ACT

ACTION ON CLIMATE TODAY

LEARNING PAPER

Climate-Resilient Water Management: An operational framework from South Asia

A.J. James, Aditya V. Bahadur and Shilp Verma
with Peter Reid and Soumik Biswas

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Children travel in a flood hit area, inundated houses visible in the background, Ubauro, Pakistan.
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Abbreviations and acronyms

ADB	Asian Development Bank
ACT	Action on Climate Today
AWS	Automated Weather Station
BAU	Business As Usual
CEC	Commission of the European Communities
CRWN	Climate-Resilient Water Management
CWC	Central Water Commission
EWS	Early Warning System
GDP	Gross Domestic Product
GWP	Global Water Partnership
IRBM	Integrated River Basin Management
ISET	Institute for Social and Environmental Transition
IWRM	Integrated Water Resource Management
JSA	Jalyukta Shivar Abhiyan
M&E	Monitoring and Evaluation
NAP	National Adaptation Plan
NGO	Non-Governmental Organisation
UN	United Nations
WMO	World Meteorological Organization

Executive summary

One of the most prominent ways in which climate change is manifesting itself is through its impact on global water resources. The complex inter-linkages of water with other critical systems such as food, energy and the economy provide an urgent imperative for the adoption of Climate-Resilient Water Management (CRWM) at scale. This paper presents the tools, approaches, evidence, paradigms and experiences of developing and deploying CRWM interventions in South Asia, one of the world's most water-stressed regions.

High population density, poverty and the dependence of a majority of the population on agriculture as a source of livelihood mean water resources in South Asia are already stressed, overexploited, degrading and depleting fast. Climate change is aggravating the situation, threatening human development, peace and security. The scale of the problem is such that, instead of isolated and *ad hoc* action to adapt water management practices, policy-makers in the region need to ensure resilience is effectively mainstreamed within policies and programmes across scales of governance.

This is the challenge that Action on Climate Today (ACT), an initiative funded by the UK Department for International Development, has taken up since 2014. The programme is focused on climate-proofing governance systems in five South Asian countries at the national and subnational levels, and is designed to transform systems of planning and delivery for adaptation to climate change. Climate-proofing the water sector across these countries is one of ACT's main objectives, and the initiative has thus been championing CRWM as one approach to battling the impacts of a changing climate across the region.

The paper presents a conceptual framework that distinguishes CRWM from other paradigms of water management. CRWM interventions distinguish themselves through:

1. Using the best available climate information and data to go beyond business as usual;
2. Systemically integrating the principles of resilience, such as using 'buffers' and having flexibility and adaptability;
3. Sharply focusing on reducing the vulnerability of poor and marginalised communities.

Water management interventions are then sorted into three broad categories:

1. Water resource management (including assessment, supply augmentation and demand management);
2. Management of extreme events (floods and droughts); and
3. Creating an enabling environment (through mainstreaming climate impacts in sectoral and cross-sectoral policies, among other governance instruments).

Embedding the three conceptual tenets of CRWM across these three broad areas of interventions helps operationalise the concept of CRWM.

The paper explores this conceptual framework by presenting 12 examples of CRWM interventions developed and deployed by the ACT programme across South Asia. This provides a high-resolution picture of the manner in which the programme has integrated the three conceptual pillars across its work on water resource management to bring a vision of CRWM to life.

The paper concludes by outlining the main challenges and learnings from implementing CRWM interventions in the region, including the need to:

- Move beyond 'business as usual' to integrate the best available climate data and information in managing water resources;
- Adopt a multi-disciplinary approach to mainstreaming the risk of climate change in programmes and policy;
- Map and lock into existing government priorities at different levels to secure political will;
- Firmly acknowledge that CRWM is political as opposed to being a purely technical or scientific paradigm;
- Frame and communicate about climate change using language and concepts that are relatable and impacts that are tangible.

1. Introduction

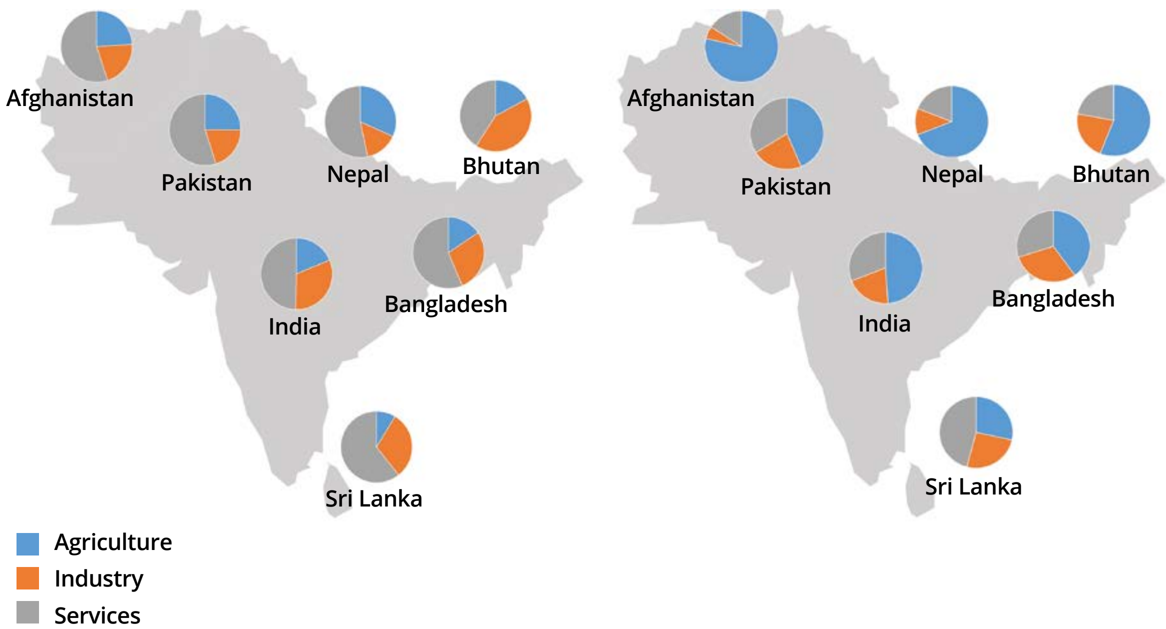
South Asia is one of the most densely populated regions in the world (UN, 2015). It accounts for less than 4% of global gross domestic product (GDP) and is home to one of the largest concentrations of rural poverty (World Bank, 2016a). Meanwhile, scientists argue that one important way in which climate change will manifest itself is through its impact on the water cycle. In South Asia, given its high dependence on agriculture, this is likely to lead to substantial social, political and economic challenges.

All the countries of South Asia face serious water management challenges; they also have weak institutions and protocols for managing transboundary waters (Price, 2016). While climate change in itself plays only a secondary role in the origin and aggravation of water conflicts (Kloos et al., 2013), it will certainly put South Asia's water management and governance institutions to a formidable test.

This is the reason why one of the four pillars of the Action on Climate Today (ACT) programme is sharply focused on enabling Climate-Resilient Water Management (CRWM) in the region. This five-year initiative funded by the UK Department for International Development is aimed at providing direct technical assistance to national and subnational governments on mainstreaming climate change adaptation in policies, plans, programmes and budgets. It works on strengthening institutions to develop and deploy climate change adaptation policies, access and mainstream climate finance, promote climate-resilient agriculture and enable CRWM.

Section 2 of this paper briefly describes the history of water management in South Asia. Section 3 looks at the context of climate change and water resources in the region. Section 4 presents the current state of knowledge and practice on CRWM to synthesise an analytical framework. Section 5 then provides examples of ACT's interventions in this domain and explains the manner in which these are contributing to enhancing resilience across the region. Section 6 provides concluding thoughts and issues.

Figure 1: Relative share of agriculture, industry and services in GDP (left) and employment (right) in South Asia



Data source: World Bank (2016a).

2. History of water management in South Asia

The earliest human settlements in South Asia developed along rivers, with the management of river water implemented through direct extraction and minor diversions. As human settlements spread further away from riverine areas, the need to 'harness and husband' water resources arose. We can distinguish different phases of water management in South Asia (Shah, 2009a):

Until the early 19th century, water resource development and management reflected South Asia's hydrogeological reality and largely involved adapting local needs to resource availability using simple technologies. Everyday water management lay more in the domain of village communities than the state (Aggarwal and Narain 1997). Shah (2009a) calls this 'adaptive water management'.

The early 19th century saw the large-scale reconfiguration of river basins through the construction of reservoirs and canal networks, with the major focus on expanding irrigation potential.[1] Water management moved from being predominantly a local community responsibility to the domain of the state.

In the second half of the 20th century, concepts of sustainable water resource development, including that of Integrated River Basin Management (IRBM), came to the fore globally. It became widely accepted that water resource planning, development and management needed to happen at the river basin level and in a way that integrated current and future water uses along with environmental flows.

From the 1970s, propelled by developments in drilling technology and rural electrification, millions of farmers started taking back control over water resources by investing in dug wells and tube wells and engaging with the resource without any intermediary or central authority.[2] Some have argued that the Green Revolution would not have been successful without the groundwater revolution (Dhawan, 1982). Surveys in India—the world's largest user of groundwater—show that groundwater not only sustains hundreds of millions of agrarian livelihoods but also plays a crucial role in meeting domestic and industrial water demand (Shah, 2005). South Asia is already witnessing several instances of over-exploitation and a long-term decline in water tables.

From the 1980s, contemporary thinking on water management has proposed ideas such as Integrated Water Resource Management (IWRM), which represents a quantum leap from the former water management paradigms and highlights the need for coordination and incorporation of the concept of sustainability. IRBM can be seen as a subset of IWRM. Implementing IWRM in the largely informal water economies of developing countries in Asia and Africa presents unique challenges (Shah and van Koppen, 2006). For one, a large majority of water users are directly connected to water resources, making regulation difficult.

Brahmaputra river near Jorhat and Majuli island, Assam, India.

1 Even today, agriculture uses more than 80% of the region's freshwater.

2 Well irrigation was not new to South Asia, and around 1970 accounted for nearly 30% of irrigation from all sources in India, Pakistan and Bangladesh. After 1970, however, it expanded rapidly, and by 1999–2000 it accounted for nearly 60% of all irrigation (Shah, 2009a).

3. Climate change and water resources in South Asia

Various impacts of climate change can be predicted for South Asia. Sea level rise may have catastrophic consequences for island states such as the Maldives and Sri Lanka, for low-lying delta regions in Bangladesh and eastern India and for coastal ecosystems in India and Pakistan. Climate-induced changes in the rate of glacial melting coupled with higher incidence of extreme precipitation events will increase the frequency of floods and droughts. Rising temperatures will lead to more evaporation and transpiration, reducing the productivity of dry-land agriculture and increasing dependence on irrigation. All of these will have significant impacts on food and livelihood security, agriculture, urbanisation and industrialisation in the region. It has been suggested that, if current trends are allowed to persist, climate-driven water scarcity will likely reduce GDP growth rates in the region by as much as 6% (World Bank, 2016b).

The water balance equation can be used to generate a deeper understanding of the likely impacts of climate change on different processes of the water cycle in South Asia, and, through this, to help us design interventions that may help improve climate adaptation and reduce vulnerability to climate change. The water balance equation explains the partitioning of precipitation into its different components as a linear representation of the water cycle.

In its simplest form, the water cycle comprises four basic processes: precipitation, evapotranspiration, runoff and storage, which can be represented in linear form as the water balance equation:

Precipitation = Evapotranspiration + Runoff + Change in Storage

Table 1 presents the likely impacts of climate change on water resources in four distinct geo-hydro-ecologies of South Asia with regard to these four processes.

The implications of these are given in Box 1.

Box 1: Implications of climate change on water resource management in South Asia

- **Climate change in South Asia will increase rainfall uncertainty and variability.** South Asia already has high geographical and temporal variability in precipitation, and this variability is expected to grow even more with climate change. In semi-arid South Asia, one in every two or three years is a drought year. The region also sees some extreme rainfall events that can cause flash floods.
- **The best way to address increasing climatic variability is to improve dependable surface water storage.** Given that this variability is expected to grow even more with climate change, the dependability of surface water storages will need close reassessment. An increase in large dams is not necessarily the answer, but, for instance, the 75% dependability thumb-rule irrigation engineers and planners have historically applied will need to be revised downward to enable meaningful investment decisions[3] under conditions of high evaporation, uncertain precipitation and increased incidence of extreme climate events.
- **Groundwater storage management is critical.** With growing variability in precipitation and higher temperatures, surface water storages are less reliable and more susceptible to higher evaporation rates. Groundwater storages, on the other hand, react slowly to changes in rainfall and temperature. Thus, if managed well, groundwater can become a more resilient buffer for long periods of water stress. They can also help reduce the intensity of extreme flood events by absorbing part of the excess runoff (Khan et al., 2014; Amarasinghe et al., 2016). Although South Asia has limited sub-surface storage capacity, farmers believe that even tiny storages close to their farms can provide life-saving irrigation in periods of moisture stress—thus making agrarian economies more resilient to climate extremes (Shah, 2000; Kumar et al., 2012).

3 Irrigation engineers plan reservoir storage in such a way that, given the rainfall pattern, the reservoir should fill up every four years (i.e. 75% dependability). However, with growing inter-year rainfall variability and the expected higher frequency of extreme precipitation events, we may need to plan for water storages with lesser dependability in order to capture the surplus runoff in the high precipitation periods.

Table 1: Likely impacts of climate change on water resources in four distinct geo-hydro-ecologies in South Asia

Hydrological process	Region	Key climate impacts expected
Precipitation	Northern mountain ranges	• Higher snowmelt and precipitation • Greater temporal variability
	Indus–Ganges–Brahmaputra plains	• Marginal decline in precipitation • Reduction in number of rainy days; • Increased incidence of extreme precipitation events
	Peninsular Plateau	• Marginally higher (5–10%) precipitation • Greater temporal variability
	Coastal, delta and island ecosystems	Marginally higher (5–10%) precipitation
Evapotranspiration	Northern mountain ranges	Little or no change
	Indus–Ganges–Brahmaputra plains	• Higher evaporation and transpiration • Lower productivity of rain-fed agriculture
	Peninsular Plateau	• Higher evaporation and transpiration • Lower productivity of rain-fed agriculture
	Coastal, delta and island ecosystems	Little or no change
Runoff	Northern mountain ranges	Increased stream flows up to 2030; gradual decline thereafter
	Indus–Ganges–Brahmaputra plains	• More runoff (5–20%) • Less natural groundwater recharge
	Peninsular Plateau	• More runoff • Less natural groundwater recharge
	Coastal, delta and island ecosystems	Little or no change
Storage	Northern mountain ranges	Declining glacial storage over time
	Indus–Ganges–Brahmaputra plains	• More siltation of surface reservoirs • Growing reliance on sub-surface (groundwater) storage
	Peninsular Plateau	• More siltation of surface reservoirs • Little multi-year storage capacity • More frequent and more severe drought events
	Coastal, delta and island ecosystems	• Risk of seawater intrusion in groundwater storage
Any other changes	Northern mountain ranges	• No other significant changes
	Indus–Ganges–Brahmaputra plains	• No other significant changes
	Peninsular Plateau	• No other significant changes
	Coastal, delta and island ecosystems	• Rising sea level a key challenge for coastal and island ecosystems • Increase in incidence and severity of arsenic contamination • Higher frequency of coastal floods and cyclones

Source: Shah (2009b).

4. Climate-Resilient Water Management

The likely impact of climate change on water resources can be condensed into a simple statement: climate change will shorten or hasten the water cycle. Higher temperatures mean evaporation rates will rise and this, in turn, will affect all other processes in the water cycle and their interrelationships.[4] Any response aimed at reversing such changes should, in effect, attempt to slow down the hydro-geological processes in the water cycle.

CRWM aims to reduce the vulnerability of at-risk populations to the adverse impacts of climate-change—or, to put it more broadly, to increase the resilience of human populations, the built environment and the natural environment to short- and long-term impacts of climate change. 'Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist' (Holling, 1973).

CRWM interventions will demonstrate a direct contribution to improved resilience to climate change, which includes the ability to maintain services and support livelihoods in the face of short-term shocks to the system (such as extreme events) as well as to adapt to an uncertain and longer-term future (e.g. with sea level rises and changes in existing patterns of temperature and precipitation variations) (Bahadur et al., 2015). Every CRWM measure proposed (including some popular ones in the literature such as drip-irrigation and laser land-levelling) thus needs to demonstrate how exactly it expects to increase resilience (either on its own or in conjunction with other measures).

Table 2 summarises the differences between the various approaches to water resource management, highlighting the key characteristics of CRWM.

4.1. Criteria necessary to frame activities as CRWM

We can use three criteria to distinguish CRWM activities from those of other water management paradigms.

Criterion 1: Does it use the best available data and information to go beyond BAU?

'Climate change resilience' has become a buzzword, which far too many development interventions are using without adequately demonstrating that they are not merely following BAU (Cortes, 2014). Practitioners and planners can consciously differentiate CRWM interventions from BAU through active use of the best available climate information while designing and planning interventions. CRWM actions are essentially based upon information on natural and physical exposure and socioeconomic vulnerability of people and assets within social, economic and infrastructural systems to climate change-related shocks and stresses (Wilby et al., 2009).

These datasets can cut across administrative boundaries, sectors and timescales to include information about past events and performance, current trends and future projections on the impact of climate change. These could entail acquiring data and information from 'top-down' methods such as downscaled climate models, meteorological data trend analysis or remote sensing imagery from satellites (ADB 2016). It could also involve acquiring data and information using 'bottom-up methods', including crowd-sourced geo-referenced data on climate-induced hazards, participatory vulnerability assessments, transect walks or shared learning dialogues with vulnerable populations (Shaw and Sharma, 2011).

Criterion 1:	Criterion 2:	Criterion 3:
Does it use the best available data and information to go beyond business-as-usual?	Does it integrate 'buffers', flexibility and adaptability and provide systemic solutions?	Does it specifically aim to reduce the vulnerability of poor and marginalised communities to climate change?

4 A prime example is the rainfall–runoff relationship. Runoff is as much a function of the quantum of rainfall as it is of its frequency. Two regions experiencing the same total quantum of rainfall can experience significantly different runoff depending on the frequency of the rainfall process. A few large rainfall events are likely to generate a lot more runoff than the same quantum of rainfall distributed over larger number of smaller, less intense, rainfall events.

Table 2: Water management paradigms and CRWM

	Large Water Infrastructure Development	Integrated River Basin Management	Integrated Water Resource Management	Climate-Resilient Water Management
Primary focus on large engineering projects	√	√	×	√
Supply-driven approach	√	√	×	×
Managing water at river basin scale	×	√	√	√
Integrating environmental needs and multiple uses	×	√	√	√
Integrated approach: ecosystem services	×	×	√	√
Water resource 'management' perspective	×	×	√	√
Techno-economic principles	×	×	√	√
Climate-driven global changes incorporated	×	×	×	√
Uses best available data and information to go beyond business as usual (BAU)	×	×	×	√
Prioritises redundancy, flexibility and adaptability	×	×	×	√
Specifically aims to reduce vulnerability of poor communities	×	×	×	√

Given the differential dependability and the variability of many sources of data on climate change, those designing or delivering CRWM interventions could also use scenarios whereby planning is done on the basis of multiple possible outcomes regarding exposure and vulnerability to climate change impacts. Best practice underlines the importance of combining different types of information from these diverse sources to build as comprehensive a picture a possible. These data then need to be deployed in a way that alters, or adds an element to, planned actions over BAU. Crucially, those planning and deploying CRWM interventions must understand that climate change will render the extrapolation of patterns from historical data alone less useful, as uncertainty, extremes and variability are increasing in unprecedented ways.

The challenges in acquiring and using high-quality data on climate change-related shocks and stresses are well recorded but there is consensus that, even in data-scarce contexts, there is some data that can be used in decision-making for enhanced climate resilience.

A forthcoming ACT Learning Paper will focus exclusively on the challenges and opportunities in using climate information to inform decision-making in South Asia.

Criterion 2: Does it integrate 'buffers', flexibility and adaptability and provide systemic solutions?

After decades of research on the nature of resilience for critical systems like water, consensus has emerged on the need to operationalise resilience by integrating particular principles into their management.

First, extra precaution must be accounted for, based on higher rather than lower risk scenarios in water management. For instance, plans should be designed around lower-probability high-risk events—which would provide a degree of 'redundancy' or 'buffer' capacity in water management systems. More specifically, as we cannot fully prepare for all eventualities that climate change will induce, programmatic interventions to enhance climate resilience in the water sector must build in spare capacity to buffer against residual risk (Bahadur et al., 2016). Thus, management interventions need to go a step further than the usual 'precautionary principle'.[5]

Second, we can enhance resilience by prioritising flexible and adaptable systems over static solutions. This includes maintaining services and supporting livelihoods in the face of shocks and stresses to the system through the ability to switch from one coping strategy/option to another (e.g. strategic use of valves that can de-network one part of a water system from another) (Tsegaye 2013). It could also entail the use of techniques such as 'adaptive management', whereby institutional arrangements and environmental knowledge are tested, adjusted and revised in a dynamic, ongoing, self-organised process of learning from action (Folke et al., 2002).

Third, resilience also results from the participation of multiple stakeholders in decision-making (e.g. water utilities, water user groups, academics, civil society) and from ensuring that multiple bodies with a stake in the governance of water interact and collaborate to make rules within a specific policy arena or location (Biggs et al., 2015). This is because resilience thinking underlines the importance of viewing water management systems as an integrated whole and acknowledging the dynamic relationships between diverse parts of a system (ibid.). Understanding these complex relationships permits water managers to respond and adapt to risks the system may face. Systems thinking that is inherent to the resilience concept underlines the importance of breaking down sectoral silos and engaging across scales of governance and political boundaries (Bahadur et al., 2016).

Therefore, CRWM interventions enhance redundancy, and are flexible, adaptable, based on a holistic understanding of complex systems and supported by policies grounded in multi-stakeholder interactions.

Criterion 3: Does it specifically aim to reduce the vulnerability of poor and marginalised communities to climate change?

In South Asia and elsewhere, the majority of water users access the resource directly from nature, meaning that the poor and marginalised often are the most vulnerable and have the least resilience to climate-induced shocks and stresses. There are major equity deficits in water management in South Asia. Equity spans several contexts—water allocation across sectors; access to water services; water for life, productive activities and cultural needs; decision-making around water; etc.—but, across all of them, the poor and marginalised have heightened vulnerability to climate risks.

A new water pump has made domestic chores easier and reduced waterborne diseases in Nechem, Afghanistan.

5 The precautionary principle is a strategy to address unknown and uncertain future risks (owing to the limits of scientific knowledge) by taking the less risky course of action. The principle is considered when a dangerous or irreversible outcome is identified but scientific knowledge about the probability of the outcome is limited (e.g. CEC, 2000). The principle asserts a societal preference for risk averseness under uncertainty and prevents uncertainty from becoming an argument for limited response, delayed response or complete inaction.

CRWM interventions emphasise the reduction of this vulnerability. Neglecting equity can fuel water conflicts, already endemic and growing in South Asia, and shift risks onto poor and vulnerable populations (Verghese, 1987; Siddiqi and Tahir-Kheli, 2004; Baqai, 2005; Joy and Paranjpe, 2007; Kalair, 2012).

For interventions to be framed as CRWM, they must demonstrate adherence to Criterion 3. Criterion 3 is essential because the need for CRWM becomes apparent only when there is vulnerability. At the same time, interventions should also demonstrate adherence to one or both of Criteria 1 and 2. Some interventions may use the best available information and data to go beyond BAU (Criterion 1); for instance, the design and location of a water storage facility may change to enhance resilience after modelling the impacts of climate change in the area. Others may choose to build in redundancy, flexibility and adaptability that permit a system to function under multiple potential scenarios (Criterion 2) without specifically integrating climate information. An example of this could include an urban water supply system that draws on multiple and diverse water sources.

4.2. A classification of CRWM interventions

CRWM interventions may be classified into three broad categories, depending on their primary implementation approach (see also Figure 2):

1. **Water resource management**, which includes water resource assessment, water supply augmentation and water demand management;
2. **Management of extreme events**, which includes integrated flood management and drought management;
3. **Supporting environment**, which includes policies (water, food, agriculture, energy, etc.), budgets (water and other departments), institutions and laws (water and others).

The following sections describe CRWM interventions and highlight how they may adhere to the CRWM criteria. All the examples aim to enhance redundancy, flexibility and/or adaptability (Criterion 2). They all carry the potential to be designed or run using the best available information and data (Criterion 1). They all have the potential to reduce the vulnerability of poor and marginalised communities to climate change (Criterion 3).

4.2.1. Water resource management

Water resource assessment

A starting point in planning water resource interventions is to assess current and future needs across sectors using an appropriate hydrological model (James et al., 2015; Kumar et al., 2017). The use of such models is now standard; what distinguishes CRWM modelling is the use of simulated short- and longer-term climate change scenarios to assess their potential impacts on water availability. These can be created using projections both from existing climate change models and from simulated, scenario-based impacts (e.g. twice the maximum rainfall observed to date; consecutive years of droughts) and can help identify climate-related impacts. This can help in planning water infrastructure investments and their management (e.g. operating rules of existing infrastructure)—besides avoiding potential 'mal-adaptation' (adaptation options that seem appropriate are found to be inappropriate later owing to information not considered earlier).[6]

Information from such exercises must underpin all decisions on water allocations, supply augmentation and demand management—and be updated as new information becomes available (in line with Criterion 1). Information for decision-making must also include 1) high-impact but highly unlikely events (Taleb, 2007) that affect water availability and demand; and 2) insights from bottom-up methods of assessment such as

Figure 2: The three components of water management

Water resource management	Management of extreme events	Supporting environment
• Water resource assesment • Water supply augmentation • Water demand management	• Integrated flood management • Drought management	• Policies • Budgets • Institutions • Laws

6 See, for instance, Magnan et al. (2016).

'Shared Learning Dialogues', with their iterative deliberations and sharing of sector- or group-specific information and knowledge from both local practitioners and external experts (ISET, 2010). None of this is currently standard practice in water resource assessments.

Water supply augmentation

'Supply augmentation' covers all options to increase the availability of surface and ground water. These could include cloud seeding (to catalyse precipitation); the design and construction of large infrastructure to transfer surface water within and across river basins and smaller infrastructure (such as village tanks and rainwater harvesting); treatment systems to reduce and reuse domestic wastewater, sewage and industrial effluents; and methods to reduce groundwater contamination (e.g. by naturally occurring chemicals such as arsenic or fluoride and seawater ingress into groundwater in coastal areas).

While such investments have taken place throughout history (e.g. village-level water harvesting structures) and have always been sensitive to climatic variability, they have not been designed for sharply rising short-term climatic variability (erratic and delayed monsoons, more intense and shorter-duration rainfall) and longer-term climate change (shifting rainfall patterns and temperatures, sea level rise). Application of CRWM to augment water availability in the context of a rapidly changing climate will therefore require changes from BAU, in terms of both operating and creating new infrastructure. Some illustrative examples of such CRWM activities include:

- **Large water infrastructure**

Modification of existing dams: Even without building new dams,[7] several measure can be taken with existing dams, including raising dam heights to cope with additional future inflows of water following higher-intensity rainfall; providing for and operating spillways to carry away excess inflows (without having to release water from the dam itself); and linking canals to surface storage structures (tanks and water harvesting structures in semi-arid regions) and sub-surface storage (groundwater aquifers and wells) for use during low-rainfall periods. These modifications could emanate from the use of the best available information, in which case they would align with Criterion 1. As they enhance buffer capacity or redundancy of the system, they align with Criterion 2.

Improved reservoir management: Changing from fixed reservoir operating schedules to dynamic management based on more reliable forecasting (hydro-met) systems will not only increase storage but also facilitate controlled releases during high-rainfall events and low-rainfall years. This is in line with Criterion 2, as it addresses the aspects of flexibility and adaptation in reservoir management based on emerging information.

Design of new canals and refurbishment of existing canal systems: It is possible to revisit design factors such as flow calculations, safety margins and spillway and bypass features to take into account the potential impacts of climate change; redesign canals to carry larger volumes of flood waters; and reassess the need to line canals by balancing the advantages (reduced 'seepage', 'leakage' and waterlogging) against the disadvantages (reduced infiltration to groundwater, reduced recharging of surrounding wells) depending on local conditions. This is largely in line with Criterion 2 but may also align with Criterion 1 if canals are located in areas likely to experience climate-induced shocks and stresses, as seen through top-down or bottom-up sources of data.

- **Local-level water infrastructure**

Increasing surface water harvesting and storage: The most common approach to augmenting local resource supply, particularly during the dry season, is water harvesting. Soil moisture conservation interventions, typically undertaken in watershed programmes, are also employed. Soil and water conservation as well as tank repair, rehabilitation and de-silting are popular in South Asia but the critical distinction for CRWM is whether their design

Kodar water reservoir in Mahasamund District, Chhattisgarh state, India.

7 The environmental and social impacts of dams are well recorded and need to be considered in individual contexts. There is a large and growing body of evidence that demonstrates the substantial contribution of dam construction to global greenhouse gas emissions as well as growing scepticism over the long-term impacts of large dams on the resilience of catchments on basins. In contrast, certain dams have reduced incidence of extreme inundation (see box 1), provided stable power generation, sustained supply for irrigation, etc. as well as reducing incidence of flooding.

and management systems aim to harvest water during periods of excessive rainfall and make it available for use during times of low rainfall (James et al., 2015). This aligns with Criteria 1 and 2.

Enhancing groundwater storage and capacity: Groundwater resources were intended to serve as drought buffers in semi-arid and arid regions, but groundwater mining is now one of the causes of drought. In most parts of semi-arid India, annual groundwater pumping has exceeded natural recharge, and groundwater levels have been falling. Groundwater is most commonly enhanced through artificial recharge (Sakthivadivel, 2007; Shah, 2009a) and, less frequently, through sub-surface dykes. Other initiatives include inter-basin water transfers[8] (Rai et al., 2015) and tank de-silting (Sakthivadivel et al., 2004; Dayal and Iyengar, 2006; Pant and Verma, 2010; Aheeyar, 2013). Treating groundwater contaminated with naturally occurring fluorides and arsenic not only reduces debilitating diseases associated with consumption of such contaminated water but also increases the supply of potable water (Ranade and Kumar, 2004). CRWM interventions here comprise infrastructural investments and flexible and adaptive management aimed at capturing and storing groundwater for use in low-rainfall years.

- **Reusing municipal wastewater in agriculture**

There are numerous examples of farmers in peri-urban areas across South Asia using (treated and untreated) wastewater released by urban centres. But this is at best CRWM by default. Where wastewater—which is available throughout the year and irrespective of climate conditions—is used for agriculture, CRWM by design would mean using optimally treated wastewater to provide critical irrigation and thus minimise the impacts of climatic variability (e.g. low-rainfall periods and droughts). As before, this clearly aligns with Criterion 2, as it expands the range of water sources, permitting the system to draw flexibly on the optimal source in times of stress.

Water demand management

- **Reducing water demand**

A sound strategy to address anticipated water shortfalls—and more frequent and intense droughts—is to reduce demand. Allocating water to economically and ecologically more efficient uses (within the water sector and across sectors) and reducing water pollution are two key sets of demand management interventions (Frederick, 1992). In agriculture, by far the largest user of water in South Asia, options include shifting to less water-

Traditional agricultural practices in Assam, India.

intensive crops (e.g. System of Rice Intensification) (Palanisami et al., 2012); adopting crop mulching to reduce evaporation; covering canals ; and using legal, social (e.g. community-based) and economic means (e.g. pricing of domestic, industrial and institutional water supplies and irrigation water) to bring demand in line with availability projections (Calow and Macdonald, 2005; Mukherji et al., 2009; Verma et al., 2012). All of these are relevant even in the absence of climate change but can become part of a set of CRWM activities if their objective is to reduce the adverse impacts of climate-related water scarcities on industrial, agricultural and urban growth by storing saved water and making it available to vulnerable communities during periods of climate-related water stress.

- **Water allocation**

Allocation objectives should take into account the need to maintain flows in rivers; safeguard the livelihoods of the vulnerable; and provide for agricultural, industrial and urban growth (Frederick, 1992; Kumar, 2010). Such objectives, in that order (i.e. environment, social equity, (urban) development), can be used to appropriately weight a social and environmental analysis of potential impacts (to favour more vulnerable communities) while analysing trade-offs. Where demand exceeds the basin's utilisable resource, inter-basin transfers can be used to augment availability (although, much like large dams, these entail the navigation of important social, economic and environment trade-offs) (Kumar, 2010). Climate-sensitive water allocations will thus account for future changes in the hydrological system owing to climate events, through scenario modelling, which can affect water availability for different sectoral demands. The CRWM challenge here will be to ensure allocations for the poor and marginalised are protected and the best available climate data are used to estimate availability to allocate water for different uses.

8 The debate on the costs/benefits of these is far from settled as their social, ecological and economic impact remains unclear.

4.2.2. Management of extreme events

In relation to the increased frequency and intensity of extreme events, while disaster management agencies are tasked with preparedness, relief and rehabilitation, longer-term (and thus advance) preparations to minimise impacts can fall within the ambit of CRWM.

Flood management

CRWM in this area aims to increase system resilience to cope with more frequent and more intense floods brought by climate change and to thus minimise their adverse impacts on human, animal and plant populations and public and private infrastructure. Using a climate lens helps us identify two key sets of CRWM activities:

- **Long-term measures**

Integrated catchment and flood plain management measures (e.g. upstream afforestation, pastureland development, wetland protection, maintenance of green cover in peri-urban environments, erosion control measures to reduce sediment flows, fortified embankments) can reduce the siltation of reservoirs and canals and minimise flood damage to crops, livestock, human populations and infrastructure (Hooper, 2003). Intensive abstraction of groundwater on agricultural land alongside the flood plains will also reduce base flows into the rivers and runoff intensity (WMO and GWP, 2007; WMO, 2009)—and thus increase the 'flood cushion' (i.e. the 'space' in the river to carry flood water). A key issue not addressed well currently is river sediment management, as siltation is likely to worsen with more intense flooding owing to climate change (Hardy et al., 2006).

Integrated flood management can also include regulating unauthorised sand mining (which can cause rivers to change their normal flow patterns) and operating reservoirs to reduce the impacts of low-frequency high-impact floods *and* high-frequency low-impact floods (ADB and CWC, 2016). CRWM requires additional planning and preparation (e.g. creating redundancies in critical flood control infrastructure and safe-fail mechanisms) for greater resilience and to account for the residual risk from the uncertainty of climate embedded in Criterion 2.

- **Short-term actions**

Although this is usually the domain of specialised disaster management agencies, a 'CRWM lens' can help identify additional ways to minimise damage to and rapidly restore the livelihoods of the poor and marginalised. Measures to minimise damage include strengthening flood warning systems (with improved rainfall prediction models, SMS-based community warning systems, etc.) and identifying populations at risk from unprecedented floods (using revised flood-risk models with climate change scenario analysis, thereby aligning with Criterion 1), with a special emphasis on the poor and marginalised (Criterion 3). Measures to restore livelihoods include coordination of donor and non-governmental organisation (NGO) efforts; insurance to cover the loss of crops; forecast-based financing; access to cheap credit and retraining for those whose livelihoods have been affected; and learning from experience (thus satisfying Criterion 2). Climate information could be used to ensure disaster management policies and guidelines accommodate expected climate change impacts and have the flexibility to engage with unexpected events (O'Keefe et al., 2006).

Drought management

As climate change brings more intense and frequent droughts, special CRWM efforts are needed to prepare for, for instance, several consecutive years of drought. Hydrological modelling with climate change scenario analysis can help identify the magnitude of potential impacts, but coping mechanisms will have to be identified to minimise these, particularly on vulnerable rural populations (James et al., 2015; Kumar et al., 2017). We can once again identify two key sets of CRWM activities.

- **Long-term measures**

Multi-departmental and large-scale programmes are needed to build the resilience of the natural resource base to withstand continuous periods of droughts (World Bank, 2008). Activities include using the latest climate information to prepare drought risk maps that factor in climate change (Criterion 1); preparing for longer-term droughts by rehabilitating tanks as 'buffer' water sources; constructing field bunds, sub-surface dykes and farm pits (even in areas not traditionally drought-prone); incentivising farmers to make appropriate crop choices given local agro-ecological conditions and potential climate change; enabling access to drought-resistant seeds (so some yield is possible even under moisture-stress conditions); training in adaptive cultivation methods (like late sowing) to cope with untimely and erratic rainfall; planting locally viable fodder grasses and tree species (that do not withdraw much water from aquifers) and removing alien and inappropriate plant and tree species (e.g. weeds and water-extracting trees); promoting drought-resistant and locally appropriate livestock breeds; increasing soil moisture-holding capacity; and training and credit to pursue rural livelihoods that are not water-dependent.

- **Short-term actions**

As with floods, governments strive to ensure droughts claim no human or animal casualties but there are few efforts beyond short-term humanitarian support to support the poor and marginalised in rural communities to rebuild their livelihoods (Ichikawab et al., 2015). CRWM measures (planned and implemented in advance) to promote the resilience of drought-prone communities, especially the poor and marginalised, include insurance to cover distress sales and credit and retraining to start new livelihoods—especially given the prospect of more intense and frequent droughts. As in the case of floods, these measures (and the policies, programmes and funding that support them) must be adaptable and flexible, and focused on the vulnerable (satisfying Criteria 2 and 3).

4.2.3. Supporting environment

CRWM can be sustainably operationalised only if there are policies, standards, laws, financial instruments, processes and protocols in place to support CRWM domains, not only within the water sector but also in allied sectors. Broadly, both sectoral (e.g. energy, agriculture, water, industry, urban development) and cross-sectoral policies (e.g. national development plans, national adaptation plans (NAPs), livelihood development initiatives, social protection policies) have to provide an impetus for CRWM.

As a sectoral example, pricing mechanisms within energy policy that disincentivise excessive groundwater abstraction (through altering subsidy regimes) could greatly support CRWM.[9] Similarly, co-management of energy and groundwater to reduce the stress on groundwater aquifers could have a substantial impact (Shah, 2005; Shah and Verma, 2008). Pro rata pricing of electricity and energy supply rationing can improve energy and groundwater use efficiency and reduce pumping (Kumar et al., 2011, 2013).

Agricultural policy can also support CRWM by aligning food production with regional water resource endowments (Verma et al., 2009) to minimise potential impacts of climate change and support the drive for food security (a prime driver of irrigation and water management investments in South Asia). It could do this by providing water-scarce regions with more water from water-rich regions to prevent mining of local (ground) water resources (Kumar et al., 2012). Financial incentives (and disincentives) to encourage the cultivation of crops best suited to different agro-climatic zones and thus better able to withstand climatic variability

Flood affected areas in Multan, Pakistan.

and anticipated change (e.g. measures to sustain soil fertility and its moisture-holding capacity) can also be promoted through the nudge and push by policy.

With regard to cross-sectoral plans, enshrining CRWM in the policies that guide macroeconomic development can be immensely helpful. Section 5 of this paper reviews the example of Nepal, whose NAP is helping provide a framework for CRWM interventions. In India, there has been increasing recognition of the potential use of the country's nodal social protection mechanism as an instrument to induce CRWM across the rural heartland (Steinbach et al., 2016).

Similarly, there is a large body of evidence proving that constituent elements of an enabling environment for mainstreaming climate change include finance, evidence, research, institutional capacity and political will (Gogoi et al., 2017). These areas must be kept in mind when designing interventions to operationalise CRWM. Section 5 discusses tangible examples of how the ACT programme has utilised some of these.

4.2.4. Summary schematics

Table 3 provides examples of tangible CRWM activities across the traditional domains of water management and shows how the three CRWM pillars are integrated across these.

9 Energy subsidies for pumping groundwater are common across South Asia. While several governments have attempted to rationalise these, most attempts have been met with stiff opposition from farmers. The advent of solar-powered irrigation presents both a challenge and an opportunity in this respect.

Table 3: Traditional domains of water management and pillars of CRWM

Domain	Theme	Examples of actions that address the CRWM criteria		
		1. Use best available information/data for additional action beyond BAU	**2. Support redundancy, flexibility and adaptive responses**	**3. Focus on poor and marginalised**
Water resource management	**Water resource assessment**	Run climate change-based simulations (including scenarios) on hydrological models set up with best available data	• Assess even 'low-probability high-impact' outcomes • Provide information and lessons from iterative multi-stakeholder dialogues (learning from experience) to decision-makers	Analyse potential impacts on water resources accessed by poor and marginalised
	Water supply management	Use improved hydro-met predictions of rainfall for dynamic operations of dams	Set up and operate multi-annual water storage and supply systems (linking dams with smaller storages, providing treated wastewater for critical irrigation)	Ensure equitable allocation and access to water in face of increasing water insecurity—especially critical irrigation—to poor and marginalised
	Water demand management	Use downscaled climate models and scenario planning to estimate impact on water demand from various sectors to inform action and appropriate policy measures	• Provide ways to convert plot-level into sector-level water savings—and to transfer across sectors (e.g. agriculture to drinking) • Store water 'saved' through effective water demand management and make it available during periods of water stress	Allow small and marginal farmers to benefit from water-saving transfer systems during periods of water stress
Managing extreme events	**Flood management**	• Identify *additional* at-risk populations (using revised flood-risk models with climate change scenario analysis) • Work even in areas not traditionally flood-prone	Prepare for more intensive flooding by building redundancies into flood control structures; creating 'flood cushions'; and reducing sediment loads in rivers through upstream activities	• Protect poor from flood damage (e.g. community-based flood early warning systems (EWSs)) • Rapidly restore livelihoods post-event
	Drought management	• Identify *additional* at-risk populations (using revised drought-risk models with climate change scenario analysis) • Work even in areas not traditionally drought-prone	Prepare for longer-term and consecutive years of droughts by rehabilitating tanks as redundant water sources, increasing soil moisture-holding capacity; training farmers in adaptive farming practices (to counter erratic and untimely rainfall); and providing access to locally adapted seeds and breeds	• Give access to Insurance that covers damage to livelihood assets • Rapidly restore livelihoods post-event with training and credit to pursue alternate rural livelihoods (not water-dependent)
Supporting environment				

5. Climate-Resilient Water Management and ACT

This section explores salient examples of interventions led by the ACT programme in light of the typologies, frameworks and criteria presented above.

ACT works with governments of partner countries in South Asia to mainstream climate change into development plans and policies using multiple entry points. The programme trains and builds the capacity of governments; enhances decision-making tools and policy options within institutions; shares knowledge; and forges networks and partnerships. Since 2014, ACT has initiated more than 150 activity areas aimed at mainstreaming climate change across governance, climate-proofed 44 high-level policies across sectors, built the capacity of 1,700 individuals in climate-resilient development and mobilised USD 189 million in fresh financing for climate change adaptation from national and international climate change funds.

In the water sector, ACT works across the three main areas of water resource management, managing extreme events and building a strong supportive environment for CRWM.

5.1. Water resource management

5.1.1. Bihar: Integrating data from automated weather stations into the hydro-met system

Bihar is highly vulnerable to natural disasters and consists of flood-prone regions as well as regions prone to severe droughts. These vulnerabilities are expected to worsen with climate change. Discussions with the Government of Bihar indicated an urgent need for relevant data on water planning to inform not only on-going, day-to-day water management but also changes in strategies and priorities. The Planning Department had installed a number of automated weather stations (AWSs) but the data collected were not being analysed and integrated within the the plans and operations of the Water Resources Department.

ACT is providing coordination support to the government to link the data being collected by the Planning Department with the Water Resources Department. In the medium term, ACT plans to facilitate the use of data from these AWSs to benchmark, refine and enhance data from downscaled climate models, to improve the availability of actionable climate data for climate-resilient development (including water management in the state). This intervention aligns most strongly with Criterion 1 of CRWM, as it aims to strengthen existing information systems providing weather data that are vital for dealing with the impacts of climate change.

5.1.2. Pakistan: Water demand assessment

Pakistan has experienced unprecedented increases in temperature over the past decade, and high variability in precipitation—resulting in a super flood in 2010 and devastating floods in 2011, 2014 and 2015. Several studies of water availability and climate change impacts on the country's water resources existed, but there was insufficient exploration of the extent and nature of demand for water under diverse climate change scenarios. The Ministry of Climate Change identified this gap and asked ACT to conduct a study to assess the current and future water demands of various economic sectors under various scenarios.

The ACT water demand study overlays data on water demand and projections of socioeconomic change and population growth with climate change scenarios (A1 and A1B of the Fifth Assessment Report), from which it infers the estimated deficit in water availability by 2025 and 2050. This vital information on the climate change-induced gap between supply and demand aligns with Criterion 1 of CRWM, as it uses the best available data and information to factor in the projected impacts of climate change.

5.1.3. Chhattisgarh: Water resource assessment for improved climate resilience

The Mahanadi River in Chhattisgarh is the lifeline for major economic activities in the state, supplies water to major cities and industrial areas and irrigates thousands of hectares of agriculture land. In this context, the Government of Chhattisgarh and other stakeholders identified water resource planning and management under present and future climate scenarios as an important step towards reducing the vulnerability of water resources to climate change, and therefore building the resilience of the state economy.

ACT has provided technical support to the government to carry out a detailed modelling-based analysis of water resource management in the state, to enable climate adaptation in the water resources sector by identifying gaps and challenges (institutional and technical) in current state policies, institutions and programmes. ACT

Handpump with iron water in Mandawa village, Chhattisgarh state, India. .

is also developing strategies to institutionalise climate-informed water resource planning and management.

A key element entails overlaying models of water availability at the basin level that traditionally consider social, demographic, economic and environmental variables with additional variables on climate change. This initiative adheres most strongly to Criterion 1 of CRWM, as it makes active use of the best available climate data to enable decision-makers to design resilience-enhancing interventions that can plug the adaptation deficit.

Meanwhile, through the use of diverse climate scenarios, this analysis has highlighted a relatively high degree of uncertainty in water availability, including stream flows, ground and surface water storages and usage patterns, especially for agriculture and industry, over the long term, owing to potential climate impacts. This has reinforced the case for water management solutions that can accommodate a broader range of uncertainties through flexible policy options, and hence adheres to Criterion 2 of CRWM. The interventions and strategies put forward remain people-centric and intend to create an enabling environment to ensure water security especially for the marginalised of the state, thus strongly adhering to Criterion 3.

5.1.4. Odisha: Groundwater management

Odisha is one of the most drought-affected states in India, with one severe drought occurring every eight years on average. Agriculture is still largely monsoon-dependent, and depleting groundwater and increasing variability in rainfall owing to climate change have led to a growing gap between the irrigation potential created in the state and the irrigation utilised. The Water Resource Department of the Government of Odisha is keen to demonstrate a planning process that integrates sustainable and equitable ground and surface water use with the agricultural production planning process.

ACT is providing technical support to the government to demonstrate an integrated planning process that ensures the sustainable use of ground and surface water for irrigated agriculture. More specifically, it is working in two districts and developing a demonstration toolkit for integrated planning and (long- and short-term) strategies for managing water resources more sustainably.

This process will assist in substantially streamlining interventions aimed at the sustainable use of water for agriculture, enhancing livelihood security and ensuring more judicious distribution of water for irrigation. Therefore, this aligns most clearly with Criterion 2 of CRWM, as it integrates redundancy, flexibility and adaptability in the forms of anticipating future water scarcity, thereby designing measures of sustainability and providing systemic solutions to address the same. ACT's support thus also adheres to Criterion 3, by reducing the vulnerability of poor and marginalised communities to potential future water scarcity owing to climate change and other socioeconomic and demographic imbalances.

5.2. Managing extreme events

5.2.1. Assam: Climate-resilient flood management for cities along the Brahmaputra

Assam's topographic and geographic characteristics make it prone to flooding. The Brahmaputra and Barak Rivers that cross the state carry a large amount of silt and other debris, which over the years has raised the river bed, inducing spill-over. River bank erosion is also a serious problem, with nearly 400,000 hectares (around 7% of the land in the state's 17 riverine districts) lost in the past 50 years. Meanwhile, floods experienced in urban areas are significantly different from rural flooding. Human interventions like encroachment on watershed areas and unplanned infrastructure development have resulted in the formation of urban catchments, leading to an increase in flood peaks and flood volumes up to 6 times, when compared with rural flooding.

In this context, ACT is supporting the Disaster Management Authority to develop comprehensive flood management action plans for three flood-prone cities along the Brahmaputra and Barak Rivers. Short- and long-term interventions are linked with budgets, financing schemes, implementation strategies, monitoring and evaluation (M&E) systems and capacity-building. This comprehensive approach provides information on local risks and a set of plausible interventions designed for cities to enhance their preparedness to tackle and adapt to floods. Interventions range from solid waste management (to enhance the efficacy of drainage) and the construction of flood protection walls to establishing flood EWSs and conserving flood plains (so rivers can flood safely).

Thus, these plans strongly align with Criterion 2 of CRWM—that is, integration of redundancy, flexibility and adaptability and provision of systematic solutions based on a holistic understanding of complex systems and supported by policies based on multi-stakeholder interactions. Also, as the most exposed locations in cities are inhabited by people from low-income groups, the plans and ensuing interventions will focus sharply on their resilience to the impacts of flood in a changing climate scenario, thereby adhering to Criterion 3 of CRWM: reduction of the vulnerability of poor and marginalised communities to climate change.

5.2.2. Bihar: Silt and flood management in the Kosi River

The Kosi River, which flows into Bihar from Nepal, brings with it a large quantity of silt annually, causing the river bed to rise and the river to change course over time, both of which increase the impact of floods. While the nutrient-rich silt can be beneficial for agriculture, larger quantities of sediment and high-velocity flood waters can cause widespread damage to fields, livestock and houses, as well as to public infrastructure.

The adverse impacts of climate change are expected to exacerbate the already severe intensity and frequency of floods in the region. Two effective adaptation strategies are reduction of future siltation and removal of accumulated silt. The former depends largely on afforestation and biomass restoration initiatives in the upstream areas of Nepal. The Government of Bihar can adopt the latter to adapt effectively to future flooding.

In this context, the government requested assistance to manage the dredged silt. ACT has produced estimates of quantities of silt in the Kosi River, and analysed the chemical composition of silt from different stretches of the river and identified different products that could be created from it, such as in in construction, brick-making and fertiliser production.

ACT will build on this to support by proposing a comprehensive plan for the commercial development of products from silt. The programme will look at the availability of silt and the products that can be commercially produced from this. Moreover, for these products, ACT will outline technical specifications, marketing approaches, costs of production, economies of scale, sources of finance terms and conditions to be signed with the state government.

The removal of silt will enhance the carrying capacity of the basin, provide a buffer for any excess runoff that may result from climate-induced extreme events (such as extreme precipitation) and reduce the likelihood of flooding. Therefore, this intervention aligns most clearly with Criterion 2 of CRWM, as it integrates redundancy and provides systemic solutions (technical and financial) to the issue of silt accumulation. It also aligns with Criterion 3, since those most affected by floods tend to be the poor and marginalised living next to the river.

5.2.3. Odisha: Mahanadi flood forecasting

In the Mahanadi River Basin in Odisha, ACT is supporting the Department of Water Resources to design and develop a hydrology model to provide a better decision support system for the government to use in managing and minimising flood damage (see Box 2 for more information).

The intervention is strongly aligned with Criterion 3—that is, reduction of the vulnerability of poor and

Box 2: A flood forecasting model for the Mahanadi River

What is the problem?

The Mahanadi River Basin is one of 12 major river basins in India, and the delta region is the most prone to flooding of all river basins in India, because of the large catchment area but inadequate carrying capacity of its channels. The main aim in building the Hirakud Dam in 1953 was to provide flood relief through storage of excess water in flood years. Prior to this, Odisha witnessed eight severe floods every ten years; since, this figure has been reduced to over three. The dam provides good protection against floods of lesser magnitude.

However, Hirakud was not designed for the kind of rainfall that the catchment area now receives, given changing rainfall patterns. Its carrying capacity is inadequate, and this is now exacerbated by a growing siltation problem. High-volume flood discharges of a magnitude that its designers considered would arise only once in 1,000 years have been recorded 10 times since construction of the dam. Frequent floods are a regular occurrence, and climate change poses a growing risk.

The current flood forecasting system allows a maximum of eight hours of lead time in times of heavy rain, which is not sufficient for a full response, such as evacuation. This has led to heavy loss of lives and livelihoods over recent decades, with serious floods in 2003, 2008, 2011 and 2013 and many smaller ones between.

What is ACT doing about it?

ACT has supported the Department of Water Resources of the Government of Odisha to design and develop a hydrology model that includes a huge range of detailed geophysical information, builds in localised weather forecasting and can predict with a much higher degree of accuracy and much longer reaction times how the catchment area and downstream river flows will react in times of heavy monsoon rainfall.

Effective flood forecasts need to provide flood warnings 48–72 hours ahead, and this is what the new system aims to do. This intervention responds to the need for an EWS that will allow the highly vulnerable communities living in affected downstream areas to take precautionary measures, and possibly evacuate in a timely manner when serious flooding occurs.

How does government benefit?

This activity is intended to provide a better decision support system for government to use in managing and minimising flood damage. The work conducted is the first step in providing a better forecasting and early warning system. Early warning is a major element of disaster risk reduction, and early response can often stop a hazard turning into a human disaster by preventing loss of life and reducing the economic and physical impacts on lives, livelihoods and property. This forecasting system is being set up to avoid or reduce the impact of flood hazards, and as such will significantly increase resilience.

Owing to cumbersome processes and ways of working, governments often find it difficult to respond to short-term priorities, and do not have the financial flexibility to take on the high-quality technical support they need. In this instance, ACT was able to supply just such inputs, and this has enabled the government to develop an EWS designed specifically for local conditions.

How do the poor and vulnerable benefit?

This work will have a very positive impact on resilience and on the lives and livelihoods of hundreds of thousands of very poor people in the predominantly agricultural delta area. When combined with other response activities, the EWS will permit people to evacuate to safe places during flooding. This is likely to provide a hugely increased sense of domestic safety and security. From this should emerge growing confidence in secured livelihoods, with an increased likelihood of investment of human, financial and physical livelihood assets.

Source: Peter Reid and Soumik Biswas (personal communication).

marginalised communities to climate change-induced increases in the intensity and frequency of flooding. By enhancing the government's ability to issue more effective and early flood warnings during extreme precipitation events, this intervention is providing a greater degree of flexibility and increasing the adaptive capacity of vulnerable communities in the catchment (Guhathakurta et al., 2011), and thus adheres to Criterion 2. As this intervention is predicated on the use of a more sophisticated hydrology model that delivers better quality information, it also aligns with Criterion 1.

5.2.4. Maharashtra: Climate proofing the Jalyukta Shivar Abhiyan

Droughts have been recurrent in Maharashtra, with different districts facing varying degrees of it almost every third year. In 2014, droughts were much more severe, with 19,059 villages in 22 districts declared affected; 188 blocks covering 2,234 villages showed groundwater depletion of more than 2m. Continued droughts and irregular rainfall patterns have led to crop failures and a considerable decline in agricultural productivity, which has adversely affected food security and farmers' livelihoods.

To address this and ensure sustainability in the availability of water for drinking and agriculture, the state government launched Jalyukta Shivar Abhiyan (JSA) in December 2014. The aim was to generate a permanent solution to drought-like situations through integrated actions such as decentralising rainwater harvesting; increasing groundwater levels; protecting irrigation areas and water storage potential; rejuvenating defunct water supply schemes and water resources; increasing storage potential; and community awareness on water budgeting, water harvesting and water use efficiency, to increase water availability.

The sectors of agriculture and water are integrally linked, and are also highly vulnerable to climate change-related events. Thus, the state Agriculture and Water Departments asked ACT to review their existing programmes and plans to assess the degree to which they were climate-sensitive, and the measures that could be taken to make them more resilient. Through a scoping study and in consultation with the Department of Agriculture, ACT identified JSA as an important initiative that needed to be 'climate-proofed'.

ACT used a CRWM lens to make a range of technical and policy-oriented recommendations. These included a firm direction that the JSA account for increased rainfall in the future leading to increased soil erosion, excess runoff and stream scouring. ACT also advised the JSA to account for increasing temperatures leading to increased evapotranspiration, which, in turn, will lead to an increase in crop water demand. It is suggested that the JSA focus on increasing vegetative cover (for enhanced soil stability), enhance groundwater reserves, conduct water budgeting (to make efficient use of increasingly scarce water resources) and develop improved agro-meteorological services to better plan for climate variability.

Therefore, the intervention aligns with Criterion 1 of CRWM, as it integrates information on future climate change and variability in the JSA. It also aligns with Criterion 2, as it proposes actions to enhance redundancy (e.g. groundwater reserves) and adaptability (e.g. improved advisory services). Such measures would substantially reduce the vulnerability of farmers in the state, most of whom are small and marginal, as well as other socio-economically compromised sections of the population, to water scarcity caused by climate change. Therefore, it aligns with Criterion 3 as well.

Farmer in his sorghum crop field, Amravati, Maharashtra, India.

5.3. Creating a supporting environment

5.3.1. Assam: Supplementing efforts to develop a climate-resilient state water mission

Assam is highly prone to the consequences of climate change, through erratic monsoons, frequent floods and droughts and changes in the hydrological response of basins. The State Action Plan on Climate Change has identified an urgent need for integrated water resource planning and management across sectors—taking into account increasing climatic variability—to address these challenges. Also, the National Water Mission in the Ministry of Water Resources has mandated state water resource departments to set up their respective state water missions. However, Assam, like all states, has around 14 water-using departments, including those related to engineering, agriculture, groundwater and soil conservation. A basic starting point for coordinating and streamlining the work of these departments, in the context of potential climate change threats, requires a consolidated data-driven picture of water resource use across the state.

The government is thus setting up a Climate-Resilient State Water Mission with its own state-specific goals, strategies, institutional structure, policy framework, regulatory structures and M&E systems. This will strengthen efforts towards effective water resource management in the state, taking into account the impacts of rising climate variability on the water sector, and thus complying with the National Action Plan on Climate Change. The first step entails developing a Mission Document, which will include the institutional structure, scope, objectives, vision, operational strategy and plan for the State Water Mission. It will also mainstream climate change in state government policies and programmes, through coordination and cooperation mechanisms involving key stakeholders (e.g. government departments, NGOs, academics, media, international agencies). ACT's role in this initiative is supplementary and supports the on-going efforts of the Government of Assam.

As an adjunct to the initiative, ACT is developing a framework for wetland regulation. Assam has more than 3,000 wetlands under different categories. These areas are vital to maintaining an ecological balance, buffer capacity as well as livelihoods of the dependent populations in the periphery of the wetlands. All in all, they are essential for reducing risk from extreme events making their protection, conservation and regulation paramount. This framework will aim to ensure these wetlands are maintained and restored, so as to sustainably provide ecological services that serve a variety of needs, including that of supporting adaptation to climate change-induced disturbances at scale, and hence addresses the objectives outlined in Criterion 2.

5.3.2. Bihar: Upgrading the state policy architecture for CRWM

More than 90% of people in Bihar are dependent on agriculture for their livelihoods and thus the state is both highly dependent on the monsoons and adversely affected by floods and droughts. Climate change, with increasing frequency and intensity of extreme events and longer-term changes in temperature and rainfall, is thus a central concern.

The Government of Bihar had been aware for some time of the impact of erratic monsoons, floods and droughts on agriculture-based livelihoods (such as fisheries and livestock). However, there was a need for clear policy directions on water management in

Houses in Raxaul, Bihar State, India.

the state, informed by climate change imperatives to address these issues. ACT is providing technical assistance to upgrade the state's policy architecture for CRWM through a set of focused interventions.

ACT is helping the state draft a State of the Water Report by integrating climate resilience-building tools, decision support systems and policy recommendations that will align with the Agricultural Road Map and the design of the State Water Mission. First, it is sourcing and utilising downscaled climate data with support from key technical institutions to tease out implications for water management at the state level, thereby aligning the intervention strongly with Criterion 1 of CRWM (usage of best available data and information on climate change). Second, ACT is analysing the engagement of women and other marginalised groups with issues of water from a climate change perspective to ensure any state policy on water management is inclusive and representative. This adheres to Criterion 3 (significant reduction of the vulnerability of poor and marginalised communities to climate change). Finally, as described in Section 5.2.2, ACT is ensuring that findings on siltation and sediment management in the Kosi River will inform state-level policy, which informs Criterion 2 (integration of redundancy, flexibility and adaptability and providing systemic solutions).

In essence, ACT is providing targeted technical input to ensure Bihar's policy architecture for water management, and specially the State Water Mission, is robust in the face of climate change-induced disturbances.

5.3.3. Nepal: Including CRWM in the NAP

Nepal's socioeconomic, demographic and geographic characteristics make it exceptionally vulnerable to climate change. Therefore, the country's National Adaptation Plan (NAP) must identify the most vulnerable sectors and design interventions to make them resilient. Around 42% of Nepal's population is below the poverty line and does not have access to sufficient and safe drinking water. Clean usable water resources, both ground and surface water, are deteriorating owing to various anthropogenic and natural contamination. This has adverse implications not just for human health and sanitation but also for water-dependent sectors such as agriculture and energy.

ACT is supporting the government to formulate the country's first NAP, which will be Nepal's nodal policy on adaptation over the long term. This is being done through the formation of seven thematic working groups led by different line ministries (including the Ministry of Water Resources), which are helping determine adaptation priorities for each sector through a high degree of stakeholder consultation. Defining the water resources element of the NAP has entailed understanding climate impacts on the country's water resources (through modelling and scientific analysis, thus adhering to criterion 1); assessing vulnerability and risk in different sectors/sub-sectors within water resources (using both top-down analyses through national-level data and bottom-up through stakeholder engagement for validation); identifying and appraising adaptation measures (using cost–benefit analysis); and, finally, developing adaptation strategies for the water sector by mainstreaming into national plans. Strategies to build the resilience of the water sector will all be aimed at enhancing its adaptability and flexibility, and therefore the support also aligns with Criterion 2.

Crucially, running through this process is an active consideration of the differential impacts of climate change on the engagement of women and other marginalised groups with water resources through a 'cross cutting working group on gender and social inclusion'. Thus, this activity essentially also aligns with Criterion 3.

5.3.4. Afghanistan: Climate-proofing the National Water Sector Strategy

Afghanistan is highly prone to intense and recurring natural hazards, including floods, flash floods, landslides, avalanches and droughts. Climate change also poses a threat to natural resources, on which most of the population depends for livelihoods. Over the past decades, Afghanistan has experienced warming of about 0.6 °C since the 1960s. Similarly, it has witnessed a decrease in precipitation and an increased number of heat extremes and days with extremely high temperatures. Current climate models suggest climate change will act as a threat multiplier for Afghanistan, aggravating already existing climate hazards and water problems. It is expected that the most likely adverse impacts will include those related to drought, such as desertification and land degradation.

In this context, ACT has been supporting the government to climate-proof its Water Sector Strategy of 2008 to enhance the resilience of Afghanistan's water sector to the impacts of a changing climate. It is doing this through a rigorous, consultative process that is making use of the best available knowledge on climate change and the views of a range of important stakeholders, including the Ministry of Energy

Farmer with his newly planted walnut saplings, reforestation project in Baharak, Afghanistan.

and Water and other relevant line agencies, civil society and academia. The strategy, currently under development, presents a range of measures aimed at enhancing:

1. Persistence: The degree of disturbance Afghanistan's water sector can be subject to without critical disruption;
2. Adaptability: The ability of Afghanistan's water sector to adapt, self-organise and learn from disturbances;
4. Transformability: The ability of the sector to transform into a new state after crisis or shock.

Addressing these three pillars through the revised strategy will offer a menu of specific responses to the pressures of climate change. For instance, under a relatively mild climate change, persistence of irrigated systems can be achieved by applying more irrigation water to compensate for an increase in evaporation. If climate change intensifies and total water availability decreases, adaptation requires a shift to less water-intensive crops and use of technologies that optimise water use in agriculture, such as drip irrigation. Finally, if climate change intensifies droughts and causes water deficit, transformation becomes an imperative, with agriculture replaced by other less water-intensive economic activities. Overall, the strategy argues that resilience requires early and pro-active planning and preparation.

ACT's strategy focuses primarily on the integration of climate change into Afghanistan's water management plans, thereby strongly aligning it with Criterion 1 of CRWM. The strategy will also lead to the recommendation of resilience-enhancing activities (aimed at enhancing persistence, adaptability and transformability) and therefore will align with Criterion 2. As the end result of the strategy is to ensure reduced vulnerability and strengthened resilience of the people, specifically the marginalised, in terms of access to adequate and safe water, it clearly adheres also to Criterion 3.

Table 4: Summary—ACT's interventions in CRWM

Thematic area		ACT programme location	ACT CRWM activity	C1 Integration of climate information to go beyond BAU	C2 Redundancy, flexibility, adaptability and systemic solutions	C3 Reduction of vulnerability of poor and marginalised communities
Water resource management	Water resource assessment	Bihar	Improving hydro-met system by adding more AWSs	■		■
		Chhattisgarh	Water resource assessment for improved climate resilience	■		■
	Demand management	Odisha	Groundwater management		■	■
		Pakistan	Water demand assessment	■		■
Managing extreme events	Flood management	Assam	Climate-resilient flood management of cities		■	■
		Bihar	Silt and flood management in the Kosi River	■	■	■
		Odisha	Mahanadi flood forecasting	■		■
	Drought management	Maharashtra	Climate-proofing of Jalyukta Shivar Abhiyan	■	■	■
Supporting environment		Afghanistan	Climate-resilient Water Sector Strategy		■	■
		Assam	Supplementing efforts to develop a climate-resilient State Water Mission		■	■
		Bihar	Upgrading policy architecture for CRWM	■	■	■
		Nepal	Including CRWM in NAP	■		■

Dark grey = direct alignment with the criterion; white = no direct alignment with the criterion.

6. Conclusion: Key lessons

Having reviewed the state of global knowledge on CRWM and analysed ACT's intervention within this framework, a few key lessons and ways forward become apparent.

First, it is vital to ensure that action on CRWM is not 'business as usual' in managing water resources. We have argued that there are three ways in which CRWM is not BAU: 1) integrating best-available climate information and scenarios to influence policy decisions; 2) prioritising redundancy, flexibility and adaptable systems over static solutions; and 3) focusing on the poor and marginalised. Employing these principles will ensure that approaches for water management are geared towards ameliorating the impacts of a changing climate on water resources.

Second, successful water management under uncertain climatic conditions needs adaptive planning and inputs from multiple stakeholders from diverse disciplinary backgrounds (engineers, economists, climate scientists, hydrologists, social development experts, sanitation specialists, along with locally relevant indigenous knowledge through participatory processes). ACT's interventions across the programme locations bring technical experts from these diverse disciplinary backgrounds in touch with members of various government departments and communities. Also, given that women and other marginalised groups tend to be more vulnerable to the impacts of climate change on water resources, their views must be kept front and centre when designing and delivering CRWM interventions.

Third, mapping and locking into government priorities is essential for sustainable and institutionalised CRWM. Governments continue to own the physical systems and organisational mandates for regulating water supply, managing demand and preparing for extreme events. In South Asian countries as elsewhere, the dynamics of water policy are governed by complex configurations of provincial and national governments. CRWM must not be operationalised in the form of individual projects that stand apart from these government systems. This paper has argued the need to mainstream CRWM into governments' existing priorities, approaches and initiatives and to realise the benefits of reductions in future risk and potential avoided losses in service delivery owing to climate change. ACT's work with Indian state water missions is a good example of trying to ensure these take on board a clearer understanding of climate change.

Fourth, water management is a politically contentious domain in South Asia, as elsewhere. International and domestic squabbles on water relate to issues around inadequate river flows, damming and transparency over water data. Climate change adds a layer of complexity to water management issues that are already incendiary. CRWM initiatives that are not alive to local political-economy contexts thus risk being undermined and derailed. This is why all of ACT's initiatives commence with detailed context assessments and in-depth political economy analysis, and maintain an iterative, context assessment–feedback loop embedded in the political economy of water management at subnational levels. ACT also ensures it does not make value judgements about water uses or allocations, and focuses on connecting decision-makers with the best available scientific evidence and appropriate policy or management options, while also keeping equity concerns front and centre.

Fifth, climate change can be a 'bridge too far' for government officials overburdened with dealing with the urgent but 'everyday' priorities of water supply, food production, health, education and infrastructure. However, an immediate and perceptible connect is the sharply rising and very visible variability in rainfall in recent years, leading to extreme events like droughts and floods. All government departments and officials are keenly aware of unseasonal, more intense and frequent, instances of drought, monsoon rains and floods, and urgently seek ways to address the impacts citizens face. This is an immediate opportunity to showcase climate change analysis and possibilities—and to demonstrate that acting on climate change is not just a privilege of developed countries but also a vital component in the fight against poverty and disasters in the developing world today. Framing and communicating about climate change using phenomenon that are relatable and impacts that are tangible has been key to the ACT programme's *modus operandi* across South Asia.

Keeping these learnings in mind when designing and deploying interventions will ensure marginalised populations in some of the world's most vulnerable areas are able not only to function but also to flourish—despite the impacts of climate change.

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