B6 Water management for Climate-Smart Agriculture

Overview

This module looks at water management and its critical role in climate-smart agriculture. The introductory chapters present an overview of the status and trends in water management in agriculture. Chapter B6 - 3 reviews the current state of knowledge of the impacts of climate change on water for agriculture and the overall context in which water is managed in agriculture, including the trends and challenges. Chapter B6 - 4 looks at the possible adaptation options to address the impacts of climate change. These options can be applied at various scales, on individual farms, in larger irrigation schemes, throughout entire river basins and at the national level. This chapter also presents the tools and approaches for preparing the responses to climate change taking into account the vulnerability of rural populations and farming systems. Chapter B6 - 5 considers aspects related to water management that may contribute to climate change mitigation. Chapter B6 - 6 covers the requirements to create an enabling environment for the adoption of climate-smart water management practices. Chapter B6 - 7 offers some concluding insights on water management and climate change.

Key messages

- The major impacts of climate change on agriculture are expected to result from its effect on the water cycle. An approach that views potential responses to climate change through a 'water lens' must be used when designing climate-smart agriculture strategies.
- Climate change, which will increase crop evapotranspiration, change the quantity of rainfall and rainfall patterns, and lead to greater variations in river runoff and groundwater recharge, will affect both rainfed and

irrigated agriculture.
- The impacts of climate change on water resources used for agriculture must be situated in a wider context. Responses to address these impacts need to consider the other pressures that are affecting water resources, such as the increasing demand and competition for water by all sectors, and the degradation of water quality.
- Addressing the risks associated with climate change requires an understanding of the impacts of climate change on the different components of the water balance and the vulnerability of rural communities. Equity must be included in the criteria for assessing the suitability of adaptation options.
- Adaptation to climate change has the potential to substantially reduce the vulnerability of rural communities and improve the sustainability of agricultural water management. Climate change adaptation interventions related to water use in agriculture will need to integrate actions that target policies, institutions, investments, crop and water management practices and capacity development. These initiatives will also need to engage multiple sectors.
- The integration of climate change into the planning and design of investments can considerably reduce the risks to the water infrastructure used for agriculture.

Introduction

Water management plays a crucial role in food production and the management of ecosystems. Climate change is expected to affect the hydrological cycle and the availability of freshwater resources for agriculture. The relationship between climate change and water cannot be analysed in isolation. It must be situated within the larger context of socio-economic development. The drivers that are shaping this development, particularly population growth, increased food consumption, and urbanization, all have significant influences on the quantity and quality of water resources. Climate change puts greater pressure on water resources in areas where the sustainable management of water resources is already extremely challenging.

The objective of this module is to explore the relationship between climate change and water management in agriculture and help stakeholders assess and define climate-smart agriculture strategies for addressing changes in water supply and demand. The module also analyses the overall development context in which water is managed in agriculture and provides an overview of the current status, trends and challenges in this area.

The module is addressed to a broad audience, including policy makers, project managers, researchers, rural advisory services and agricultural extension agents, and farmer organizations and civil society organizations engaged in issues related to water resource management, climate change and agricultural development. The module is intended to inform them about potential adaptation and mitigation options that are based on a sound understanding of the impacts of climate change and the vulnerability of rural communities.

Water management and climate change

Observed data and climate projections show that changes in water quantity and quality due to climate change are expected to negatively affect food security and increase the vulnerability of poor rural farmers, especially in arid and semi-arid areas. In many regions, agricultural production is already being adversely affected by climate change (FAO, 2016a). Higher temperatures, less reliable supplies of water and more frequent droughts and floods are likely to reduce yields in many areas.

Agriculture is clearly highly dependent on climate. However, there are many non-climatic factors that strongly influence agricultural production systems, such as expanding populations and urbanization, global economic growth, increasing competition for natural resources, agronomic management practices, technological innovations, and trade and food prices. These factors have more immediate impacts on water resources 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 impacts of climate change.

B6 - 3.1. Water management in agriculture: status and trends

Between 1961 and 2011, global agricultural output more than tripled. The higher demand for food, fibre 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 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 the intensification of agricultural production.

With the doubling of irrigated area, water withdrawals for agriculture have been rising sharply. Globally, agricultural water withdrawals represent 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 demands 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 repercussions for water users and the environment. Competition over water use is growing in river basins where there are no measures in place for arbitrating conflicts. Biodiversity is declining more rapidly for species that depend on freshwater ecosystems than for species from other types of ecosystems (Comprehensive Assessment, 2007). The large-scale public surface irrigation systems, which were built during the green revolution and dominated the landscape until the early 1980s, have had a profound impact on the flow of many rivers. Private investments, stimulated by the availability of cheap pumps and well-drilling capacity, have been used to tap groundwater. Consequently, aquifers are being depleted in countries with key agricultural production systems, including China, India, and the United States of America.

Water demand from cities and industries has been booming as a result of rapid economic growth in emerging economies. 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 expanding populations and economic growth increase the consumption of food and manufactured goods.

Given the limits of water resources, the rate of expansion of land under irrigation is slowing substantially. FAO has projected that the global area equipped for irrigation may increase at a relatively low annual rate of 0.1 percent (Alesandratos and Bruinsma, 2012). At that rate, it would reach 337 million hectares in 2050, compared to around 325 million hectares in 2013. This represents a significant slowdown from the period between 1961 and 2009.

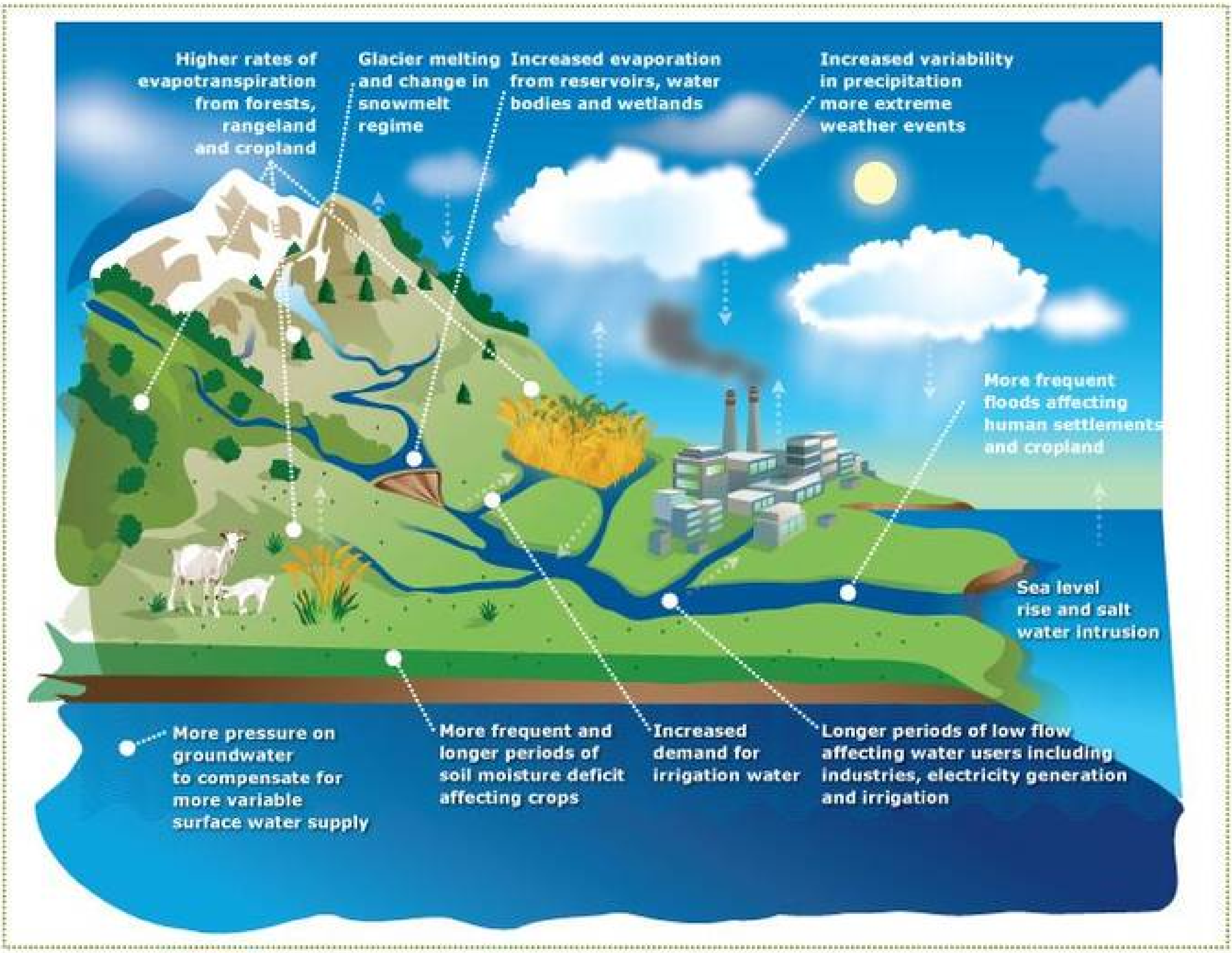
The role climate change will play with regards to water in agriculture must be considered in this context of rapid increases in water withdrawals, the degradation of water quality and the competition for water at all levels. Chapter B6-3 looks at the current state of knowledge about the impacts of climate change 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 associated with changing climatic conditions and require specific responses.

Climate action and the 2030 Agenda for Sustainable Development are closely connected. It will be difficult, if not impossible to eradicate poverty and end hunger without building resilience to climate change in smallholder agricultural production systems (FAO, 2016a). Sustainable Development Goal (SDG) 6 (Ensure availability and sustainable management of water and sanitation for all) has six targets that focus on improving access to drinking water and sanitation services; preserving water quality and reducing sources of pollution; strengthening integrated water resources management with the participation of the local population; and increasing efficiency in the use of water resources. By calling for substantial increases in water-use efficiency across all sectors, and the sustainable use of freshwater resources to reduce the number of people suffering from water scarcity, SDG 6 has a close relationship with SDG 2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture) and SDG 1 (End poverty in all its forms everywhere).

B6 – 3.2 Climate change impact on water in agriculture

Water is the prime channel through which the impacts of climate change on the world's ecosystems and livelihoods will be felt. Climate change has the potential to affect every element in the water cycle (UN-Water, 2010). Agriculture will be affected by increased evaporative demand, changes in the amount of rainfall and rainfall patterns, and variations in river runoff and groundwater recharge, which are the two sources of water for irrigation (Figure 3.1).

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



B6 - 3.2.1 Impact on water supply and demand

The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report, published in 2014, describes the expected impacts of climate change on water resources. Its findings are summarized in this section.

Renewable surface water and groundwater resources

Precipitation and evaporation are the main climatic phenomena affecting freshwater resources. Climate models predict decreases of renewable water resources in some regions and increases in others. In many areas, there is considerable uncertainty in this regard. However, there is high agreement and robust evidence that water resources will likely decrease in many mid-latitude and dry subtropical regions, and increase at high latitudes and in many humid mid-latitude regions. Even where increases are projected, there may be short-term shortages due to more variable streamflow caused by greater variability in precipitation. There may also be seasonal reductions in water supply due to reduced snow and ice storage. The availability of clean water may also be reduced by the negative impacts of climate change on water quality.

The decrease of renewable surface water and groundwater resources in dry subtropical regions will intensify competition for water by different users (e.g. agriculture, ecosystems, settlements, industry, and energy production). This will have an impact on regional water, energy and food security. How changes in vegetation brought about by increasing concentrations of greenhouse gas in the atmosphere will affect water resources and irrigation requirements remains uncertain.

Floods and droughts

Climate change is also projected to alter the frequency and magnitude of floods and droughts. The impact is expected to vary from region to region. Despite limited evidence, there is high agreement that floods will increase over more than half of the globe, particularly in central and eastern Siberia, parts of Southeast Asia, including India, tropical Africa, and northern South America. Decreases in floods are projected in parts of northern and Eastern Europe, Anatolia, Central and East Asia, central North America, and southern South America. The Fifth Assessment Report stated with high confidence that since the mid-20th century, socio-economic losses from flooding have increased mainly due to greater exposure and vulnerability. There is limited evidence and medium agreement that global flood risk will increase partly due to climate change.

In some regions, including southern Europe and West Africa, metereological droughts, which are characterized by significantly reduced rainfall, and agricultural droughts, which are characterized by significant declines in soil moisture that affect crop production, have become more frequent since 1950 (Seneviratne *et al.*, 2012). Climate change is likely to increase the frequency and length of both kinds of droughts by the end of the 21st century. However, it is still uncertain what these rainfall and soil moisture deficits may mean for prolonged reductions of streamflow and lake and groundwater levels. Droughts are projected to intensify in southern Europe and the Mediterranean region, central Europe, central and southern North America, Central America, northeast Brazil, and southern Africa.

Water quality

There is medium evidence and high agreement that climate change negatively impacts freshwater ecosystems by changing streamflow and water quality. Climate change affects the quality of water through a complex set of natural processes and anthropogenic factors.

There is medium evidence and high agreement that climate change will likely reduce raw water quality, which will pose risks to drinking water quality even with conventional treatment. The sources of these risks are increased temperatures, higher levels of sediment, nutrient and pollutant loading due to heavy rainfall, the reduced dilution of pollutants during droughts, and the disruption of treatment facilities during floods.

Streamflow seasonality

In regions with snowfall, climate change has already altered the seasonality of streamflow. There is robust evidence and high agreement that this variability will increase. Except in very cold regions, warming in the last decades has reduced the spring maximum snow depth and brought forward the spring maximum of snowmelt discharge. Smaller snowmelt floods, increased winter flows, and reduced summer low flows have all been noted. River ice in Arctic rivers has been observed to break up earlier.

Groundwater recharge

The impact of climate change on groundwater recharge is difficult to predict. Changes in precipitation intensity will affect the amount of total runoff that recharges groundwater. In humid areas, increased precipitation intensity may decrease groundwater recharge because the infiltration capacity of the soil will be insufficient. In semi-arid areas, increased precipitation intensity may increase groundwater recharge due to the faster rate of percolation through the root zone, which will reduce evapotranspiration.

Crop water demand

Changes in climate will affect the water demand of crops grown in both irrigated and rainfed systems. An increase in temperatures will trigger a higher demand for water for evapotranspiration by crops and natural vegetation, which will lead to more rapid depletion of soil moisture. This scenario, combined with changes in rainfall patterns may lead to more frequent crop failures. The Fifth Assessment Report provides different projections on the effect of climate change in crop water demands. In general, projections show that the water demand to produce a given amount of food on either irrigated or rainfed systems will increase in many regions due to climate change. By the 2080s, there is high confidence that irrigation demand will increase significantly in many areas – perhaps by more than 40 percent across Europe, the United States of America, and parts of Asia. Other regions, including major irrigated areas in India, Pakistan, and southeastern China, may experience a slight decrease in irrigation demand, as a result of higher precipitation. However, this is only projected in some climate change scenarios. Wada *et al*. (2013) suggest an increase in irrigation demand by the 2080s, with a global average increase of 7 to 21 percent, depending on the emissions scenario, and with pronounced regional variations. By contrast, Zhang and Cai (2013), predict a slight global decrease in crop water deficits in both irrigated and rainfed areas by the 2080s. The decrease can be explained partly by a smaller difference between daily maximum and minimum temperatures. Where poor soil is not a limiting factor, increases in crop water productivity due to carbon dioxide fertilization might partly moderate the adverse effects of climate change, and potentially reduce global irrigation water demand (Konzmann *et al*., 2013).

The Fifth Assessment Report states with medium confidence that climate change will increase the interannual variability of crop yields in many regions. The differences in yield and yield variability between rainfed and irrigated land may also increase with changes in climate and greater climate variability.

Sea level

There has been significant progress in the understanding of sea level rise since the release of the IPPC's Fourth Assessment Report in 2007. It is virtually certain that sea level will continue to rise during the 21st century and beyond. For all scenarios, the rate of 21st century of global mean sea level rise is very likely to exceed the average rate during the 20th century. The expected rise in sea levels will affect agriculture in coastal areas, particularly river deltas. Higher sea levels combined with variations in the distribution of runoff and more frequent floods in upstream areas, will result in an increased incidence of flooding and saltwater intrusion in estuaries and aquifers. This will affect some of the world's most productive agricultural areas.

B6 - 3.3 Combined impacts climate change and non-climatic drivers of change in water for agriculture

Rapid increases in water withdrawals driven by intensified agricultural production, overall economic development, population growth and urbanization have modified the water balance in many watersheds and aquifers. Unsustainable water withdrawals and pollution are threatening ecosystems and the livelihoods of rural communities in an increasing number of river basins and aquifers.

The extent to which changing climatic conditions will affect the water cycle and agriculture will be determined by non-climatic drivers of change. In arid and semi-arid areas, climate change will place additional burdens on already stretched water resources. However, in these environments, agriculture will first need to respond to the challenges posed by increasing human pressures on water resources. In other places, climate change will be the main factor driving changes in water resources and will necessitate specific climate-smart responses. Table 3.1 shows the relative importance of climatic and non-climatic factors in determining changes in water resources for agriculture. The impacts of climate change will vary from one agricultural system to another. It is important that climate-smart strategies take into account the overall socio-economic and environmental setting in which they are to be implemented.

Of particular relevance is the time frame for the projected impacts of 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 anthropogenic demands for water. However, changes in climate variability and extreme events associated with climate change may already be having impacts on water resources for agriculture, and deserve particular attention when preparing short- and medium-term responses.

Table 3.1. Impacts of climate change and non-climatic drivers of change on water resources for agriculture

Type of hydrological change	Impact from	
	Non-climatic drivers	**Climate change**
Change in annual precipitation	No or minor impact	Expected to increase globally during the 21st century, with potentially significant spatial variations
Interannual precipitation variability	No impact	Expected to increase everywhere
Seasonal precipitation	No impact	Expected to increase everywhere

Type of hydrological change	Impact from	
	Non-climatic drivers	Climate change
Agricultural 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 (i.e. longer periods without rain) and increasing temperatures.
Exposure to floods	Moderate impact: flood intensity and impact can be exacerbated by changes in land use and unplanned development in alluvial plains	Percentage of global population annually exposed expected to increase.
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.
Change in 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.
Change in groundwater resources	High impact: large-scale development of infrastructure to withdraw 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.
Increase evapotranspiration	Limited impact in agriculture: some crops have higher evapotranspiration rates than natural systems, other less	Increases as temperatures rise
Water quality (in rivers, lakes and aquifers)	High impact from pollution in highly developed areas	Moderate impact due to increased temperatures
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

Water management options for climate change adaptation

There is a large range of possible response options for adapting to climate change. These options can be related to policies, investments, institutions, water management, farming practices and capacity development, both within the water and agriculture sectors and beyond. These options will need to be applied at different scales: on fields and farms; in irrigation schemes, particularly in large-scale schemes; in watersheds or aquifers; in subnational and transboundary river basins; and at the national level. Table 3.2 presents a list of potential response options and indicates their relevance for different scales. The list, which includes both supply-side and demand-side options, is not exhaustive, and should not be taken as a set of policy measures. 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. Their implementation depends on the local conditions and the specific climate change risks that need to be addressed (e.g. water scarcity, changes in water availability, extreme events, increased irrigation requirements, water quality).

Table 3.2. Potential 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	X		
Introduction of new irrigation areas		X	X	X
Development of climate change-resilient crops				X
Dam construction and improved reservoir capacity		X	X	
Drainage	X	X	X	
Introduction of appropriate fish species	X		X	
Desalination and wastewater reuse			X	X
Wetland restoration			X	X
Climate proofing of Irrigation and drainage infrastructure		X	X	
2. Land, water and crop management				
Improve 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	X		
Alternate wet and dry rice production system	X	X		
Drainage and flood management		X	X	
Irrigation scheme operation improvement		X		
Integrated water resources management			X	
Conjunctive use of surface and groundwater resources			X	
Adaptation of dam operation rules			X	
Riparian habitat restoration or creation in rivers			X	
Introduce drought resistant crops	X			
Protection against soil erosion	X			
3. Policies, institutions and capacity building				
Reallocation of water (between or within sectors)		X	X	X
Strenghtening right of access to land and water		X	X	X
Crop insurance against losses due to floods and drought				X
Improved weather forecasting capacity	X	X	X	X
Improved monitoring and early warning			X	X
Improved water charging and trade				X
Implementation of national adaptation plans				X
Improved coordinated and integrated planning			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 long been promoted 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 many areas of overlap between climate change adaptation and sustainable development, activities with an explicit focus on adaptation and climate change will be required. Box 3.2. proposes four categories of responses that cover development actions for reducing the overall vulnerability of rural communities to all types of shocks to targeted actions for adapting to the specific impacts of climate change.

Box 3.1 A continuum of adaptation activities: from development to climate change-specific actions

Adaptation activities that span the continuum from sustainable development to climate change can be organized in four categories. The first category, which includes activities that foster human development, focuses on reducing poverty and addressing factors that make communities vulnerable, regardless of the cause. The second category of activities stresses the improvement of response capacities. Activities in this category are mostly directed to capacity development and tend to involve institution building and technological approaches adapted from development efforts. In the third category, activities focus on managing climate risk. They concentrate on climate-related hazards and their impacts and embrace the concept of climate risk management. The fourth category involves activities for addressing climate change. They almost exclusively deal with the impacts of climate change and tend to target climate change-related risks that are not connected to historic climate variability.

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

Adaptation at the field and farm levels

Many farm-level adaptations will be spontaneous and will be done in response to changing conditions, but they will not necessarily designed for climatic changes. Other adaptations will need to be planned, often with external financial support. Of prime importance is increasing the ability of farming systems to cope with more variable supplies of rainwater. This will require an improving the capacity to store water in the soil, surface reservoirs or underground reservoirs. Any action that increases the capacity of the farming system to access water when needed will increase the resilience of the system to climate variability. Actions in this area include on-farm water harvesting; the enhancement the soil's capacity to hold moisture (see also module B7 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.

Demand-side options include more efficient irrigation technologies that reduce evaporation losses and increase crop production. These actions can be combined with deficit irrigation that can help 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. It is preferable to use crops varieties that are more resilience to dry spells.

Increased agricultural diversification and the better integration of trees, crops, fish and livestock will reduce risk and increase the resilience of farming systems. In particular, the capture and farming of aquatic species that do not require extensive migrations and have wide environmental tolerances will help the aquaculture and fisheries sector adapt to new climatic conditions.

Farmers will also need to be more systematic in the adoption of 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 in irrigation schemes

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 to allow for a more flexible and reliable delivery of water (FAO, 2007). Intermediate storage within the irrigation scheme and, where possible, access to groundwater are some of the options for building the resilience and reliability of the 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, which may be simpler and more effective for fostering more productive water-use behaviour. Box 3.3, which provides an example of a climate change adaptation programme of irrigation in China, illustrates how adaptation activities are closely linked to overall irrigation modernization programmes.

Box 3.2 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 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. Climate change, combined with increasing industrial and domestic water demands, will reduce the amount of water 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 was added to mainstream climate change adaptation activities into the project's activities.

The overall aims of the project were to make the use of water for farming more efficient 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 deliver 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 to better manage irrigation water, which were introduced through pilot programmes, were widely adopted after farmers saw the benefits in terms of lower 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 improvements 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-intensive 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, the adaptation approaches to floods and droughts used by water managers and farming communities should be considered systematically. Examples of potential options 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 the impacts of flood, control erosion, and provide soil nutrients, shade and oxygen. This will also create suitable environments for aquaculture and fisheries.

Integrated water resources management in river basins will become more and more important as the combination of greater water use and the occurrence of extreme events increases the interdependency of people and communities living in river basins, and as actions in one part of a basin have repercussions for downstream users. 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, 2012a). Improved governance of land and water use will be required to accommodate the multiple uses of water, including for livestock and fish.

Enhanced management of water under climate change requires a much better understanding of the available supply and demand. Water accounting, the systematic study of the current situation and trends in water supply, demand, accessibility and use (FAO, 2016c) will become increasingly important for providing the data and evidence that will be needed at each level of management to ensure sound water management.

Improved weather forecasting and hydrological monitoring will also become a critical element of modern adaptation strategies (Faurès *et al*., 2010). Currently, reliable weather forecasting is limited to a few days. However, progressive improvements in the timing and reliability of seasonal forecasts offer new opportunities for farming communities. As efforts focus on increasing the accuracy of these forecasts, more emphasis should be given to improving the way information is conveyed to farmers and building their capacity to make the 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.

Resilience to climate change 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.

Insurance represent a potential solution that should also be considered in adaptation strategies. There has been renewed interest in various types of crop insurance, as well as aquaculture and fishing insurance schemes, 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 their cost and institutional settings. So far, few commercial insurance companies have found these schemes 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 insurance must reflect national interests and at the same time ensure the smooth operation of private insurance companies. Efforts in this area must be based on the concept of shared risk between producers, insurance companies and governments.

A type of insurance that 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 appears to have good potential for hazards with regional impacts, such as hurricanes or droughts (Gommes *et al*., 2010).

Box 3.3 Coping with water scarcity: adaptation strategies on the supply and demand side

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 to reduce water scarcity both on the supply side and on the demand side.

Activities that enhance the supply of water include increasing users access to conventional water resources and improving the management of these resources; rehabilitating natural habitats; improving dam operations; reusing drainage water and wastewater; transferring water between river basins; increasing desalination; and controlling water pollution.

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 run the spectrum from the source of water, to the end users and beyond, to the consumer of agricultural goods (FAO, 2012a). A combination of technical, managerial, legal and investment options are needed to help agricultural producers 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 increase 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.

B6 - 4.2 Making adaptation choices: understanding the vulnerability of farming systems to climate change

Efforts to develop adaptation options for water management will benefit from a greater understanding of the risks and potential impacts of climate change in different agricultural systems and the vulnerability of the different groups in rural areas.

The impact of climate change on agricultural systems and rural communities depends on a combination of the exposure to climate change and the sensitivity of the system. The adaptive capacity of these systems in relation to potential changes in water supply and demand will determine their vulnerability. The risk associated to climate change will vary substantially from one system to the other depending on the exposure and vulnerability. The table in the Annex (A.6.1) 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 (SOLAW) (FAO, 2011a).

Table A.6.1 indicates 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 communities the most at risk are those that rely exclusively on farming for their livelihoods, 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 enhanced conservation of soil moisture, particularly by improving the soil's capacity to retain water or increasing access to supplementary irrigation; drought preparedness strategies that improve grain storage; and better access to markets. Climate change only represents an additional justification for actions that are already needed.

The distinction between rainfed and irrigated production systems will determine the impacts and associated risks related to climate change. Rainfed systems in subtropics 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 the availability of animal feed. Irrigated systems are better protected against rainfall variability. However, these systems will increasingly require greater storage capacity to respond to more frequent droughts and floods, and changes in the annual distribution of runoff. This could affect water distribution over the entire river basin. For surface or groundwater systems already 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.

Production from aquaculture systems and capture fisheries will be affected by changes in quantity and quality of freshwater. 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). More or larger reservoirs could promote integration of fish farming through cage culture and enhance fisheries production.

B6 - 4.3 Tools and approaches for risk assessments and development of adaptation options

Many governments and development partners have developed tools to assess the risks associated with climate change in relation to a given population's vulnerability (OECD, 2009). Examples of these tools include:

- Opportunities and Risks of Climate Change and Disasters (ORCHID);
- Community-based Risk Screening Tool – Adaptation and Livelihoods (CRisTAL);
- Tools developed by CARE and the International Federation of Red Cross and Red Crescent Societies;
- The Self-evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists (SHARP), developed by FAO, which includes specific modules on water and irrigation (FAO, 2015).
- The Climate Change Decision Tree Framework, developed by the World Bank (Ray *et al.*, 2015)

These tools use two types of approaches:

- The top-down approach, which focuses on potential changes in the water cycle that may result from climate change, uses different quantitative models and designs response options to anticipate and prevent the negative impacts of these changes. By nature, this approach favours long-term responses.
- The bottom-up approach seeks to understand the causes of the vulnerability of rural communities, and design solutions that help increase their resilience to external shocks. This approach, which is more generic in nature, does not specifically focus on climate change. It 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.

Bottom-up approaches give the opportunity to address the needs of vulnerable communities in terms of resilience and development. By acknowledging that resilience is closely linked to a community's state of development, its level of economic diversification and the strength of livelihoods assets, community-based climate change response programmes offer the opportunity to progressively build capacities 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 approach is to avoid maladaptation (i.e. designing development actions that are excessively sensitive to climate change and increase the vulnerability of beneficiaries). For instance, the SHARP tool addresses the need to gain a better understanding of the interests of family farmers and pastoralists with regard to climate resilience to ensure that their needs, including those associated with water and irrigation issues, are incorporated in decision-making processes.

Water infrastructure generally has a lifetime of 30 to 50 years. Investments for new water infrastructure or the rehabilitation of old infrastructures will be shaped by changes in climate. The changing frequency and intensity of droughts, floods, precipitation and heat waves will have a particularly significant impact on water supply and demand. Improving the resilience of water infrastructure to withstand climate change-related shocks and extreme events is a vital part of any effective water investment planning. Traditionally, climate change and disaster risks are factors that have not been assessed or integrated into plans for water investments. A World Bank study (Cervigni *et al*., 2015) states that the proper integration of climate change in the planning and design of infrastructure investments can considerably reduce future climate-related risks to the physical and economic performance of hydropower and irrigation. The results of the study show that not integrating climate change in the planning and design of water infrastructure could entail a loss of 10 to 20 percent in dry scenarios and a foregone gain of 1 to 4 percent in the wet scenarios for most basins.

The concept of ‘climate-proof’ investments is central to the design of programmes for reducing climate change-related risks. It is necessary to maintain a clear perspective on resilience when screening water development programmes. Governments and development agencies have prepared guidelines for incorporating climate change considerations into investment programmes. Some examples are:

- Guidelines for Climate Proofing, Investment in Agriculture, Rural Development and Food Security, developed by the Asian Development Bank (ADB, 2012)
- Incorporating climate change considerations into agricultural investment programmes, developed by FAO (FAO, 2012b)

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 valid under a variety of alternative futures (see Box 3.4). 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 infrastructure. This approach 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 3.4 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

B6 - 4.4 Livelihood approach to prioritize water adaptation options

The combination of impact assessments, vulnerability assessments, and the screening of response options usually produces a long list of possible actions to cope with climate change. The effectiveness of an option needs to be assessed as a potential 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 that deliver benefits to many groups, with low costs per beneficiary and high levels of effectiveness should be selected. Adaptation options need to be discussed with stakeholders to ensure there is a clear understanding of possible trade-offs between costs and effectiveness.

Criteria for assessing the impacts of climate change and adaptation options must also consider social equity. Particular focus should be placed on the most vulnerable rural groups. The latest IPCC assessment makes clear that climate change will exacerbate existing gender inequalities. Women farmers represent more than half of the agricultural workforce in some low and middle-income countries, and play a crucial role in food security and natural resources management. Understanding the different adaptive strategies of men and women, including those related to water access and management, is necessary to prioritize water adaptation options. Securing water rights in a way that is both effective and equitable will also become more and more 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 strategies 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 water use in rural livelihoods:

- access to basic water services;
- crop and livestock water security;
- a clean and healthy water environment; and
- secure and equitable entitlements to water.

Using these 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.

An assessment of the ease of implementation considers the possible barriers to carrying out a given option that could delay or reduce its impact. These 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.

The adequacy of a proposed option for the current climatic conditions is also an important criterion to consider. 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 involve higher costs and have possible negative consequences under current climatic conditions, and require careful consideration in terms of risk analysis.

All options must be considered in light of the uncertainty associated with climate change predictions. Their robustness in terms of the above criteria, particularly their effectiveness and adequacy for current climatic conditions, must be assessed against different climate change scenarios and global circulation models (see module C8 on assessments).

Water management and climate change mitigation

Over the past 50 years, greenhouse gas emissions resulting from agriculture, forestry and other land uses have nearly doubled, and projections suggest a further increase by 2050 (FAO, 2014).

Climate change mitigation practices in agriculture will have both positive and negative impacts on water resources. For instance, the cultivation of bio-energy crops, or afforestation and forestation activities that may have mitigation benefits will often translate into more water use and can reduce streamflow or groundwater resources, particularly in arid and semi-arid regions. Land management practices implemented for climate change mitigation may also affect water resources. For example, soil carbon conservation practices such as reduced tillage, prevent erosion and improve the soil's capacity to retain water. More efficient use of fertilizers can also improve water quality.

At the same time, water management can have an impact on greenhouse gas emissions and mitigation. Some examples are listed below.

Irrigation

Irrigated agriculture accounts for only 20 percent of the total cultivated land, but irrigated lands are more intensively managed. On average, irrigated agriculture uses greater amounts of inorganic fertilizer and other agrochemicals than most rainfed systems. Irrigated lands can enhance carbon storage in soils and enhance yields by using crop residues to cover the soil surface.

Irrigation also affects energy consumption, as energy is needed to pump and treat water. Water scarcity and irrigation development are expanding the use of groundwater resources both in absolute and relative terms (Siebert *et al.*, 2010). Water scarcity is also causing the agricultural sectors to tap into non-traditional means, such as desalination and wastewater reuse, to obtain water for irrigation. All these water sources have high energy requirements, which are often met by burning fossil fuels. Groundwater is used for irrigation on 38 percent of all irrigated land, and energy consumption for groundwater irrigation can be significant. For instance in China, it accounts for 16 to 25 million tonnes of carbon dioxide emissions, and in India, it is responsible for 4 to 6 percent of the total national emissions (Shah, 2009). Modern irrigation technologies, such as drip irrigation also increase energy demand. In Spain, irrigation modernization reduced water consumption by 21 percent between 1950 and 2008, but energy demand soared by 657 percent (Corominas, 2010).

The use of solar energy for irrigation is a potential option for reducing the emissions associated with irrigation. Solar irrigation is an increasingly reliable, relatively low-cost, clean-energy solution for agricultural water management in areas with high incident solar radiation. In many rural areas where reliable access to electricity is lacking or diesel fuel is expensive, solar irrigation initiatives can be a way of providing broader access to energy for agriculture and other uses (FAO and GIZ, 2015). Some countries are promoting solar irrigation in their national action plans on climate change as a way of reducing agricultural greenhouse gas emissions. However, given their low cost of operation, solar irrigation systems also have the potential to encourage farmers to overuse groundwater. Appropriate policies and regulations should be put in place to control water use.

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

Water management in rice production systems

Agricultural methane emissions account for more than 50 percent of methane emissions from human activities. One-third of these emissions come from flooded rice production (28 to 44 million tonnes of methane per year). More than 90 percent of global rice production is concentrated in the monsoon area of South and Southeast Asia. Since the area of irrigated rice is growing relatively slowly, future increases in methane missions from rice fields are expected to be small. Furthermore, rice fields are converted, at least partially, from natural wetlands, which also emit methane, and extend over a much larger area at the global level. The effective increase in net emissions from transforming wetlands into irrigated rice has not been well studied. However, when emissions from natural wetlands are taken into account, gross emission estimates from rice cultivation 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 methane emissions from rice fields. Currently, aerobic rice yields tend to be poor (less than 2 tonnes per hectare), which is a strong disincentive for adoption even when natural drainage conditions are favourable (Comprehensive Assessment, 2007). The System of Rice Intensification, which is promoted in many rice-producing countries, can increase the productivity of irrigated rice by adjusting the management of plants, soil, water and nutrients. Because the System of Rice Intensification reduces the amount of flooding of irrigated rice, it also likely reduces methane emissions. It also saves water and may possibly reduce nitrous oxide emissions (HLPE, 2012). However, well-quantified data on reductions in methane emissions achieved by adopting this system are not yet available. The System of Rice Intensification is usually more labour-intensive than paddy rice, and not easily adoptable in countries where labour is scarce.

Water management in livestock production, fisheries and aquaculture

In some areas of the world, irrigated pastures are an important part of livestock production systems, As the demand for animal feed increases, their importance is growing. Better pasture management, combined with the use of feed additives that suppress methane fermentation in ruminants, can substantially reduce livestock methane emissions (Turral *et al*., 2011).

In inland fisheries and aquaculture, the restoration or creation of riparian habitats can 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) production systems (see module B4 on fisheries and aquaculture).

Creating an enabling context and removing barriers for adoption of climate-smart water management

In developing countries, programmes designed to promote sustainable water management that can lead to the successful adoption of climate change adaptation practices face a number of barriers. In most cases, the potential exists to implement sustainable water management practices to adapt to climate change, improve the livelihood situation of rural communities and promote sustainable practices. However, achieving these goals demands that a certain set of conditions be put in place to remove constraints and build resilience and flexibility (FAO, 2011b). Some of these conditions include improvements in land tenure and secure access to water; strengthened and more collaborative land and water institutions; efficient support services (e.g knowledge exchange services, 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), not carried out on a separate track. Water, land, energy and food policies must become 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 C5 on disaster risk reduction).

Conclusions

The major impacts of climate change agriculture and rural livelihoods are expected to result from changes in the water cycle. Rainfall variability and the increase in frequency of extreme weather events, including droughts and floods, combined with an acceleration of the water cycle caused by 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 in the agriculture sectors must view potential responses through a 'water lens'.

Many of the development activities for improving 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 vulnerability of agricultural communities 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. All adaptation initiatives need to engage multiple sectors to be successful.

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

Annex

A typology or major agricultural systems at risk and response options

Major agricultural systems	**Sub-system and location**	**Vulnerability**			**Typical response options**
		Main climate options 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 onfarm 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 totemperature 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

Major agricultural systems	Sub-system and location	Vulnerability			Typical response options
		Main climate options change exposure	Sensitivity	Adaptive capacity	
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
Groundwaterbased 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

Major agricultural systems	Sub-system and location	Vulnerability			Typical response options
		Main climate options change exposure	Sensitivity	Adaptive capacity	
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

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Acronyms

INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
SDG	Sustainable Development Goal
UNFCCC	United Nations Framework Convention on Climate Change

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