Agricultural water use supports life

Artists: Jhun Jhun Jha and Hira Karn, Nepal

1 Setting the scene

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We face unprecedented challenges of water management—how to use water sustainably to respond to the increasing demand for agricultural products in many areas and how to find practical solutions where water use has exceeded sustainable limits. We need both more solutions and innovative ways of looking for them. This assessment starts with the premise that there are ways to ensure economic and social development while satisfying the increasing needs for safer and more sustainable agricultural practices.

Modern agricultural practices, including major investments in high-yielding plant varieties and farming systems using high inputs of agrochemicals and water, have enabled growth in world food production to outpace population growth and caused global food prices to fall. Increased water use for agriculture has benefited farmers and poor people globally. But there remains much unfinished business and many complex challenges for the agriculture sector: providing rural people with resources and opportunities to live healthy and productive lives, producing more and better quality food using less water per unit of output, applying clean technologies that ensure environmental sustainability, and contributing productively to local and national economies.

And despite abundant food and lower food prices, the task of providing food security to all remains incomplete. At the beginning of the 21st century 850 million people in the world remain food insecure, 60% of them living in South Asia and Sub-Saharan Africa, and 70% of the poor live in rural areas. Many of these people live in regions where financial and institutional resources and ill-adapted policies constrain agricultural and human development. In households responsibility for food security falls mainly on women, who receive insufficient attention in policymaking related to this basic need.

Relatively neglected during the green revolution in agriculture has been the role of water for healthy ecosystems. There are too many examples of fragmented, desiccated, and polluted rivers; endangered aquatic species; accumulations of agricultural chemicals; and loss and degradation of natural ecosystems (MEA 2005). Rapidly growing urban areas, burgeoning industries, and rising use of chemicals in agriculture have undermined the quality of many rivers, lakes, aquifers, and other ecosystems. Groundwater resources, an increasingly preferred source of agricultural and drinking water, are becoming polluted or are depleted to levels that make access difficult or uneconomical and unsustainable.

Ensuring equitable access to water and its benefits now and for future generations is a major challenge as scarcity and competition increase

The aim of the Comprehensive Assessment of Water Management in Agriculture

The outlook for the coming decades is that agriculture will require more water to meet the demands of growing populations. Ensuring equitable access to water and its benefits now and for future generations is a major challenge as scarcity and competition increase. With growing concern for the environment, some difficult choices will have to be made. Further tradeoffs cannot be avoided and will be politically contested. Choices about water use and management in agriculture will determine to a large extent whether societies reach the interlinked multiple goals of economic and social development and environmental sustainability as articulated in the Millennium Development Goals (table 1.1).

How should water be managed for agriculture in the future? World Water Vision, culminating in The Hague in 2000, produced the *Vision for Water and Nature* (IUCN 2000) and "A Vision for Water for Food and Rural Development" (van Hofwegen and Svendsen 2000). These two "visions" contain widely diverging views on the need to develop additional water resources for agriculture, on how society should use water, and on the benefits and costs of such developments. A major reason for the divergence? The difference in understanding of some basic premises, such as how effectively water is used for

table **1.1** **Relationship of water management in agriculture to the Millennium Development Goals**

Millennium Development Goal	Role of water management in agriculture
Goal 1 Eradicate extreme poverty and hunger	Increase agricultural production and productivity to keep up with rising demand and maintain affordable food prices for the poor; improve access to factors of production and markets for the rural poor.
Goal 3 Promote gender equality and empower women	Enhance equitable access to water and thus the ability to produce food.
Goal 4 Reduce child mortality	Contribute to better hygiene and diets, particularly through the appropriate use of marginal-quality water and the integration of multiple water-use approaches into new and existing agricultural water management systems, including domestic and productive functions.
Goal 5 Improve maternal health	
Goal 6 Combat HIV/AIDS, malaria, and other diseases.	
Goal 7 Ensure environmental sustainability	Integrate the principles of sustainable development into agricultural water development to reverse the loss of environmental resources.
Goal 8 Develop a global partnership for development	Involve the diverse range of practitioners, researchers, and decisionmakers in the preparation of water management actions.

poverty reduction, the extent of ecological impact, the contribution of groundwater, and the current use and future potential of rainfed agriculture. Both technical and institutional solutions are proposed, but uptake is difficult and potential impacts are under debate. Lacking is adequate knowledge of past impacts and a clear sense of the present situation of water use.

A major step toward creating more equitable and effective use of water in agriculture in developing countries is to take stock of how water is currently managed for agriculture and of the impacts of its use on food and environmental sustainability. To move forward we need to combine knowledge of what has worked and what has failed and who has benefited and who has not, with information on promising and less conventional approaches that may hold the key to future water management. And we need to identify the range of sources of potential increases in agricultural water productivity and the ways to realize them. The Comprehensive Assessment of Water Management in Agriculture was designed to come to grips with these issues on a practical level, provide a better understanding of approaches that are likely to succeed, and identify key gaps in knowledge.

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Key concepts

Water management in agriculture requires an interdisciplinary and integrated approach. The issues span numerous fields of inquiry and dimensions of livelihoods. Key concepts that are used repeatedly throughout the assessment are explained below.

Agricultural water sources and flows

The Comprehensive Assessment starts with rain as the ultimate source of water. This is different from the conventional view of water for agriculture, which focuses on withdrawals of water from surface sources (rivers, lakes) and groundwater sources for irrigation. Rainfall is partitioned into runoff, which contributes to river flow, and water stored temporarily within soils, which is converted to liquid vapor through evaporation and transpiration. We use concepts of *blue water* and *green water* to describe this complex of sources and flows. Blue water is water in rivers, groundwater aquifers, reservoirs, and lakes and is the main water source for irrigated agriculture. Green water refers to the soil moisture generated from rainfall that infiltrates the soil and is available for uptake by plants. It constitutes the main water resource in rainfed agriculture. Agricultural water management systems rely on several sources, including rainfall, groundwater, water withdrawals from surface water, and water that is used and then recycled.

Agricultural water management

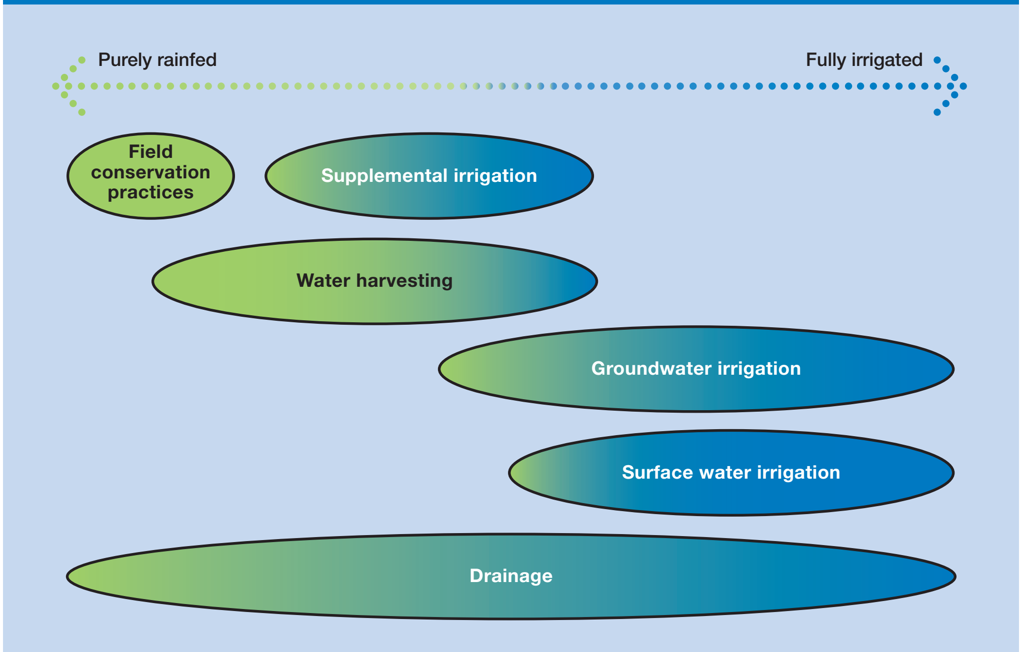
In agriculture, water is managed for the production of crops for food, fiber, fuel, and oils and for fisheries and livestock husbandry. In generating outputs, agricultural producers aim to meet their specific livelihood objectives. Water is only one input to production, and its relative importance and the way it is managed vary by agricultural system. The impacts of water uses for agriculture are far-reaching because water management draws heavily on natural and human resource bases.

The Comprehensive Assessment considers a range of agricultural water management systems. It assesses the increasing use of groundwater and marginal-quality water (saline, brackish, urban wastewater, irrigation drainage water) by smallholders for wealth generation. It also looks at the pressure imposed by the increasing use of water resources on livelihoods. It follows the flow of water from rain to the sea; how water is used and reused by cities, agriculture, and ecosystems; and how it is used and consumed by various uses and users.

There is a palette of water management options between purely rainfed and purely irrigated agriculture (figure 1.1). The Comprehensive Assessment considers farming systems that rely fully on rainfall, those that use supplemental irrigation in combination with rainfall, and those that rely fully on abstracting and transporting surface water or groundwater directly to the fields (irrigation).

These systems are categorized based on the relative reliance on green water sources (soil moisture) or blue water sources (groundwater, rivers, and lakes). Field conservation practices tend to conserve rain on the field, while both groundwater and surface water irrigation have critical blue water components. Toward the middle of the continuum—supplemental irrigation, water harvesting, and groundwater irrigation—is where some of the most interesting, but perhaps less explored solutions are found. These sources of water can be small or large scale, serving one or several people. Agricultural drainage (removal of water to create a favorable environment for agricultural production) is considered important for increasing productivity and sustainability for both rainfed and irrigated systems.

figure **1.1** **Agricultural water management: a continuum of practices**



Many rural poor people depend on livestock raising for their livelihood. Domestic animals provide meat, milk, hides, blood, cash income, farm power, and manure for fuel and soil nutrients (see chapter 13 on livestock). Like other agricultural activities, livestock raising requires large quantities of water. When livestock systems are poorly managed, they can contribute to degradation and contamination of land and water resources. Similarly, fishing is an important source of food and income for many poor people (see chapter 12 on inland fisheries). Nearly all inland waters support fisheries in one form or another, and fish production is one of the most basic services provided by these ecosystems. Thus fisheries and livestock are included in the water management palette of options.

Important dimensions of agricultural water management are:

- The scale and management of systems, and whether they are individually or communally managed.
- The institutional environment, including land and water rights, and policies toward infrastructure development, water allocation, and environmental protection.
- Payment for infrastructure, its operation and maintenance, and the water services provided, and whether these are from individual, private, community, or public funds.

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Livelihoods

The concept of livelihoods encompasses the various ways of living that meet individual, household, and community needs. The livelihoods approach to development places people at the center of development strategies by assessing the strengths and vulnerabilities of poor people in terms of five types of capital: human, social, natural, physical, and financial.

Achieving sustainable livelihoods is a means of supporting human well-being through measures to enhance human health, education, and opportunity and to ensure a healthy environment and a decent standard of living. The sustainability component of the livelihood approach is achieved by helping people build resilience to external shocks and stresses, maintain the long-term productivity of natural resources, move away from dependence on unsustainable outside support, and avoid undermining the livelihood options of others. Effective responses to livelihood issues generally emerge from policies and approaches that address the needs of individual groups or subgroups rather than those that view the poor as a homogeneous group. Appropriate responses can be developed by listening to poor people and involving them in the policy processes (Chambers and Conway 1991) and by emphasizing governance issues that can support livelihood outcomes.

Power balance, gender, social settings, and diversity

Roles, rights, and responsibilities of women and men are socially defined, culturally based, and reflected in formal and informal power structures that influence how management decisions are taken and that may favor or deprive certain groups. Agriculture, water management, and all other activities related to it have an impact on social interactions and structures. Therefore any change in water management or in production systems will affect the relations between men and women of different classes and age groups. Understanding social dynamics in water management in agriculture requires looking at the diverse forms of social differentiation such as gender, poverty, class, caste, religion, and ethnicity and analyzing them within their context of diversity. All of these aspects are interlinked and are equally important when working with communities.

Thus, practitioners, extension workers, scientists, and policymakers will always directly or indirectly affect these social relations when trying to guide or change management or production dynamics. Water management interventions, by taking these impacts into account, can be designed to strengthen, break, or adapt existing gender patterns and dynamics within the specific social, cultural, economic, technical, and productive contexts.

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Ecosystems and ecosystem services

An ecosystem is a functional unit consisting of all the living organisms (plants, animals, and microbes) in a given area and all the nonliving physical and chemical factors of their environment, linked together through nutrient cycling and energy flow. Ecosystems vary widely in size and type, but they always function as a unit. Ecosystem services are the benefits that people derive from ecosystems (see chapter 6 on ecosystems). The Millennium Ecosystem Assessment (MEA 2005) identifies four categories of sometimes overlapping services:

- *Provisioning services.* The products obtained from ecosystems, including food, freshwater, fuel, and genetic resources.
- *Regulating services.* The benefits derived from the regulation of ecosystem processes, including pollination, erosion control, storm protection, biological control, regulation of human diseases, climate and water regulation, and water purification and waste treatment.
- *Cultural services.* The nonmaterial benefits obtained from ecosystems, including cultural diversity and heritage, aesthetic values, and recreation and tourism.
- *Supporting services.* The services that are necessary for the production of all the other services, often with only indirect impact on people, including soil formation and retention, primary production, nutrient and water cycling, and provisioning of habitats.

Agricultural systems (agroecosystems) are ecosystems that are being modified by activities designed to favor agricultural production. The difference between an agroecosystem and other ecosystems is largely conceptual and based on a qualitative opinion about the degree of human intervention that favors agricultural production. The same does not necessarily hold for fisheries production, which tends to focus on wild catches, although in places fish stocking and habitat modifications have been used to increase catches and overall production. Aquaculture, the farming of fish and other animals, involves increased management of production through highly diverse extensive to intensive farming systems. Whether highly managed or not, many ecosystems contribute other valuable services that support food production, such as pollination, pest control, water storage, and soil formation.

Biodiversity. Biodiversity includes all ecosystems—managed or unmanaged—and the species and genetic resources that they support. Biodiversity is an encompassing concept that supports managed and unmanaged systems. Many managed systems have unique biodiversity associated with them. Such biodiversity is often maintained by human activities, in particular agriculture. Agriculture in turn depends on biodiversity, which supports ecosystem functions beyond the limits of the managed system itself.

Biodiversity is important for agriculture as a source of agricultural products, such as animal and plant genetic resources. It supports agriculture indirectly, such as by sustaining pollinators for agricultural crops, maintaining soil quality though soil biodiversity, and contributing to nutrient recycling and control of land erosion. It is important for sustaining water provision for agriculture (by maintaining the water cycle and condition of catchments). And it contributes to recycling and absorbing pollution caused by agriculture.

Agriculture also has a major impact on biodiversity, as it is the dominant human use of land, a major driver of biodiversity loss, and the major user of water. But it also relieves other stresses on the environment such as poverty and hunger. Consequently, agriculture plays a significant role in the improved management of biodiversity for the benefit of agriculture itself and also in providing substantial benefits beyond agriculture.

Agriculture has left a footprint on the environment that is reflected in changes in biodiversity. Reducing that footprint benefits other users of biodiversity and agriculture. Looking at how biodiversity responds to management therefore offers a tool to assist in planning for sustainable agriculture. Global agreements such as the Convention on Biological Diversity and the Ramsar Convention on Wetlands support the development process to conserve and sustainably use all forms of biodiversity, backed by commitments to significantly reduce the rate of biodiversity loss and an understanding that this is required to achieve human development targets (see www.biodiv.org).

As water becomes more scarce, output per unit of water—water productivity—becomes more relevant than output per unit area as the measure of agricultural productivity

Water productivity

The amount of output per unit area—such as yield in tons per hectare—is the most common measure of agricultural productivity. But as water becomes more scarce, considering the output per unit of water—water productivity—becomes more relevant (see chapter 7 on water productivity). We consider physical water productivity as the mass of agricultural output from crops, fish, or livestock products per unit of water. Economic water productivity is the value of output per unit of water, reflecting gross returns plus livelihood and ecosystem values, benefits, and costs. The unit of water is important and is expressed as either water delivered to a use (from rainwater plus withdrawals from blue water sources) or depleted by a use (by evaporation, transpiration, pollution, or flows to a sink where it cannot be reused).

River basins—open, closed, and closing

River basins are the geographic area contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body. Basins are an important unit of analysis in this assessment because water flows within a basin connect users and ecosystems. In many river basins use of water for human purposes through investments in water infrastructure for urban, industrial, and agricultural growth is approaching or exceeding limits, so that river discharges cannot meet downstream environmental needs (for example, environmental flows, flushing of salts or sediment) or allocation commitments during all or part of a year—a process of basin closure. Basins are "closed" when there is an overcommitment of water to human uses, and "closing" when the situation is approaching this condition.

The conceptual framework

The Comprehensive Assessment thus examines options for improving water management in a context of increasing tension between agriculture and ecosystems over conflicting requirements for water. Its aim is to reach the common goals embodied in the Millennium Development Goals: to use water and other resources to produce enough food for everyone and to do so in a way that is environmentally sustainable. The approach recognizes that water management lies within the sphere of agricultural systems and that that sphere is a part of the greater natural resource base that includes land, water, biodiversity, and people. The entire arrangement is embedded in a social and political context (figure 1.2).

> The Comprehensive Assessment framework considers dynamic interactions between agricultural systems, people, management, and life support systems across time and scales

The Comprehensive Assessment framework considers dynamic interactions between agricultural systems, people, management, and life support systems across time (50 years back and 50 years forward) and scales (from local to global levels). It relates drivers of change to agricultural water management and the evolution of agricultural systems and to their outcomes and impacts and goals. The framework provides a perspective on the interactions between these key components, but it is only a snapshot of the linkages; it cannot fully capture the importance of the social, cultural, political, and institutional dimensions of water management in agriculture and all their permutations in rural and local settings.

Drivers

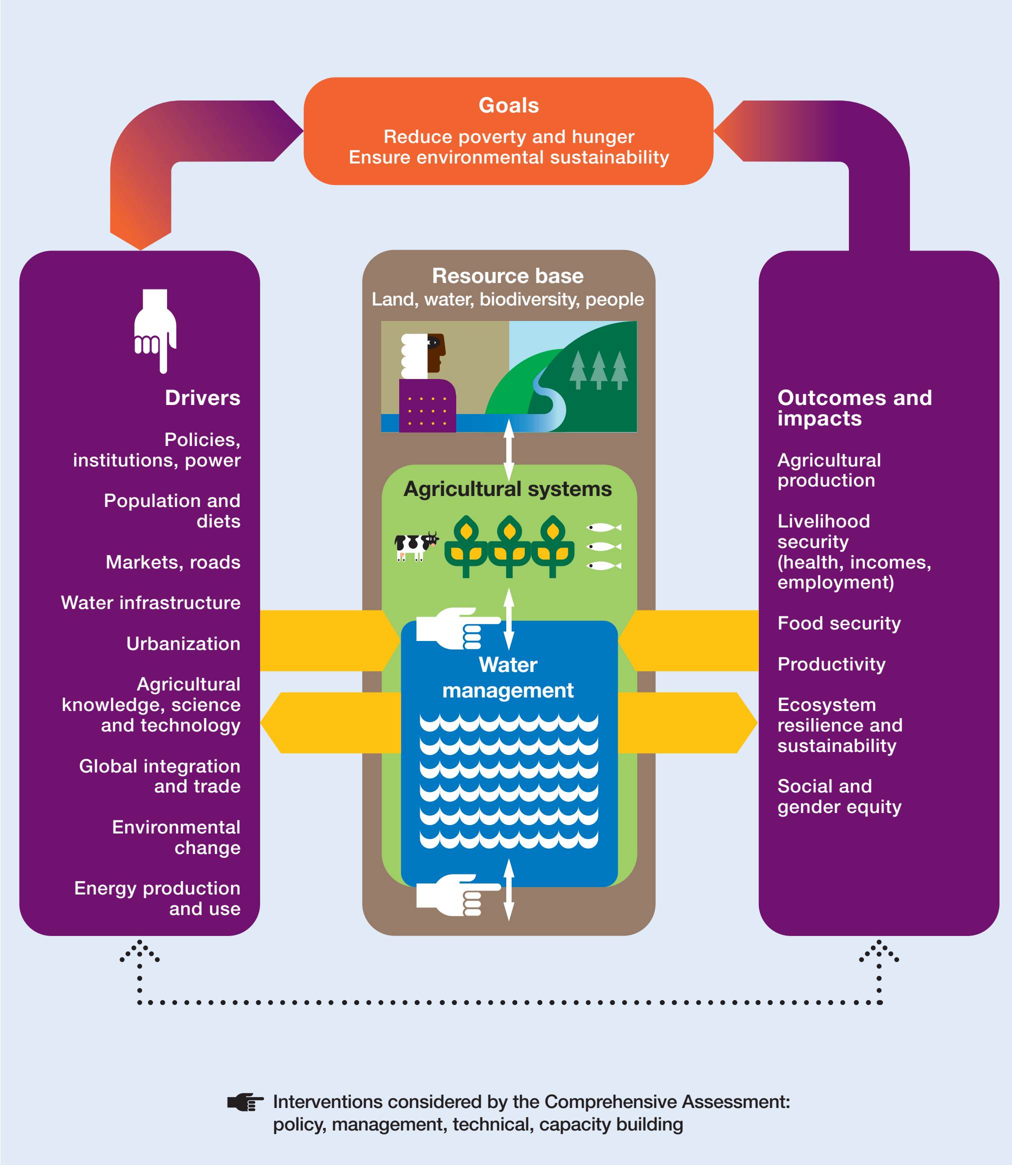
The Comprehensive Assessment recognizes that water management in agriculture does not operate in isolation. A complex, interlinked set of drivers has affected the evolution of agricultural systems, their water management, and their capacity to produce and will continue to do so over the next 50 years. Furthermore, these drivers will themselves undergo change over the coming decades. The Comprehensive Assessment has identified eight drivers as especially important to agricultural water management: policies, institutions, and power; population and diets; availability and access to markets; water storage, delivery, and drainage infrastructure; urbanization; agricultural knowledge, science, and technology; global integration and trade; environmental change; and energy production and use.

In some cases there will also be direct and indirect feedback loops, so that changes in water management will affect the dimensions, direction, rate, and impact of the drivers, which in turn will affect water management. Some drivers can be influenced this way, but many others are manifested only over decades or centuries, and their magnitude and rate of change cannot be influenced in the short term. Further, many of these drivers are influenced much more strongly by other processes, such as global political developments.

Outcomes and impacts

Agricultural water management contributes to the production of agricultural outputs, which in turn contribute to livelihoods through food and nutrition, health, income, and employment. Clearly, to meet the Millennium Development Goals it is important to consider the consequence of investments and management decisions for the various dimensions of the outcomes.

figure **1.2** **A conceptual framework for the Comprehensive Assessment of Water Management in Agriculture**



The types of outcomes and impacts that the Comprehensive Assessment considers include agricultural production, livelihood security (health, incomes, employment), food security, productivity, ecosystem resilience and sustainability, and social and gender equity.

Because agriculture manipulates the natural resource base, it affects ecosystems. Whether these outcomes are positive, negative, or mixed depends on what management choices are made. Some interventions could increase the amount of food within a country without improving food security for individuals. Many past interventions increased food production at the cost of environmental sustainability.

Different spatial and temporal scales

International, national, regional, and local levels have different stakeholders and actors, and intervention decisions are made at different levels, from those of individual farmers and their families and communities to those of international development banks. Interventions at one level can influence outcomes at others. Individuals and groups command different levels of power, wealth, influence, and ability to express their needs, concerns, and rights. Temporal and spatial connections across scales, both hydrologic and policy, require the engagement of multiple disciplines that can consider the dynamics within and across levels.

> Many past interventions increased food production at the cost of environmental sustainability

Various actors can change power and authority by working at different levels. They can alter access to resources and decisionmaking processes with respect to those resources. Scale choices can be a means of inclusion or exclusion of people from water management choices and benefits. Water management and agricultural development problems are often experienced and managed at a scale different from that corresponding to the jurisdiction of decisionmaking bodies. How water is managed on a farm or in an irrigation system can affect other users within a river basin. This can result in a mismatch between development, policies, and needs.

While strategies described as "local" can be associated with a clear objective, things get blurred as the scale gets larger. For example, increasing water supply locally through farm ponds, groundwater use, water harvesting, or small tanks may capture water that would have been used downstream. In certain circumstances such uses of water may be a more productive and sustainable alternative to larger reservoirs further downstream, so the picture is increasingly complex.

National interventions by governments and adjustments by local actors are also interrelated. For example, subsidies for adoption of microirrigation or soil conservation techniques are meant to foster local conservation by farmers, while farmers' use of groundwater will provoke national interventions or policy responses. Politics and social structures will have a direct bearing on the kinds of agricultural choices adopted by local actors and the kinds of water development actions at all levels.

At the global level sectoral and market linkages have spatial implications for basin agricultural production and water use. Relative or shifting factor prices, taxation or subsidies, migration, the World Trade Organization or other free trade agreements, and the evolution of world markets can have sweeping consequences.

Time also matters. Agricultural and water systems are the results of thousands of years of interventions and evolution. Some processes happen in a relatively short period—the application of water to crops—but others critical to sustainability may take years, such as the buildup of salinity or a drop in groundwater levels.

Interventions and response options

The Comprehensive Assessment considers the use and effectiveness of a range of interventions and options for responding to the need for sustainable water management in agriculture for poverty reduction and environmental sustainability. It considers the most important entry points for attaining these goals through three processes:

- Changing the way water is managed in agricultural systems (changes in technologies or management practices).
- Managing the interaction with the natural resource base and other ecosystems (withdrawals of water from the resource base, return flows of altered quality to the resource base).
- Influencing the relevant drivers through policies and institutional changes.

An effective strategy will involve a mix of interventions through all three entry points.

Interventions can be implemented through laws, regulations, incentives, structural investments, and enforcement schemes; partnerships and collaborations, including with civil society; information and knowledge sharing, including capacity building; and public, collective, and private actions. The choice of options will be greatly influenced by the temporal and physical scales, the uncertainty of outcomes, cultural contexts, gender and power relations, politics, and the implications for equity and tradeoffs. Institutions at different levels have different response options available to them, and special care is required to ensure policy coherence.

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Decisionmaking processes are value laden and combine political and technical elements to varying degrees. Management choices may be based on synergies or tradeoffs between goals and outcomes that may be in competition and that change the type, magnitude, and relative mix of services provided by agriculture and ecosystems.

Several pathways are possible, but which is just and sustainable? The use of scenarios

The future of agricultural water management is highly uncertain. First, there is insufficient information on the current state of agricultural systems and their driving forces, including the interconnectivity of different systems and the extent of adverse feedback from degraded ecosystems in the wider landscape. Second, even with exact information it is not possible to predict surprises and random events such as major disasters and the consequences of declining ecosystem resilience and increasing climate variability. Recurring floods and droughts have a major impact on agricultural water management, but there is relatively high uncertainty regarding the specifics of future climate change and resulting changes in the frequency of extreme events. Third, the future is unknown because it depends on decisions that have yet to be made. For example, will water or ecosystem services be priced? Will integrated water resources management be the guiding principle in future water decisions? How will declining ecosystem resilience affect agricultural systems?

Instead of trying to predict the most likely future, the Comprehensive Assessment uses a set of scenarios to explore possible futures based on different types of investment choices. Scenario analysis provides insights about how different drivers of change work by exploring the consequences of a range of investments.

The Comprehensive Assessment recognizes that solutions must address all of the issues of poverty, environment, and food security collectively. It also recognizes that trying to attain any one of these goals without simultaneously considering the other goals eventually leads to a worsening of the situation because the three are so closely linked. Thus, it is also necessary to identify and to try to minimize the negative effects that these components have on each other.

Uncertainty in the Comprehensive Assessment

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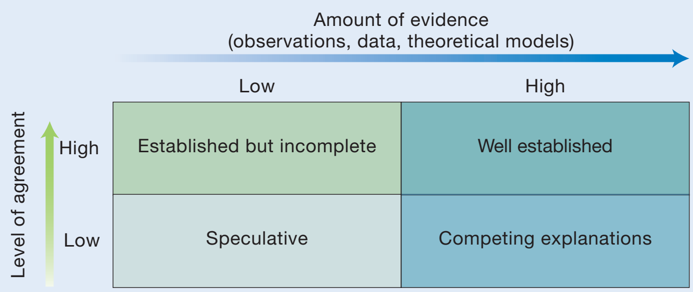
Given the need for synthesis and judgments on the veracity and uncertainty of evidence, the uncertainty associated with the conclusions and outcomes of the assessment has to be clearly labeled. This can be done quantitatively or qualitatively. The Intergovernmental Panel on Climate Change (IPCC) assessments that deal with the global climate system and that are based on models of the coupled atmosphere-ocean systems use a quantitative scale with a probabilistic outcome (IPCC 2001). This assessment uses a qualitative scale based on the scheme for judging uncertainty developed for the IPCC (Moss and Schneider 2000) and subsequently used in the Millennium Ecosystem Assessment. The scale is based on the amount of evidence and the extent of agreement within the scientific and expert community on that evidence (figure 1.3) and is used throughout the report.

Structure of the assessment

Part 2 of the Comprehensive Assessment synthesis volume begins by examining *trends* in water management in agriculture that have shaped thinking and influenced past interventions and investments. The volume then looks ahead to the future and discusses *scenarios* for water management in the context of a number of key drivers of water management in the future (see figure 1.2). Part 3 looks at the major cross-cutting issues that we consider crucial to all water management decisions and activities: *poverty*, *policies and institutions*, *ecosystems*, and *water productivity*. In part 4 thematic chapters capture the essence of current knowledge on major components of water management: *rainfed agriculture, irrigation, groundwater, marginal-quality water, inland fisheries, livestock, rice, land,* and *river basins.*

figure **1.3** **Qualitative scale of uncertainty**



Source: Adapted from Moss and Schneider 2000.

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