CHAPTER 6

Irrigation to Transform Agriculture and Food Systems in Africa South of the Sahara

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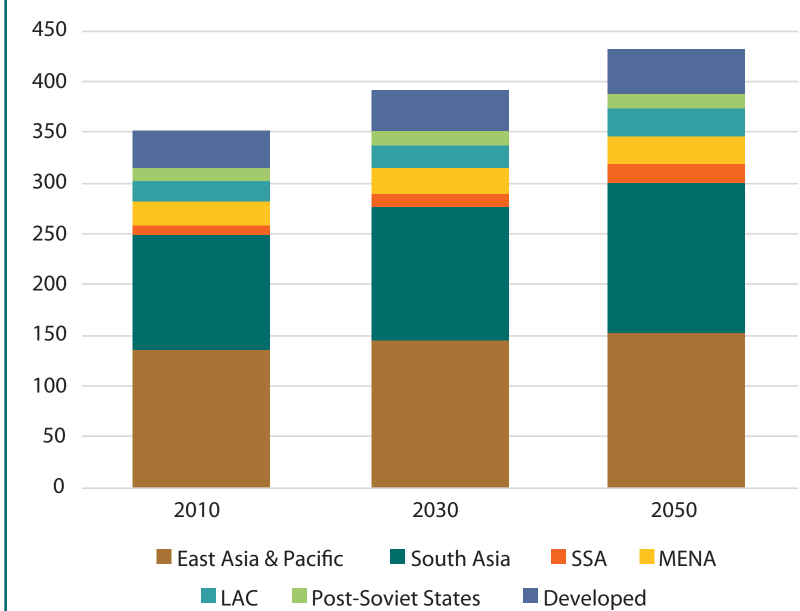
The contribution of irrigation to food security has been essential, and irrigated production currently accounts for 40 percent of global food production on less than a third of the world's harvested land. Irrigation will be even more essential for future food production because of climate change and associated variability in water availability (Rosegrant, Ringler, and Zhu 2009; Ringler 2017). Irrigated agriculture supports food production in dry seasons and in areas that receive too little rainfall to grow food, and increasingly supplements production in areas with less-certain rainfall regimes. Irrigated yields are generally 30–60 percent higher than yields of rainfed crops, as irrigation supports higher-yielding seeds and stimulates application of other inputs, such as fertilizers (Rosegrant, Ringler, and Zhu 2009). Irrigation accounts for approximately 70 percent of total global water withdrawals, including from groundwater, and for more than 80 percent of consumptive water use of withdrawn water (FAO 2016; Ringler 2017; WWAP 2019). Livestock watering and freshwater aquaculture are additional small, but growing agricultural water uses.

We differentiate between large-scale irrigation; community-managed systems; and small-scale, farmer-led irrigation systems. Large-scale irrigation systems are usually publicly constructed and are often continually supported by governments. They tend to focus on the production of staple crops, such as rice, or cash crops for export, such as cotton or sugarcane. We define small-scale irrigation here as an activity in which individual farmers, households, or small groups of farmers self-supply irrigation from different sources using a variety of technologies, either to supplement rainfall during the rainfed season or irrigate during the dry season, often for high-value crops such as vegetables and where the same source might be used for multiple purposes, including livestock watering or domestic uses. These systems generally lack formal governance over water sources. A third type of irrigation system is community-managed irrigation, where a larger group of farmers co-manages an irrigation system, generally with self-developed institutions for management.

While East and South Asia feature the world's largest irrigated areas, supported by many decades of public investment in the sector propelled by the Green Revolution, followed by the Middle East and North Africa regions, there has been little investment and thus little expansion of irrigated area in Africa south of the Sahara until recently (see Figure 6.1). This is due to a variety of reasons, including the relative abundance of land and lower dependence on water control for the region's main staple crops, compared to Asia; the overall lack of political will, as reflected in long-term weak support for agricultural research and development (IFPRI 2019); and the overall underdevelopment of rural infrastructure that enables market development and growth, such as roads and electricity (IEA 2019). Additionally, several of the larger irrigation schemes that have moved forward have focused on staple crops or the generation of foreign exchange rather than cost recovery and profitability, leading to underperformance based on pure economic criteria, which together with regulatory and other challenges has dampened private investor interest in the sector.

At the same time, irrigation would be of particular importance in Africa south of the Sahara in the context of efforts to meet a number of Sustainable Development Goals (SDGs), such as SDG 2 on zero hunger, SDG 6 on water and sanitation, SGD 7 on affordable and clean energy, and SDG 13 on climate action.

FIGURE 6.1—IRRIGATED HARVESTED AREAS, 2010 AND PROJECTED 2030 AND 2050 (IN MILLION HECTARES)



Source: IFPRI IMPACT modeling, 2018.

Note: Irrigated harvested areas reflect the harvest index, that is, how often a crop is harvested on the same (net) irrigated area. Both harvested irrigated area and net area have associated uncertainties linked to lack of data for many countries and differences in definitions in use; see, for example, Meier, Zabel, and Mauser (2018). MENA = Middle East and North Africa; SSA = Africa South of the Sahara; LAC= Latin America and Caribbean.

Irrigation, in fact, is key to agricultural intensification and transformation in Africa south of the Sahara, supporting food security, nutrition, rural incomes, employment, and economic growth goals. As irrigation also contributes to lower food prices, real net incomes of consumers increase; lower costs and increased scale of production boost the competitiveness of products for increased trade. Multiplier effects from increased nonfarm employment associated with irrigation in rural and urban areas are additional benefits from irrigation.

Irrigation has been identified as a key investment to end hunger by 2025 as part of the Malabo Declaration (AUC 2014). As a result, the African Union released a Framework for Irrigation Development and Agricultural Water Management in Africa in 2019 (see additional details below). Finally, the Comprehensive Africa Agriculture Development Programme (CAADP) recognizes the development of sustainable land management and reliable water control systems as one of the four pillars for transforming agriculture and ensuring sustainable economic development. Most of the 24 countries in Africa south of the Sahara that signed CAADP compacts with investment plans mention the need for irrigation development to achieve the envisioned food security and agricultural transformation goals, and the plans generally call for a variety of irrigation investments. CAADP members' commitment to substantially increase investment in agricultural and rural development could help cover some of the irrigation investment needs (Rosegrant, Ringler, and De Jong 2009). Similarly, many Nationally Determined Contributions in the region list irrigation development as a key climate adaptation strategy.

As in other regions of the world, irrigation has multiplier effects in Africa. Beyond its contribution to crop production and food security, irrigation has tempered the high net food import dependency in North Africa and can reduce the growing net food import dependency in Africa south of the Sahara as well. Xie et al. (2018), for example, found that accelerated irrigation investment can effectively reduce food import dependency, from 54 percent under a business-as-usual scenario to a much smaller 17–40 percent, depending on irrigation technology cost and other factors, and can also reduce the share of the population at risk of hunger and child undernutrition.

Additional potential benefits of irrigation include the production of more diverse, high-value, and nutrient-dense crops as well as irrigated fodder to intensify livestock systems, the generation of higher incomes, and the provision of water supply for domestic uses and sanitation. Irrigation can also increase women's empowerment if women own or can drive decisions on irrigation technologies and irrigated land or if their time spent fetching domestic water and engaging in agricultural activities declines as a result of irrigation (Domènech 2015; Passarelli et al. 2018). All these additional benefits can only be achieved if irrigation is developed with these goals in mind.

Table 6.1 presents selected irrigation indicators for the various agroecological

TABLE 6.1—IRRIGATION INDICATORS FOR AFRICA

	Total renewable water resources[a]	Irrigation withdrawals[b]	Harvested irrigated area[b]	Area equipped for irrigation[a]	Share of equipped irrigation potential realized[a]	Potential increase in area[c]	Total agricultural water management area[a]
	BCM/yr	*BCM/yr*	*000 ha*	*000 ha*	*%*	*000 ha*	*000 ha*
Northern Africa	103.3	79.3	8,698	6,340	85.4	1,769	7,333
Central Africa	2,856.9	1.0	58	128	0.9	1,625	139
Eastern Africa	337.0	12.1	769	621	11.0	3,450	2,788
Gulf of Guinea	1,110.6	8.8	372	576	7.8	10,005	8,003
Indian Ocean Islands	339.8	16.6	1,102	1,107	71.4	204	1,217
Southern Africa	449.3	15.3	2,076	2,063	48.1	3,655	2,407
Sudano-Sahelian	333.5	38.1	1,370	2,620	41.3	2,884	8,016
Africa South of the Sahara	**5,427.0**	**92.0**	**5,747**	**7,115**	**18.4**	**21,284**	**22,570**
Total Africa	**5,530.3**	**171.2**	**14,445**	**13,455**	**29.0**	**23,593**	**29,903**

Source: [a] FAO (2016); [b] Frenken and Gillet (2012); [c] You et al. (2011).

Note: BCM = billion cubic meters. Total agricultural water management area is the sum of total area equipped for irrigation, which covers key large-scale irrigation systems and some smaller systems, and areas with other forms of agricultural water management (nonequipped flood recession cropping area and nonequipped cultivated wetlands and inland valley bottoms). This aggregate includes some traditional small-scale irrigation. The latest available data point is taken; some of the most recent data points are from the 1980s, and not all countries have data. Irrigation withdrawals largely refer to areas equipped for irrigation.

zones of Africa. The region has a total estimated irrigation potential of 43 million hectares (FAO 2005); economic potential is largest for smaller irrigation systems that often draw from groundwater and therefore can cover larger areas far from surface water sources. Irrigated area has been evolving differently in northern Africa and Africa south of the Sahara. Given the arid and semiarid nature of northern Africa, irrigation has long been a key avenue for increasing food production and food security, and the subregion is host to 6.3 million hectares of area equipped for irrigation. Severe water resource constraints, reflected in the fact that 85 percent of the total potential for equipped area is already developed, have led to a slowdown in expansion, converting the focus toward efficiency, reuse, and productivity improvements. The region is generally characterized by large-scale public irrigation systems, but several countries also have a large number of small-scale operations. The only significant expansions in area have been linked to the exploitation of nonrenewable deep aquifers, such as the Nubian Sandstone Aquifer underlying parts of Libya, Chad, Egypt, and Sudan. While water resources for irrigation development are largely exhausted in North Africa, as the region is experiencing so-called hydrological water scarcity, irrigated harvested area in Africa south of the Sahara is projected to grow fastest globally. As growth in area starts from a small base and development is very costly, total development is expected to remain small compared to other regions of the world, due to "economic water scarcity," that is, water infrastructure development is constrained due to a lack of economic and financial resources (van Koppen 2003).

The agroecology in Africa south of the Sahara is much more varied, ranging from humid to semiarid and arid areas, with varying precipitation levels (see, for example, FAO 2005; Svendsen, Ewing, and Msangi 2009). In the past, large-scale development of public irrigation with surface infrastructure was largely limited to three countries: Madagascar, South Africa, and Sudan (which is sometimes counted as part of North Africa). With the availability and increasing affordability of individual motor pumps and well-drilling technology, small-scale irrigation took off in parts of Asia in the 1980s and, more recently, has been embraced in parts of Africa south of the Sahara as well (see, for example, You et al. 2011; Xie et al. 2014; Malabo Montpellier Panel 2018; and Nakawuka et al. 2018).

The Gulf of Guinea and the Sudano-Sahelian and East African areas show substantial differences between total agricultural water management area and area equipped for irrigation, suggesting that these regions are home to the largest seasonal (such as flood recession and valley bottom) irrigation systems (Svendsen, Ewing, and Msangi 2009). Compared with other regions, the central Africa region is relatively well supplied with water resources. Moreover, population density is somewhat lower in this region, and irrigation development has remained low.

The eastern Africa region has a particularly varied agroecology, including large areas in arid zones unusable for crop production and only marginally usable for livestock. While parts of this region, especially near the inland lakes, are relatively fertile and well endowed with water, many other parts exhibit a more fragile agroecology. Given the diverse climate and terrain, irrigation has played an important role in supporting the agricultural performance of cash crops in Ethiopia and Kenya, while the vast majority of the food crops grown in these countries are rainfed. Potential additional irrigated area is estimated at 3.5 million hectares; this includes the irrigation of fodder to overcome the seasonality of fodder availability and drive up livestock intensification (Getnet et al. 2016).

The Gulf of Guinea region is characterized by a considerable degree of climatic variation along the north-south axis of all the countries within this region—from the wet and tropical areas in the south to very dry areas, for example, in northern Ghana. Given this diversity, precipitation varies significantly between the north and the south, which makes country-level averages somewhat misleading when trying to gauge the extent to which agricultural areas are served by climate-driven water resources. Nigeria accounts for the majority of cultivated area in this region and has also been identified as the country with the largest irrigation potential in Africa south of the Sahara. A substantial share already falls under the FAO AQUASTAT category of water managed area. Total potential in this region is estimated at an additional 10 million hectares (You et al. 2011).

The Indian Ocean islands region is dominated by Madagascar, which features semiarid to tropical humid areas and thus a wide range of agricultural growing conditions. Irrigated area is substantial in this region, at 1 million hectares, and a further 0.2 million hectares can be added.

The southern Africa region features very dry areas as well as other regions with close to Mediterranean conditions, such as the Cape of Good Hope. The inland areas vary from scrub-desert terrain to more moderate environments at higher altitudes, as well as tropical and subtropical areas. Given the wide north-to-south transect of this region, there is a wide variety of precipitation and water availability, from the more humid areas in Malawi to the drier climate of Namibia. The agroecological conditions, and crop evapotranspiration, as a result, also see wide variation, from moist regions such as Mozambique, which has favorable areas for water-intensive crops such as sugarcane and other tropical agriculture, to other areas such as South Africa, where pastoral areas and dryland agriculture give way to irrigation of both cash and food-security crops. An additional 3.7 million hectares can be irrigated in this region.

The Sudano-Sahelian region includes largely hyperarid and arid countries, such as Mali, Niger, and Sudan, but also wetter areas such as South Sudan. In these countries, irrigation is key to food production, and irrigation has been long established in parts of this region, such as Sudan, and has been expanding over the last several decades in other areas, such as in Mali. The additional irrigation potential is 2.9 million hectares.

The Policy and Institutional Framework for Irrigation

While policy and institutions for irrigation are still nascent in most African countries, there are several Africa-wide irrigation visioning documents, and in 2019 the African Union developed a Framework for Irrigation Development and Agricultural Water Management (AWM) in Africa (AU 2020). The framework attempts to be a "blueprint to align and harmonize regional and national policies to accelerate agricultural growth through sustainable AWM practices," a "framework to reinvigorate interests, promote strategic thinking and redirect investments in sustainable AWM practices," and an "articulated continental guidance and vision on irrigation development and AWM" (AU 2020, 2).

The African Union irrigation framework covers the full spectrum of agricultural water management, including improved management of soil moisture in rainfed areas and watershed management, which are not addressed in this chapter, as well as farmer-led irrigation; large-scale irrigation modernization and rehabilitation; and wastewater reuse in agriculture. Specifically, the framework develops a series of pathways for irrigation that are aligned with the CAADP and Agenda 2063 objectives (see Box 6.1). Operationalization of the framework will be reflected in member state National Agricultural Investment Plans. While the framework includes important elements to strengthen irrigation on the continent, governance systems and specific irrigation policies will likely differ by country.

According to Svendsen, Ewing, and Msangi (2009), a country's institutional framework for irrigation specifies the location of investment planning and implementation responsibilities; designates the managing entity, or set of entities, for irrigation system operations; defines regulatory authorities; specifies revenue assessment and collection procedures; establishes dispute resolution processes; and assigns responsibility for allocating and protecting water rights. Svendsen, Ewing, and Msangi also summarize key principles that are supportive of irrigation development. These principles include (1) integrated water resources planning, (2) a closed financing loop, (3) beneficiaries sharing in the cost of irrigation development, (4) separating resources management functions from sector management, (5) involvement of women and men farmers in irrigation development and management, (6) organizing irrigation along hydrologic boundaries, and (7) secure water rights.

For irrigation policy and governance to be successful, various actors must be able to work together for seamless value chain development and profit generation and to ensure equity in and sustainability of water use. These actors include downstream water users, who need to have secure formal or informal water rights; a vibrant private sector and thriving markets that can provide inputs, including irrigation technology, and can absorb outputs; and a strong, highly qualified public sector that can ensure that water resources are managed sustainably and equitably.

Substantial reforms are needed in the area of water rights systems, as was recently described by Schreiner and van Koppen (2020), who noted that while statutory water laws with nationwide permit systems were introduced in several African countries in the 1990s, many of the permit systems are rooted in colonial thinking, widening inequalities in access to productive water use for millions of small-scale water users and irrigators on the continent. They suggest replacing these systems with a hybrid system that recognizes customary law while reserving permits for high-impact, large-scale commercial water users in order to increase equity in access to water for everyone. Bjornlund, van Rooyen, and Stirzaker (2017) propose the development of a business model for small-scale irrigation schemes that focuses on both input and output channels.

To secure investments for or improve the performance of large-scale irrigation systems, several countries have entered into or plan to enter into public-private partnerships for irrigation management. Examples include Dina Farm in Egypt, the Alaotra scheme in Madagascar, and Toula in Niger (World Bank 2007).

No detailed inventory of African irrigation institutions is available, but changes in some associated indicators, such as Integrated Water Resources

BOX 6.1—THE FRAMEWORK FOR IRRIGATION DEVELOPMENT AND AGRICULTURAL WATER MANAGEMENT IN AFRICA

Given the wide variation of biophysical and socioeconomic differences in Africa, the African Union developed four pathways that countries can select and combine to achieve the 2014 Malabo Declaration targets in the recently developed Framework for Irrigation Development and Agricultural Water Management in Africa (AU 2020). Seven cross-cutting themes need to be considered in relation to each pathway.

The pathways consider the full spectrum of agricultural water management, ranging from purely rainfed areas where farmers manage soil moisture through agronomic management practices to fully irrigated areas with advanced irrigation technologies, such as automated center pivot or drip systems (see also Box 6.2). The pathways are as follows:

1. Improved water control and watershed management in a rainfed environment
This pathway focuses on rainfed food grain areas where methods such as water harvesting and sustainable land-management practices, combined with a range of climate-smart agricultural practices, are implemented within watersheds to ensure optimal and sustainable use of water resources.

2. Farmer-led irrigation development
These include individual (private) irrigation systems for high-value crops as well as small groups of farmers jointly managing small irrigated areas. Irrigated areas tend to be small, often draw on groundwater resources, and focus on the production of horticultural crops.

3. Irrigation scheme development and modernization
These are often larger irrigation systems, funded publicly or through public-private partnerships, that require upgrading to increase market integration and need to increase cost recovery for the continued operation and maintenance of systems.

4. Wastewater recovery and reuse
Wastewater reuse is a common practice in peri-urban Africa. Rapid urbanization presents an opportunity to adopt wastewater reuse as an important alternative resource, but reuse is also associated with potential environmental and health impacts and thus requires strong management practices for standards and protection.

Cross-cutting themes:

1. Inclusiveness in irrigation development and agricultural water management
2. Private sector involvement
3. Climate change adaptation and resilience
4. Microcredit and farm financing mechanisms
5. Policies, institutions, and governance arrangements
6. Improving water and soil quality and other environmental problems
7. Research, monitoring, evaluation, and knowledge transfer

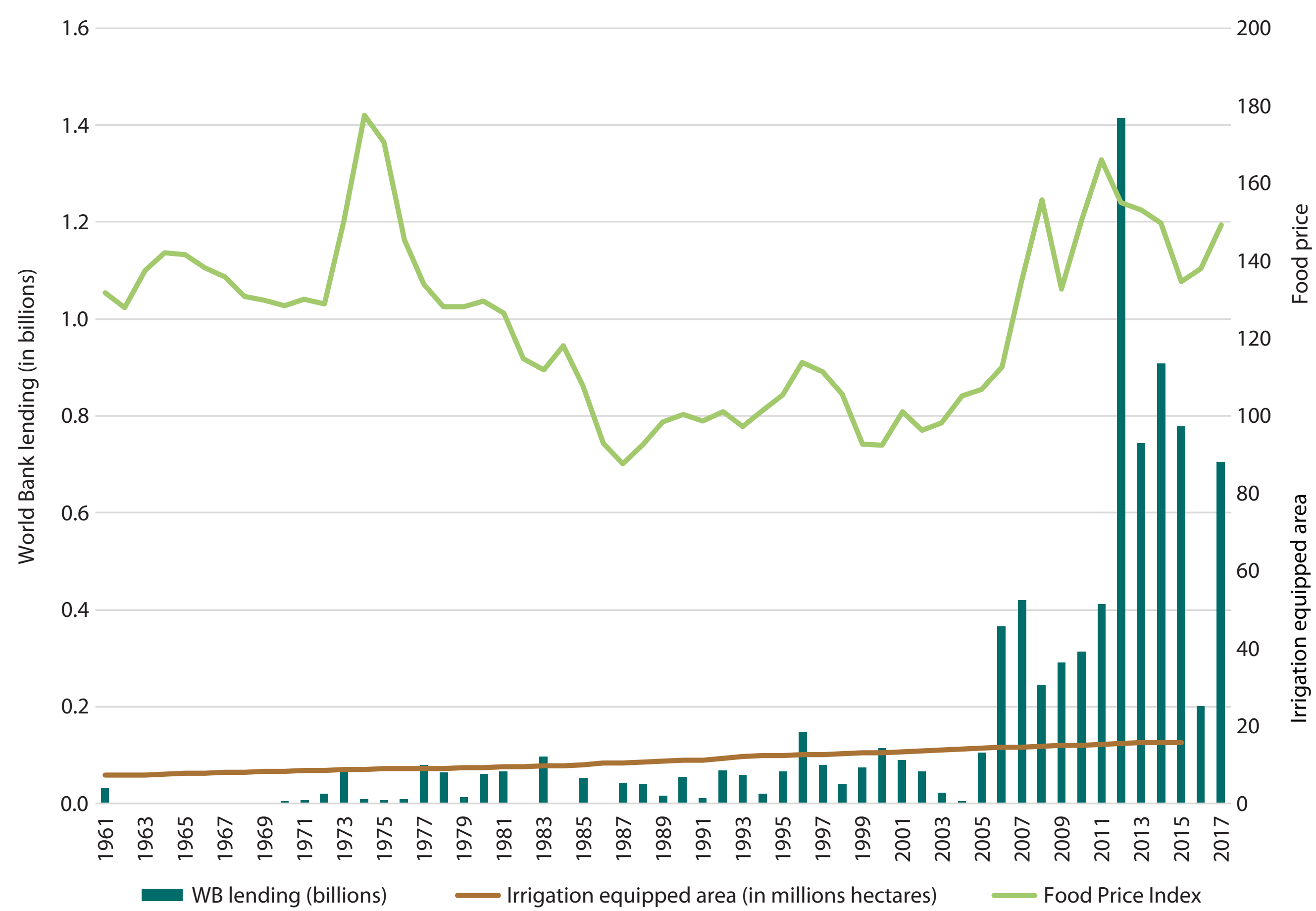
Management (IWRM), are now being collected as part of the SDGs. Specifically, SDG 6.5.1 on IWRM uses a questionnaire to assess the enabling environment, institutions and participation, management instruments, and financing for IWRM. In the first assessment of this indicator, Africa south of the Sahara was ranked as having achieved medium to low implementation of IWRM, ahead of Latin America and the Caribbean and the central and southern Asia region, with North Africa being yet further advanced.

Importantly, there is no blueprint or ideal set of irrigation water institutions. Instead, institutions need to be aligned with the specific development trajectory and biophysical and other characteristics of the country in question.

Recent Trends in Irrigation Expansion

The World Bank recently updated a graph on trends in irrigated area development and associated World Bank investments in Africa (Figure 6.2). The graph reflects the high variability in lending for large-scale irrigation investment on the continent. Unlike lending for irrigation development in Asia, a lending level above $0.2 billion in Africa was reached only in 2006, after which lending has increased considerably but not consistently. Other investors in large and medium-scale irrigation schemes include the Japan International Cooperation Agency, the African Development Bank, and the International Fund for Agricultural Development. But even taking all these investors together, medium- and large-scale irrigation development in Africa is unlikely to accelerate in the coming years. Instead, individual irrigation systems developed by farmers themselves have grown rapidly due to new technology, and this sector is now looking for increased support and recognition. You et al. (2011) estimate total irrigated area expansion potential for Africa over the next 50 years of 24

FIGURE 6.2—EVOLUTION OF AFRICA'S EQUIPPED IRRIGATED AREA, WORLD BANK LENDING, AND THE FOOD PRICE INDEX



Source: World Bank (unpublished).

BOX 6.2—AGRICULTURAL WATER MANAGEMENT IN AFRICA: A BROAD FIELD

Appropriate agricultural water management requires the use of a hydrologically grounded watershed lens. Water availability for irrigation and rainfed agriculture can be improved and variability reduced through judicious management of upstream watersheds, including reforestation and the maintenance of natural vegetation buffers, and the use of conservation agricultural practices (or abandonment of farming) on steep slopes in these important water generation areas. Ethiopia and Kenya are examples of countries that have invested or are heavily investing in upper or total watershed management.

Key technologies for rainfed water management include rainwater harvesting, conservation agriculture, minimum tillage, agroforestry practices and precision agricultural technologies that optimize soil moisture levels, and climate information systems. With increased climate variability and change, improving rainfed water management will become increasingly important but also increasingly challenging, risking the food and livelihood security of farmers relying on rainfed agriculture and requiring supportive extension and social security mechanisms.

In small-scale systems, individual water-lifting devices have advanced from shallow, hand-dug wells and manual water-lifting methods such as buckets to shallow and deep tubewell-supported solar irrigation pump technologies. Farmers tend to prefer solar irrigation technologies over more labor-intensive manual technologies and diesel and electric pumps where variable fuel or electricity costs can be high. However, solar-powered irrigation technologies can also contribute to water degradation and depletion. Like large-scale systems, small-scale irrigation additionally benefits from the use of water management tools such as wetting front detectors to avoid the over- or under-watering of crops and other precision agricultural technologies.

To improve water management, strengthen irrigation management transfer policies, and increase user participation, water user associations have been developed in several African countries for medium-scale and larger irrigation systems (see, for example, Yami 2013), in addition to the development of public-private partnership arrangements. Other systems have incorporated precision agricultural technologies, such as soil moisture sensors, or are providing irrigators with climate information (such as a pilot in the Gash River Basin in Sudan) (Amarnath et al. 2018). Other advanced irrigation technologies, such as drip and sprinkler technologies, can further increase crop production and on-field water use efficiencies regardless of scheme size but might also contribute to water depletion for downstream water users (Grafton et al. 2019). Ensuring collective action around agricultural water management is particularly challenging across large numbers of individual irrigators but can be supported by social and behavioral change interventions, such as experimental games (see, for example, Meinzen-Dick et al. 2018).

Increased investment in the development of machinery that improves profitability and labor productivity would support agricultural transformation, as would continued expansion of electricity access in rural areas, both directly for irrigation and for cold storage of irrigated produce and agro-processing (Borgstein, Mekonnen, and Wade 2020).

Innovation in these systems goes beyond more affordable precision irrigation systems and includes increased investment in agricultural research and development with a focus on crop varieties that are tolerant to drought, heat, submergence, and salt. Development of nutrient-use-efficient varieties with increased transpiration efficiency can also help transform water-stressed agricultural systems in Africa.

All these agricultural water management systems benefit from enhanced soil nutrient information as well as improved fertilizer and pest management to reduce water pollution, including salinization, nitrate pollution, and other forms of toxicity that increasingly reduce access to safe water for downstream agricultural and other uses.

million hectares, a 177 percent increase over the existing equipped irrigated area of 13 million hectares. Most of this area, 21 million hectares, would be in Africa south of the Sahara (Table 6.1). Some of this area is currently reflected in flood recession and valley bottom irrigation, but much would draw on new groundwater pumping, using diesel pumps and, increasingly, solar irrigation pumps.

The economic potential for expansion is critically dependent on the cost of irrigation, which includes the costs of the technology used, additional labor, increased agrochemical use, and better seed. Irrigation technology costs for small systems directly owned by individual farmers can range from several hundred to several thousand US dollars per hectare. As a result, small-scale irrigation is most viable for cash crops or high-value food crops that generate revenues in excess of US$2,000 per hectare. The potential for expanding small-scale irrigation by farmers for the irrigation of staple crops is limited. At the same time, public, large-scale systems can cost US$3,000 to US$8,000 per hectare or more if dams, roads, electricity, and agro-processing infrastructure are constructed as part of the irrigation system. Such systems are generally justified by reductions in food import dependency for key staple crops or by earnings of foreign exchange from cash crops, such as cotton, tobacco and sugarcane. These systems also often provide additional services, such as domestic water supply and employment opportunities in associated agro-processing (Rosegrant, Ringler, and De Jong 2009).

Given the slow development and lower cost-effectiveness of large-scale irrigation projects, much effort in Africa south of the Sahara has been placed on analyzing the potential and ways to accelerate small-scale irrigation investment. Moreover, several development partners, including the Bill & Melinda Gates Foundation, USAID, the Alliance for a Green Revolution in Africa, and the World Bank have recognized and are starting to support expansion of this sector.

While this chapter focuses specifically on irrigation, Box 6.2 describes a broader range of water management interventions and practices, ranging from fully rainfed agriculture to intensive, high-tech irrigation. In between are practices such as conservation agriculture, water harvesting, and supplementary irrigation (during the rainy season).

Key Concerns for Future Irrigation Development: Equity and Sustainability

Equity Concerns

All types of irrigation are associated with equity concerns. Even with rapid irrigation development over the next two decades, irrigation will remain out of reach for most poor farmers (Lefore et al. 2019). The key reason for this is that water resources are limited and most resources are costly to develop. Construction of roads to transport farm inputs as well as move irrigated products to markets is a typical cost component of African large-scale irrigation systems. The need to construct rural roads, electricity systems, and sometimes storage systems makes large-scale irrigation particularly expensive in Africa south of the Sahara. More remote rainfed or small-scale irrigated areas lack such roads. Large-scale systems also face gender equity challenges. Water user associations are often limited to land title holders in irrigated areas and thus to men. When women do participate in associations or have decision-making roles in irrigation, they sometimes behave more altruistically, reducing their own income (see, for example, Lecoutere, D'Exelle, and Van Campenhout 2015).

If water resources are available, or can be developed through storage or another form of harnessing precipitation or drawn from aquifers, then irrigation technologies will be needed to transfer water from the source to the crop field. However, preferred irrigation technologies such as diesel or solar pumps remain out of reach for the poorest farmers, and women farmers face additional challenges in obtaining information on irrigation technologies and securing collateral to finance the technology and benefit from it. The increased labor requirements of irrigation (compared to not growing a crop in the dry season) also pose disadvantages, particularly for women.

In the small-scale irrigation sector, women tend to use manual irrigation methods, while men use more advanced technologies such as sprinklers and drip kits. In addition, regardless of the system, women have less time available for irrigation activities. This is a particular challenge in individual irrigation, as it limits women's options for irrigating larger areas, particularly if access to advanced irrigation technologies is limited (Lefore et al. 2019; Theis et al. 2018) (see also Box 6.5).

Underdeveloped technology supply chains also hamper progress: private-sector irrigation equipment suppliers have a limited presence in most developing countries and do not target remote areas or smallholder farmers. Finally, women

BOX 6.3—SOLAR IRRIGATION IN SOUTHERN AFRICA: FROM THE FRYING PAN INTO THE FIRE?

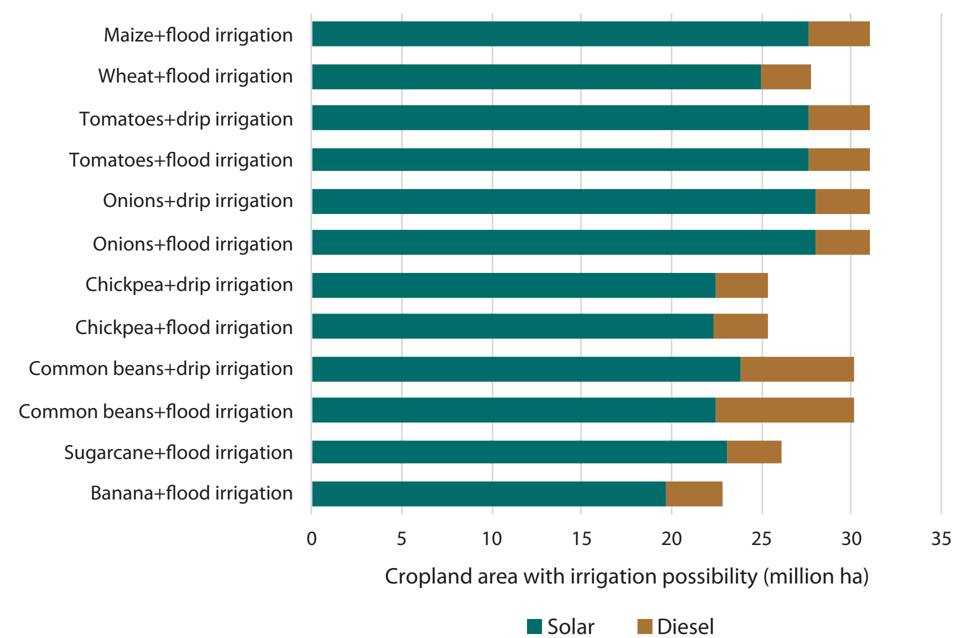
Southern Africa has ample capacity to expand solar systems for various purposes, including electricity generation but also solar-powered irrigation. Using renewable energy, solar-powered irrigation systems can offer reliable, relatively low-cost clean energy alternatives to the more commonly found diesel pumps. Solar pumps run with daylight and require limited maintenance, and high-quality solar photovoltaic pumping systems have a lifespan of 20 to 30 years (including the power unit and pump itself). The cost-effectiveness of solar pumping systems depends on many factors, such as diesel fuel costs and the installed costs of solar pumping systems, and may vary spatially (Malabo Montpellier Panel 2018).

Xie, Ringler, and Mondal (under review) compared the cost-effectiveness of groundwater pumping for irrigation for solar photovoltaic and diesel generators. Specifically, the authors compared costs under a range of crop and irrigation methods. A key factor determining the final results is the diesel price in southern African countries. At a breakeven point of US$2 per watt peak, solar is the preferred solution for more than 80 percent of all crops and irrigation systems considered (see Box 6.3, Figure 1).

While fuel prices add an element of variable cost into irrigation pumping, this cost falls away with the switch to solar irrigation. Solar irrigation thus risks the overdrafting of groundwater resources in southern Africa, a region that is already highly water stressed and was in the news not too long ago for water shortages in Cape Town. Groundwater depletion as a result of "free" energy has been observed at large scale in parts of India, where, among other factors, electricity costs for groundwater pumping were removed.

Addressing this challenge will require sustainable groundwater management to balance supply and demand. Supply-side measures may include artificial recharge, aquifer recovery, or the development of alternative surface water sources, while demand-side measures generally focus on water use rights and permits, collective management, water pricing, legal and regulatory control, and water-saving crops and appropriate technologies. Once groundwater depletion becomes serious, halting expansion of irrigated crop areas and changing crop varieties might be the only options.

FIGURE 6.3—COST-EFFECTIVENESS OF SOLAR VERSUS DIESEL PUMPING IN SOUTHERN AFRICA



Source: Xie, Ringler, and Mondal (under review).

are often excluded from access to information and training, from extension services, and from decision making, all of which reduce their ability and incentives to invest in irrigation technologies.

Environmental Concerns

If not managed and governed within the context of the wider landscape and other water users' needs, accelerated investments in smallholder irrigation could pose significant risks to environmental and human health. Sustainable development has already been exhausted in much of northern Africa and parts of southern Africa (Altchenko and Villholth 2015; Table 6.1 (FAO 2016)).

The emerging spread of affordable solar-pump technologies in Africa may enable access to irrigation in the more than two-thirds of Africa's rural areas that are not yet linked to the electric grid, but this increased use could also lead to much more rapid drawdown of groundwater resources as well as to depletion of associated surface water resources and aquatic biodiversity (Box 6.3).

Current projections out to 2050 suggest that Africa will experience the world's fastest increase in agricultural water pollution, particularly nitrogen and phosphorous pollution, albeit from low levels (Xie and Ringler 2017), with agricultural intensification spurred by irrigation as a key contributor to this trend. Inappropriate use of chemicals for fertilizer and pest management is not uncommon, despite many farmers' limited access to such inputs. Some pesticides in use by small-scale farmers, including persistent organic pollutants that remain toxic in the food chain long after use (Pretty 2018; Teklu et al. 2016), also pose a high risk to aquatic organisms. Currently, many countries in the region lack national guidelines on allowable levels of agrochemicals in water sources, as well as the technical facilities and experts required for testing and the institutional mechanisms to regulate, monitor, and enforce standards. There is currently no long-term agricultural water quality monitoring in the public domain in Africa south of the Sahara.

According to Lefore et al. (2019), the lack of rural institutions to manage natural resources collectively, including groundwater and surface water, will further restrict access by the resource-poor and will likely contribute to serious environmental degradation in some places. While farmers in some areas do manage irrigation water sources in collective systems, such as in Tanzania and Malawi, few such instances are documented, and potential for expansion is likely limited (de Bont et al. 2018). Moreover, most countries in Africa south of the Sahara lack effective institutions for water governance from local to watershed levels. While many places have traditional systems in place, these may not be well suited to address new and emerging environmental challenges such as water pollution and groundwater depletion that are complex and costly to measure and monitor, and whose solutions are difficult to enforce for the same reasons. The capacity of such institutions needs to be strengthened and big data and other tools need to be used to enable simplified yet robust measurement and monitoring. In addition, community involvement in managing water scarcity during drought or when groundwater tables decline has yet to be developed in many places (Nigussie et al. 2018; Stein et al. 2011). At higher levels of governance, absent or ineffective institutions and regulatory mechanisms deepen the threats posed by a rapid increase in irrigated production. This trend may continue in the medium to long term as natural resources become increasingly valuable, and therefore contested.

The Way Forward for Sustainable, Nutrition- and Gender-Sensitive Irrigation Development in the Region

Measure and Monitor Irrigation and Pollution

As this chapter has shown, information on irrigation development (quantity of water used) remains extremely limited in Africa, particularly in Africa south of the Sahara. It is challenging to support irrigation to become an engine of agricultural transformation without sufficient information on the location, size, and management of the many small-scale, communal, and public irrigation systems in Africa. New remote sensing and crowdsourcing tools should be used to help governments measure and monitor irrigation. A particular challenge in measuring and monitoring irrigation relates to groundwater irrigation, which tends to be more dispersed and often without basic information on aquifer size. Finally, with water pollution rapidly increasing in Africa, it will be essential to develop long-term agricultural water pollution-management systems that are in the public domain as well as to improve precision agricultural technologies for crops under all types of irrigation systems to reduce environmental degradation and pollution.

Accelerate Irrigation Development through Linkage with Energy

Energy use in agriculture has only recently increased in Africa south of the Sahara. Irrigation development, particularly from groundwater resources which represent the largest source for irrigation development in the region, requires concurrent investment in clean and affordable energy. Xie et al. (2014) estimate that Africa south of the Sahara has the potential to profitably irrigate 30 million hectares of land using motor pumps. So far, groundwater pumping has tended to rely on diesel pumps, which have high variable costs as well as adverse impacts on the environment (Box 6.4). As solar panels become more affordable over time, solar photovoltaic technologies, with their low carbon footprint, have been identified as high-potential solutions for rural electrification as well as water extraction for both domestic and irrigation purposes in Africa south of the Sahara (Schmitter et al. 2018).

Strengthen Water and Related Institutions to Support Sustainable Irrigation Development

While a growing number of irrigation frameworks and policies have been developed, including the recent African Union irrigation framework, national and local water institutions are often weak and not attuned to emerging challenges, such as those involved in supporting and regulating many thousand

BOX 6.4—MAKING A LIVING AS AN IRRIGATOR IN ETHIOPIA

Abera Tesfaye (name changed) is a 28-year-old farmer who rented 2 hectares of land to produce irrigated tomatoes around Lake Koka, in the Rift Valley of Ethiopia. He uses groundwater, taking advantage of the high groundwater table due to the nearby lake. He uses a small diesel pump (purchased at a cost of US$500) to lift water from the ground and uses furrow irrigation to apply water in the field. It takes Abera two days and 75 liters of diesel to fully irrigate his farm. A liter of diesel costs him 22 birr (US$0.70), or a total of US$53 for one irrigation. For a one-month-old tomato plant, he needs to irrigate twice a week, which amounts to a fuel cost of US$424 per month. However, water requirements almost double at two months, and so does the fuel cost. Over the growing season, Abera spends more than US$1,000 on irrigation, which is more than US$300 above the average income in Ethiopia (US$767 in 2019). Abera currently uses two diesel pumps on his farm; two other pumps broke without anyone being able to repair them. And this does not even consider the costs of other crop inputs, such as labor, fertilizer, and pesticides. Plant diseases and price uncertainties are further challenges for small irrigators that are difficult to overcome.

The arrival of solar and electric motor pumps, however, can change the economics of groundwater irrigation in Africa and can enable farmers like Abera to expand the area they irrigate and attract more farmers to irrigation. Borgstein, Mekonnen, and Wade (2020) recently estimated a daily energy requirement of 0.45 kilowatt-hours to irrigate 0.4 hectares of land using an electric pump in Ethiopia. Using an estimated general tariff rate of 2.124 birr per kilowatt-hour and additional service charges by the utility, with five days of irrigation per week, the total energy cost per month would be less than US$7, about a tenth of what Abera pays for diesel to irrigate a similarly sized piece of land. The cost of energy is further reduced with solar pumps. The key constraint for African farmers not to adopt these technologies is the up-front capital expenditure to purchase such pumps. As the cost of these solar and electric pumps decreases, the recent boom in small-scale irrigation in Africa should flourish further. For this to happen, however, there is a need for intentional programmatic support in extension services, improved supply chains of equipment, enhanced value chain infrastructure, and enabling financial mechanisms (Borgstein, Mekonnen, and Wade 2020).

Image source: Dawit Mekonnen.

individual irrigators, governing groundwater resources, or addressing water pollution. It is important that the public sector invest in these capacities to ensure that irrigation can accelerate the agricultural transformation on the continent.

In particular, the sustainable and profitable development of small and larger solar-powered groundwater irrigation systems requires high-resolution spatial understanding of the potential for shallow groundwater and access to low-cost solar pumps, even in remote areas, as well as access to financing mechanisms and loan products that are flexible in their collateral requirements and repayment schedules, reflect local cultures and are accessible to women farmers. Many other measures needed for agricultural intensification and transformation highlighted in this volume can also support the sustainability of irrigation, such as secure land tenure, appropriate near-term climate information, and the use of precision agricultural tools.

Strengthen the Benefits Gained from Irrigation

Irrigation, regardless of the type of system, can enhance household dietary diversity and the nutritional status of women and children, in addition to its role in increasing productivity, yields, and farm incomes (see Domènech 2015; Passarelli et al. 2018; Mekonnen et al. 2019; Baye et al. 2019). However, the potential for nutrition impacts is particularly significant for small-scale irrigation. To the extent that irrigation can be found to improve nutrition, it should be promoted based on its ability to improve the nutritional status of households, women, and children, and not only as a yield-improving agricultural intervention. To achieve this nutrition impact, a series of measures need to be undertaken during the design of irrigation investments, including (1) maintenance and improvement of the natural resource base underlying water and land management; (2) incorporation of nutritional considerations into the design of projects; (3) engagement of cooperatives, agricultural extension services, and water user associations on nutrition and dietary considerations; (4) leveraging of community platforms to deliver nutrition messaging; (5) empowerment of women in irrigation interventions; (6) promotion of nutrient-dense crops and incorporation of home-gardening components into irrigation projects; (7) design of formal multiple-use water systems that are culturally appropriate and safe; and (8) mainstreaming of irrigation into community-based platforms for rural service delivery (Bryan, Chase, and Schulte 2019).

Enable Irrigation for All

For irrigation to become available to a larger number of farmers, technology costs need to continue to decline, while other rural infrastructure such as electricity, rural roads, and markets needs to continue to improve. For long-term equity, stronger public sector support will be needed to ensure formal

BOX 6.5—WOMEN, WATER, AND IRRIGATION

According to Theis et al. (2018), increasing the equity and inclusivity of irrigation will require advances in four areas of the irrigation development cycle:

1. **Design.** Women's preferences regarding the design of irrigated areas often differ from those of men. These preferences relate to the location or portability of irrigation technology, its suitability for multiple uses (drinking water, irrigation, livestock watering), associated labor requirements, the social acceptability of use, and up-front and operational costs.

2. **Dissemination.** There is evidence that traditional channels providing information about irrigation technology do not reach women farmers. Channels that can effectively reach women and thus support adoption and use of irrigation technology include women community leaders, savings groups, frontline health workers, and women-led farmer and producer groups.

3. **Adoption.** Women face a long list of constraints to the adoption of irrigation technologies. They include lack of or limited access to irrigable land, water, labor, credit, and markets to buy inputs and sell irrigated produce. Additionally, women often need their husbands' consent to purchase technologies, including irrigation technologies.

4. **Use.** Ownership of irrigation technology by women does not guarantee access, and use can also be influenced by differential workloads, power to decide the plots on which to use the technology, and differential control over the income from irrigated produce.

or informal water rights and to regulate water use and address water pollution. Importantly, the total irrigation potential in Africa remains limited, particularly in arid and semiarid regions of the continent, and only a limited share of farmers will eventually benefit from irrigation.

Irrigation can be associated with women's empowerment to the extent that it is accompanied by interventions that enable women's capacity to make decisions on what crops to produce, where to sell the produce, and how to use the increased farm revenues from irrigation. Shifts from irrigation using buckets and watering cans to improved water-lifting technologies such as motorized pumps reduce drudgery and the amount of time women spend on irrigation. In larger systems, quotas and other ways to ensure equitable representation of farmers in decision-making bodies will be essential to ensure that irrigation benefits and empowers all farmers. Theis et al. (2018) describe steps that need to be undertaken to increase the gender sensitivity of irrigation initiatives (Box 6.5).

The ability of irrigation to support agricultural transformation in Africa will thus require a focus on clean energy, combined with good governance, a focus on nutrition sensitivity, and a focus on women's empowerment. Only then will agricultural systems be able to transform to support improved livelihoods and sustainable and equitable rural growth in the region.