Chapter 4
Water as the Basis for Cultivated Ecosystems

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We're all downstream—Ecologists'motto, adopted by Margaret and Jim Drescher, Windhorse Farm, New Germany, Nova Scotia, Canada (Marq de Villiers 2000)

Abstract Water is the main constituent of all living organisms including humans; it is estimated that the human body contains 70% water. Water is a basic requirement for successful agricultural production to feed the world's population. Water availability is the key limiting factor among all factors that determine crop yield. Even though the earth is named a "water planet" that uniquely accommodates life, the usable water for agriculture is extremely limited. In addition, due to a lack of knowledge and awareness, we have abused the water both qualitatively and quantitatively leading to widespread soil water deficits and water contamination worldwide. Knowledge and action on water-related issues, especially as they relate to agroecosystems, are key to our future.

Learning Objectives

After studying this topic, students should be able to:

1. Explain the significance of water for people in relation to agroecosystems.
2. Describe the hydrologic cycle.
3. Describe how human activities are affecting the hydrologic cycle; use two examples of issues concerning modern agriculture and water to illustrate these impacts.
4. Explain the social and economic impacts of these activities.
5. Define and describe the major aspects of managing water in agroecosystems.

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4.1 Water Resources in the Global Ecosystem

Water covers about 71% of the Earth's surface; however, only 2.5% of the water on the Earth is freshwater. Most of the freshwater on the Earth is locked in glaciers or too deep in the ground to be used, leaving less than 1% of water on the Earth available for human consumption (Grey et al. 2013). Important freshwater resources, such as groundwater, would diminish within a short time period without replacement via the hydrologic (water) cycle (Table 4.1). The hydrologic cycle refers to the continuous movement of water throughout the Earth, purifying, recycling, and replenishing reservoirs (Fig. 4.1). Groundwater is often used for agricultural, commercial, and industrial and personal uses when the water flows to the surface naturally forming springs, seeps, oases, and wetlands (or into man-made wells).

Freshwater is the lifeblood of the Earth and forms the human drinking water supply. However, due to human abuse and contamination of our waterways, provision of safe drinking water has become a challenge worldwide; approximately 1.2 billion people do not have access to safe drinking water and over 10 million people dwelling in mega-cities throughout the developing world heavily depend on groundwater (Vörösmarty et al. 2015). While 500 million people live in water-scarce and water-stressed countries, even in locations where water is plentiful, many poor people cannot afford a safe supply of drinking water. According to the UN agenda for the third millennium, the deficit of fresh water for human society reached 230 billion m^3 in the year of 2000, and the number will increase to 1.3–2.0 trillion m^3/year by 2025. Moreover, frequent occurrences of prolonged droughts caused by global climate change and water scarcity by human abuse kill more than 24,000 people a year and have created millions of refugees since the 1970s.

The three main pressing water-related problems confronted by humans today are:

Table 4.1 Water in the global ecosystem (Dyck and Peschke 1995)

Reservoir	Area (km^2)	Volume (km^3)	% of all
Oceans	361,300,000	1,338,000,000	96.5000
Groundwater	134,800,000	23,400,000	1.7000
Soil water	82,000,000	16,500	0.0010
Ice and snow	16,227,500	24,364,100	1.7700
Freshwater lakes	1,236,400	91,000	0.0070
Salt water lakes	822,300	85,400	0.0060
Swamps	2,682,600	11,470	0.0008
River water		2120	0.0002
Water in biota		1120	0.0001
Water in atmosphere		12,900	0.0400

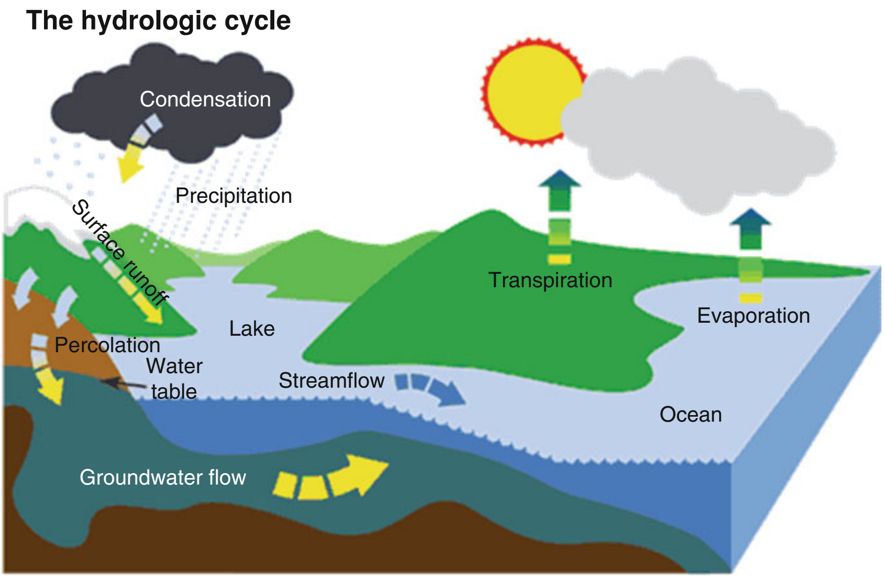

Fig. 4.1 The global water cycle (https://www.canada.ca/en/environment-climate-change/services/water-overview/basics/hydrologic-cycle.html)

1. Groundwater overexploitation. Over pursuit of economic development in the last decades both in developed and developing countries with expanse of more freshwater input usually led to overuse of groundwater, which in turn has caused water table imbalances, ecological and health issues. For example, to produce electrical power and reduce flooding, we build dams with powerful technology; these dams often increase the annual runoff available for human use, but also reduce downstream flow drastically and can prevent rivers from reaching the sea, thereby radically changing the region's entire ecosystem. Transferring water through tunnels, aqueducts, and underground pipes often draw groundwater faster than it can be renewed. These practices change the water table levels and create serious ecological and health disturbances in the ecosystem.
2. Water pollution. Worldwide water pollution occurs both on the surface and underground due to contamination by industrial wastes and overuse of agricultural chemicals. Water pollution refers to a physical, chemical, or biological change, from a point or nonpoint source pollutant that reduces water quality. Some major categories of water pollutants include oxygen-demanding wastes, inorganic chemicals, organic chemicals, plant nutrients such as nitrogen and phosphorus, radioactive material, and heat. Measuring biological oxygen demand or taking a chemical analysis can indicate pollutants from point sources. Once identified, point sources can be monitored and regulated. Unfortunately, it is more difficult to control nonpoint source pollutants. Lakes and ponds are quite vulnerable to pollution because they have little flow. However, flowing bodies of water such as streams may rapidly recover from pollution through dilution and bacterial

decay, so long as they are not inundated with contaminants. Laws concerning water-pollution control have significantly improved stream water quality in most developed countries, but political infrastructure in developing countries has not been able to enforce pollution control and stream water quality remains poor in those places. For example, in China, there is a serious water pollution issue with the paper-industry dumping toxic chemicals and waste in rivers. In 2004, one-third of factories lining the Huai River, which supplies one-sixth of the nation with drinking water, still did not meet waste dumping government standards. Many areas such as the Huai Lakes in southern China are facing this problem (Liu and Diamond 2005; Shao et al. 2006).

3. Inefficient water use (causing water cycle imbalance). Using water inefficiently is another major area of concern and only amplifies the problems to overexploit the land for more water. In the United States, the world's largest water user, nearly half of the water it withdraws is lost in some way. In China, especially in the west of the country, irrigation systems are unchanged from what was used 6000 years ago for a much smaller population.

Solving these problems will require an integrated approach to fixing each of these issue areas. The first step will require using water more efficiently. Redesigning national wateruse policies will provide incentives for water conservation and higher efficiency. Exploring more efficient irrigation system technologies for use in the world's croplands will also conserve water long term. A blue revolution will initiate and encourage more sustainable water management in the future. Improving water quality will be an important facet of sustainable water management, preventing pollutants from reaching the surface or groundwater.

4.2 Water in Agroecosystems

Agriculture uses the most freshwater of any industry sector, generally for irrigation. In fact, irrigation for agricultural purposes accounts for 80% of worldwide freshwater consumption (Liu and Song 2019). The need for irrigation is great; because water is often the limiting factor on production, worldwide; while irrigated farmland is only about one-sixth of the total farmland, it accounts for more than one-third of the global harvest (de Villiers 2000). Since the Green Revolution at the beginning of 1960, in some developing countries, irrigation takes up to 90% of the national water withdrawn; while slightly less water is used for irrigation in developed countries, it is still a significant proportion; for example, 30% of freshwater usage is for irrigation in the United States (Watson et al. 2014).

Irrigated water in agriculture gets used for growing crops, weed control, frost protection, and chemical applications. Usually, irrigated water comes from a higher percentage of surface water; however, in the USA, groundwater withdrawals for irrigation have persistently risen since the 1950s. Worldwide agriculture accounts for the largest water withdrawals and can be considered the major reason for water scarcity when water supplies cannot satisfy all demands (Sinha and Hyung 2008). But such practices cannot go on indefinitely; it damages the water ecosystem services including provision (e.g., drinking water after purification), regulation, and support services and the monetary cost of groundwater is increasing greatly. Most importantly, overexploitation of ground water unravels the hydrological cycle in agroecosystems, which does harm to agricultural production in short term and undermines the civilization in long term.

4.2.1 Water Cycle in Agroecosystems

Figure 4.2 shows a very general conceptualization, embracing most possible inputs and outputs to the water flows in an agroecosystem. Maintaining a healthy agroecosystem requires a balance among fluxes and balancing fluxes is quite complex. Agroecosystems, considered as parts of watershed ecosystems, can self-regenerate water resources via micro-cycles, which include multiple landscapes and biodiversity aggregations. Consider Fig. 4.3 which shows a micro-cycle of water. In these micro-cycles, rainfall water ("Yellow Stream") represents the basic water resource, partially assimilated by plants, partially evaporated at the water surface forming the "Green Stream" (65% of total). This is potentially very high-quality water without human interference, which is available for the next water cycle. The remaining water flow is called the "Blue Stream" (35% of total) and it flows to aquifers underground or runs off via the soil surface to rivers and the sea. This Blue Stream also has the possibility of intervention and exploitation by human activity outside the watershed (Figs. 4.3 and 4.4) (Rauba 2017).

Water cycles in agroecosystems are changing due to global warming, groundwater overuse and contamination and field temperature increases. Global warming is changing the water cycle routes in all ecosystems, including agroecosystems. Increasing CO_2 concentrations has globally and regionally changed the rainfall distribution in time and space. Rainfall (yellow stream in Figs. 6.3 and 6.4) has

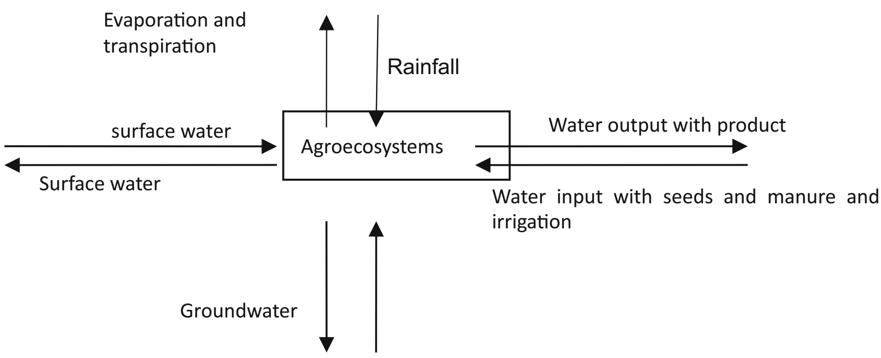

Fig. 4.2 The general pattern of water cycle in agroecosystems

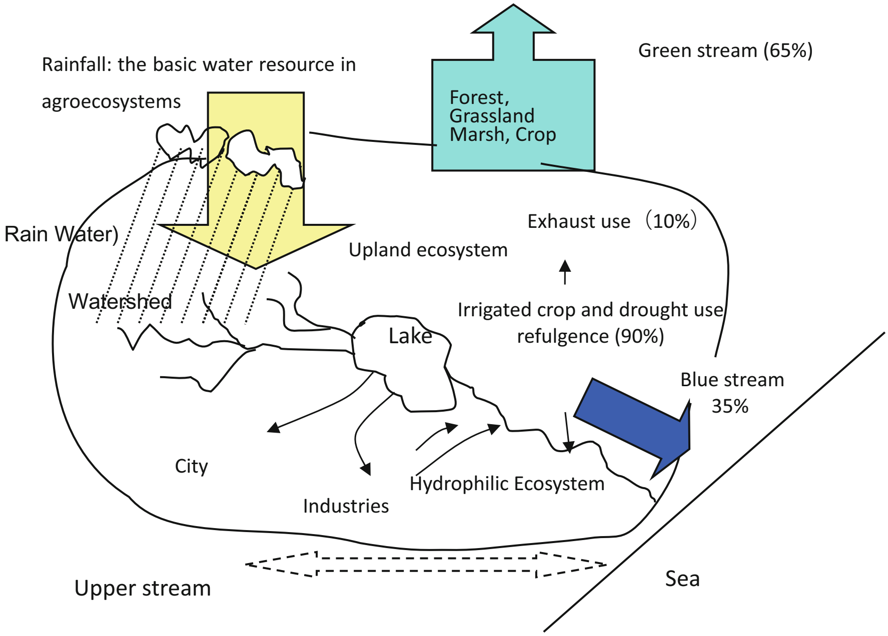

Fig. 4.3 Water cycle in agroecosystems (modified from Falkenmark and Rockström 2006)

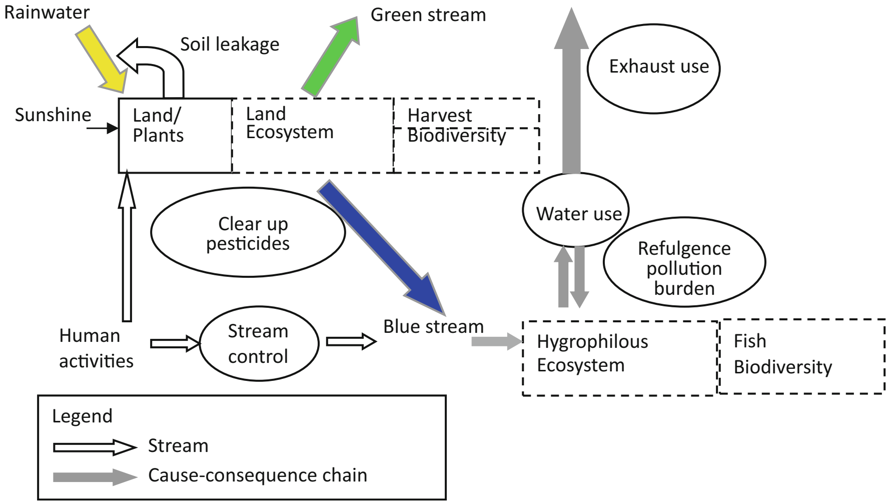

Fig. 4.4 The blue stream (surface water) with human intervention in agroecosystems. Human activities on the geomorphology change the blue stream directly by means of water controls in building and exhaust use of water, and indirectly by control of land and plants

become more variable and erratic, causing a greater incidence of droughts and flooding. In the meantime, industrialization and urbanization, especially in developing nations, has increased the acidity of rainwater, destroying water quality. Another characteristically changing aspect of the water cycle is groundwater overuse and pollution. Groundwater has been overdrawn and heavily contaminated, decreasing its availability to agroecosystems. Finally, increasing field temperatures have led to higher evaporation rates, which increase water loss in agroecosystems (Fig. 6.4).

Meteorologists have mapped the global flow of huge amounts of water in the atmosphere; these are essentially flying rivers that transfer large amounts of water throughout the globe. Both global activities that have affected climate change and local activities of deforestation have had large effects on these flying rivers. We now know that transpiration moves more water than all the rivers in the world combined.

Forests throughout the world influence the atmospheric water cycle in various ways. These interactions are complex and require more research to properly characterize them to be able to predict the effects of deforestation both locally and globally. We do know that the destruction of forest cover affects the water cycle. Increasingly, agriculture threatens forests and other diverse vegetation as we change natural ecosystems into managed ecosystems for food production. The potential consequences of large-scale forest loss are severe. A recent theory regarding these interactions of vegetative change suggests that large changes in landscape transpiration can exert a major influence over atmospheric dynamics. This theory explains how high rainfall can be maintained within those continental land-masses that are sufficiently forested (Sheil 2018).

A possible illustration on a micro-scale of this feedback mechanism may be playing out in Australia. Southwest Western Australia has experienced a decline in rainfall over the last 40 years. This is usually explained through natural variation and some effect of global warming; however, there is recent evidence to suggest that this decrease in rainfall may be substantially due to large-scale logging that has occurred close to the coastal areas. Models proposed by Andrich and Imberger (2013) show that between 55 and 60% of the decrease in rainfall is probably due to land clearing. This has disrupted the micro-water cycle in the region.

It is apparent both on a local and global level that disruption of large areas of vegetation are causing significant and, now, unpredictable changes in rainfall distribution and duration.

There are large parts of the globe that are being deforested in order to produce more food. It is now obvious that these terrestrial disruptions are causing significant changes to the water cycle both on a local and global level. These water cycle disruptions confound the overall effects of climate change and exacerbate the problems. In order to feel the world's population future, we need to find ways to maintain significant forest cover, at the same time improving efficiencies and productions on the lands that are under agricultural management.

4.2.2 Water Use Efficiency in Irrigated Agroecosystem

Agroecosystem water use efficiency (WUE) is defined as the ratio of crop carbon gain to actual water consumption. As the pressures on water use have become greater with increased water scarcity and water quality, irrigation for agricultural production has become more expensive both economically and environmentally. Plant breeders are working hard to improve the genetic basis for crop WUE but crop management is also key to optimizing this very important aspect of production. Water use efficiency on an agroecosystem scale is one of the indicators of agroecosystem sustainability.

Irrigation methods in North China have become a very hot issue due to the use of ancient and inefficient irrigation techniques. These techniques have not only resulted in low WUE but also been responsible for increases in drinking water deficit of a nearby city (Hubacek and Sun 2005). The reason is rooted in low-efficiency methods used by small-scale farmers with no opportunity to access new technology. In response, recently, small farmers in North China have built associations of water users; this has meant that groups of farmers have been able to access sustainable WUE-improving management technologies and techniques. This communal approach has resulted in significant progress (Hu et al. 2014; Wang et al. 2010) and is a model for other communities.

4.2.3 Social Aspects of Water from Agroecosystems

It is not enough to interpret water in our food-dependent agroecosystem just in geo-bio-chemical cycles within the discipline of ecology; water is a key component of the socioeconomic interactions of our society. As indicated in Fig. 4.5, human beings

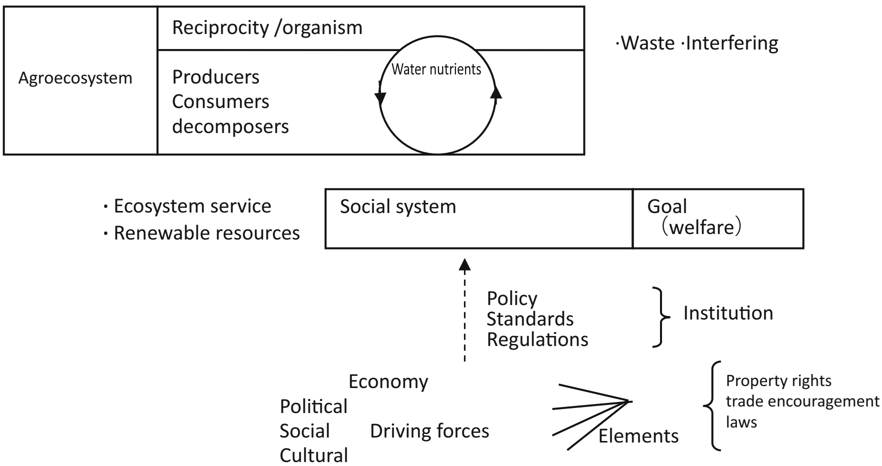

Fig. 4.5 Agroecosystem reliance on water to maintain its sustainability

rely on the acquisition of renewable resources (water) and ecosystem services on Earth. Activities that improve welfare are driven by social elements and are affected by the system. However, waste and human interfering affects the ecosystem functions generated in these activities. Human social systems act as subsystems of agroecosystems. Human activities are driven by demand for ecosystem services, including water. Society anticipates a sustainable supply of such services as water availability and purity because water in agroecosystems is both a basic human need and has a role in producing healthy food for sustaining human life. While agricultural water services are just one of the many crop production inputs, it is a critical input without which intensification and diversification of agricultural production would be impossible. In addition, water misuse elicits many negative effects on the natural cycle of water in agroecosystems thus threatening sustainability. In turn, this results in social deterioration such as hunger and poverty, disease and even political instability that exacerbates the natural degradation in water (Fig. 4.5). People are dependent upon water yet they tend to degrade that very resource upon which society is built.

Therefore, beyond the mere biological consideration of water, we need a framework of political policy informed by ecology to govern the use of water in building a sustainable food system.

4.3 Aspects of Water Management in Agroecosystems

Ecosystems naturally function as water purifiers; however, when precipitation falls on agricultural lands with altered hydrology, the water cleansing process is compromised. The intensified processes of fertilization, pesticide application, irrigation, and animal production only further stress the ecosystem and prevent it from working properly. Better management of agroecosystems to protect water supplies would include understanding quality control of soil, crop nutrients, pesticides, animal manures, and other residues, and incorporating principles of hydrology, plant cover, and stress maintenance. In the next sections, we propose a framework with five aspects for managing water in the agroecosystem.

4.3.1 Improving On-Farm Water Management

Managing root zone water application and procuring high productivity is contingent upon several factors such as soil fertility, cultivar selection, cropping density, disease and pest management, and post-harvest controls. With water restrictions on the post-harvest period of crop yield, efficient water management practices become critical. With technologies that schedule irrigation, biotechnology and geographic information systems, agricultural improvements can maximize the use of a limited water supply.

4.3.2 Improving the Performance of Irrigation System

Farmers need a reliable supply of water from irrigated systems to prepare crops in a timely manner and in the right volume. While these irrigation systems were initially designed to alleviate problems of food scarcity, poverty, and unemployment, now they benefit the farmers and communities alike. Irrigation management fulfills multiple objectives, from recharging local aquifers to maintaining shelterbelts and orchards to mitigating environmental externalities associated with waterlogging and salinity. Precision application of water on a timely basis is the key issue.

4.3.3 Using Non-conventional Waters

Increasing water supply through the reuse of drainage water has become a good option for arid, semi-arid areas, and water-scarce countries. The FAO (2007) has provided guidelines covering many aspects of water conservation at the field level, water reuse at the scheme level, and safe disposal and treatment of drainage effluent. Other non-conventional uses of water to increase supply include treating wastewater, saline water, and greywater to increase water use efficiency, reduce water losses and pollution, increase recycling and access to high-quality water for water-scarce countries.

Water harvesting refers to the process of capturing, collecting, and concentrating runoff and rainwater for an available resource. Water harvesting can ease pressure on existing available resources to supply crops with rain-fed irrigation water.

4.3.4 Recycling the Water

Using recycled and rain-fed water in agriculture will allow for the allotment of more raw water for other higher utility uses. These uses include municipal supplies, environmental reserves, and hydropower generation (FAO 2007). Addressing global water scarcity in the long run requires the emergence of new policies. These policies will rely on the pursuit of food security, investment in water-related activities, and relieving agricultural reliance on irrigation. Specifically, government expenditures will have to focus on irrigation, flood control, dams, and affiliated interventions.

4.3.5 Exploring Agroecology to Leverage Agroecosystem Water Governance

Global agriculture is facing growing challenges at the crossroad of food provision and other ecosystem services. Supply and water management in agroecosystems is in a nexus point for their tradeoffs, because at the same time needing precious water in ecosystems for food production, we sacrifice its other ecosystem services that also contribute to human welfare. Agroecology is a multidisciplinary and multiscale approach to the design and management of agricultural systems through scientific research, practice, and collective action. Under the umbrella of agroecology, we could explore Ecosystem Service as a water managerial tool to balance its provision and other services. In doing so, creating the mechanism for payment to providers of the ecosystem service of water is considered to be the first and imperative step (Ricart et al. 2019; Yousefi et al. 2017; Wang et al. 2016a, b).

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