drought at the near exclusion of other drought management measures. The National Drought Programme includes a much more comprehensive response but, if it is to be effective, a number of challenges and live issues will need to be addressed (based on Federman *et al.*, 2014):

- better alignment of the federal, state and local funding programmes to the directives of the drought plans is critical due to a very long history of a reactive approach
- enhanced consideration of future change within the planning process and scenario based planning should be the baseline for the National Development Plan and the framework for a new National Civil Protection System
- a more explicit connection between water resources planning and drought planning
- improved drought communication to foster acceptance of the national plan through the basins and states.

Engaging a wide group of stakeholders in meaningful dialogue is essential for maintaining the momentum of drought planning and implementation in the future.

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Drought risk management
A strategic approach

Water resources are increasingly a source of tension; a tension that is at its highest during periods of drought. A consensus now exists that a transformational change in our approach to drought management is required – away from an episodic process that reacts to an emergency to a continuous process that proactively manages risk. Although some progress has been made, the transition is only in its infancy.

Drawing on experiences from around the world, this book presents a framework for Strategic Drought Risk Management (SDRM). SDRM is presented as a coherent and continuous process of analysis, adjustment and adaptation of policies and actions to reduce drought risk, including modifying the probability of a drought, reducing the vulnerability and enhancing the resilience. SDRM is seen as part of a wider approach to water security and water-related basin planning activities and acts both to reduce risk and promote environmental, societal and economic opportunities now and in the longer-term.

In addition to describing the history and evolution of approaches to drought management, the book recasts the definitions of drought to be consistent with a risk approach and considers a range of methodological and practical issues, including: objectives of SDRM, the measures and instruments that can be used to manage risk (including role of ecosystems), drought monitoring and the prioritisation of action. The final section of the book presents supporting case studies including China, England, Spain, Syria, Morocco, India, United States, Brazil, Mexico and Spain.

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