MODULE 3:
WATER MANAGEMENT

Overview

This module examines the overall development context in which water is managed in agriculture and provides an overview of the current status, trends and challenges. It also reviews the current state of knowledge of the impact of climate change on water for agriculture and the vulnerability of rural populations and farming systems to climate change. This is followed by an examination of possible response options for addressing these impacts. These options can be applied at various scales, on individual farms, in larger irrigation schemes, throughout entire river basins and at the national level. The module also presents criteria for prioritizing response options, examines conditions for climate change adaptation and reviews opportunities for climate change mitigation.

Key messages

- Most of the impacts of climate change on agriculture are expected to result from changes in the water cycle. Because of this, the design of climate-smart agriculture (CSA) strategies will need to be viewed though a 'water lens'.
- Climate change will affect both rainfed and irrigated agriculture through increased crop evapotranspiration, changes in the amount of rainfall, and variations in river runoff and groundwater recharge. The impact of climate change on water use in agriculture must be considered within a wider context in which a number of issues are taken into account including: increased water demand by all sectors; the degradation of water quality; and heightened competition for water at various levels (community, river basin and aquifer).
- Climate change adaptation in water includes a range of response options related to policies, investments, water management, and institutional and technical factors. These options will need to be applied at different scales: on fields and farms; in irrigation schemes; in watersheds or aquifers; in river basins and at the national level.
- Climate-proofing will have to become central in the design of future investment plans in water for agriculture. It will become necessary to maintain a clear perspective on resilience when screening water development programmes. When designing development policies it will be necessary to systematically consider how the policies may be affected by climate change. In many cases, the challenge will be to combine more efficient use of water with increased resilience of production systems.

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3.1 Introduction

It is commonly acknowledged that most of the impacts from climate change will relate to water (UN-Water, 2010). How water is managed will be at the centre of climate change adaptation strategies. This is particularly true in rural areas and in the agriculture sector, where water plays a critical role in crop and animal production (including fish), and the management of ecosystems, including forests, rangeland and cropland. There is also scope for climate change mitigation actions in water management for agriculture.

The most immediate impact of climate change on water for agriculture will be through the increased variability of rainfall, higher temperatures, and associated extreme weather events, such as droughts and floods. In the medium to long term, climate change will affect water resources and reduce the availability or reliability of water supplies in many places already subject to water scarcity. This impact must be considered in the bigger picture of water scarcity and agricultural development in which other factors are driving changes in water use at a much faster pace than climate change. Climate change is expected to bring additional burdens on already stressed systems.

Addressing risks associated with climate change requires an understanding of the potential water-related impacts of climate change and the vulnerability of rural populations. Vulnerability, sensitivity, adaptability, resilience and exposure vary depending on the agricultural system and the importance of agriculture for the national economy. These two factors are reviewed below as a basis for action.

There is a range of possible response options to adapt to climate change. These options can be related to policies, investments, water management, and institutional and technical factors, both within the water and agriculture sectors and beyond. To have optimal impact, these options must be used in combinations that are tailored to different contexts. Focus should be placed on major systems at risk. However, there is also a need to assess the vulnerability of different categories of rural people to identify priority actions.

3.2 Water management in agriculture: status and trends

Although agriculture is highly dependent on climate, so far evidence of observed changes related to regional climate changes, and specifically to water, has been difficult to find. One of the reasons for this is that agriculture is strongly influenced by factors unrelated to climate, especially management practices, technological advances, market prices and agricultural policies. These factors have more immediate impacts on water than those induced by climate change (Bates *et al.*, 2008). For this reason, it is important to understand the current status of water management in agriculture before assessing the potential impact of climate change.

Over the last 50 years, heightened demand for food, fibers and other agricultural products has been met mostly by an increase in agricultural productivity. The expansion of agricultural land has remained relatively limited. Total cultivated land increased by only 12 percent between 1961 and 2009, but productivity more than doubled. The amount of land needed to produce food for one person has decreased from 0.45 hectares in 1961 to 0.22 hectares in 2009. During the same period, the extent of irrigated land has more than doubled, increasing from 139 to 301 million hectares (FAO, 2011a). By providing farmers with access to water, irrigation has been a key factor in agricultural intensification. The expansion of irrigated land is expected to continue in the future as farmers will increasingly look for greater control over production factors.

With the doubling of irrigated area, water withdrawal for agriculture has been rising sharply. Globally, agricultural water withdrawal represents 70 percent of all withdrawals. However, as water resources are very unevenly distributed, the impact of these withdrawals varies substantially between countries and regions. An increasing number of the world's river basins have reached conditions of water scarcity through the combined pressure of agriculture and other sectors. FAO (2011a) estimates that more than 40 percent of the world's rural population lives in river basins that are classified as water scarce.

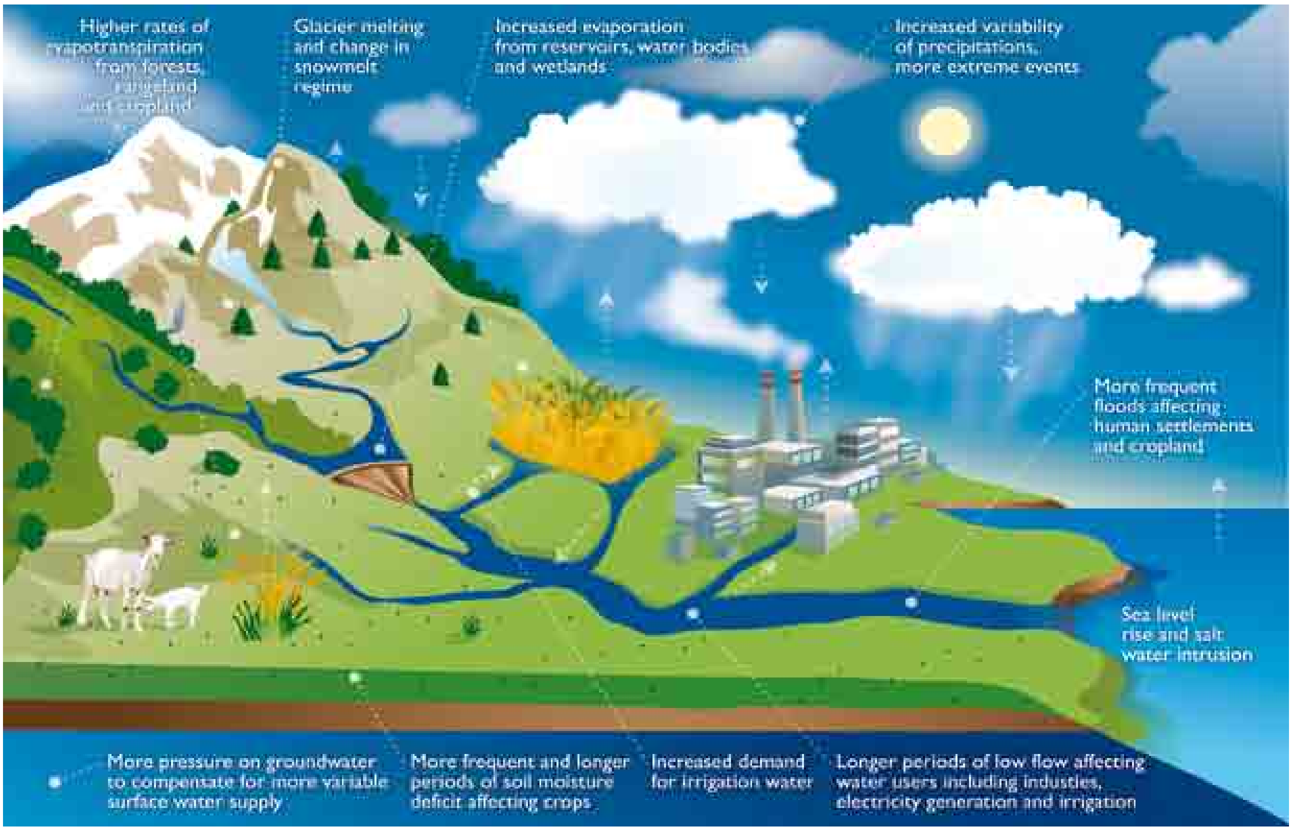
The high level of pressure on water resources has had serious impacts on water users and the environment. Competition over water use is growing in river basins where there are no measures in place for arbitrating conflicts. Evidence shows that biodiversity is declining more rapidly for freshwater-dependent species than for species from other types of ecosystems (Comprehensive Assessment, 2007). The large-scale public surface irrigation systems built during the green revolution dominated the landscape until the early 1980s and had a profound impact on the flow of many rivers. Over the last 30 years, private investments, stimulated by the availability of cheap pumps and well drilling capacity, have been directed to tapping groundwater. Consequently, aquifers are being depleted in countries with key agricultural production systems, including China, India, and the United States.

Water demand from cities and industries has been booming as a result of rapid economic growth in emerging countries. This growth has put pressure on irrigation schemes to release water for urban and industrial users. Pollution from agriculture, cities and industries has affected rivers and aquifers and further reduced the amount of water available for use. The trends towards an increasing demand for water from all sectors is expected to continue in the coming decades as the population reaches 9 billion people in 2050 and economic growth increases the consumption of food and manufactured goods.

The role climate change will play with regards to water in agriculture must be considered in this context of rapid increases in water withdrawals, the degradation of water quality and the competition for water at all levels. The following sections look at the current state of knowledge about climate change impacts on water resources and the demand for these resources. These impacts are framed within the overall perspective of the current status, trends and challenges of water management in agriculture. Of particular interest are aspects of change that are specific to climate and as such require specific responses.

3.3 Potential impacts of climate change on water in agriculture

Figure 3.1
How climate change affects all the elements of the water cycle and its impact on agriculture



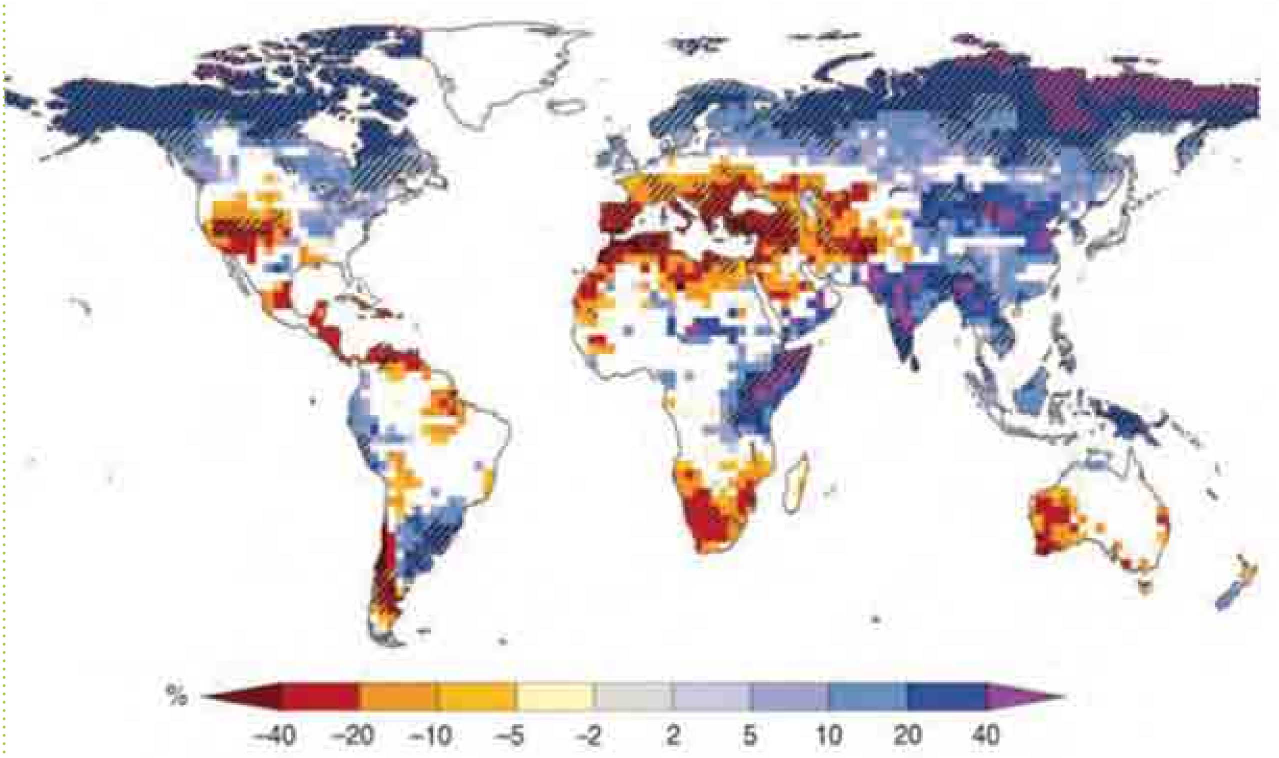
Water is the prime channel through which the impacts of climate change on the world's ecosystems and on the livelihoods of societies will be felt. Climate change will have an impact on every element in the water cycle (UN-Water, 2010). Agriculture will be affected by increased evaporative demand, changes in the amount of rainfall and variations in river runoff and groundwater recharge, the two sources of water for irrigation (Figure 3.1). These impacts are described in more details below.

Impact on water supply and demand

A global increase in atmospheric temperatures is predicted to affect agricultural productivity. Particularly affected will be areas in low latitudes, where temperatures are already high. In these areas, heat waves will affect both crops and animals. An increase in temperatures will trigger increased demand for water for evapotranspiration by crops and natural vegetation, and will lead to more rapid depletion of soil moisture. This scenario, combined with changes in rainfall patterns (see below), may lead to more frequent crop failures.

The hydrological cycle is expected to accelerate as rising temperatures increase evaporation from land and sea (Turral *et al.*, 2011). Predictions about the patterns of change of annual precipitation are still in their infancy, but models tend to agree that there will be substantial changes at the regional level, including a sharp reduction of precipitation in already water-scarce areas, including the Mediterranean, Southern Africa, the Western United States, Mexico and Australia (Figure 3.2).

Figure 3.2
Large-scale relative changes in annual runoff for the period 2090–2099, relative to 1980–1999



White areas indicate where less than 66 percent of the ensemble of 12 models agree on the sign of change (whether there will be more or less runoff). Hatched areas are where more than 90 percent of models agree on the sign of change.

Source: IPCC, 2008

Changes in the distribution of precipitation, with longer periods between rainfall events and more intense precipitation, are expected everywhere. This may lead to increased occurrence of extreme weather events, including floods and droughts. Dry spells, the short periods of rainfall deficit during the cropping season, are expected to increase in duration and frequency. This will directly affect soil moisture and the productivity of rainfed crops. Such changes will be felt mostly in areas already subject to climate variability, such as in the semi-arid and sub-humid areas of sub-Saharan Africa and South Asia, where, in the absence of alternative sources of water, the risk of increased frequency of crop failures is high.

Reductions of rainfall in arid and semi-arid areas will translate into a much larger reduction in river runoff (in relative terms). In Cyprus, for example, analyses have shown that a 13 percent reduction in rainfall translates into a 34 percent reduction in runoff (Faurès *et al.*, 2010). In rivers receiving their water from glacier or snow melt (about 40 percent of the world's irrigation is supported by flows originating in the Himalayas), the timing of flows will change, with high flows occurring earlier in the year. However, the mean annual runoff may be less affected.

The impact of climate change on groundwater recharge is difficult to predict. Local recharge will depend on the characteristics of the aquifer, the recharging processes and changes in rainfall. It is likely, however, that aquifer recharge will be reduced in arid and semi-arid areas, where runoff will decline (Bates *et al.*, 2008; Turral *et al.*, 2011).

Finally, the expected rise in sea levels will affect agriculture in coastal areas, particularly river deltas. Higher sea levels combined with upstream changes (variations in runoff distribution, more frequent floods), will result in an increased incidence of floods and saltwater intrusion in estuaries and aquifers.

Combined effects of climate change and development

As mentioned above, rapid increases in water use for agriculture and other purposes has modified the water balance in many watersheds and aquifers. The combined effects of water withdrawal and pollution are affecting ecosystems and rural populations in an increasing number of places. The extent to which climate change will affect the water cycle and agriculture needs to be considered in light of these developments.

In arid and semi-arid areas, climate change will place additional burdens on already stretched water resources. However, agriculture will first need to respond to the challenges posed by increasing human pressures on these resources. In other places, climate change will be the main driver of change and will necessitate specific climate change-related responses. Table 3.1 is an attempt to present the relative importance of climate change and development on water supply and demand for agriculture. The relative impacts of climate change will vary from one agricultural system to another, but it is important that adaptation strategies take into account the overall context in which they are to be implemented.

Of particular relevance is the time frame for climate change and its relation to the speed of change driven by development. Annual changes in runoff and recharge due to climate change are expected to occur at a slower pace than changes caused by human demands for water. However, changes in variability and extreme events associated with climate change may already be having impacts and deserve particular attention for short- to medium-term responses.

Table 3.1
Climate change and development: how they influence water supply and demand

Elements of the water cycle	Impact from	
	Development activities	Climate change
Annual precipitation	No or minor impact	Expected to increase globally during the 21st Century, with potentially great spatial variations
Interannual variations in precipitations	No impact	Expected to increase everywhere
Seasonal variability of rainfall	No impact	Expected to increase everywhere
Soil moisture stress (droughts)	Limited impact: some agricultural practices can deplete soil moisture faster than natural vegetation	Moisture stress to generally increase as a result of increasing variability of rainfall distribution (longer periods without rain) and increasing temperatures
Floods	Moderate impact: flood intensity and impact can be exacerbated by changes in land use and unplanned development in alluvial plains	Increased as a result of increasing frequency and intensity of extreme rainfall events
Snow and glacier melt	Limited impact through deposit of pollutants and change in the reflecting power of the surface (albedo)	Rising temperatures lead to accelerated snow and glacier melt with initial increases in river flow followed by decreases
River discharge	High impact in water scarce areas, where reservoir construction and water diversion for agriculture and other uses are modifying runoff regimes and reducing annual flow. Large-scale water conservation measures also have an impact on river discharge	Increased variability as a result of changes in rainfall patterns. Changes in snow and glacier melt induce changes in seasonal patterns of runoff. Changes in annual runoff expected to vary from region to region (see Figure 3.2)
Groundwater	High impact: large-scale development of groundwater resources in many regions are already threatening the sustainability of aquifers in many dry areas	Varies as a function of changes in rainfall volumes and distribution. Impact is complex, with floods contributing to increasing recharge, and droughts leading to increased pumping
Evapotranspiration	Limited impact in agriculture: some crops have higher evapotranspiration rates than natural systems, other less	Increases as a function of temperature increases
Water quality (in rivers, lakes and aquifers)	High impact from pollution in highly developed areas	Moderate impact through temperature increases
Salinity in rivers and aquifers	High impact from water withdrawal in highly developed areas (mostly in arid regions)	Potentially high impact where sea water level rise combines with reduced runoff and increased withdrawal

Source: adapted from a comparative analysis of Turral et al., 2011; Comprehensive Assessment, 2007

3.4 Vulnerability to climate change and resilience: a variety of situations

The potential impact of climate change on agricultural systems and rural populations depends on a combination of exposure and sensitivity. It also depends on the level of resilience of these systems in relation to potential changes in water supply and demand. Climate change-related risk will vary substantially from one system to the other. The table in the Annex (A.3.1) presents the main agricultural systems at risk, their exposure to climate change, their sensitivity and adaptive capacity, as well as the elements of response strategies that would be needed as part of any programme designed to strengthen adaptation to climate change. The table is based on the section, 'Land and water systems at risk', from the State of land and water resources for food and agriculture (FAO, 2011a).

The table A.3.1 illustrates that a farming system's vulnerability is directly related to its relative dependency on elements of the water cycle, and in particular rainfall variability. With or without climate change, agricultural societies most at risk are those that rely exclusively on farming for their livelihood, have little scope for diversification and are highly exposed to climate variability. Most of the responses that are needed to increase the resilience of these farmers are not necessarily specific to climate change. Actions that build resilience include: better conservation of soil moisture (in particular through improved soil water holding capacity or access supplementary irrigation); better storage of grain; and better access to markets and to drought protection schemes. Climate change only represents an additional justification for actions that are already needed.

The distinction between rainfed and irrigated production systems will dictate the impacts and associated risks related to climate change. Rainfed systems in sub-tropics and semi-arid tropics will be mostly affected by changes in rainfall patterns and temperatures. These changes will lead to greater frequency of crop failures as a result of increased variations in soil moisture. In mountainous areas, rainfed farming in marginal areas will also be affected by the impact of extreme events, including intense rainfalls, floods and erosion. Pastoral areas will suffer from more frequent drying of water points and greater variability in available animal feed.

Irrigated systems are better protected against rainfall variability. But these systems will increasingly require greater storage capacity to respond to more frequent droughts and floods and changes in the annual distribution of runoff. For surface or groundwater systems already being over-exploited, climate change will add an extra burden to water management and generally lead to a reduction in the availability of water and greater competition for water resources.

Aquatic systems and capture fisheries will be affected by changes in quantity and quality of freshwater, which will have an impact on production. Many aquatic species depend on the timing of rainfall and flood events for important migrations (e.g. spawning and feeding). Changes in precipitation may disrupt these migrations or force these species to make adaptations in their life history patterns. Integrated irrigation systems (e.g. rice and fish) could see changes in system components as climate change alters the suitability of the environment, (e.g. more or less water may require different species of fish). Increased storage (i.e. more or larger reservoirs) could promote integration of fish farming through cage culture and enhance the fisheries production (see also Module 10 on fisheries and aquaculture).

3.5 Assessing risk, preparing responses

Many governments and development agencies have developed tools to assess the risk associated with climate change in relation to expected changes and populations' vulnerability (OECD, 2009). Examples include Opportunities and Risks of Climate Change and Disasters (ORCHID), Community-based Risk Screening Tool – Adaptation and Livelihoods (CRisTAL), and tools developed by CARE and the International Federation of Red Cross and Red Crescent Societies. These tools can be classified by the type of approach they use. There are two types of approaches: a *top down* approach focuses on potential changes in the water cycle as a result of climate change, and designs response options to anticipate and prevent the negative impacts of these changes. By nature, this approach favours long-term responses. The other approach consists in assessing the vulnerability of rural populations, and designing solutions that helps increasing their resilience to external shocks. This *bottom-up* approach is more generic, not specific to climate change (but to any shock or crisis) and usually considers short- to medium-term responses. Both approaches are necessary when designing water management responses in relation to climate change. An impact-based approach is needed to ensure that long-term investments such as irrigation development take into account expected changes in water supply and demand.

Water infrastructures generally have a lifetime of 30-50 years. New investments or rehabilitation of old infrastructures are therefore subject to changes in climate. This has serious consequences for people and finances. In particular, the changing frequency and intensity of droughts, floods, and heat waves will affect water supply and demand and call for better protection of land and socio-economic assets. Improving the resilience of water infrastructure to climate change-related shocks and extreme events is a vital part of any effective water investment planning. The concept of robust decision making in water planning (Groves, 2006) acknowledges that is it very difficult to predict the future, and makes extensive use of scenarios to work out decisions that are robust under a variety of alternative futures (Box 3.1). In practical terms, resilient coping strategies are those that have the potential to be reasonably effective under the largest possible range of scenarios. This should be complemented with the adaptive management of existing and future water infrastructures, which puts the emphasis on flexible responses and requires strong monitoring and information management systems that allow for periodic upgrading of management plans and activities (UNDP, 2004).

Box 3.1
Planning under uncertainty

The current level of uncertainty associated with the impact of climate change on water availability remains high. The downscaling of global circulation models and local and regional assessments of precipitation patterns produce large variations in the assessment of runoff and aquifer recharge. When combined with the different scenarios presented in the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Emission Scenarios, the range of results shows major uncertainties in the prediction of future runoff patterns. A risk-based approach that uses a wide range of scenarios is needed and must be systematically used in hydrological assessments.

Source: Strzepek and McCluskey, 2010

Bottom-up approaches give the opportunity to address vulnerable populations' needs for resilience and development. By acknowledging that resilience is closely linked to a population's state of development, level of economic diversification and the strength of their livelihoods assets, community-based climate change response programmes offer the opportunity to progressively build a capacity to reduce climate change-related risks. Most of the options that will be considered on the basis of bottom-up approaches will not differ from classical agricultural development options for reducing poverty and increasing the standard of living of rural populations. The challenge in this case is to avoid maladaptation (i.e. designing development actions that are excessively sensitive to climate change and will therefore increase the vulnerability of beneficiaries). The concept of 'climate-proof' investments is central to the design of programmes for reducing climate change-related risks. It will become necessary to maintain a clear perspective on resilience when screening water development programmes. When designing development policies it will be necessary to systematically consider how the policies may be affected by climate change (OECD, 2009).

3.6 Options for adaptation to climate change

Options for adaptation to climate change will necessarily combine investments, improved or adaptive management, and modifications in or development of policies, institutions and capacity development. Such options will need to be applied at different scales: on fields and farms; in irrigation schemes (particularly in large schemes); in watersheds or aquifers; in river basins (including transboundary river basins); and at the national level. Table 3.2 lists typical response options and indicates their relevance for different scales.

Table 3.2
Options for climate change adaptation in water at different scales

Options	Field/farm	Irrigation scheme	Watershed/ aquifer	River basin	National
1.Investments					
On-farm water storage: water harvesting	X				
Groundwater development	X				
Modernisation of irrigation infrastructure		X			
Breeding for resistance to droughts and floods	X				
Dam construction/enhancement		X	X	X	
Drainage	X		X	X	
Introduction of appropriate fish species	X		X	X	
2. Land, water and crop management					
Enhancing soil moisture retention capacity	X				
Changing cropping pattern and diversification	X				
Adapting cropping (and fish harvesting) calendar	X				
Supplementary irrigation	X	X			
Deficit irrigation		X			
Alternate wet and dry rice production system	X	X			
Drainage and flood management		X	X	X	
Irrigation scheme operation improvement		X			
Integrated water resources management				X	
Adaptation of dam operation rules				X	
Riparian habitat restoration or creation in rivers				X	
3. Policies, institutions and capacity building					
Climate proofing of I&D infrastructure		X	X	X	
Reallocation of water (between or within sectors)	X	X	X	X	X
Strenghtening land/water right access	X	X	X	X	X
Crop insurances	X				
Improved weather forecasting capacity	X	X	X	X	X
Improved hydrological monitoring			X	X	
Development of flood/droughts				X	X
Review of food storage strategies					X

Source: adapted from Turral et al., 2011

Most of these options are not new to development programmes. Options for on-farm water conservation have been promoted for a long time as a response to water scarcity and climate variability. Options to address increasing water scarcity through better co-management of water at the watershed, aquifer and river basin level are needed in many water-stressed areas. Although there are overlaps between climate change adaptation and development, activities with an explicit focus on adaptation and climate change will also be required. Box 3.2, adapted from OECD (2009) proposes four categories of responses, from development responses to reduce the overall vulnerability of rural communities to all types of shocks, to targeted climate change adaptation options.

Box 3.2
A continuum of adaptation activities: from development to climate change-specific actions

Adaptation activities that span the continuum from development to climate change can be organized in four categories. The first category includes activities that are fundamentally about fostering human development. These activities focus on reducing poverty and addressing factors that make people vulnerable to harm, regardless of the cause. The second category of activities focuses on building response capacity. Mostly of a capacity-building nature, these activities tend to involve institution-building and technological approaches adapted from development efforts. The third category involves activities to manage climate risk. Activities in this category focus specifically on hazards and impacts and follow the concept of climate risk management. The fourth category involves activities for confronting climate change. They focus almost exclusively on addressing climate change impacts. Activities in this category tend to target climate change-related risks that are beyond historic climate variability.

Source: McGray *et al.*, 2007 in OECD, 2009.

Coping with water scarcity

In many river basins, water scarcity is already the main challenge facing agriculture. In areas where water is scarce, climate change is expected to exacerbate tensions and increase competition for water. If agriculture is to continue meeting the demand for food and other commodities, efforts will be needed both on the supply side and on the demand side. Enhancing supply includes: increased access to and improved management of conventional water resources; habitat rehabilitation; dam operations; re-use of drainage water and waste-water; transfer of water between river basins; desalination; and pollution control. Demand management is defined as a set of actions that control water demand, either by raising the overall economic efficiency of its use as a natural resource, or operating intra- and intersectoral reallocation of water resources. Options to cope with water scarcity in agriculture can be seen as running a spectrum from the source of water to the end user (the farmer and fisher), and beyond, to the consumer of agricultural goods (FAO, 2012). A combination of technical, managerial, legal and investment options are needed to help farmers produce more with less water. These options need to be backed with a policy and incentive framework that alerts farmers to water scarcity and rewards more productive use of water at the farm level.

Increasing the reliability and flexibility of access to water for farmers is of prime importance. Many wasteful behaviours on farms are linked to the uncertainty associated with water distribution practices that do not allow farmers to optimize water application or raise the productivity of their crops. Water storage, and the combined use of groundwater and canal irrigation water, can go a long way towards improving the productivity of water used for irrigation. Economic incentives, in particular the use of subsidies for pumping, must be designed in a way that promotes the efficient use of water and avoids wastage of both energy and water resources.

Building resilience

From a livelihood perspective, building resilience involves reducing farmers' exposure or sensitivity to shocks, or increasing their capacity to respond. Of prime importance is the ability to increase the farming systems' buffering capacity in the face of more variable supplies of rainwater. This necessitates an increased capacity to store water in the soil, in surface reservoirs or in underground reservoirs. Any action that increases the capacity to access water when needed will increase resilience to climate variability. These actions include: on-farm water harvesting; the enhancement the soil's capacity to hold moisture (see also Module 4 on soils); on-farm water retention and enhanced infiltration; and, where possible, more systematic access to groundwater. Supplementary irrigation at critical periods of the cropping season can reduce losses and boost productivity.

Resilience is closely linked to improved access to land and water. The strengthening of land and water rights will have a positive impact on resilience as it will encourage farmers and other rural people to invest in their land and build the assets that are needed for increased productivity and diversification.

Adaptation at field and farm level

Many farm-level adaptations will be spontaneous and will be done in response to change but not necessarily designed for climate. Others adaptations will need to be planned, often with external support. Farmers will favour more efficient irrigation technologies that reduce evaporation losses. These actions can be combined with deficit irrigation approaches to maximize productivity per volume of water applied rather than per area of land. Crop selection and changes in crop calendars will help farmers adapt to new temperatures and rainfall patterns. The use of crops or varieties with better resilience to dry spells will be preferred. (It should be noted however that there is little prospect for breakthroughs in developing 'drought resistant' crops in the near future.) Increased agricultural diversification, including better integration of trees, crops, fish and livestock will reduce risk and increase the resilience of farming systems. In particular, the farming and fishing of aquatic species that do not require extensive migrations and that have wide environmental tolerances will help aquaculture and capture fisheries adapt to new climatic conditions. Farmers will also need to adopt more systematically measures to respond to increased frequency of floods and more intensive rainfalls. A combination of erosion control actions and better drainage capacities will be needed.

Adaptation at irrigation scheme level

Actions for adapting to climate change in irrigation schemes need to be considered in the overall context of irrigation modernization. Modern irrigation systems require better water allocation mechanisms, the clear transmission of alerts about water scarcity to farmers, and the adaptation of both infrastructure and management for more flexible and reliable delivery of water (FAO, 2007). Intermediate storage within the irrigation scheme and, where possible, access to groundwater are part of the options for building the resilience and reliability of water supply and must be considered in adaptation plans for irrigation schemes. Water pricing and the establishment of water markets are often advocated as demand management tools for promoting better water use and reducing water wastage. While these options have proven effective in some places, they are often difficult to apply for a combination of technical, institutional and policy reasons. There are other options, such as limiting seasonal allocations to users or to groups of users, that may be simpler and more effective for inducing more productive water use behaviour. Box 3.3 provides an example of a climate change adaptation programme of irrigation in China. It illustrates how adaptation activities are closely linked to overall irrigation modernization programmes.

Box 3.3
Adaptation to climate change in the Huang-Huai-Hai Plain of China

The Huang-Huai-Hai Plain of China is critical to the country's agricultural economy and to national food security. Future productivity in the area is being jeopardized by higher annual temperatures and reduced rainfall, which has led to more frequent spring droughts. Combined with increasing industrial and domestic water demands, climate change will mean that less water will be available for irrigated agriculture. In 2004, a project financed by the World Bank started working with farmers and technical experts to implement water-saving measures across five provinces. In 2006, a grant from the Global Environmental Facility (GEF) was added to mainstream adaptation activities into the project activities.

The overall aims of the project were to reverse the inefficient use of water for farming and increase farmers' profits. A range of irrigation-centred engineering, agronomic and management measures were implemented to improve water management in over half a million hectares and bring benefits to 1.3 million farming families. Research and demonstration activities focused on the testing of adaptation measures and advanced agriculture and water saving technologies. Experts also introduced new drought- and pest-resistant wheat varieties that were more closely matched to expected future growing conditions. New techniques were introduced through pilot programmes to better manage irrigation water and were widely adopted after farmers saw the benefits in terms of reduced irrigation costs, reduced groundwater depletion and especially increased water productivity. Critical to the project's success was the strong coordination and partnership with leading scientific and agricultural research institutions, as well as the efforts that were made towards creating joint ownership with farmers.

Source: Qun, 2011 in FAO and World Bank, 2012.

Adaptation at watershed, river basin and national levels

Climate change adaptation at higher levels will involve a combination of policy adjustments and investments in infrastructure and management. In river basins, increased frequency and intensity of extreme weather events will require adjustments in the storage capacity and management of dams and river protection works. More than in the past, flood management plans will need to combine infrastructure upgrades with non-structural, information-rich approaches that can better mitigate the impact of floods through a combination of land planning, early warning and insurance schemes. Similarly, there will be a need to shift from drought emergency response to drought management plans that include prevention, preparedness, relief and rehabilitation and long-term measures to mitigate the impacts of droughts (FAO and NDMC, 2008).

In all these cases, adaptation approaches to floods and droughts used by water managers and farming communities should be considered systematically. Examples include flood mitigation through the cultivation of varieties of rice that respond differently to different levels of flooding, or the combined cropping of bean varieties with varying resistance to droughts. Habitat engineering and rehabilitation will also be needed to reduce the severity of flood impacts and provide erosion control, nutrients, shade and oxygen. This will also create suitable environments for fish production.

Integrated water resources management in river basins will become more and more important as the combination of increased water use and the occurrence of extreme events will increase the interdependency of people and communities living in river basins, and as actions in one part of a basin will have repercussions for people further downstream. In places where climate change contributes to increased water scarcity, the whole package of supply enhancement and demand management options will need to be considered (FAO, 2012). Improved governance of land and water use will be required to accommodate the multiple uses of water, including for livestock and fish.

Improved weather forecasting and hydrological monitoring will become a critical element of modern adaptation strategies (Faurès *et al.*, 2010). Currently reliable weather forecasting is still limited to a few days. However, progressive improvements in the timing and reliability of seasonal forecasts offer new opportunities for farming communities (more on assessments in Module 12). As efforts focus on improving the accuracy of these forecasts, more emphasis should now be given to improving the way information is conveyed to farmers and building their capacity to make best use of climate information (Gommes *et al.*, 2010). Monitoring and early warning during the cropping season remain a priority to help farmers make informed decisions.

Insurances represent a potential solution that should also be systematically considered as part of adaptation strategies. There is a renewed interest in various types of crop insurance, as well as aquaculture and fishing insurances, that could be adapted to developing countries. National crop insurance schemes have been tested in some countries, but they face substantial challenges in terms of costs and institutional settings. So far, few commercial insurance companies have found it to be an attractive business opportunity. Roberts (2005) focused on the need to smooth tensions between insurance that is run as business for commercial profit and the protection of small farmers that is in the strategic national interest. Insurance companies need to be solid and well-backed. International reinsurance could play an important stabilizing role and provide backup for emerging national companies. The role of national governments in promoting crop insurances must reflect national interests and at the same time ensure the smooth operation of private insurance companies. This must be based on the concept of shared risk between producers, insurance companies and governments.

A type of insurance which has recently been applied in developing countries is known as index-based insurance. In index-based products, compensation is paid to the insured if the agreed threshold of an index is exceeded. The indices must be defined in such a way that they bear a direct relationship with the performance of the product insured. Index-based insurance is difficult to apply to small-scale hazards but seems to have good potential for hazards with regional impacts like hurricanes or droughts (Gommes *et al.*, 2010).

3.7 Prioritizing options with an eye on vulnerable categories of people

The combination of vulnerability assessments, impact assessments and screening of response options usually produces a long list of possible actions. USAID (2007) has proposed a screening process for these actions using a series of criteria. The effectiveness of an option needs to be assessed as a solution to a problem arising from climate change, and be measured in terms of its cost and the size of the beneficiary group. Where possible, actions with impacts on large groups, with low costs per beneficiary and high levels of effectiveness should be selected. Currently, such assessments are rarely done. Adaptation options are often discussed with no clear understanding of possible tradeoffs between costs and effectiveness. A much more systematic approach to adaptation will be needed in this field.

Criteria for assessing the impacts of climate change and adaptation options must also include considerations of equity. Particular focus should be placed on the most vulnerable categories of rural people. Women's access to water must be considered, both in terms of the impact of climate change and response options. Securing water rights in a way that is both effective and equitable will become increasingly important as water scarcity increases. In irrigation schemes, 'tail-enders', farmers located at the end of the irrigation canals, usually suffer more than other farmers during water shortages and floods. In river basins, downstream water users suffer from excessive water withdrawal from upstream users. Technologies and policies for climate change adaptation are not neutral in terms of equity. It is therefore important that they be analysed in terms of their impact on different groups of vulnerable people and that actions that would increase inequalities be eliminated from climate change adaptation programmes.

The adoption of a livelihood approach to water-related adaptation is a useful way to ensure that proposed actions will be beneficial to the people they are supposed to serve. Sullivan *et al.* (2008) consider four key dimensions of the water-related conditions of rural livelihoods: access to basic water services; crop and livestock water security; clean and healthy water environment; and secure and equitable water entitlement. Using such entry points to screen the impact of adaptation options ensures that they will be assessed in ways that are in line with the concerns and priorities of rural populations.

Ease of implementation considers possible barriers to the implementation of a given option that could delay or reduce its impact. Such barriers could be policy-related, structural, institutional or social. Social barriers are related to the acceptability of proposed actions by local stakeholders. Specific policy or technical assistance may be required to overcome these barriers. Other relevant criteria include technical feasibility and the time frame for implementation.

Adequacy for the current climate is an important criterion to consider. Here, possible options should be analysed in terms of their 'level of regret'. Low-regret or no-regret options are those options that are valid whether expected climate change impacts occur or not. In general, these options increase the resilience of rural populations and reduce their vulnerability to water-related shocks. Instead, many options, in particular options dealing with infrastructure, can be considered high-regret options: they would be valid for future climate scenarios but not necessarily for the current climate situation. They would therefore involve higher costs and have possible negative consequences under current climate conditions, and require careful consideration in terms of risk analysis.

All options must be considered in relation with the uncertainty associated with climate change predictions. Their robustness in terms of the above criteria (in particular effectiveness and adequacy for current climate) must be assessed against different climate change scenarios and global circulation models (see Module 18 on assessments and monitoring).

3.8 Conditions for successful adaptation

In developing countries, programmes designed to promote sustainable water management face the greatest number of barriers to the successful adoption of climate change adaptation practices. In most cases, the potential exists to adapt to climate change, improve the livelihood situation of rural communities and promote sustainable practices. Achieving these goals demands that a certain set of conditions be in place to remove constraints and build resilience and flexibility (FAO, 2011b), including: improvement of land tenure and secured access to water; strengthened and more collaborative land and water institutions; efficient support services (including knowledge exchange, adaptive research, rural finance); and changes in incentive frameworks that remove ineffective subsidies and focus on incentives that promote resilience, improve productivity and induce sustainable behaviours.

Climate change adaptation must be mainstreamed in both rural development and water scarcity programmes (FAO, 2011a; FAO, 2011b) and not carried out on a separate track. Water, land and food policies must be more aligned and viewed through the perspective of climate change. In particular, agriculture and rural development goals must be brought into water planning and take into consideration other water use sectors. Links must also be made with disaster risk management strategies, which are in a large part directly related to water management (see Module 15 on disaster risk reduction).

3.9 Water management for climate change mitigation

Irrigated agriculture accounts for only 20 percent of the area of global agriculture, but is more intensively managed. On average, irrigated agriculture uses greater amounts of inorganic fertilizer and other agrochemicals than most rainfed systems. Consequently, efforts to reduce greenhouse gases through improved crop management practices are likely to have more impact in irrigated lands than in rainfed areas.

Groundwater is used for irrigation on 38 percent of all irrigated land. The use of groundwater is expanding both in absolute and relative terms (Siebert *et al.,* 2010), and this is increasing the use of fossil fuels and raising the energy costs of water supply. At a regional level, energy consumption for groundwater irrigation can be significant. In China, energy consumption in this area is significant, accounting for 16–25 million tonnes of carbon emissions. In India, it is responsible for 4–6 percent of the national total emissions (Shah, 2009).

On balance, the options for direct climate change mitigation through irrigation are the same as those of agriculture as a whole. There is likely greater potential in areas of intensive groundwater irrigation. The possibilities are governed mostly by the increased intensity of irrigation, which will allow for a greater potential for carbon sequestration in tropical conditions and greater productivity, but may be offset by more intensive use of inputs (Turral *et al.*, 2011).

Agricultural methane (CH_4) emissions account for more than 50 percent of CH_4 emissions from human activities. One-third of these emissions come from flooded rice production (28-44 teragrams of CH_4 per year). More than 90 percent of global rice production is concentrated in the monsoon area of South and Southeastern Asia. Since the area of irrigated rice is growing relatively slowly, future increases in CH_4 emissions from rice fields are expected to be small. Furthermore, rice fields are converted at least partially from natural wetlands, which also emit CH_4, and extend over a much larger area at the global level. The effective net emissions growth from transforming wetlands into irrigated rice has not been well studied. However when emissions from natural wetlands are taken into account, gross emission estimates are probably substantially smaller than effective net emissions (HLPE, 2012).

Emissions during the growing season can be reduced by using various water management practices, such as cultivating aerobic rice and, where conditions allow, alternate wetting and drying. Avoiding water saturation when rice is not grown and shortening the duration of continuous flooding during the rice growing season are effective options for mitigating CH_4 emissions from rice fields. Currently, true aerobic rice yields tend to be poor (less than 2 tonnes per hectare), and this is a strong disincentive for adoption even when natural drainage conditions are favourable (Comprehensive Assessment, 2007). Promoted in many rice-producing countries, the System of Rice Intensification (SRI) is a practice that aims to increase the productivity of irrigated rice by changing the management of plants, soil, water and nutrients. Because SRI reduces the amount of flooding of irrigated rice, it is also likely to reduce CH_4 emissions. It also saves water and may possibly reduce nitrous oxide emissions (HLPE, 2012). However, well-quantified data on reductions in CH_4 emission are not yet available.

In inland fisheries and aquaculture, riparian habitat restoration or creation can be promoted to absorb carbon and create suitable environments for capture fish production. The modernization of fishing and aquaculture facilities also has the potential to contribute towards low impact fuel efficient (LIFE) systems (see Module 10 on fisheries and aquaculture).

Irrigated pastures are important in some areas of the world, and their importance is growing as demand for animal feed increases. Better pasture management, combined with the use of feed additives that suppress CH4 fermentation in ruminants, can reduce livestock CH_4 emissions substantially (Turral *et al.*, 2011).

3.10 Conclusions

Most of the impacts of climate change agriculture and rural livelihoods are expected to result from changes in the water cycle. Rainfall variability and the subsequent increase in frequency of extreme weather events, including droughts and floods, combined with an increasing acceleration of the water cycle through increased evapotranspiration, will have an impact on every element in agricultural ecosystems: crops, livestock, trees, fish, rural communities and physical infrastructure. For this reason, climate change adaptation strategies for agriculture will need to be viewed though a 'water lens'.

Many of the development activities for improving the socio-economic conditions in rural areas will have a positive impact on climate change adaptation as they reduce the vulnerability of local communities to shocks and increase their resilience. However, new programmes must become more strategic. The resilience of these populations to climate change must be assessed systematically to avoid maladaptation and increase the robustness of development programmes. In addition, specific climate change adaptation actions will need to be designed and mainstreamed into development programmes.

Given that most intensive agricultural practices with potential for climate change mitigation use some form of irrigation, there is some scope for mitigation actions addressing how water is managed in agriculture.

Notes

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Acronyms

CARE	Cooperative for Assistance and Relief Everywhere
CH_4	methane
CRisTAL	Community-based Risk Screening Tool – Adaptation and Livelihoods
CSA	climate-smart agriculture
GEF	Global Environmental Facility
HLPE	High Level Panel of Experts on Food Security and Nutrition
IPCC	Intergovernmental Panel on Climate Change
LIFE	low impact fuel efficient
NDMC	National Drought Mitigation Center
OECD	Organisation for Economic Co-operation and Development
ORCHID	Opportunities and Risks for Climate Change and Disasters
SRI	System of Rice Intensification
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WHO	World Health Organization

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Annex

A.3.1
A typology or major agricultural systems at risk and response options

Major agricultural systems	Sub-system and location	Vulnerability			Typical response options
		Main climate change exposure	Sensitivity	Adaptive capacity	
Highlands	Densely populated highlands in poor areas: Himalayas, Andes, Central American highlands, Rift Valley, Ethiopian plateau, Southern Africa	Rainfall variability, droughts, floods	High: mostly rainfed agriculture, marginal lands, poor soil moisture capacity	Low: high prevalence of poverty, limited options, knowledge, social safety nets and resources	Watershed management and on-farm water storage for water conservation; integrated water resources management in river basins; investment in social infrastructures
Semi-arid tropics	Smallholder farming in Western, Eastern and Southern Africa savannah region and in Southern India; agro-pastoral systems in the Sahel, Horn of Africa and Western India	High temperatures, rainfall variability, droughts	High: crop and animal sensitivity to high temperature and droughts, high population density on marginal lands	Low: high prevalence of poverty, limited options, knowledge, social safety nets and resources, limited capacity for water storage	On-farm water storage; crop insurance; increased productivity through better crop-livestock integration; integrated water resources management
Sub-tropics	Densely populated and intensively cultivated areas, concentrated mainly around the Mediterranean basin	Reduction in annual rainfall, increased rainfall variability, reduction in runoff and aquifer recharge, high temperatures, higher occurrance of droughts and floods	Variable, depending on the region and level on reliance on agricultural activities. Agricultural systems highly sensitive to changes in temperature and water availability.	Low adaptive capacity for agriculture in water scarce areas	Water conservation where possible; integrated water resources management; crop insurance; improved floods and drought management plans; shifting out of agriculture
Temperate areas	Highly intensive agriculture in Western Europe. Intensive farming in United States, Eastern China, Turkey, New Zealand, parts of India, Southern Africa, Brazil	Increased rainfall variability, reduced water availability in places.	Medium to low. Some high yielding varieties more sensitive to temperature and water stress	Possibilities to compensate water stress through supplemental irrigation in many regions; low capacity in water scarce areas	On-farm storage for supplemental irrigation; integrated water resources management at river basin level
Rice-based systems (irrigated)	Southeast and Eastern Asia, Sub-Saharan Africa, Madagascar, Western Africa, Eastern Africa	Increased rainfall variability, increased rainfall, increased occurrence of droughts and floods	Medium, depending on the capacity to cope with floods and droughts	Medium, depending on the capacity to invest in protection against droughts and floods	Increased water storage for flood control and for second and third crop; alternate wet-dry rice production systems where feasible
Large irrigation systems in dry areas (mostly canal irrigation)	Colorado River, Murray Darling, Krishna, Indo-Gangetic plains, Northern China, Northern Africa and the Middle East	Change in seasonality of runoff and groundwater recharge and progressive reduction in runoff in snowmelt systems; reduction of rainfall and runoff in Northern Africa and Middle East, higher occurrence of droughts and floods	High sensitivity to variations and reduction in water supply as most areas are already under water stress	Low due to already heavy pressure on water resources. Limited possibilities in places through increased storage and increased water productivity through conservation measures	Increased water storage and drainage; improved reservoir operations; changes in crop and land use; improved soil management; water demand management including groundwater management and salinity control; revision of flood management plans

Major agricultural systems	Sub-system and location	Vulnerability			Typical response options
		Main climate change exposure	Sensitivity	Adaptive capacity	
Groundwater-based irrigation systems in interior arid plains	India, China, central USA, Australia, North Africa, Middle East and others	Complex interactions between climate change and groundwater leading to possibilities of increase or decrease of aquifer recharge	High sensitivity to variations and reduction in water supply as most areas are already under water stress	Low due to overexploitation of aquifers and competition with other sectors. Limited possibilities in places through increased water productivity.	Increased productivity where possible; better groundwater management through controlled pumping
Rangelands	Pastoral and grazing lands, including on fragile soils in Western Africa (Sahel), North Africa, parts of Asia	High temperatures, rainfall variability, droughts	High sensitivity due to reliance on biomass and water for livestock	Very low: high prevalence of poverty, limited options, knowledge, social safety nets and resources	Where possible, better integration of water supply and grazing land management; reduction of livestock density
Deltas	Nile delta, Red River delta, Ganges/ Brahmaputra, Mekong, ect. and coastal alluvial plains: Arabian Peninsula, Eastern China, Bight of Benin, Gulf of Mexico	Sea level rise and salinisation of aquifers and estuaries. Higher frequency of cyclones (E/SE Asia); increased frequency and intensity of floods	Usually high, depending on population density and the capacity to cope with floods, droughts and salinity levels	Variable	Minimise infrastructure development; better conjunctive use of surface water and groundwater; integrated flood management plans; improved management of coastal aquifers
Small islands and coastal alluvial plains	Including Caribbean, Pacific Islands	Hurricanes, sea-level rise, floods, changes in aquifer recharge	High sensitivity due to fragile aquifers, saltwater intrusion	Variable	Improved management of coastal aquifers; disaster risk reduction plans; water conservation
Peri-urban agriculture	Everywhere	Depending on location	Relatively low	Highly adaptive and dynamic systems	Climate change is rarely the prime source of risk. Actions would focus on competition for water and land with cities, pollution control and health issues