Handbook for Scaling Irrigation Systems

International Finance Corporation
The International Fund for Agricultural Development

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Acknowledgments

Richard Colback from the International Finance Corporation (IFC) and Tarek Kolb from the International Fund for Agricultural Development (IFAD) led preparation of this joint IFAD–IFC handbook, with significant input from Audrey Nepveu de Villemarceau (IFAD) and Mawira Chitima (IFAD).

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The team expresses its deepest appreciation to the above-listed experts and institutions and would like also to acknowledge the contributions that the dedicated members and hardworking professional staff made:

IFC: Tania Lozansky for inspiring, supporting, and guiding the completion of the handbook; Alan Johnson for providing valuable detailed review of the book; Ivan Ivanov for reviewing from a client perspective; Natia Mgeladze for a comprehensive review for technical and publishing guidelines; Liudmila Pestun for a content review; Jemire Lacle for coordinating with the authors; Unnatti Jain for editorial inputs and coordinating the content, edits, and publishing of the book; Beverly McIntyre, Dieter Fischer, and Mutsa Masiyandima for technical inputs.

IFAD: Thouraya Triki for her continuous supervision and guidance; Valeria Ida Silvestri for the technical inputs and co-coordinating the publication; Paxina Chileshe for reviewing the environmental, climate, gender, and social inclusion sections; Hedwige Croquette for organizational processes and budget management; Nerina Muzurovic for her guidance on the procedures for knowledge management; and Pauni Obregon for legal advice.

The handbook was edited by Joyce Antone Ibrahim (IFC) and designed by Veronica Elena Gadea (IFC).

Limitations

This handbook forms a key part of IFC's and IFAD's cooperation and provides policy makers, government agencies, private sector actors, and development institution partners with tools and guidance on how to deliver effective designs, combined with financing models, to implement and sustainably expand the use of irrigation and associated equipment. The guide focuses primarily on individual small-scale irrigation systems at an individual farmer level rather than larger schemes that leverage large, complex shared infrastructure.

Overall, the guide seeks to simplify the process of supporting and scaling up irrigation systems, but does not prescribe specific designs or technologies as these can only be determined within context, after assessment of conditions and consultation with the farmer stakeholders who ultimately determine the success of the system. The guide discusses the challenges and constraints and offers solutions for developing and scaling more durable systems that meet the technical, financial and environmental needs of farmers. Challenges that remain significant include:

- Risks of extreme weather such as droughts and floods that invalidate the benefits of irrigation
- The need for a combination of farm inputs and equipment to enable irrigation to deliver optimal increase in yields
- The limitations of equipment designed for larger scale commercial application, for gender-specific use or for financial returns that may not be present in each market or at a small-scale farming level
- The need for cultural acceptance of the use of irrigation methods and technologies adoption by small-scale farmers and the development of a sustained commercial level demand of equipment

It is for these reasons that ***the information provided in this guide should be used with caution***. The guide is intended to be an informative, useful tool that provides a starting point for a more detailed analysis of the specific market requirements for irrigation systems. It should not be used as a substitute for direct engagement with farmers, equipment suppliers and distributors present in the local market or seeking expert advice, as needed.

Foreword

The demand for more efficient use of land and water resources to enable farmers to produce food using climate-resilient processes continues to grow in the face of a growing global population and the impacts of climate change and other shocks such as COVID-19. Although irrigation has been widely promoted as important for productivity and resilience, it has not been sufficiently expanded. For example, more than 90 percent of arable land in Sub-Saharan Africa is still rainfed, which prevents farmers from optimizing their productivity and incomes. Large, well-established irrigation projects developed by public institutions and select private sector projects play an important role in providing access to irrigation, but they are insufficient to meet need. In parallel, farmers have been developing effective small-scale irrigation (SSI) options that include a range of technologies, financing methods, and operating models. This handbook discusses how to use these solutions to improve peoples' livelihoods and increase crop productivity.

The World Bank Group's mandate is to reduce extreme poverty and increase shared prosperity. As an institution within this group, the International Finance Corporation (IFC) provides investment and advisory support to the private sector, including agribusinesses, which source commodities from smallholder farmers or offer them services, and financial intermediaries, which enable IFC to provide access to finance and financial services to the agricultural sector. The profitability and sustainability of smallholder agriculture as a business is increasingly tied to farmers' ability to manage water as a key input on their farms. IFC's support in increasing the productivity and resilience of these farmers by introducing or supporting irrigation helps meet the broader objectives of food system transformation.

The International Fund for Agricultural Development (IFAD) is an international financial institution and specialized United Nations agency that invests in rural people, helping them increase their food security, improve their families' nutrition, and increase their incomes. IFAD helps its target smallholder farmers and producers build resilience, expand their businesses, and take charge of their own development. IFAD considers irrigation development a pillar of rural development strategies. Since its establishment in 1978, IFAD has shifted its focus from public sector food security to direct engagement with the private sector. IFAD's goal is to double its impact over the next 10 years, using innovative tools. Irrigation will play a key role in this process. No longer dependent on rainfall, irrigated land is expected to produce greater, more stable yields, leading to greater food security and income.

This handbook is written to share lessons learned and insights drawn from the combined experience of IFC and IFAD in promoting and expanding access to irrigation throughout their overlapping client bases. Teams from both institutions have combined their technical and commercial backgrounds and expertise to produce hands-on guidelines on SSI that provide a practical way to implement solutions; case studies illustrate best practices. This handbook takes a practical approach in guiding its target readers, which comprise policy makers, governments and government agencies, private sector actors, and development institution partners, on how to deliver effective design and operation strategies, combined with financing models, to implement and sustainably expand use of irrigation.

IFC and IFAD are global organizations focused on promoting resilient agriculture and food system transformation. Both organizations are committed to supporting solutions that increase sustainable use of SSI, particularly for farmers operating in water-stressed areas.

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Introduction by Farmer Organization

Since the dawn of time, farmers in all parts of the world have used water, from underground or on the surface, for the purposes of agricultural, animal, and fishery production. In West Africa, especially in the Sahel countries, family farmers and their organizations in different communities developed many innovations during the successive droughts of the 1970s, making the best use of very scarce rainwater, ensuring good water management, and thus supporting their production activities in the face of the adversity of nature. This adaptive capacity and knowledge of family farms and communities saved the Sahel in West Africa during this period.

Governments and their partners have developed many irrigation projects and models in our countries since the 1970's. Dams have been built with a variety of irrigation models (e.g., gravity, pressure). Irrigation has great potential to increase productivity. Diversity of cultivated plants and activities is also supported in irrigated basins. Well-designed irrigation is one way to increase the income of small producers, although the success of irrigation projects in West Africa is mixed. In our countries, and elsewhere in the world, family farms supply most agricultural and agri-food products and are the main source of jobs, especially for women and young people. In West Africa, family farms employ more than 62 percent of the working population, account for more than 80 percent of cultivated land, and develop approaches to sustainable management of natural resources. Family farms in West Africa have shown greater resilience than the agro-industrial model, and where used, irrigation has been effective in guaranteeing food and nutritional security and reducing poverty on family farms. Unfortunately, most irrigation solutions proposed in public development policies and programs do not (or rarely) consider the real concerns of these family farmers through use of appropriate technology. In addition, a range of supporting services is necessary for development and diversification of irrigated agricultural production. These improve the business case for irrigation and ensure good nutrition for families, sustainable use of resources, access to value added services such as food processing, and marketing of agricultural products.

The challenges of large-scale public irrigation schemes include low levels of water-use efficiency, limited profitability, environmental challenges, and poor maintenance of facilities. Furthermore, the separation of responsibility for irrigation systems from individual end users and local communities reduces the overall sustainability of schemes. At the individual farmer level, limits to fundamental rights for access to land, water, and natural resources and the deficits of agricultural credit systems prevent full exploitation of the potential of irrigation systems in West Africa and probably in other regions of the world.

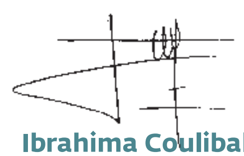
Irrigation solutions must be supported by an integrated set of sectoral policies that encourage investments, including policy measures and support for financial instruments. Capacity building of the service sector is also required to increase local support for design, supply, installation and operation of irrigation systems. Seventy percent of food products consumed in West Africa are domestically produced. Local markets are therefore important for smallholders who access these markets to sell the increased quantities and quality of crops produced in irrigated systems. However, many of these markets operate outside the formal sector, reducing the visibility of financial transactions required to develop credit scoring mechanisms that support access to finance.

West Africa is experiencing some of the greatest demographic growth in the world, with strong urbanization of populations, which increases demand for food and exacerbates pressure on natural resources. Our region is also experiencing the extreme, growing effects of climate change, affecting the productivity and production of family farms and increasing pressure on land. This often generates a gap between supply from family farms and demand. Some political decision-makers rely on this supply-demand gap to justify support for food imports, making imported food cheaper than domestically produced food; these imports inundate markets and compete with products from family farms. We must reverse the trend, which is morally unacceptable and socially and economically untenable. Appropriate irrigation solutions are one way to meet these challenges.

The absence of coherent public policy and operational strategies to increase irrigation is a key limiting factor for development of irrigation, especially in developing countries. Key supportive policies include those that guarantee equitable, sustainable access to land and water resources for family farmers, especially women and young people, and policies that support greater access to credit. The United Nations Decade for Family Farming (2019-2028) and the conclusions and recommendations of the Paris Climate Agreement, which put agriculture on the agenda as a priority for adaptation and mitigation of climate change, offer opportunities to sustain and reorient policies in support of irrigation, especially in developing countries.

Developing countries in Africa and Asia offer access to vast areas of underdeveloped agricultural land, a growing smallholder farmer workforce, and a range of agroclimatic zones ideal for growing a broad variety of crops. With the aid of irrigation, smallholder farmers can play a valuable role in meeting global demand for food, feed, fiber, fuel, and medicines. Irrigation could diversify sourcing and open large markets to national, regional, and multinational companies; financial institutions; equipment providers; off-takers; and processors along the irrigated agricultural value chain, whose active participation is essential to sustainable development.

It is important to guide and support efficient private and public investments in irrigation by sharing and building upon lessons learned from previous experience. In this fight for a better future, IFAD and IFC play an important role in building and sharing the practical methods and technical knowledge required for design and management of irrigation systems by family farmers and communities, gained from global programs that support smallholder farm irrigation. This handbook is a collaborative effort of IFAD and IFC to highlight the collective voices and experiences of a range of practitioners and technical experts. We hope that this knowledge, co-constructed with irrigation stakeholders in several regions, can be widely used to support new irrigation policies to ensure transformation of family farming and resilience of rural communities around the world. We therefore encourage readers to promote this handbook among irrigation stakeholders, in particular those focused on small family farms.



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Abbreviations

AWM	Agricultural water management
AMP	Asset management planning
GDP	Gross domestic product
ICT	Information and communications technology
IFC	International Finance Corporation
IFAD	International Fund for Agricultural Development
I&D	Irrigation and drainage
ISF	Irrigation service fee
LMIC	Low- and middle-income country
MOM	Management, operation, and maintenance
PASIDP	Participatory Small-Scale Irrigation Development Programme
SSI	Small-scale irrigation
WUA	Water user association

Executive Summary

With the global population growing rapidly, demand for food is also growing, along with pressure on agricultural land and water resources. The world's family run farms produce around 80 percent of the world's food on 80 percent of the area of land under production, (FAO, Lowder, Sánchez, and Bertini 2021). However, the smaller farms of less than 2 hectares in size operate on only 12 percent of agricultural land and produce 35 percent of the world's food, the majority of this under increasingly vulnerable rainfed production. There remains significant additional scope for improvement in production, with a key focus on water-scarce tropical regions where more than 95 percent of cropland is still rainfed, and irrigation is not widely practiced. In Africa, total cultivated area is estimated to be 271 million hectares, only 18.6 million hectares of which is irrigated. This includes all forms of irrigation, water harvesting, and drainage control. Irrigation has many benefits and plays a vital role in increasing global food production, including greater, more stable production (Schultz, Thatte, and Labhsetwar 2005).

International platforms established to advance food security, such as the United Nations Food Systems Summit, have recognized the need for an ecosystem approach to food systems transformation—one that embraces multistakeholder approaches to increase productivity, resilience, and empowerment for smallholders. Implementing sustainable irrigation will be key in increasing yields, closing the gap between supply of and demand for food, adapting to climate change, and addressing scarcity of water resources.

The International Finance Corporation (IFC) and the International Fund for Agricultural Development (IFAD) have joined efforts to produce this handbook to present best practices, case studies, and hands-on guidelines on small-scale irrigation (SSI) for better soil and water management in the context of small-scale agriculture, with a particular focus on Sub-Saharan Africa and South Asia. The handbook is also a call to action for stakeholders in this ecosystem. It spotlights the integrative approach required from the public and private sectors to create a more equitable and attractive agricultural sector, including farmers, private companies, irrigation equipment providers, agri-finance institutions, agriculture-focused government institutions, water and resource planning agencies, and development partners.

Diagnostics and approaches from the public sector are already well supported through a range of publications that the World Bank Group, Food and Agriculture Organization, and IFAD have issued, notably the World Bank's farmer-led irrigation development[1] guide, which provides governments with practical strategies to catalyze and expand farmer-led irrigation development, making it a faster, more sustainable, more inclusive process. This handbook complements the existing literature by presenting case studies that highlight the benefits of SSI and showcasing how interventions have been implemented, including lessons learned from implementation. It provides stakeholders with practical guidance on conditions necessary for implementation of sustainable, economically viable SSI.

1 SSI refers to irrigation systems that serve smallholders and are typically adapted to the local context. Farmer-led irrigation is when farmers drive establishment, improvement, and expansion of irrigated agriculture and influence the location, purpose, and design of irrigation development through small-scale, on-farm, locally relevant, market-oriented solutions.

Chapter Outlines

Chapter 1 introduces SSI systems, outlining the various contexts in which SSI is practiced, the potential of SSI to improve quality of life and enhance incomes, and challenges that must be addressed to expand use of irrigation and achieve benefits at scale in developing countries.

Chapter 2 outlines the elements of design, development, operation, and management of SSI, providing a detailed outline of SSIs focusing on technologies that increase productivity and smallholder farmers' capacity to manage risk. It also provides guidance for lifting barriers to entry for female farmers.

Chapter 3 addresses asset management planning (AMP) for irrigation and drainage (I&D), which is key to increasing irrigation performance of systems which include infrastructure and equipment requiring maintenance and replacement. The chapter highlights a structured, systematic mechanism for determining investment costs and outlines how AMP can be adapted to different types and scales of irrigation systems and capacity of farmers. It also provides guidance for irrigation planners, water managers, and water user associations to plan for equipment replacement and to ensure that the fees collected are in line with the needs of the project.

Chapter 4 addresses SSI operation models, highlighting what works in different contexts and outlining successful approaches. The chapter provides guidance on selecting suitable operational models for local contexts and outlines nine determinants of success that should be considered in relation to drivers such as water resource availability, land tenure, and markets.

Chapter 5 presents the business case for structuring irrigation financing products for smallholder farmers, discusses several opportunities for stakeholders (smallholder farmers, commercial producers, financial service providers, governments, development partners, agricultural input suppliers and agribusinesses in irrigated value chains), outlines the barriers to access to financing, and recommends solutions to overcome them.

Chapter 6 identifies pathways for transforming SSI. It is important to consider all interventions and adapt them to local contexts to ensure their maximum benefit. The chapter discusses the tools and practices needed and how they must continually evolve to meet the challenges arising from growing competition for water resources.

Key Messages

SSI can increase agricultural production while reducing risks of climate change. With families living on small farms representing 84 percent of agricultural households (FAO 2021), promotion of SSI systems will be key to safeguarding and improving livelihoods though decentralized and productive irrigation interventions. SSI can yield higher returns than large-scale irrigation and has lower investment costs, easier maintenance, more control for water end-users, and less need for enterprise and management capability for operations. The difference in cost efficiencies in supplying irrigation from large- or small-scale systems is particularly notable when considering the gap between the cost of providing water delivery services and water service fees recovered from farmers in public projects, both in terms of rate charged per unit area and percentage of farmers paying. A World Bank (2014) study found gaps in all countries assessed, ranging from 6 percent to 15 percent of actual costs recovered in government-led projects. SSI systems can also support environmental sustainability; by using SSI, farmers can increase or continue production on land that has already been converted for agriculture rather than clearing new land or accelerating land degradation.

SSI operating models vary greatly, but successful, sustainable models share several features. There are three main operating model categories: shared system (farmers have control over their own in field irrigation system but receive water from a source owned by someone else), collective system (a group of irrigators own and share the hydraulic infrastructure), and individual farmer (farmers have control over their irrigation system and have their own water source). Although models may differ in day-to-day management, governance, payment mechanisms, and land ownership arrangements, most successful models have adopted effective approaches such as participatory management, accountability of irrigation unit leadership, youth involvement, and capacity strengthening of farmers.

Involvement of individual farmers (male and female) or small groups of farmers in SSI systems makes the systems more effective. With SSI, farmers drive establishment, improvement, and at times, expansion of their farms. SSI typically consists of individual household irrigation infrastructure and practices or community-driven group-owned SSI systems with shared or commonly acquired and operated equipment. Farmers often must collaborate with other actors, including irrigation equipment suppliers, traders who sell irrigated products, craftspeople, government extension agents, local and national policy makers, civil society, financial institutions, and development organizations. Women's roles in implementation of irrigation systems are critical, because their involvement yields significantly better outcomes at all levels of agricultural production, greater efficiency of water use, and system sustainability. Involving farmers in the various stages of designing, supplying, installing, and operating irrigation promotes a sense of ownership. In particular, the engagement of end users in the planning of irrigation projects ensures greater system acceptance and operational sustainability.

I&D systems often do not maximize the potential of irrigation because maintenance, repair, and renewal of the physical infrastructure are not adequately invested in, which can lead to deterioration of the system. AMP addresses this central problem by assessing the condition and performance of I&D infrastructure and determining the investment needed to maintain that infrastructure in the short, medium, and long term. In this way, irrigators have a structured, systematic mechanism for determining investment costs and the level of service to be provided.

Farmers, particularly women, face several barriers to investing in irrigation equipment, including access to financing. Many countries have a burdensome regulatory framework that limits access to water and equipment. Farmers also face numerous barriers to access to financing for agricultural inputs and irrigation technology. Women, youth, and marginalized groups face additional barriers to access to financing. Limited access to financing from formal credit providers can prevent marginalized farmers included in irrigation projects from obtaining and using inputs to achieve high yields. Although women can benefit from microfinance, it is often insufficient for the purchase of irrigation equipment, and the terms and conditions often make it an expensive form of credit for smallholders. Ensuring that women benefit from access and support as irrigators would vastly increase the area of land under irrigation, the productivity of water through multiuse systems, nutritional outcomes, and labor savings from collection of water in dry seasons.

Future Outlook

A holistic approach supported by the public and private sectors can be effective in addressing barriers to uptake of irrigation. This approach should provide an enabling environment by adopting supportive legislation and import tariff structures; offering smart equipment subsidies; increasing access to private sector loans in the agricultural sector; securing off-take markets; and making irrigation equipment, technical skills, and high-quality inputs available. Public and private contributions can be directed toward both operations and maintenance. Although it may be a challenge to create a business case for smallholder irrigation financing, doing so reduces risks to farmers and investors.

Photo Credit: Liudmila Pestun, IFC

Chapter 1: Overview of Small-Scale Irrigation Systems

Key messages

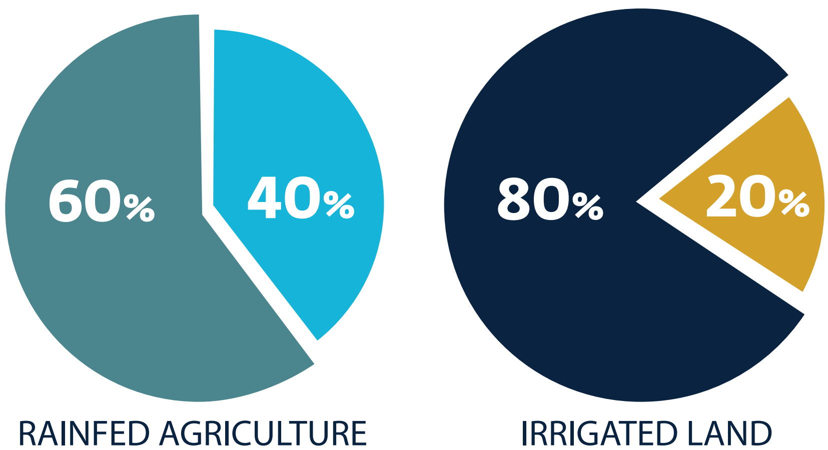
- Irrigation can lead to agricultural yields two to three times as great as those of rainfed agriculture, allowing for investment in irrigation systems to be recouped because higher-value or higher-yielding crops can be produced.
- Irrigation technologies and practices help address climate change, reduce risks related to investment in inputs, and increase agricultural productivity to improve livelihoods.
- Irrigation system development in the private and public sectors is shifting from large-scale to small-scale irrigation systems (SSI) that serve 1 hectare or more and where investment costs can be repaid fully in 3 years.
- Providing access to a range of low-cost, portable SSI technologies provides flexibility for farmers to extend systems across their farms to reach scattered fields.
- SSI systems may be designed to draw water from various sources. However, access to information regarding the quantity, depth and replenishment rates of subsurface water resources is largely lacking at a smallholder farmer level.
- Subsurface or groundwater-based irrigation holds promise, especially in Sub-Saharan Africa, where the widespread presence of aquifers underground in remote areas provides greater access for farmers to water needed for irrigation systems.
- Addressing the challenges of scaling up SSI to achieve transformative change requires a collaborative approach that combines and coordinates the interests of the public and private sectors with those of farmers.
- The sustainable use of SSI requires that an integrated group of stakeholders build technical, operational, and maintenance experience or a network of service providers. This ecosystem must be developed before irrigation technologies can be efficiently expanded.
- Scaling up the use of irrigation would contribute to a wide range of objectives, such as gender equality, improved livelihoods, sustainable use of natural resources, improved nutrition, and greater climate resilience.

Summary

Irrigation is any process that supplies water to crops or any other cultivated plants through means other than natural precipitation, enabling or improving crop production in ways that would not be possible through natural precipitation or reliable because of climate change.

Irrigation can lead to agricultural yields two to three times as great as those of rainfed agriculture, allowing for investment in irrigation systems to be recouped because higher-value or higher-yielding crops can be produced.

Irrigation technologies and practices offer opportunities and solutions to a range of challenges, particularly for smallholder farmers, who are increasingly looking to water management as the key to addressing climate change, reducing risks related to investment in inputs, and increasing agricultural productivity to provide for improvements in livelihoods. SSI can also provide flexibility to farmers to leverage underused land, especially in the dry season, and thus has the potential to play a vital role in improving the quality of life of vulnerable populations, including women and youth.

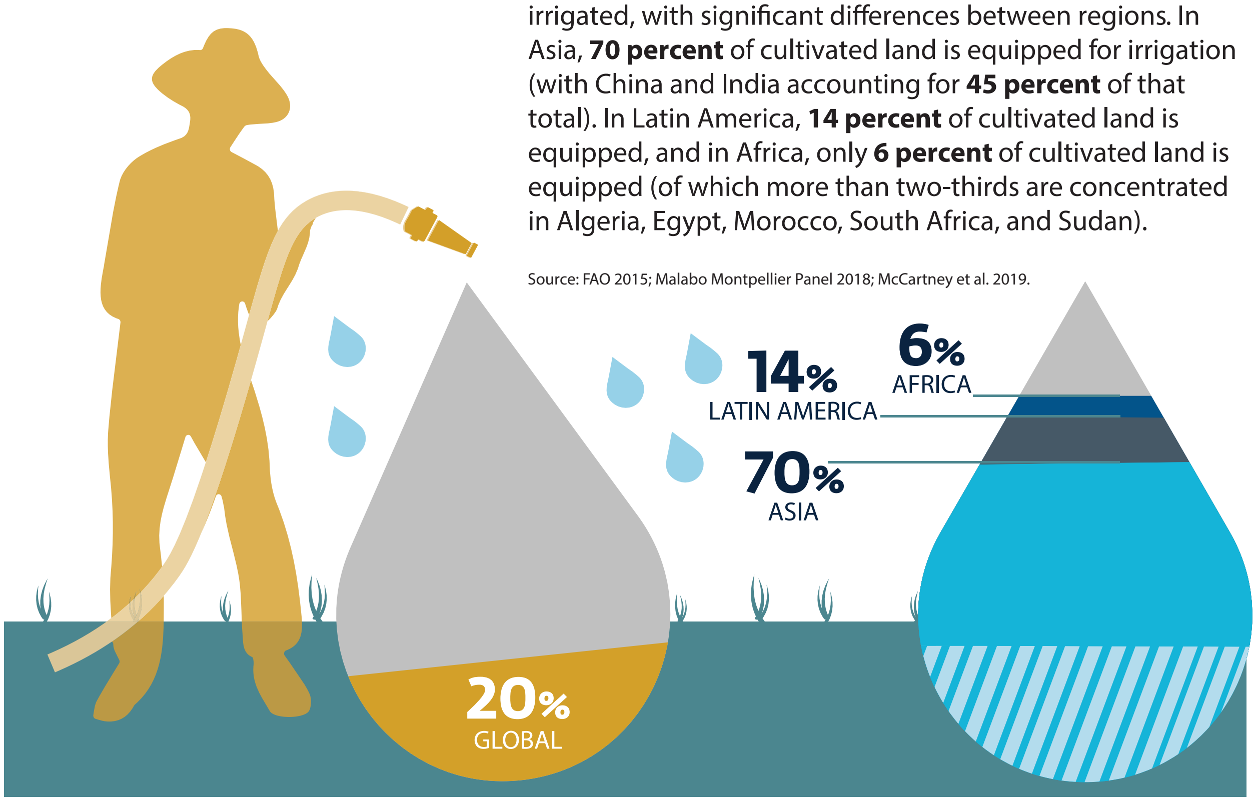


Whereas rainfed agriculture supplies more than **60 percent** of the world's food supply, on **80 percent** of cultivated land, irrigated land provides **40 percent** of the world's food supply on only **20 percent** of agricultural land.

Source: World Bank 2021.

Globally, about **20 percent** of total cultivated land is irrigated, with significant differences between regions. In Asia, **70 percent** of cultivated land is equipped for irrigation (with China and India accounting for **45 percent** of that total). In Latin America, **14 percent** of cultivated land is equipped, and in Africa, only **6 percent** of cultivated land is equipped (of which more than two-thirds are concentrated in Algeria, Egypt, Morocco, South Africa, and Sudan).

Source: FAO 2015; Malabo Montpellier Panel 2018; McCartney et al. 2019.



This chapter introduces SSI systems, outlining the various contexts in which SSI is practiced, the drivers for its use, its potential to improve quality of life and enhance incomes, and challenges that must be addressed to introduce irrigation at scale in developing countries, which have been slow to adopt these technologies and practices.

Figure 1. Percentage of Cultivated Land under Irrigation

Source: Nagaraj, Deepak, Proust, Eleanor, Todeschini, Alberto, Rulli, Maria Cristina, & D'Odorico, Paolo. (2021). A new dataset of global irrigation areas from 2001 to 2015. Zenodo. https://doi.org/10.5281/zenodo.4659476

Small-Scale vs Large-Scale Irrigation Systems

Irrigation system development in the private and public sectors has traditionally targeted investment in large systems aimed at reaching thousands of farmers and hundreds to thousands of hectares through centrally managed irrigation systems. These provide water to the edge of the farm, with farmers operating individual in-field systems themselves, but these large systems have faced challenges in Africa because they are inflexible and designed to irrigate a single crop type to allow for effective scheduling. In practice, many of these systems have low water-use efficiencies, operate at high unit costs, and are poorly maintained, leading to poor reliability. Given the dispersed areas of typical farms, canal systems used to transport water under gravity are also complex and require that some fields that were previously used for crops must be converted to allow the passage of canals used solely for water distribution.

DESCRIPTION OF SSI SYSTEMS

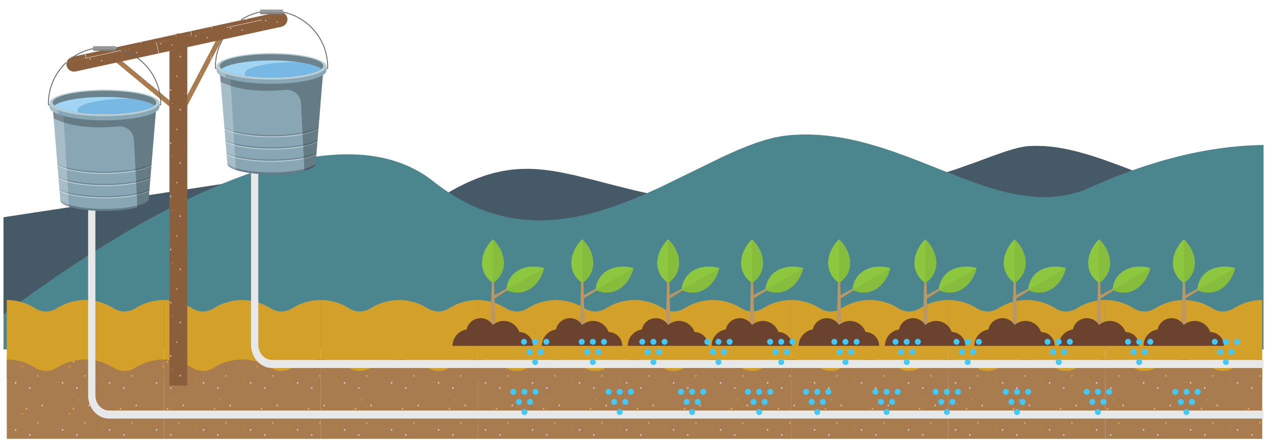
Irrigation systems can be classified in many ways, with major distinctions being farm size or system scale, source of water, method of application of water, and frequency of irrigation. IFAD estimates that small farms of up to 2 hectares supply 70 percent of the food and constitute 75 percent of the land in

Africa; globally, 90 percent of farms are small farms, which makes small farms essential to food supply and development of economies, although use of irrigation is not financially viable on all such farms.

SUBSISTENCE SCALE FARM

A typical smallholder farm in Africa allows a family to meet its basic nutritional needs and obtain limited income. Despite the need to increase individual farm sizes to allow economies of scale and commercialization, historic or traditional land rights constrain the ability to consolidate land into larger areas. Increasing population sizes further divide ownership as land is passed on through successive generations of farming families. Smaller subsistence farms growing food crops are not optimal for commercial irrigation systems that require cashflow to repay capital and operating costs. These subsistence-scale farms are often less than 1 hectare, and where irrigation systems are installed, they are typically donor supplied or fully subsidized by government programs with limited longevity. Under current technology and cost scenarios, farms in this sector of the market are likely to remain mostly rainfed (see figure 2).

Figure 2. Subsistence Small-Scale Irrigation

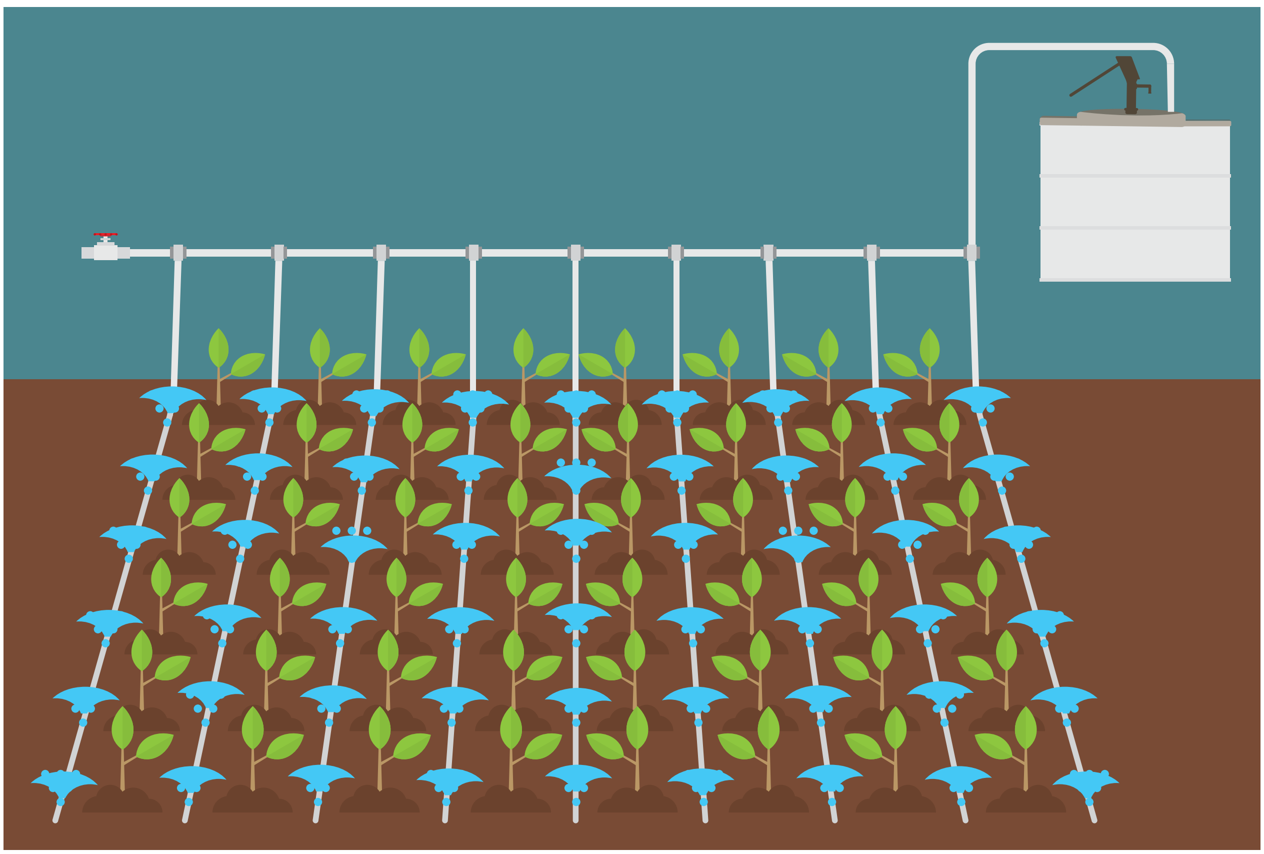


SSI is technically feasible in areas that have reliable supplies of surface water, such as reservoirs, lakes, streams, and rivers, or areas with shallow subsurface water that can be accessed through wells and boreholes and soils suitable for irrigation. Some farmer-operated and -owned SSI systems may include access to an on-farm water supply (e.g., borehole, river diversion, stream diversions, reservoir) and thus do not require the public or bulk water supply component, allowing for faster development and greater flexibility. Other farmers rely on larger-scale, aggregated bulk water supplies delivered to the field edge, but remain responsible for the in-field system that delivers water to the crops. Farmers often select SSI solutions that are designed to optimize productivity in the face of financial and technical constraints and may use components that are low cost but lack durability.

SSI systems may be considered financially and commercially feasible when system costs, crop values, and demand for crops would allow for farmers to retain some profit in addition to covering the costs of purchase and repayment of SSI capital (interest), operating costs, and replacement costs within 3 years. This 3-year time frame reduces risks to lenders, and access to the increase in profits by the farmer within a short payback period creates a necessary incentive. Systems should be designed and selected to last a minimum of 7 years to allow for an attractive return on investment by farmers, the building of savings, and the ability to replace the system, if needed, without need for additional subsidies or grants.

Financial subsidies or grants are often needed to support the adoption of SSI technology on farms smaller than 1 hectare because this scale of farm typically does not produce crops in excess of household needs, and therefore lacks the cashflow for savings or repayment of a loan. Farms that are larger than 1 hectare offer the greatest potential for successful, sustainable use of irrigation systems, because they can meet food security needs and produce excess food or crops that can be sold. This handbook, therefore, focuses on how to support and develop SSI systems operating on farms that are larger than 1 hectare, where a combination of public, private, and donor-driven support is most effective.

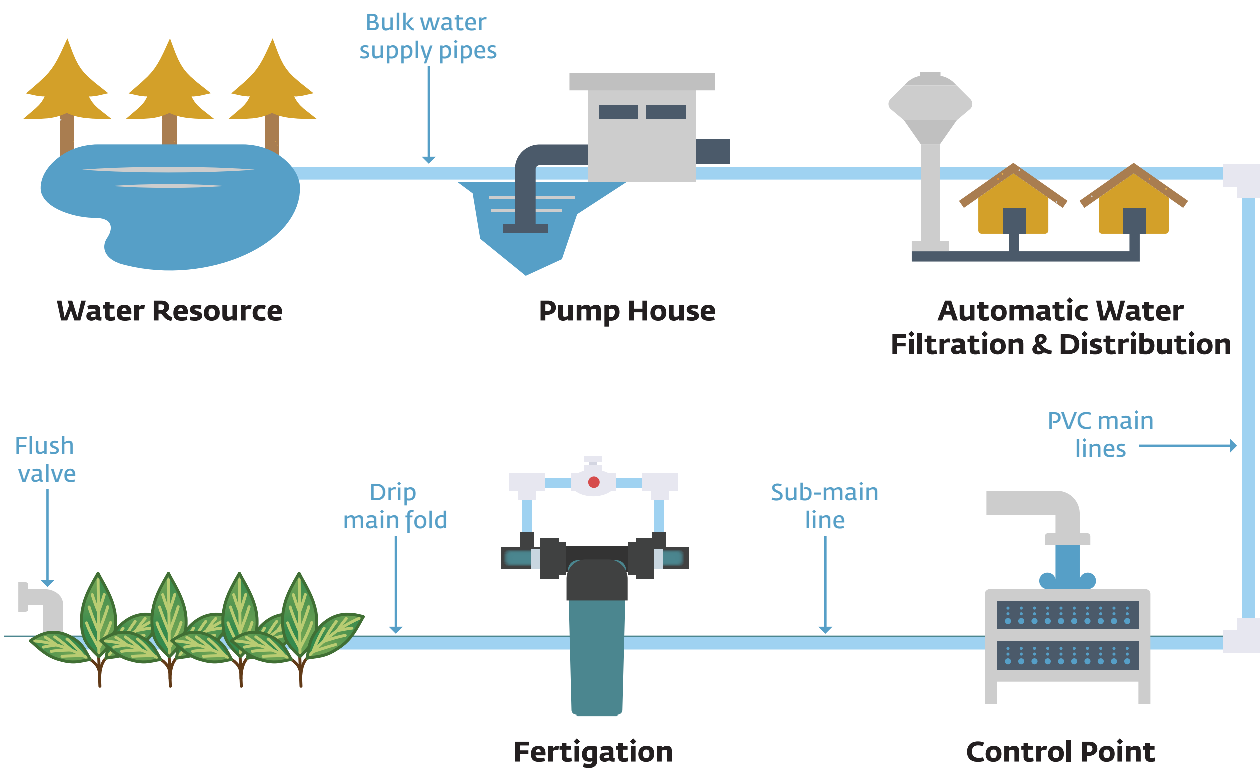
Figure 3. Small-scale irrigation (1ha to 4ha) – Fields near home, Often in different locations



COMMUNITY SSI SYSTEM

Water user associations (WUAs), cooperatives, and groups of farmers offer another important way that installation of individual in-field irrigation systems on farms smaller than 1 hectare may become commercially viable. In these cases, the land consolidation allows the supply of a larger amount of water (bulk water supply) from source to the group of farmer fields. These community-level SSI systems typically cover less than 200 hectares, with a centralized water source that serves a group of farmers in commonly managed but individually operated systems. This community SSI approach may also provide farmers with access to mechanization and allow for economies of scale in purchasing inputs and selling outputs, providing additional support in commercializing production. Farmers using this system are required to manage water allocations, financial obligations, and operation of the irrigation system through some form of a WUA.

Figure 4. WUA / Community Small-Scale Irrigation System: Several families, several groups of fields, one major source of water



Irrigation systems require management of water at several distinct points: securing a sustainable water source; transporting water to fields; applying water to crops; and returning excess water to rivers, streams, and aquifers. Most SSI systems use underground sources of stored water located on the farm, such as boreholes and wells, or nearby surface water bodies such as rivers and streams.[2,3] SSI typically consists of individual household-level irrigation infrastructure and practices or community-level systems where equipment is shared or commonly acquired and operated.

2 FAO. https://www.fao.org/news/story/en/item/1395127/icode/
3 World Bank. https://www.worldbank.org/en/topic/water-in-agriculture#1

Figure 5. Large irrigation Scheme

Photo Credit - Richard Colback, IFC

Figure 6. Small irrigation Scheme

Although the performance of larger irrigation systems has often been disappointing, SSI systems have gained popularity by demonstrating their suitability for expanding irrigation because they lead to higher returns on investment,[4] lower overall investment costs, easier maintenance, more control for end users over their water supply, access to controlled water in remote areas, and less need for enterprise and management capability for operations. Nevertheless, SSI should be introduced in a sustainable manner that addresses systemic challenges such as lack of access to financing for capital and operating expenses; inadequate technical training and support for equipment maintenance and operation; and the need for sustainable, balanced use of water resources.

Public sector support for the use of SSI systems, in particular farmer-led irrigation systems, reduces the burden on public finances, increases the pace of irrigation development, and shares benefits more broadly from a political and geographical perspective (ref: FLID guide).[5]

4 Food and Agriculture Organization of the United Nations. 2015. "The State of Food and Agriculture: Social Protection and Agriculture: Breaking the Cycle of Rural Poverty." Available at https://www.fao.org/3/i4910e/i4910e.pdf; Malabo Montpellier Panel. 2018. "Water-wise: Smart Irrigation Strategies for Africa." Available at https://www.mamopanel.org/media/uploads/files/Irrigation_report_FINAL_ONLINE.pdf; McCartney, Matthew P., Louise Whiting, Ian Makin, Bruce A. Lankford and Claudia Ringler. 2019. "Rethinking Irrigation Modernization: Realizing Multiple Objectives through the Integration of Fisheries." Marine and Freshwater Research 70: 1201–10.

5 Food and Agriculture Organization of the United Nations and the International Fund for Agricultural Development. 2019. "United Nations Decade of Family Farming 2019-2028: Global Action Plan." Available at https://www.fao.org/3/ca4672en/ca4672en.pdf.

Drivers for adoption of SSI

Most of the water required for the growth of crops on smaller farms must still be provided through rainfall, which has historically allowed sufficient production of indigenous crops adapted to the climate and soils of the region. Climate change has altered this harmonious balance, and patterns of rainfall are changing faster than farmers can adapt. In many tropical countries, rainfed production systems have become unreliable, and ongoing reliance on agriculture as a source of livelihood, global sourcing of commodities from smallholder farmers by the private sector, and export of commodities by state-owned enterprises as a source of public funding have become a challenge. The top 10 most climate vulnerable countries[6] that face the greatest risks because of their reliance on rainfed crop production are all tropical countries. These countries also face rapid population growth and are included in the United Nations list of the world's 48 poorest countries. Use of supplementary irrigation designed to address short-term rainfall shortages or support introduction of high-value crops is therefore becoming a requirement where these crops can no longer be reliably cultivated under purely rainfed conditions because of climate change. Additional factors creating demand for individually owned and operated SSI systems include:

- Poor performance of public irrigation systems
- Reduction in farm size, especially in South Asia, requiring an increase in productivity per unit of land
- Government promotion (as in the case of India's pumped groundwater revolution)
- Decreasing costs of technologies such as pumps for accessing surface or groundwater resources
- Greater market demand for food supply (as in the urban and peri-urban areas of Sub-Saharan Africa) raising prices paid to farmers
- Ease of maintenance and repair of equipment
- Support for policy reforms and liberalization of imports (e.g., Bangladesh in the 1980s[7])
- Demand for high-value, nutritious crops

Key trends in SSI development

MAPPING OF WATER RESOURCES

SSI systems may be designed to draw water from various sources. Access to information regarding the quantity, depth, and replenishment rates of subsurface water resources is largely lacking at a smallholder farmer level. Subsurface water sources provide a major opportunity to broaden the use of irrigation; from systems limited by the need to pump water across distances between fields and points of access

6 https://www.maplecroft.com/risk-indices/climate-change-vulnerability-index/
7 https://www.brookings.edu/blog/future-development/2021/07/09/bangladeshs-remarkable-development-journey-government-had-an-important-role-too/

to surface sources of water, to a much broader area that could be served by subsurface water stored in aquifers that can be pumped to the surface directly adjacent to fields. Subsurface or groundwater-based irrigation holds promise, especially in Sub-Saharan Africa, where the widespread presence of underground storage of water in aquifers in remote areas would provide access to enough groundwater to irrigate an estimated 44.5 million to 105.3 million hectares. The increase in use of remote sensing technologies combined with physical measurements of water depths throughout the year to identify season variations of boreholes and wells provides greater accuracy and reliability than traditional maps showing water stored at a uniform depth across a vast area. These data are being combined in geographic information systems that are accessible online and can allow stakeholders to assess the commercial and technical potential of water resources.

GROWTH PROJECTION

The potential area suitable for the immediate expansion of SSI in Sub-Saharan Africa is about 7.3 million hectares, with higher internal rates of return than large-scale irrigation has historically provided. One study has projected a doubling of irrigated areas between 2010 and 2050 in Sub-Saharan Africa (McClain 2013), although to ensure sustainable access to water as the climate changes and rainfall patterns affect replenishment of rivers, aquifers, and large surface water bodies, policy instruments that provide environmental protection and resource sustainability must precede irrigation modernization. The risk of overexploitation of water resources for irrigation remains distant in most parts of Africa, where current levels of pump use for irrigation are low. However, the experience of unregulated pumping for irrigation in India provides lessons that should be taken into consideration. The immediate gains in productivity made by increasing the use of irrigation in India led to unsustainable depletion rates in the longer term. This risk of groundwater eventually becoming too deep to effectively reach for irrigation may reverse gains and has led some models to predict that cropping intensity may decrease by approximately 68 percent in the groundwater-depleted regions and 20 percent overall in India, unless water governance controls excessive use.

SUSTAINABILITY VERSUS PRODUCTIVITY

The increasing pressures of climate change, population growth, and the need to improve people's quality of life also require efficient, productive use of water where competition may arise. For example, linkages exist between increasing conflict in the Sahel driven by the water needs of migratory herds of livestock and development of irrigated land that attracts grazing and draws water from common access points. When irrigation is introduced across a large area, it is vital to monitor and regulate potential risks, including downstream pollution from agrochemicals and potential environmental impacts on surface water, underground aquifers, and ecosystems. Frameworks such as the IFC performance standards available for use in assessing risks and developing plans to reduce tensions between water use have taken into consideration these environmental and social factors (IFC n.d.).[8]

Measuring water use efficiency also offers a quantitative method of increasing water use efficiency and strengthening sustainability. Metrics including tons yielded/cubic meter of water or water use versus

8 FAO and the 2030 Agenda for Sustainable Development. https://www.fao.org/sustainable-development-goals/overview/fao-and-the-2030-agenda-for-sustainable-development/sustainable-agriculture/en/

duration of supply allow project monitoring and evaluation to demonstrate the benefits of introducing technology and improved practices. Rapid expansion of irrigation to increase yields and people's quality of life must therefore be balanced through a combined public and private sector approach of public policy focused on long-term resource management to secure future generations of water users and short- to medium-term economic development. This increasingly aligns with the private sector focus on balanced resource use to ensure sustainability of supply chains and profitability.

Overcoming barriers to expanding SSI

Farmers face a range of conflicting, complex, interconnected factors that must be addressed to deliver theoretical objectives from SSI systems. A checklist of major factors includes:

- Competition for water and land resources
- Limited, unequal access to appropriate technologies
- Limited access and linkages to markets
- Lack of institutional guidelines for resource management
- Inadequate land rights and land use policies required to support investment
- Limited technical capacity of farmers, farmer organizations, and extension services providing support to farmers

Addressing the challenges of SSI to achieve transformative change requires a holistic approach that combines and coordinates the interests of the public and private sectors with those of farmers—beyond supplying a pump to a field or a seed to the ground to strengthening the overall enabling environment equitably and inclusively.

SSI has the potential to support agricultural growth and resilient food systems in developing countries, but it must be expanded in a way that ensures social equity, economic feasibility, and environmental suitability. Expanding SSI will depend on the context and should involve actors from various sectors. Therefore, actors must offer social-technical solutions that can overcome not only technological, but also cultural and economic barriers. Of critical importance is creating an enabling environment with respect to services for SSI, financing mechanisms, and access to technologies and innovations.


Photo Credit - Photo by USAID

Photo Credit - ©EU/ECHO/Anouk Delafortrie

CASE STUDY 1: Evaluation of Ethiopia's Participatory Small-Scale Irrigation Development Programme

Country:	Years:	Organizations involved:	Crops:	Areas of impact:
Ethiopia	**2008-2015 2016-2024**	**IFAD; government of Ethiopia**	**Various**	**SSI systems**

The PASIDP was implemented to increase the food security, family nutrition, and incomes of poor rural households living in drought-prone and food-deficit areas in Amhara; Oromia; Tigray; and Southern Nations, Nationalities and People's Region through a sustainable farmer-owned and -managed system of small-scale irrigated agriculture.

The project had three main components:

- The institutional component involved forming WUAs in each community participating in the project. The project's extension agents trained WUA leaders and members in how to manage and distribute water efficiently and effectively. The beneficiaries received capacity-building and skills training to increase their knowledge and awareness of agricultural technologies and improved practices.
- Catchment area planning of SSI systems was improved. With a well-functioning irrigation system in place, project beneficiaries would obtain a more constant supply of water, substantially more water overall, and timely water supply for agricultural production over the course of the cultivation seasons.
- The agricultural development component strengthened agricultural support services; improved farming practices, particularly in seed production systems, postharvest management, watershed-based soil management, and water conservation; and promoted home gardens for women.

The SSI systems, along with the other capacity-building and skills training, were expected to help beneficiaries increase household consumption, achieve higher and more stable incomes by increasing agricultural production, and increase their resilience to shocks by allowing them to manage and recover from negative shocks. These interventions may also allow beneficiaries at the bottom of the income distribution to move out of poverty. Farmers with access to irrigation are better able to grow crops throughout the year, providing them with greater opportunities to earn income from crop sales than they would have had if they relied mostly on water from rainfall. Irrigation may also help beneficiaries reduce their need to adopt negative risk-coping strategies such as selling assets, reducing consumption, or migrating to other areas in search of other wage opportunities.

The impact of irrigation development on beneficiaries depends on their adoption of agricultural technologies and practices that are complementary to irrigation. Lack of adoption of such technologies and practices, which might be necessary to harness the potential of irrigation fully, could hinder the full impact of irrigation projects.

Key metrics

- Number of irrigation systems constructed
- Hectares of land irrigated
- Number of households reached
- Number of beneficiaries reached
- Number of WUAs established and strengthened
- Number of female-headed households trained in home garden development

Key results

- **121** irrigation systems constructed
- **12,000** hectares of land irrigated
- **62,000** beneficiary households
- **311,000** beneficiaries
- **175** WUAs established and strengthened
- **7,144** female-headed households trained in home-garden development

Lessons learned

- Investing in irrigation is transformative for farmers, particularly the poorest farmers, and generates returns that increase farmers' resilience to climatic shocks. To this end, irrigation may act as a risk management strategy, increasing farmers' income and building their resilience.
- SSI infrastructure increases production of high-value crops but must be bundled with marketing and market access interventions to allow farmers to maximize the benefits from increased production. Commercialization and marketing support continue to be areas for improvement and should be bundled with interventions aimed at improving agricultural production.
- Adopting irrigation technologies reduces negative coping strategies that households resort to in times of distress. This reduction is particularly significant if a short rainy season immediately follows the dry season, illustrating the persistence of project impacts beyond the dry season.
- Measuring the impact of IFAD-supported project interventions on resilience requires adequate data. Projects that aim to enhance resilience and protect smallholders from climate shocks need data systems that are different from conventional monitoring and evaluation approaches. Resilience data must be collected frequently to capture the impacts of stressors and shocks (and responses to shocks) using shock-sensitive indicators. The data must also be collected over the long term because vulnerability to shocks is the product of slower-moving stressors as well as of long-term, multisector interventions for building resilience. To minimize data collection costs, specific data should be collected at sentinel sites—small samples of sites strategically selected to monitor risk, shocks, and welfare outcomes while maintaining the representativeness of key structural characteristics, such as specific agro-ecologies or livelihood zones. Remotely sensed data can be used to provide more frequent objective shock metrics.

Photo Credit: CIF/Amel El Abed

CASE STUDY 2: Niger Irrigation Project: Establishing an Irrigation Market Ecosystem in a Fragile Market

Country:	Years:	Organizations involved:	Crops:	Irrigation system:
Niger	**2016-2019**	**IFC; Netafim; Agrimex, Talbus, Nirritech, Afroplast, Climate Investment Funds**	**Horticulture crops**	**Drip irrigation system**

Despite acute vulnerability to climate change and significant potential for SSI technology to increase climate resilience and food security, the large-scale adoption of irrigation has been unsuccessful in Niger over the past two decades. Irrigation is vital during the dry season when food shortages are most acute given the country's arid climate, but previous focus on the irrigation market was largely led by donor projects that resulted in limited, short-term uptake and longer-term mistrust of irrigation technologies. Market analysis indicated that lack of sustained technical support, limited training for operation and maintenance of the systems, lack of a sense of ownership of the technology by farmers, and poor availability of spare parts limited market growth and created significant barriers to commercial viability.

The Niger Irrigation Project demonstrated how a sustainable and scalable commercial market can be established to provide irrigation equipment by focusing on a business ecosystem rather than a single company. The project combined the experience and technical resources of Netafim, a global leader in irrigation, launched local service providers, and provided market creation assistance and financial support of IFC. The project also focused on generating demand by building awareness of the strong benefits of irrigation, the credibility of the equipment and service providers and improved inventory management, market development and after-sales service technical capacity of smallholder farmers through practical training and agronomic support provided by Netafim. Existing companies participating in the irrigation market were strengthened and new service providers established and trained to deliver design, supply, installation, and maintenance of drip irrigation equipment to Nigerian farmers. The ministries of agriculture and finance provided support to the market by promoting the use of irrigation at the smallholder level and linking grants and subsidies to commercially viable solutions.

The SSI technology system designs used in the project included a solar-powered irrigation pump, drip irrigation, and secure access to crop input supplies. The project also focused on the need for irrigation by women who controlled land during the dry season, which was typically a less productive season. The combined approach brought together water-efficient technology, national companies with the capacity to support farmers locally, public sector policy and tariff support, and donor financing. This combination was critical in overcoming initial barriers to entry that would have prevented a private sector solution in isolation. The ecosystem approach enabled Netafim to develop a critical mass of business in Niger to lower unit costs and provide enough demand for services to sustain local small and medium-sized enterprises. Several key elements of the project were based on the successes of Netafim in other markets including:

- designing drip irrigation kits suitable for the local context.
- setting up demonstration plots to show the benefits of drip irrigation.
- building local capacity by training community field assistants in drip technology installation, use, and post-sale support (with community field assistants training farmers and providing maintenance services).
- linking farmers to markets for their increased yields.
- identifying irrigation financing options for expansion.

Several challenges were also faced including the land ownership structure in Niger, which prevented the project from identifying larger, more-cost-effective farms where equipment could be centrally controlled and operated. In addition, much of the smallholder-managed agricultural land in Niger lacks access to large-scale bulk water supply infrastructure, leading to a lack of use during the dry season. Access to a reliable source of water during the dry season required that individual borehole and water transport systems be developed for each system. Netafim faced restrictions in accessing much of the market because of an unstable security situation. Finally, the project faced significant challenges in establishing access to commercially viable equipment financing because of the high fees associated with processing agricultural loans and high interest rates charged on agricultural loans to smallholder farmers. As a result of the lack of locally available financing, the project extended its own source of funding through a credit scheme that Netafim and Agrimex delivered and administered. Two public subsidy schemes were identified, the Investment Fund for Food and Nutrition Security and the Niger Small-scale Irrigation Strategy, operated by the Ministry of Agriculture and Les Nigeriens Nourrissent les Nigeriens. The funding was designed with a 40 percent subsidy from the project, 10 percent down payment, and 50 percent loan, which reflected these public subsidy schemes for irrigation that the government of Niger proposed as part of its plan for the expansion of irrigation.

As a result of these challenges, Netafim invested significant fixed costs in time and resources to install irrigation for farmers who were operating individual plots as small as 1/40th of a hectare and to construct boreholes and install solar pumps that served a group of these small farmers within a community scheme. Nevertheless, these initial project sites provided the opportunity for Netafim to address market and design constraints faced in a fragile market and to develop a successful solution, ultimately demonstrating how combining a focus on women-led dry season farming and production of high-value crops could succeed, for farmers who were able to repay costs within 2 years. The project also established that a working irrigation market ecosystem requires international companies entering the market to establish national level expertise and technical capacity first, to enable them to serve a fragile market safely and sustainably.

Key metrics

- Percentage increase in yields, incomes, and water savings
- Percentage of female farmers trained
- Number of small and medium-sized enterprises launched

Key results

- **46** percent Increase in average yield, 71 percent increase in farmer incomes, 56 percent decrease in water use
- **538** female farmers out of 900 farmers (60 percent) trained
- **Increase** in food security, dietary diversity, and resilience to climate change
- Decrease in **gender gap**
- Establishment of a commerical **irrigation market ecosystem**
- **Three** small and medium-sized enterprises launched because of the project

Lessons learned

- Securing support from local partners is extremely important. International expertise alone will not yield sustainable commercial market development. Hence, when designing interventions in fragile markets, it is critical to identify potential local partners and stakeholders that should be part of project scoping and implementation.
- Stakeholder expectations should be managed. Yield increases are unlikely in the short term. Public sector irrigation subsidy schemes are typically underfunded or operationally inefficient, and financial institutions do not have enough capacity or capital to support seemingly risky investments in SSI at the interest rates required for a successful outcome for all parties.

Photo Credit - Richard Colback, IFC

VOICE OF A FARMER: Adopting Irrigation and Water Harvesting to Increase Crop Production

Kinaro Waithaka, a small-scale farmer from Kavaru village in Kenya's Embu County, wanted to purchase a relatively large but affordable piece of land for farming. At the time, land was cheaper in Embu than in other regions of the country. Kavuru village consisted of mostly dry grassland, where only a handful of people had settled, and Kinaro was able to purchase a 10-acre (4 hectare) plot of land in 1978. Four years later, he started cultivating his plot of land, operating from Nairobi. Like all other residents of the village, Kinaro engaged in rainfed farming, growing maize and beans and some mangoes as a cash crop and feeding a few cows on fodder. Because of low and erratic rainfall, crop choices were few, with poor harvests and sometimes total crop failure. Kinaro found it difficult to recoup his investments in rainfed farming, even when rainfall was plentiful. Kinaro was facing poverty, but he was focused on improving his quality of life, and his sons were ready to help.

In 2017, Kinaro attended an agricultural seminar alongside other local farmers at a nearby church, with trainers from Nairobi. Participants were trained on water harvesting and irrigated agriculture. Kinaro had seen a hand-dug farm pond at a neighbor's farm. He spent 30,000 shillings ($300) to dig a pond, but he had to feed the pond diggers every day, the cost of which he had not taken into consideration.

Kinaro had also excavated two shallow wells on his farm using his own labor and money to pay well diggers. He used the wells for supplementary irrigation of other crops such as bananas that were not connected to an irrigation system. Kinaro also bought a 10-m^3 plastic tank that he set on a wooden platform and connected to the farm pond and a shallow well in the compound that he used for irrigation.


Photo credit: Adam Öjdahl / IWMI

He had a petrol-powered pump that he used to pump water from the well and a smaller tank that he used to collect rainwater from the roof for domestic water.

Kinaro had a solar panel on the roof of his house connected to a submersible pump in the pond. The roof also collected rainwater channeled through gutters to an outlet pipe feeding into the farm pond. When the sun was shining (even with minor clouds), solar energy pumped water from the pond to the raised tank. Then Kinaro opened the gate valve of the tank, which would release water into buried pipes that would supply drip irrigation in the field. Thanks to the tank, he could irrigate his crops anytime he wanted to. He preferred to irrigate crops that were in high market demand, such as tomatoes, watermelon, butternut squash, and green leafy vegetables.

Kinaro earned at least KES 40,000 ($400) in profit from the tomatoes alone and sold other vegetables grown under drip irrigation. He also sold bananas (no income records) and provided supplemental irrigation to maize when it rained. His crops are no longer failing, and he is happy with water harvesting and irrigation to increase crop production.

Call to action

The agricultural sector is the largest user of water in many parts of the world, accounting for up to 80 percent of water use in developed countries, where irrigation is widely used. To balance the needs of industry, municipalities, and agriculture and ensure that policy and practice align as climate change creates greater shortages of water, a coordinated landscape-based approach must be taken (World Bank n.d.). Within the agricultural sector, this requires a climate-smart approach, considering geographic and socioeconomic factors to manage land, water, and forest resources to meet food security and inclusive green growth goals (IFC 2017).

Key areas of coordination by private sector and development agencies seeking to scale up irrigation commercially include providing guidance to public sector legislators in areas that will improve poorly developed irrigation supply chains, setting effective import duties and tariffs on inputs and irrigation equipment that adjust to the maturity of the market, and preparing for expansion and success by developing a roadmap that transitions farmers' sources of financing from donors and public subsidies to the private sector or government-supported financial markets. This coordination and transfer of roles related to financing irrigation should be timed to match the private sector's capacity to fund and price risks and returns at scale with the increased demand for these financial products as public and donor-driven subsidies are tapered off.

The sharing of non-commercial data between stakeholders to improve the sustainability and efficiency of individual irrigation projects and the development of the sector remains a critical challenge. Projects frequently overlap or introduce competing financial models, exacerbated by a lack of transparency regarding supply and demand. This leads to significantly less effective private sector engagement in early-stage markets as servicing short-term individual projects is prioritized over development of a longer-term sectoral approach that responds to predictable timing, scale, and system design and encourages competition between companies.

Each project shows a common set of data including:

- Date
- Budget
- Irrigation technology
- Crops
- Water source / pump technology
- Number of stakeholders / area
- Finance mechanisms / subsidies

In a more effective irrigation market development system, a summary of data should flow through a government ministry back to the development and private sector for future planning.

Industries outside of agriculture may also play a role in success, with physical and nonphysical infrastructure such as roads, markets, telecommunications, energy, and institutional frameworks that provide access to inputs, extension services, financing, and credit systems boosting the effectiveness and profitability of SSI systems. The demand for SSI systems generated from farmers and large public sector or donor-driven projects serving smaller farmers creates a critical mass of demand that supports the stocking of spare parts, personnel dedicated to training and aftersales service support, and development of credit or loan mechanisms. Widespread, sustained use of irrigation also requires access to markets that can absorb additional crop production. This need for a combination of supply, demand, and coordination of markets creates a significant barrier to expansion that limits development of a commercial market for irrigation equipment and services in remote areas where SSI systems are required.

Table 1. Role of Key Stakeholders in Promoting Small-Scale Irrigation (SSI)

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
PRIVATE SECTOR		
Smallholder farmers	• Move from low-value crops to high-value crops to access premium prices for production • Use irrigation during dry season or for supplementary irrigation in rainy season	• Provide stronger return on investment that demonstrates the benefits of irrigation • Increase income from land by adding additional production season, improving yields and quality in rainy season
WUAs, Farmer groups	• Promote locally proven and effective forms of irrigation to farmers within system catchment, particularly women and youth • Highlight and support good agricultural practices	• Increase use of efficient SSI within broader range of farms • Improve financial results for farmers, improve relevance of farmer organizations
Equipment supplier and input providers	• Develop marketing materials and offer demonstrations / training at public events focused on ensuring success of early adopters • Establish demonstration plots in farmer fields in areas of highest potential for market development	• Address concerns about operating and maintaining equipment, create awareness of the benefits of SSI • Create demand by demonstrating the positive impact and benefits of irrigation through farmer advocates
Off-takers	• Create and support an off-take market that buys a wider range of crops grown by farmers using irrigation	• Enable farmers to sell a portion of all crops grown (including rotational crops) to leverage the system most effectively to repay irrigation system costs
PUBLIC SECTOR		
National Government	• Leverage extension services to promote farmer-led SSI system development • Extend and improve rural infrastructure, including roads, crop storage and energy • Strengthen security of access and tenure to land including for women and youth; create public database of land ownership	• Reduce burden on public finances, scale up use of irrigation faster, increase number of farmers reached • Improve market access for equipment supply and farmers' ability to sell high-value crops to support profitable use of SSI • Improve ability of farmers and financial institutions to use land as collateral and improve security of investment in irrigation system

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
Local government	• Use participatory approaches and consultative processes to develop agricultural support programs	• Create an environment where SSI systems can be more easily introduced with greater acceptance and uptake
DEVELOPMENT SECTOR		
Development Institutions	• Support the development of irrigation infrastructure through funding, assistance with program design, and provision of technical expertise	• Increase adoption of SSI systems, improve incomes, reduce food security risks, improve nutrition
Donors	• Work with implementation partners to assess results of prior irrigation projects and alignment with new proposals	• Build strategic results-based proactive approach to funding future projects to ensure that irrigation moves from pilot to scale-up wherever possible.

Photo Credit - Richard Colback, IFC

Chapter 2: Design and System Development

Key messages

- For an efficient irrigation system, a combination of finances and natural conditions determine choice of irrigation design
- Design and development of SSI requires an integrated approach: engineering, agronomic, socioeconomic, and environmental
- Smallholder preferences for trade-off between capital costs, operating costs, and durability of technologies should be considered in irrigation design and development.
- Irrigation should be considered as part of the holistic farm system including management of soil, field layouts, crop selection, and agronomic practices.
- Access to data is a driving factor in adoption of irrigation, allowing technologies to be deployed in support of accurate, lower-cost irrigation that matches the demands and needs of crops.
- Irrigation can improve health and development outcomes by reducing excessive labor for women; increasing yields of nutrition-sensitive, high-value crops; increasing personal security; and increasing income by allowing year-round crop production.
- The role of the public sector includes promoting, developing, and operating irrigation systems. Public programs should transition from "subsidy-driven and enabling legislation" to "subsidy-supported and resource management" to encourage private sector participation.
- The role of the private sector grows once demand for SSI systems reaches a scale that justifies investment in human resources and infrastructure.
- Development agencies and donors enable early adoption of irrigation through capacity building and financial support. A longer-term market-making role may include financial risk sharing during expansion.

Summary

The approach to irrigation that the development community and the public and private sectors have taken has evolved over the past two decades, shifting from support of larger centralized systems to introduction and support of solutions for small-scale systems designed to serve widely dispersed farmers. This shift in support also requires a transfer of skills and knowledge from centralized irrigation system by professional engineers, to enable decentralized decision-making by the farmers themselves. Although individual farmer systems (SSIT) may be simple and do not require detailed analysis and feasibility studies, schemes designed to aggregate farmers are more complex and must balance a combination of financial, professional, environmental, and social perspectives. The analysis and feasibility studies of irrigation

schemes that serve groups of small farms are typically financed and supported by public sector, large-scale commercial agribusiness and development institutions, but should take a participatory engagement approach. Many of these farmer-led designs and systems have lower capital and maintenance costs and are simple to operate, enabling rapid deployment. Nevertheless, adoption of irrigation remains slow, and key components of irrigation systems such as pumps and boreholes are required to enable an estimated 85 percent of the Sub-Saharan African population that lives more than 10 kilometers from a major river or lake to benefit from irrigation (World Bank 2020). However, the introduction of new technologies requires a threshold of experience and capacity in design, operation, and maintenance that is often overlooked, leading to poor sustainability and performance of many of these systems. Providing access to a bulk supply of water from a reliable source is a tangible, clear target for public and private sector programs. International agencies and governments may be required to support the early adoption of irrigation in fragile and conflict situations, where traditional crop production systems are rainfed, and where lack of skills and experience and the cultural context do not allow for large-scale use of irrigation technologies in a commercial context.

Despite the clear advantages of promoting and supporting irrigated agriculture, transforming rainfed farms into irrigated ones is a gradual process that should be factored into project design. In addition to securing funding, completing environment and social assessments, and designing irrigation systems, the process of converting rainfed farms to irrigated farms takes 2 years. This time should be considered a requirement even for small-scale systems purchases directly, for which many of the more formal design and evaluation stages are not required.

Irrigation system design is an iterative process that includes evaluation of available resources (e.g., water, land, topography, climate, labor, technology, capital) in the context of expected outputs (e.g., crop yields and profits). The process also accounts for externalities such as markets, costs, social norms, and risks before a feasible plan is finalized. Irrigation can be designed for individual farms or groups of farmers.

Irrigation development is a process that implements the irrigation plan, including setting up the physical infrastructure and the activities required to deliver water to the crops in a field through the irrigation system. Although design precedes development, the two are intertwined, because the designer and developer must collaborate to achieve an optimal system. The justification for irrigation design and development should be clear and aligned with the project's objectives while accounting for local biophysical and socioeconomic factors.

The pace of development of irrigation in Africa has been slow, despite the huge potential. Natural, technological, human resource capacity, financial, environmental, and socioeconomic factors should all be considered, including some of the following.

Technical factors

Technical design of an irrigation system considers several fundamental factors that influence the initial design of the system:

- **Natural resources:** Measured and reported through topographic surveys and soil and water resource mapping. Access to water for irrigation is a major constraint, because large parts of Africa are arid or semi-arid and lack surface and groundwater resources.
- **Climate:** Focusing on how rainfall volumes, frequency, seasonality, temperature, evaporation, relative humidity, solar radiation, and wind affect crop water use.
- **Existing agricultural production systems:** Focused on the adequacy of rainfed systems to meet new challenges posed by climate change and declining productivity of land.
- **Proposed cropping system:** Cropping systems may include a range of crops grown in rotation or together, requiring flexibility of spacing and flow rates to allow an irrigation system to serve differing water needs.
- **Capacity of the irrigation system:** The system must be designed to deliver a flow rate that meets peak crop water demands. This requires water not only for the crop, but also to allow for any losses in transport and losses to areas outside the reach of plant root systems (between and beneath crops).
- **Environmental degradation:** Irrigation disturbs the natural environment through transfer of water to naturally dry areas. Poor water application methods and management may lead to environmental problems, including:
    - **Drainage water management:** Management of drainage and waste water poses problems, especially in low-lying areas and floodplains. For many crops, excess water applied by irrigation must be controlled and managed to reduce risks of standing water in the root zone.
    - **Depletion of groundwater:** When irrigation uses ground water, underground aquifers can be depleted, which can cause ground subsidence.
    - **Salinity build-up:** Irrigating saline soils or using poor-quality water can increase soil salinity, which can lead to accumulation of toxic salts on the soil surface, especially in hot areas.
    - **Raising water tables:** Deep percolation from overirrigation may result in rising water tables, which can lead to waterlogging.
    - **Pollution:** Irrigation may lead to pollution of water resources because of the increased use of fertilizers, pesticides, and other chemicals.
    - **Soil structure damage:** Irrigation with saline or high-sodium water may damage soil structure and make the soil too alkaline.
- **Efficiency of system:** Open earthen canals and surface irrigation methods cover more than 95 percent of irrigated lands worldwide. This wastes far more water than more efficient water conveyance using pipes or lined canals.

Financial factors

A combination of direct and indirect factors affect the commercial and financial viability of irrigation and should be considered when designing systems. Some standard measures and associated factors that may be used on assessment of irrigation systems include:

DIRECT

- **Lifespan cost-benefit analysis:** The analysis compares a range of costs with the incremental benefits of the project over the useful lifespan of the equipment. This may require trade-offs in capital costs paid at the start with operational costs paid as the system is operated and repaired—for example, the higher capital cost solar-powered motors on pumps vs the ongoing operating cost of fuel-powered motors.
    - **Investment costs:** These typically attract the greatest level of support from donors and subsidy programs because they create a barrier to entry. Investment costs may be required upfront in the form of a down payment, with links to loan repayments or as a lump sum to pay the full purchase price.
    - **Operation costs:** These include costs of operating and maintaining the system and may be timed for repayment after the harvest to allow cash inflows to match payments.
    - **Repair and rehabilitation costs:** These include repairs, improvements, and replacement of less durable components of irrigation systems and typically occur annually or after the main harvest once excess cash is generated.
    - **Return or break-even period:** Total costs are compared with expected incomes from the irrigated crop to determine incremental benefits and calculate how long it will take to show a return on investment (break-even period). Designs should allow for breakeven in the first 3 years.

INDIRECT

- **Market access:** Justification for the investment in irrigation may rely on availability of markets, costs, transport, and stability of prices.
- **Storage facilities:** High-value horticulture crops that typically support the use of irrigation may require post-harvest storage or processing facilities to obtain optimum prices and losses reduce.
- **Labor inputs:** Irrigation requires a range of labor inputs from initial installation to ongoing operation and maintenance that have direct costs and opportunity costs. These can affect selection of the water application method and irrigation design

Socioeconomic factors

Irrigation design and development affect households and entire communities. Whether the system succeeds or fails often depends on the balance between the desire to increase incomes and ensure food security and the desire to maintain cultural and social practices that dominate smallholder agricultural communities:

- **Socio-cultural considerations:** These can affect the desire of local communities to participate in irrigation and include literacy levels, disruption of cultural practices, farming knowledge and skills, previous experience with irrigated agriculture, and ability to adapt to change.
- **Land tenure, communal rights, and individual land ownership:** These affect a community's willingness to invest in longer-term improvements to agricultural systems. Security of land tenure affects the choice of equipment that farmers are willing to invest in. For example, female farmers may opt for mobile pumping units that they can move around.
- **Water access:** Most water sources are multiple-use and multiuser systems, and although they may be physically or financially viable, social and legal challenges must be considered.
- **Social challenges:** Conflicts between water users arise especially when multiple users and uses depend on the same water sources. Abstraction of water can also reduce flows to downstream areas or competing users in the same area, resulting in water-related conflicts.
- **Health and environmental impacts:** Development of irrigation sometimes entails clearing natural vegetation to create agricultural lands. Water abstraction also affects the overall water balance of ecosystems, and irrigated agriculture can cause pollution within and beyond the boundaries of the fields where water is applied.
- **Externalities:** Irrigation development must include coping and resilience measures against unexpected shocks such as natural disasters that may require crop loss and life insurance for farmers or first loss guarantee mechanisms for financial institutions.

When development institutions or public sector and commercial private sector organizations design and develop irrigation schemes that comprise many SSI systems, feasibility studies should include recommendations for measures to reduce or mitigate the negative impacts identified while assessing these factors. In addition to the basic list of factors outlined above, several other combined technical / financial factors that constrain or support expansion of irrigation are summarized below:

ENERGY

SSI systems in Sub-Saharan Africa typically use a nearby source of water and have limited access to mechanized pumps to transport to fields that are far away. In many countries this means labor-intensive irrigation methods use water during the dry season to provide supplemental irrigation to address short-term water shortages. For example, in Mali, Niger, and Nigeria, farmers used water-lifting devices with simple rope-and-bucket arrangements to collect water for irrigation.

Photo Credit: Liudmila Pestun, IFC

A broader range of small-scale technologies designed specifically for small farms has become more widely available, from treadle pumps to motorized solar-powered and fossil fuel–powered or electric pumps. Systems have shifted from manual power to mechanization as pumps, in particular solar-powered pumps, become more affordable and available. This provides a range of social and technical benefits, including allowing water to be transported over greater distances under pressure and to be applied efficiently, reducing the gross water requirement. This also increases security by eliminating travel to distant water sources, particularly for women. Nevertheless, gravity-fed and river diversion methods of surface irrigation have remained the dominant form of accessing and distributing water for irrigation in remote areas because of challenges with sourcing and maintaining pumps.

In a study conducted in 2021, irrigated cultivation of more than 80 percent of cropland in southern Africa and a large proportion of cropland in central Africa was identified as being cost effective using solar-powered irrigation (Xie et al. 2021). Recent reports show that use of solar-powered irrigation systems is increasing, with lower costs of solar panels making these systems competitive with fuel-powered pumps when considered across their lifecycle (capital plus operating costs / duration of use), although according to a recent global lighting report, government subsidies are the main force behind the market for solar-powered irrigation pumps (The 2020 Global off-grid solar market trends report).

One of the markets leading conversions to solar-powered irrigation is India, where it is reported that more than 150,000 solar-powered water pumps have been sold, largely because of significant government subsidies that combine state and federal incentives. Conversely, lack of subsidies has been identified as a limitation on broader adoption of these capital-intensive pumps by smallholder farmers in developing countries where subsidies are not provided or reliance on limited scope and scale become the primary driver of demand. The private sector approach to increasing market demand includes introduction of paying in installments or use of the product as a service, and the leasing and service provider models. These business models to provide financing had shown great promise in 2019, but the COVID-19 pandemic has limited them because of the need for social distancing and isolation to prevent the spread of the disease (GOGLA 2020).

WATER RESOURCE AVAILABILITY

Access to water for irrigation is a major constraint, because large parts of Africa are arid or semi-arid and lack surface and groundwater resources. Irrigation system designs therefore vary depending on water source, delivery method, and volume of water required. Low-operating cost gravity fed irrigation methods such as furrow, basin, and micro-basin may be used where water can be distributed in large quantities using height differences from source to field but, if pumping is required, access to energy pipelines must be installed to transport the water and operational costs are higher. As water scarcity reduces the efficiency of water use, donors and governments are promoting the use of more-advanced, sustainable irrigation systems such as drip irrigation and low-pressure sprinkler systems for use in SSI. Advanced systems rely almost exclusively on fossil fuel or solar energy-powered pumps or access to low-cost, reliable energy from the grid. Research suggests that pumped irrigation from groundwater and surface water bodies has contributed almost entirely to expansion in irrigated area in the past 50 years (Lu and Grundy 2017). In areas where market demand is concentrated, technical capacity can also be developed. This has typically been closer to urban centers or clustered around key offtake markets, including commercial farms and contract outgrowing areas. Use of irrigation in these cases is part of an integrated shift in production, including use of inputs such as improved seed, fertilizers, herbicides, and pesticides, often supported by the private sector. This is particularly important for international manufacturers and distributors of irrigation technologies such as drip irrigation and low-pressure sprinkler systems, which require local networks of small and medium-sized service providers who can deliver technical support directly to individual farmers.

INFORMATION TECHNOLOGIES

Increasing access to data is also a driving factor in adoption of irrigation, with low-cost weather stations recording and forecasting climate data and remote sensing and field-based crop monitoring allowing for more accurate, lower-cost use of irrigation to match the demands and needs of crops. This provides additional incentives to a younger generation of farmers, who understand and seek to leverage information technology, particularly through wireless data that can be easily accessed on mobile devices such as cellphones. The demand for modernization of agriculture is therefore closely linked to emerging generational differences and rising education levels. The rapid adoption of mobile phones also provides insights into the potential of other technologies that can serve off-grid communities.

Gender

Irrigation can improve health and development outcomes by reducing excessive labor for women; increasing yields of nutrition-sensitive, high-value crops; increasing personal security; and increasing income by allowing year-round growing. Women's role in implementation of irrigation systems is critical, because their involvement yields significantly better outcomes at all levels of agricultural production, greater efficiency of water use, and greater sustainability of systems. Decision-making processes during a project's feasibility assessment, design, and implementation stages should include women and support their access to ownership through farmer organizations or WUAs.

Photo Credit: Liudmila Pestun, IFC

A recent baseline assessment that IFC conducted on the gender contribution of labor to the rice sector in India found that women provided 60 percent to 80 percent of the labor, much of it focused on planting, harvesting, and managing water flows during irrigation cycles, yet women continue to face significant barriers to purchasing and owning irrigation systems. The design and implementation process of irrigation development programs should ensure that equipment design and operational requirements, access to financing and training, and land access rights support women's use of irrigation. Changing the focus and design of private and public sector irrigation projects to account for the perspectives of women and the challenges they face will have the largest impact on productivity and efficiency.

To that end, engagement and consultations with women throughout the process are essential to addressing their concerns and priorities and ensuring sustainability. Technical and commercial training for women, equitable land access rights, and access to financial resources should be the core prerequisites and elements of project design. Targeted extension and advisory services may also be needed, including training equipment and service providers who provide "last mile" linkages to farmers. Such services are currently not targeted toward women, and there is often no clear institutional framework to support them.

Key roles of stakeholders

The private and public sectors play key roles in the supply of and demand for irrigated agriculture, indicating the importance of a coordinated approach that leverages the strengths of each and reduces the risk of competing objectives and solutions.

PUBLIC SECTOR

The role of the public sector is ongoing throughout the process of promoting, developing, and operating irrigation systems in a country, but the scale of requirements is vast in many countries and requires that the private sector also be engaged when a sufficient return on investment can be made. Government programs should therefore be designed to transition from largely "subsidy-driven and enabling legislation" to "subsidy-supported and resource management" to reduce competing financing models and support the increasing role of the private sector. The transition should be made once commercially viable sustainable demand has been established and the private sector can deliver a suitable supply of equipment supported by well-functioning distribution and service models in the country.

The public sector also has an essential role in building and operating bulk water supply infrastructure such as dams and reservoirs that provide strategic reserves of water, may contribute to energy production, and affect downstream water flow. This infrastructure has strategic importance and is seldom developed solely by the private sector for smallholder benefit. At the farm level, the public sector has traditionally focused on promoting and delivering financing and policy to increase food security and improve the quality of life of farmers operating at a subsistence or precommercial level, although a transition in the role of government to focus on supporting adoption of irrigation by farmers operating at a commercial scale is critical. Policies aimed at supporting sustainable land and water resource management; promoting establishment of companies that can provide irrigation equipment, services, and training; and strengthening land rights and land ownership provide the basis for broader use of SSI and community-level irrigation. The ongoing public sector role of subsidizing irrigation for small and vulnerable farmers also contributes to the critical mass required for the private sector to engage, and where significant donor presence plays a part in the market dynamic, the public sector should encourage coordination of all stakeholders to reduce competing models—for example, where public grants or donor subsidies might crowd out private financing solutions.

PRIVATE SECTOR

The role of the private sector should grow as demand for SSI systems reaches a scale that justifies the private sector's investment in human resources and infrastructure required for a sustained market presence. This includes infrastructure such as warehouses for inventory and spare parts as well as retail outlets in rural areas where irrigation is required. This relies in part on withdrawal of competing development sector projects and public sector projects to allow farmers to become customers. A transition in roles prevents short-term grants and project subsidies from crowding out sustainable commercial solutions, although in some cases, a blended or partial subsidy model may be required to allow loan payback periods to be shortened, interest rates to be lowered, or irrigation services to reach the most vulnerable populations in an inclusive system.

Private sector equipment providers are typically more engaged in products and services related to irrigation that occur on the farm itself (last-mile irrigation systems) than in bulk water supply. The broader agribusiness sector, however, has a broader role, with supply-side and demand-side roles that require a combination of financial and technical contributions to support the commercial scale-up of SSI systems. In terms of supply, a network of equipment manufacturers, distributors, retailers, and service providers is essential to enable farmers to design, install, operate, and maintain systems. On the demand side, the private sector may operate as the key market off-taker, providing secure pricing and a volume of demand to contract farmers or outgrowers that allow these farmers to access crop season financing. The security of this financial model may be extended to SSI systems using agreements that link banks, off-takers, farmers, and donor agencies to reduce payment default risks that occur in multi-season or multiyear SSI system loans.

DEVELOPMENT AGENCIES AND DONORS

The primary role of development agencies and donors is to enable early adoption of new irrigation technologies and practices through capacity building and financial support. A longer-term market-making role may include financial risk sharing during expansion within a blended public-private model of engagement.

A variety of organizations ranging from public sector–focused agencies such as the World Bank and IFAD to private sector–focused agencies such as the International Finance Corporation (IFC) provide this support. Specialized teams at IFC and IFAD also provide additional technical assistance at the farm level. The combined technical and financial support is designed to play a catalytic role of introducing innovation and reducing commercial or financial risks that may prevent early adoption of SSI, particularly in fragile and conflict-affected situations or less developed markets.

FARMERS

Strategic engagement with smallholder farmers is at the center of public and private sector activities related to irrigation, in particular progressive farmers who play a key role as irrigation system innovators and promoters. Progressive farmers are supported and encouraged to promote the successful technologies and practices that they have used and to support further localization of SSI systems to meet the specific needs of their crops and growing conditions. This "farmer to farmer" validation of benefits that are being promoted is often a key factor in building confidence in irrigation within a broader base of farmers, many of whom have predominantly operated rainfed production systems and lack experience and trust in the technology. Organization of farmers into groups can provide more efficient access to bulk water supplies and ensure effective maintenance and equipment, such as through local WUAs. WUAs can also receive extension services and technical skills. Groups of farmers, including WUAs and system operators, also play a role in ensuring that individual farmers are organized effectively to ensure that demand is predictable, timely, and at scale.[9]

Matching irrigation design to landscape, water source, and crop

For an efficient irrigation system, natural conditions such as land topography, soil type, climate, water source, and crop to be grown determine choice of irrigation design. It is essential to evaluate the water supply system from water source to irrigated field. In most cases of SSI, local companies, typically small or medium-sized enterprises that provide the design and supply of irrigation equipment as a combined product, design SSI systems, although, in cases in which large groups of farmers are making design decisions from a limited number of options, extension services, development assistance projects, or government agencies who are supporting the scale-up of SSIT may also provide technical capacity building to enable them to make a selection. Table 2 shows which irrigation methods are suited to respective natural conditions.

9 Sumuni, P.M. 2016. "Influence of institutional set-up on performance of traditional irrigation schemes, a case study of Nyandira Ward, Mvomero District Tanzania." Master thesis, Sokoine University of Agriculture, Morogoro, Tanzania.

- **Soil Type:** Sandy soils have low water-holding capacity and high infiltration rates and so need frequent but small irrigation applications, in particular when the soil is shallow. Under these circumstances, sprinkler or drip irrigation is more suitable than surface irrigation. On loam or clay soils, all types of irrigation methods are suitable. Clay soils with low infiltration rates are ideally suited to surface irrigation but require proper management to enhance internal drainage to avoid water logging and erosion. When there are different soil types within one irrigation system, sprinkler or drip irrigation is recommended to facilitate even water distribution.

- **Land Slope:** Sprinkler and drip irrigation are preferred over surface irrigation on steep or unevenly sloping lands because they require little or no land leveling. An exception is rice grown on terraces on sloping lands.

- **Climate:** Strong winds can disturb water spraying from sprinklers. Under very windy conditions, drip or surface irrigation methods are preferred. In areas of supplementary irrigation, sprinkler or drip irrigation may be more suitable than surface irrigation because of its flexibility and adaptability to varying irrigation demands on the farm.

- **Water Source Availability:** Quantity of water available will determine the area and type of crop that can be put under irrigation throughout the year. Such factors as quantity and quality of water, type of water source, and cost of developing the water source should be assessed for a proposed project. Water application efficiency is generally higher with sprinkler and drip irrigation than surface irrigation, so these methods are preferred when water is in short supply.

- **Water Quality:** Surface irrigation is preferred if the irrigation water contains sediments, which would otherwise clog drip emitters or sprinkler nozzles. Sprinkler irrigation is generally not recommended if saline water is used to irrigate sensitive crops such as leafy vegetables because of the risk of leafy burn. If the irrigation water contains dissolved salts, drip irrigation is particularly suitable, because less water is applied to the soil than with surface methods.

- **Crop Type:** Type of crop is usually matched to irrigation method. For instance, surface irrigation methods are commonly used for staple food crops (e.g., rice, maize, legumes), although they use a lot of water. Sprinkler and drip irrigation methods, because of their high capital investment, are mostly used for high-value cash crops such as vegetables, coffee, fruit, and flowers. Drip irrigation is used for almost all crop types because the technology has become more affordable.

Water application technologies in SSI

Water application methods commonly used to apply water at the field level in SSI include:

- **Buckets or cans:** Water is abstracted from rivers, shallow wells, and other sources and poured on crops.

- **Surface irrigation**

    - Basin irrigation involves applying water to crops grown in artificially depressed fields surrounded by small bunds that retain the water for ponding.

    - Furrow irrigation consists of parallel channels (furrows) separated by slightly raised beds or ridges running at a slight gradient to allow for the slow flow of water and wetting of the soil from the entry point (the head) to the tail end.
    - Spate irrigation uses flood water diverted and channeled to bunded basins containing a crop during and immediately after a rainfall event.
- **Sprinkler irrigation**
    - Sprinkler irrigation is a method of applying irrigation water under pressure to crops in the form of a thin spray, designed to mimic natural rainfall.
    - Micro-sprinkler irrigation, a variation of the conventional sprinkler system, uses mini-sprinklers or spray jets that use lower operating pressures and apply water more uniformly.
- **Center pivot irrigation**
    - A circular irrigated area is created across one or several fields.
    - A center pivot is a type of sprinkler irrigation system made of steel towers called span pipes that rotate in circles around a fixed pivot structure covering 25 to 70 hectares.
- **Drip irrigation (fixed sets, drum kits, bucket kits, home-made drip systems)**
    - Water is delivered drop by drop at or near the root zone of the planet
    - The system consists of a network of lateral pipes, which is particularly suitable for SSI, because it is efficient and saves water.

Photo Credit: Stephan Gladieu / World Bank

Table 2. Criteria for Selecting In-Field Irrigation Methods for Different Conditions

IRRIGATION METHOD	SUITABLE CROPS	SUITABLE SOILS	SLOPE	WATER REQUIRED/ TIMING	LABOR (DAYS/ HECTARE)	MAIN ADVANTAGES	MAIN DISADVANTAGES
Bucket	Horticultural	Most soil types	Relatively flat	Small quantity over extended time	11.4	Inexpensive, requires little land leveling	Labor intensive
Basin	Row field crops and horticultural crops; rice and trees	Fine-textured soils	Relatively flat	Large quantity at same time	10.5	Good control of large flows; can be used to leach excess salts	May require land leveling and hence costly; labor intensive
Furrow	Row field crops and horticultural crops	Most soil types	Very gently sloping (2 percent)	Large quantity over extended time	9.5	Permits irrigation of large fields; relatively inexpensive to operate	Difficult to achieve uniform water application without land leveling; labor intensive
Spate	Drought-resistant crops that can also withstand temporary water logging (e.g., grasses)	Deep alluvial soils	Very gently sloping (<2 percent)	Large quantity at same time. (uses flood water)	11.2	Permits irrigation in areas where convectional off-river storage for irrigation is not practical because of high sediment loads during floods	Relies on rainfall and requires sites where all conditions are right; sedimentation; labor intensive
Sprinkler	Most crops except rice	Light-textured, highly permeable soils	Wide range of slopes, including uneven terrain	Medium quantity, required regularly	7.2	Highly efficient and can be used in area with limited water supply; suitable for rolling topography	High installation and maintenance costs; relatively high energy requirements; requires skills in management and operation

IRRIGATION METHOD	SUITABLE CROPS	SUITABLE SOILS	SLOPE	WATER REQUIRED/ TIMING	LABOR (DAYS/ HECTARE)	MAIN ADVANTAGES	MAIN DISADVANTAGES
Center pivot	Most crops, including plantation crops such as sugarcane	Most soil types	Relatively flat	Large quantity over extended time	2.9	Highly water efficient and can be used in area with limited water supply; can be installed rapidly; advanta-geous for new devel-opment projects	High installation and maintenance costs; requires skills in management and operation; affected by wind; excessive runoff at last pivot tower
Drip irrigation	Trees and low-density crops	Wide range of soil types	Wide range of slopes	Medium quantity, continuously required	2.5	Efficient water use; low energy require-ments; suited to fertiga-tion; low labor require-ments; not limited by topography	High initial cost; risk of clogging of dripper lines; requires skills in management and operation

Sources: Mati 2012

Case studies

The case studies below from Africa demonstrate that SSI can be viable and sustainable and can be used to increase agricultural production, sustain rural lifestyles, and reduce rural poverty. The key ingredients for success include farmer participation throughout the development process from planning, design, and installation to operation and maintenance; selecting appropriate irrigation technology; mainstreaming women and youth during the process; and setting up support systems such as farmer training, extension services, access to financing, and links to markets.

Photo credit: Joe Ronzio/IWMI

CASE STUDY 3: Using Pumps and Drip Irrigation Technology in Burkina Faso

Country: **Burkina Faso**	Years: **2015-2016**	Organization involved: **IFC**	Crops: **Maize, tomato, onion, eggplant, green beans, papaya, potato, cabbage, green pepper**	Irrigation systems: **Drip irrigation, semi-Californian**

In Burkina Faso, 70 percent of agricultural production is rainfed, and farmers typically own or operate areas of less than 1 hectare. The agricultural sector employs approximately 92 percent of the working-age population and accounts for 34 percent of the country's GDP, so adopting the most efficient irrigation systems will be critical to boosting agricultural productivity and reducing malnourishment.

Selection of an irrigation system is based on a series of technical, commercial, and financial factors that typically include initial capital costs, ongoing operating costs, crop types, equipment availability, and water source. IFC assessed three commonly promoted smallholder irrigation systems in Burkina Faso. The costs and benefits of each system were calculated to identify the increase in gross margins that farmers investing in these efficient irrigation technologies could achieve. The systems were selected to allow for comparison of crop requirements, pump type, and in-field irrigation water delivery system variables.

- Manual pump (treadle) for water abstraction with drip irrigation for water application
    - The treadle pump required more labor (higher opportunity cost of time) but had a lower direct operating cost because it did not require fuel or maintenance.
    - The drip irrigation kit had a high capital cost, but it took less time to irrigate or operate the system in the field with optimized water use efficiency.
- Motor pump to transport water to the field with drip irrigation water delivery
    - The motor pump required less direct labor but required fuel and greater maintenance, resulting in higher direct operating costs. The capital cost was like that of the manual pump because low-cost motor pumps were readily available.
    - The motor pump was also combined with a drip irrigation kit to optimize water use efficiency and reduce the time to irrigate, decreasing operating costs.

- Motor pump and semi-Californianan water distribution in the field
    - The semi-Californian system provides high water flows at each outlet to a field, but this high flow rate is not efficiently distributed, resulting in lower water use efficiency and higher pump operating costs than with drip.
    - In a semi-Californian system, water is distributed through a buried pipe to a network of pipes that deliver water to open channels running into individual parcels of land. There are also small intermediate reservoirs to balance water between distribution branches.

The assessment found that using a motor pump in combination with drip distribution resulted in higher crop yields, more efficient water use, and the ability to apply water and fertilizer exactly where and when needed, all of which led to much higher gross margins.

Gross margins were also significantly higher for the system using a manual pump combined with drip irrigation delivery. Although the pump operating cost was the lowest, frequency of irrigation was suboptimal, because farmers did not want to use manual labor to operate the pump, resulting in lower yields.

Finally, combining the motor pump with semi-Californian delivery led to lower margins, because water had to be applied to the entire field, which increased operating costs per irrigation cycle and lowered the distribution efficiency of water and fertilizer. Farmers also reduced the frequency of irrigation, which resulted in water stress to crops and reduced yields, despite a large amount of water applied during the season.

Photo Credit: Photo by Isaac Masingati, Feed the Future Malawi Ag-Diversification

Key metrics

- Capital cost
- Annual operating cost
- Annual gross margin increase
- Increase in gross margin from baseline

Key results

Drip kit and motor pump: maize, tomato, and onion cultivated on 0.25 hectares

- Capital cost: **$7,000** per hectare
- Operating cost: **$1,500** per hectare per year
- Increase in gross margin: **$36,000** per year (400 percent from baseline)
- Capital cost: **$7,000** per hectare
- Operating cost: **$500** per hectare per year
- Increase in gross margin: **$10,000** per year (120 percent from baseline)
- Semi-Californian and motor pump: maize, eggplant, tomato, onion, potato, cabbage, and green pepper cultivated on **0.25** hectares
- Capital cost: **$200** per hectare
- Operating cost: **$2,000** per hectare per year
- Increase in gross margin: **$850** per hectare per year (10 percent from baseline)

Lessons learned

- Adoption of the most effective and efficient irrigation technology depends on farmers' initial awareness of it and knowledge of its proper use. This includes suitability of farmers' land, choice of crops, level of intensity of cropping practices, and proper maintenance of equipment. Equipment manufacturers' willingness and ability to provide important technical support and after-sales service to farmers play an essential role.
- Lack of access to financing that farmers need to invest in efficient irrigation equipment such as motor pumps and drip irrigation equipment is the main constraint on technology adoption. In Burkina Faso, for instance, only 5 percent of overall bank lending is for agriculture because of high operating costs, the high risk of the sector, and the need to tailor financial products. An even smaller proportion supports efficient irrigation investments.
- Although treadle pumps and semi-Californian systems may be installed for lower capital costs, the requirement for more manual labor limits their use. The water application methods typically used in the field also deliver significantly lower water use efficiency and insufficient water to meet peak demand, resulting in lower yields and returns on investment.

Photo Credit: Mulugeta Ayene/WLE

CASE STUDY 4: Drip irrigation Technology, Solar-Powered Solutions, and Conservation Agricultural Practices in Ethiopia

Country:	Years:	Organizations involved:	Crops:	Irrigation systems:
Ethiopia	**2013 – present**	**Feed the Future Innovation Laboratory for Small-Scale Irrigation; U.S. Agency for International Development**	**Onions, garlic, cabbage, lettuce, carrots, chilis, tomatoes**	**Drip irrigation technology and shallow ground water systems**

Ethiopia has a population of 110 million, and its economy relies heavily on rainfed agriculture, which is the main source of livelihood for 85 percent of its population, generating 39 percent of its GDP. Despite this economic and social significance, the population is vulnerable to food shortages and income shocks because of unreliable rainfall. The use of SSI by a large number of users is emerging as a key solution to the impact of climate change.

The U.S. Agency for International Development conducted a study on the use of irrigation by smallholder farmers in Ethiopia's Amhara region. The main water source in the region is groundwater at depths of 4 to 8 meters after the rainy season and 10 to 20 meters during the dry season. Water is accessed through hand-dug wells that individual farmers own and are located close to their homes or fields. Use of this water varies across the region, with some wells also providing water for livestock or domestic use and others for perennial crops such as khat. Although growing perennial crops increases the income of households, these crops are not nutritious. Fodder crops, including Napier grass for feeding livestock, and short season irrigated crops such as onions, garlic, cabbage, lettuce, carrots, chilis, and tomatoes improve nutrition while also yielding high incomes. Rainfed systems produce crops during the rainy season, with farmers mainly planting staple cereals such as teff, maize, and finger millet.

Solar-powered pumps have recently been introduced to lift water without risk of injury or need for manual labor. These pumps can be connected directly to a closed system of low-cost pipes for use in handheld spray and drip irrigation or to surface irrigation in fields that are further from the well.

Households with access to labor can use surface irrigation effectively if the water is managed during the irrigation cycle to direct its flow across the field or moved through a field with handheld spray hoses. Households where labor is scarce prefer to use systems in which the water flow across the field can be controlled centrally, such as drip irrigation, which requires fewer people to control the water flow, but drip irrigation technology is significantly more expensive and can be complicated to operate because of the need for regular maintenance and careful control over the quality of water to prevent blockages.

Drip irrigation technology, complemented by solar-powered solutions and conservation agricultural practices, offers an ultimate solution that has proved sustainable and efficient. Where used, these approaches have helped vegetable farms increase productivity by 30 percent while reducing water use by up to 30 percent. These systems can be multipurpose, increasing incomes and improving crops for nutrition while giving households (and women in particular) access to a secure source of water close to their homes.

Key metrics

- Irrigation labor productivity: labor hours per kg
- Yield: percent age increase
- Water use efficiency
- Area under irrigation: Ha

Key results

Increase in labor productivity by up to 10 times:

- Hand pulley and manual irrigation: **3.6 hrs**/kg of onions
- Solar-powered pump and handheld spray: **1 hr**/kg of onions
- Solar-powered pump and drip irrigation: **0.3 hr**/kg of onions

Irrigated area doubled

Yield increased by **30 percent**, water use reduced by up to 30 percent (drip plus solar pumps plus conservation agriculture)

Lessons learned

- Tailoring technological solutions to specific site conditions is the most effective way to meet farmers' and ecological needs. Use of shallow groundwater and pressurized irrigation can supply sufficient water to meet requirements for vegetables and fodder while avoiding negative environmental externalities.
- Conservation agriculture uses less water and labor than conventional tillage and therefore offers a potentially important avenue for improving household nutrition and diversifying livelihood options for women.
- Solar-powered pumps are preferred over other SSI technologies because they reduce household labor and enable water to be used for multiple purposes.
- Production of irrigated fodder is becoming more strategically competitive with other crops (e.g., crops for human consumption and industrial use) as farmers focus on optimizing their overall farm profitability, with an awareness of forage's contribution to increasing milk production.
- Limited access to agricultural inputs or to markets and credit constrains the ability to expand SSI.
- Availability of labor may determine selection of irrigation system technologies.

Photo Credit: Nabin Baral / IWMI

VOICE OF A FARMER: The Benefits of Introducing Productive Irrigation Technologies - Solar Water Pumps

Rupy Praja, a farmer in Raksirang, a village in the remote Makwanpur district of central Nepal, was struggling to make ends meet. Like many farmers in her village, she faced many challenges, including lack of reliable sources of water and electricity, partly because Nepal, one of the most vulnerable countries to climate change, was experiencing increasingly turbulent weather, characterized by extended droughts that gave way to sudden landslide-triggering rains.

Rupy's challenges began to ease when Saral Urja Nepal, an energy services start-up, installed a solar-powered water pump in her village. Gender-Smart Solutions and the SUN5P project installed these solar-powered pumps to distribute water for drinking and irrigation to 107 homes in seven villages, providing approximately 150,000 liters of water per day. Of the 15 percent work required from the villagers in form of "labor for equity," women contributed 33 percent, and men contributed 67 percent. The women were not generating income before the project. Through their work in the project, they generated up to 1,000 rupees per day. Saral Urja Nepal has since expanded its IFC-supported work in Rupy's village to include training in greenhouse use and opening seedling production centers for female farmers.[a]

The solar water pumping technology has allowed Rupy to install water taps for domestic and agricultural use. Access to water provided her with new opportunities, allowing her to grow vegetables to supplement her income and provide food for her family with less work. This has not only helped her dedicate more time to her home and children, but also encouraged her to increase her economic activity and graduate to growing ghost peppers (fiery chilis popular in regional cooking) using drip irrigation and greenhouses.


Photo Credit - Richard Colback, IFC

Similarly, solar-powered pumps allowed fish farmers to increase their yields through greater supply of water and aeration, and for livestock herders, it increased income by providing water for their animals.

The use of solar energy, community water reservoirs, and smart water management systems is helping communities like Rupy's mitigate variations in local water availability. Private equity funds can invest in providers of village-scale multiple-use solar pumping systems, although there are financial and market access barriers to generating large-scale commercial sales of solar water pumping systems. Nevertheless, Nepal has shown that, with access to financing, the challenges can be overcome by taking advantage of relative cost savings, increasing reliability of electricity and irrigation systems, increasing access to technology and technological assistance, and reducing greenhouse gas emissions. Other barriers, including lack of awareness of technology, high upfront costs, and absence of technical repair services, can be overcome through demonstration projects, linkages with finance institutions, and partnerships with technology providers.

a. IFC invested in Saral Urja Nepal through Business Oxygen as part of IFC's Global Small and Medium Enterprises Ventures initiative, with funds from IFC and the Climate Investment Funds Pilot Project for Climate Resilience. Business Oxygen is Nepal's first private equity fund with a climate focus.

Call to action

The design and development of sustainable irrigation systems require a coordinated approach that considers the needs of farmers from a variety of disciplines including engineering and the agronomic, socioeconomic, and environmental fields. These disciplines may be found in either the private or public sector teams who are responsible for conducting analysis, feasibility, design, and development of schemes. In addition, smallholder farmers, particularly women and youth, must be involved in the process from the outset to ensure that broader equity across a fuller range of stakeholders is achieved.

The public sector plays a key role in removing structural barriers at a national level that hinder the development of SSI systems by weakening land collateral or reducing incentives to invest in irrigation infrastructure. This includes expanding land ownership rights, improving recordkeeping of land titles, and setting quality standards for equipment to qualify for subsidy participation. Local governments can also remove barriers affecting water resources by ensuring that multiuser water source systems are legally permissible and by improving local water delivery, transportation, and market infrastructure.

Table 3. Role of Key Stakeholders in Designing and Developing Small-Scale Irrigation (SSI) Systems

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
PRIVATE SECTOR		
Smallholder farmers	• Participate in farmer field days, visit demonstration plots, and share feedback on system performance with equipment providers • Join savings group to collect sufficient funds for down payments or loan eligibility • Ensure equality in decision-making around irrigation and water use between men and women within a household • Assess local water resource availability to ensure adequacy to meet crop water requirements • Consider lifecycle cost of system to ensure that initial capital cost and replacement costs are balanced	• Equipment providers receive direct feedback from their customers and improve service and range of products • Use loan from group for down payment, access to commercial loan, or farmer contribution to subsidies • Improved water management and equitable access to water resource • Purchase a system that is not over specified for available water supply or results in over-abstraction • Establish realistic costs of system to allow for return on investment and replacement when needed
WUAs, Farmer groups	• Provide reliable, suitable, equitable water supply to farm edge - right amount, right place, right time • Involve women and youth in the design process and provide them with targeted access to training • Evaluate seasonality and adequacy of water sources to ensure sufficiency of bulk water supply • Ensure that aggregated demand will be met more efficiently than a collection of individual systems	• Demonstrate value to community to maximize area served and ensure ongoing operation of WUA over time • Irrigation designs meet needs of all users, build broader capacity , leverage innovation and experience of all participants • Match supply and demand of bulk water during peak season demand in system, set realistic delivery targets • Improve sustainability of resources and financial benefits for farmers by managing water resources as a WUA
Equipment supplier and input providers	• Develop local partner network with input and service providers • Provide training to retailers, distributors, and extension officers to optimize performance of equipment • Promote use of technical and commercial assessments during design (e.g., markets, labor, operational) • Develop detailed program for training in equipment operation by farmers, particularly women	• Increase financial impact by combining irrigation with inputs that are enhanced by irrigation, and maximize return on investment • Reduce design failures, improve matching of equipment to resources and farmer needs • Improve return on investment for farmers, sustainable use of systems throughout season, increased capacity to repay full costs of systems • Improved knowledge by system operators on how to use and properly maintain equipment, leading to greater market demand

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
Off-takers	• Provide agronomy extension services for targeted crops • Enter agreements to provide direct repayment to equipment providers or banks for irrigation loans from proceeds of farmer crop deliveries	• Improve yields and quality of irrigated crops to maximize profits • Reduce risk of non-payment for loans, thereby increasing availability of financing and lowering interest rates (default rate reduction)
PUBLIC SECTOR		
National government	• Update the regulatory framework that governs access to water, irrigation equipment, and high-quality agricultural inputs • Improve security of access and tenure to land and improve recordkeeping of land titles • Legislate to prevent over abstraction and monitor environmental impact of irrigation solutions • Evaluate optimal systems for SSI and provide menu of approved options eligible for grant support	• Increased private sector participation, enhanced effectiveness of irrigation, balancing of short-term productivity with sustainability • Increased willingness of communities to invest in longer term improvements to agricultural systems • Ensure sustainability of natural resources and equitable access to clean water for the full range of water users • Improve effectiveness of grants and support farmers to make optimal decisions; build critical mass of common systems with improved spares, servicing, and replacement
Local government	• Build technical skills in irrigation through extension agencies • Coordinate activities of stakeholders working to promote long-term use of irrigation • Promote multiple-use water systems • Support training to strengthen local capacity to design, install, and manufacture irrigation equipment and to provide repair and maintenance services • Set up support systems such as farmer training, extension services, access to finance, and links to markets	• Improve effectiveness, sustainability, and profitability of using SSI systems • Reduce competition between models (donor, subsidy, commercial) and improve sustainability of solutions • Reduce conflicts over water resources • Prolonged life of SSI systems • Empower farmers to be more self-reliant in operating SSI systems
DEVELOPMENT SECTOR		
Local government	• Coordinate project development with private sector, public sector, and peer organizations • Test and implement projects, scalable and sustainable projects • Adopt a holistic approach when supporting development of the rural sector	• Reduce competition between models (donor, subsidy, commercial) • Demonstrate effective solutions that the private sector can scale up • Develop irrigation in context with other inputs, infrastructure, and market capacity
Local Government	• Support programs to de-risk irrigation, such as first loss guarantees • Provide finance to climate funds that provide blended credit terms for irrigation	• Increase early-stage engagement by financial institutions and equipment providers • Provide access to longer term funding that seeks lower rates of return

Chapter 3: Asset Management

Key messages

- Irrigation and drainage (I&D) schemes often fall short of their potential because of deterioration of physical infrastructure due to failure to invest adequately in maintenance, repair, and renewal.
- Asset management planning (AMP) provides a way to assess I&D infrastructure and determine short-, medium-, and long-term investments needed for performance maintenance.
- Water users and irrigation service providers can use AMP to set and collect fees and provide services.
- AMP links investments and expenditures to clearly defined user-driven levels of service, ensuring adequately functioning I&D infrastructure and proper management.
- Irrigation systems deliver different levels of service based on their operating costs. Farmers should be aware of the corresponding irrigation service fee (ISF).
- AMP combines the technical aspects of an I&D system's management, operations, and maintenance with high levels of user participation in planning and decision-making.
- Irrigation planners, managers, users, and funding institutions are advised to adopt AMP for their irrigation systems to ensure that investments and assets live up to their potential in the long term.

Summary

AMP is a process for assessing the condition and performance of I&D infrastructure and determining the investment required in the short, medium, and long term to maintain that infrastructure so that it can deliver the required level of service.

A core principle related to the use of asset management for infrastructure is that the assets (e.g., canals, drains, structures) serve a function from which benefits can be derived. Maintaining or enhancing that function results in sustained or enhanced benefits by facilitating operation of the I&D system and thereby crop production.

I&D systems, regardless of size, often fail to perform to their potential because of deterioration of the physical infrastructure that results from failure to invest adequately in maintenance, repair, and renewal of the infrastructure. AMP addresses this by providing a structured, systematic mechanism for determining investment costs and linking these costs to the investment required, the level of service to be provided, and the ISF that can feasibly be charged to cover the investment required.

AMP principles and practices

ROLES AND RESPONSIBILITIES

Private sector companies that own or are hired to manage I&D schemes or groups of farmers who want to properly maintain and sustain their I&D schemes can use AMP. Regulatory authorities can also use it in the public sector, where publicly owned infrastructure has been sold, franchised, or transferred to non-governmental bodies. Such infrastructure often serves a monopoly function (e.g., delivery of irrigation water, potable water supply and sanitation), and the public sector has a duty of care to ensure that the infrastructure is properly managed and sustained. Failure on the part of the public sector in this respect may mean that the private management entity "mines" the value of the assets by failing to invest sufficiently in the infrastructure over time, leading to failure of the system in the long term.

The AMP process provides data required to ensure that costs charged in the service fees are tied to performance over the long term and that there is transparency regarding operation, maintenance, and repair costs relative to the profits that an operator makes.

The goal of AMP is to maintain the condition and performance of physical assets so that they can deliver an adequate level of service to water users. This is important because it determines the potential increases in the level of income that can be generated by using the system and influences water users' ability and willingness to pay the irrigation service fee (ISF). Where the ISF is collected successfully but levels of maintenance are low, irrigation system performance will deteriorate and a cycle of poor service delivery, poor fee recovery, and system deterioration will accelerate.

IDENTIFYING ASSET STOCKS, CONDITION, AND PERFORMANCE

AMP identifies asset stocks (e.g., headworks, pumps, irrigation canals, drains, structures) and quantifies their condition and performance (Table 4). The investment and expenditure required to maintain, improve, or extend the assets to satisfy the specified levels of service can be quantified using the assessment of asset condition and level of performance.

Table 4. Examples of asset types, components, and estimated life span

ASSET TYPE	SIZE MEASURES TO BE RECORDED	COMPONENTS TO CHECK	DEPRECIATION LIFE (EST.)
River weir	Crest length Crest height	Weir wall Dividing walls Abutments Crest Apron Sluice gate Offtake gate Stilling basin superstructure	Civil 50 Years Mechanical and electrical 10 Years

ASSET TYPE	SIZE MEASURES TO BE RECORDED	COMPONENTS TO CHECK	DEPRECIATION LIFE (EST.)
Head Regulator	Total gate width Design flow	Gate(s) Structure Notice board Shelter	Civil 25 Years Mechanical and electrical 10 Years
Cross Regulator options -fixed crest -gate(s) -stop logs -flume	Total gate width Design flow	Control section structure Notice board U/s wingwalls D/s wingwalls Gauge(s) Shelter	Civil 25 Years Mechanical and electrical 10 Years
Measuring Structure	Total crest width Design flow	Control section gauges Structure U/s w/walls D/s w/walls Stilling box	25 Years
Canal linings -earth -masonry -concrete tile -cont. concrete	Design flow Length	Embankment Side slopes (Note type) Bed	Civil 25 Years
Drain linings -earth -masonry -concrete tile -cont. concrete	Design flow Length	Embankment Side slopes (Note type) Bed	Civil 25 Years
Hydraulic Structure -aqueduct -culvert -drop structure -escape structure	(Depends on structure) Design flow Length Fall	Conveyance support struct. U/s w/walls D/s w/walls Stilling basin	Civil 25 Years Mechanical and electrical 10 Years
Supplementary Structure e.g., bridge, cattle dip	(Depends on structure) Design flow Length	Structure Safety Other features	Civil 25 Years Mechanical and electrical 10 Years
Access Roads	Width Length	Structure Surface Drains	Civil 25 Years

Source: IIDS 1995b, ICID 2003

TRANSFERRING MANAGEMENT, OPERATION, AND MAINTENANCE

An important application of AMP is transfer of the management, operation, and maintenance (MOM) of the I&D system to WUAs, thereby identifying water users' desired level of service and their capacity and willingness to pay for it. Applying AMP procedures at the transfer stage can have important benefits, including identification and audit of all infrastructural assets, identification of water users' desired level of service, identification of the cost of maintaining the system over time commensurate with the agreed-upon level of service provision, understanding by water users of the relationship between infrastructure condition and system performance, and development and ownership by water users and irrigation service provider of the relationship between fee payment and service provision.

System performance will include a combination of

- the condition and performance of the physical infrastructure
- the performance of the people and organizations that operate the infrastructure
- the performance of the farmers who irrigate the fields

Although asset management focuses on the infrastructure, an assessment of the ability of management and farmers to operate the infrastructure and use the water provided is also required.

PROCESS AND TIMELINE OF AMP

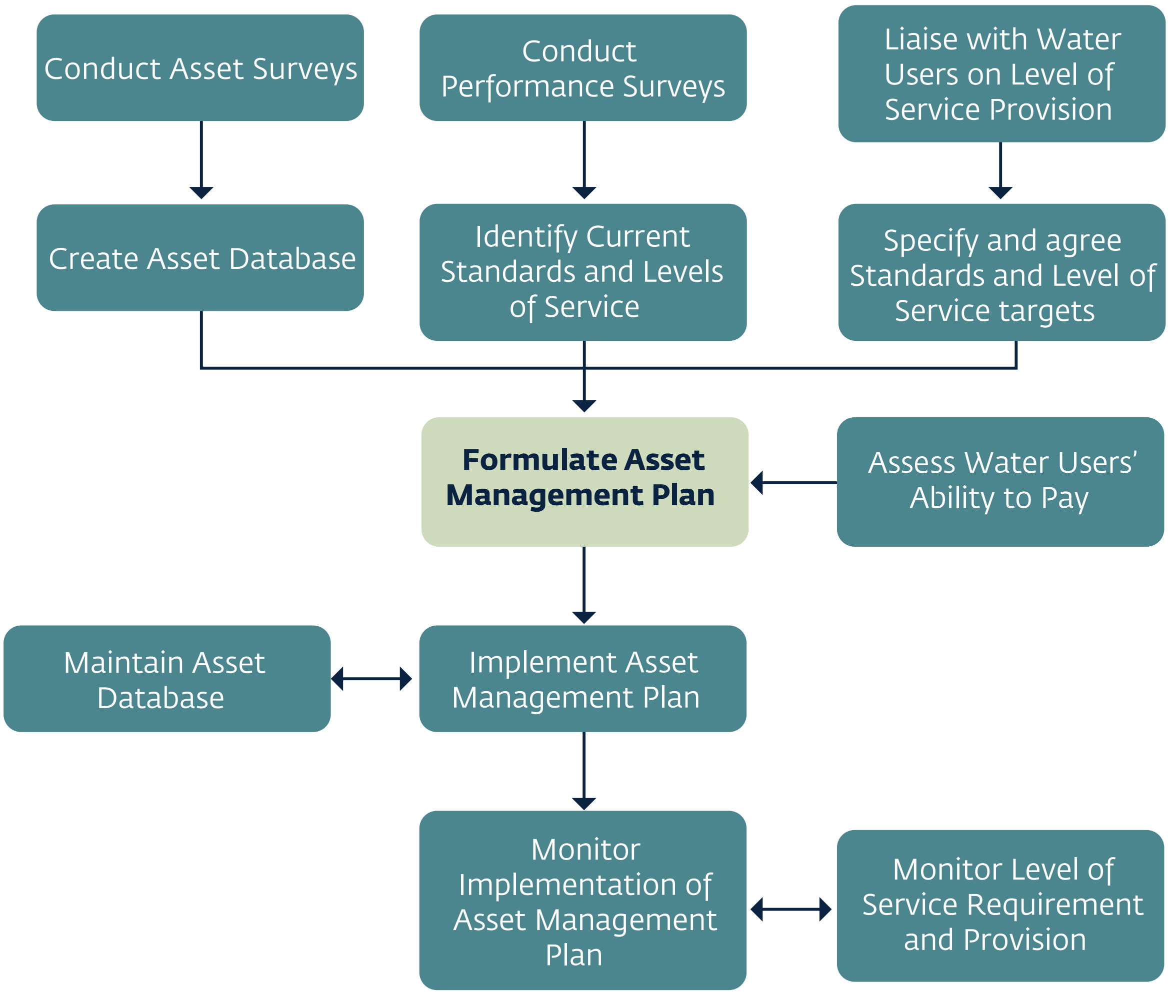
AMP is not a short-term, one-off exercise. It can be started at different times in the life cycle of an irrigation system—at commissioning, when the system is rehabilitated or modernized, or any other time.

An obvious opportunity is when the system is being rehabilitated or modernized. In this case, the AMP can be prepared as part of the rehabilitation or modernization survey and plan or when the rehabilitation or modernization work has been completed.

The first option might be preferable if there are limited funds and the rehabilitation or modernization process must take place over a long period of time, and the second option might be preferable if adequate funds are available (e.g., from a funding agency) and the rehabilitation or modernization works takes place over a relatively short period (2-5 years depending on system size).

Once started, the process should continue for the duration of the physical system(s) that the process serves. An AMP is typically prepared every 5 years, but this 5-year plan can fit within a 15- to 25-year plan in more sophisticated formats (Figure 5).

Figure 5. Framework for asset management planning



Source: Burton et al. 1996

Process and application of AMP

ASSET CONDITION, PERFORMANCE, AND VALUE

The first step is to determine the type and number of physical assets in the irrigation system (Figure 6) using a walk-through of the system to identify:

- The **category (type)** of the asset (e.g., canal, drain, head regulator, bridge).
- The **extent** of the assets (how many in each category).

- The **size** of the asset (e.g., canal flow capacity, structure flow capacity and leading dimensions) to group assets into size bands.
- The **condition** of the asset and its components or facets (e.g., gates in a head regulator). The condition will affect the level of investment required in the structure. **Condition grades** are then used to categorize condition (Table 5).
- The **performance or serviceability** of the asset and its components or facets. The performance may be different from the condition (e.g., a head regulator gate may be in a poor condition but still able to perform its function fully). **Performance grades** are used to categorize performance.
- The **importance** of the asset. This relates to the impact that malfunction of the asset might have on the system as a whole. For example, the head regulator at the river intake is more important than a secondary canal head regulator further down the system.
- The **value** of the assets in each size band. The value is based on the modern equivalent asset (MEA – the cost of replacing the structure at today's costs. If the asset survey and valuation are performed when the system is being rehabilitated or modernized, the MEAs can be determined using the bill of quantities, prices, and details of the work performed. Figure 7 provides examples of photographs used to categorize asset condition and serviceability in Sri Lanka.


Photo Credit: IFAD/Susan Beccio

Figure 6. Example of an asset survey form (IIS 1995b, ICID 2003)

ASSET SURVEY

Form CR for Cross Regulator

CR

System Details

Cabang Dinas ____________________

Ranting Dinas ____________________

Name of DI ____________________

DI Reference No. ____________________

Data Collected

By (Name) ________________

On (Date) ___◊___◊___

Asset Details

Area Served (ha) __________ Asset Ref. No. ________________

Location (km) __________ Canal Name ____________________________

Type of Canal: Primary ☐ Secondary ☐ Supplementary ☐

Reported Age (years): 0-5 ☐ 5-10 ☐ 10-20 ☐ 20+ ☐

Control section width (m) ______ Design Flow (l/s) ______

Control section type: Gate(s) ☐ Fixed Crest ☐ Stop Logs ☐ Flume ☐

Component Condition

	General Condition Grade				Worst Case Local			
	1	2	3	4	1	2	3	4
Structure	☐	☐	☐	☐	☐	☐	☐	☐
Control Section	☐	☐	☐	☐	☐	☐	☐	☐
Upstream Wingwalls	☐	☐	☐	☐	☐	☐	☐	☐
Downstream Wingwalls	☐	☐	☐	☐	☐	☐	☐	☐
Gauges	☐	☐	☐	☐	☐	☐	☐	☐
Bench Mark	☐	☐	☐	☐	☐	☐	☐	☐
Superstructure	☐	☐	☐	☐	☐	☐	☐	☐
Notice Board	☐	☐	☐	☐	☐	☐	☐	☐

Asset Serviceability

Overall Serviceability Grade			
1	2	3	4
☐	☐	☐	☐

Notes:

Table 5. Example of condition and serviceability grades for canal cross regulators

CONDITION GRADES (IMPLYING COST)				
COMPONENTS	**GRADE 1**	**GRADE 2**	**GRADE 3**	**GRADE 4**
Structure upstream wingwalls downstream wingwalls superstructure notice board	**GOOD:** Structurally sound with no deformation of dimensions or profile. Well maintained with few or no signs of deterioration. Upstream and downstream bed having only minor, or no, silt deposition and clear of debris.	**FAIR:** Generally sound but with some deterioration of structure or dimensional deformation. Needing maintenance attention with a review of condition in the medium term.	**POOR:** Significant deterioration of structure or dimensional deformation, requiring urgent corrective work.	**BAD:** Serious structural problems causing actual or imminent collapse and requiring partial or complete reconstruction.
Control Section (note type)		**- OR -** Structural and dimensional condition as (1) but with silt or debris significantly affecting functionality.	**- OR -** Structural and dimensional condition worse than (1) with silt or debris significantly affecting functionality.	
Gauge(s)	Gauges securely fixed and readable	Gauges generally satisfactory but may be difficult to read under some flow conditions	No proper readable gauge, but level mark present from which to measure	No gauge or level mark available **OR** unreadable **OR** unreliable
Benchmark	Benchmark secure, apparently undamaged and readable	Benchmark condition generally as (1) but difficult to read	Benchmark present but of uncertain reliability	Benchmark missing, damaged, or unreadable
SERVICEABILITY GRADES (IMPLYING PRIORITY)				
FUNCTIONS	**GRADE 1**	**GRADE 2**	**GRADE 3**	**GRADE 4**
Hydraulic: To pass the design flow safely. **Operations**: To control **'command'** (water level) across the required range (except for a **fixed** crest) AND...to allow measurement of flow	**FULLY FUNCTIONAL**: Apparently properly designed and constructed with capacity to pass the design flow safely AND fully capable of being operated to control command across the desired range AND allowing measurement of flow by means of its own components or an adjacent measuring structure. Performance unaffected by silt or debris.	**MINOR FUNCTIONAL SHORTCOMINGS:** Normally able to pass the required flows AND capable of being operated to control command in a measured manner, BUT performance likely to be unsatisfactory under extreme conditions of demand or climate. Deficiencies may be due to design or construction inadequacies, insufficient maintenance, measuring devices that are difficult to read or due to the presence of silt or debris.	**SERIOUSLY REDUCED FUNCTIONALITY:** One or more of the three defined functions seriously impaired through deficiencies in design, construction, or maintenance or due to the presence of silt or debris. (Likely to have a significant detrimental effect on system performance.)	**CEASED TO FUNCTION:** Complete loss of one or more of the three functions or serious reduction of all three for whatever reason.

(IIS 1995a, 1995b)

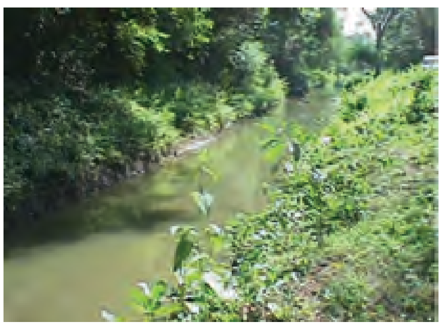
Figure 7. Examples of photographs used to categorize asset condition and serviceability in Sri Lanka

GRADE 1

Very well maintained. No overgrown vegetation. Clearly defined channel, no obstruction to flow. Good access for inspection and maintenance.

GRADE 2

Generally well maintained, but with some overgrowing vegetation. Capacity of channel not impaired. Good access for inspection and maintenance



GRADE 3

Vegetated banks and side slopes. Capacity of channel reduced by up to one third. Impaired access for inspection and maintenance.

GRADE 4

Highly vegetated banks and weed growth from canal bed. Poorly defined channel. Reduction of channel capacity (by up to 2/3). Poor access for inspection and maintenance.

GRADE 5

Channel overgrown with vegetation. Seriously impaired channel capacity. Restricted access for inspection and maintenance.

Photo Credits: Martin Burton

SYSTEM PERFORMANCE

Irrigation system performance is assessed at two different levels. At the bulk water supply (main system) level, it is important to know how well the system is delivering water. At the farm level, farmers are interested in knowing how it is being distributed across the farm. At both levels, reliability, adequacy (to meet crop needs), timeliness, and equity are key indicators of performance. Thus, the condition and performance of the physical assets and how well those assets are managed and operated influence irrigation system performance.

At the on-farm and field level, the supply of inputs, including water, to crops and how well the WUA (if there is one) controls and manages these inputs influences performance.

An irrigation system's performance is important because it affects farmers' income and their ability and willingness to pay the ISF. The overall performance of the system is assessed in terms of outputs (crop yields, crop production) and outcomes (farmer food supply and income).

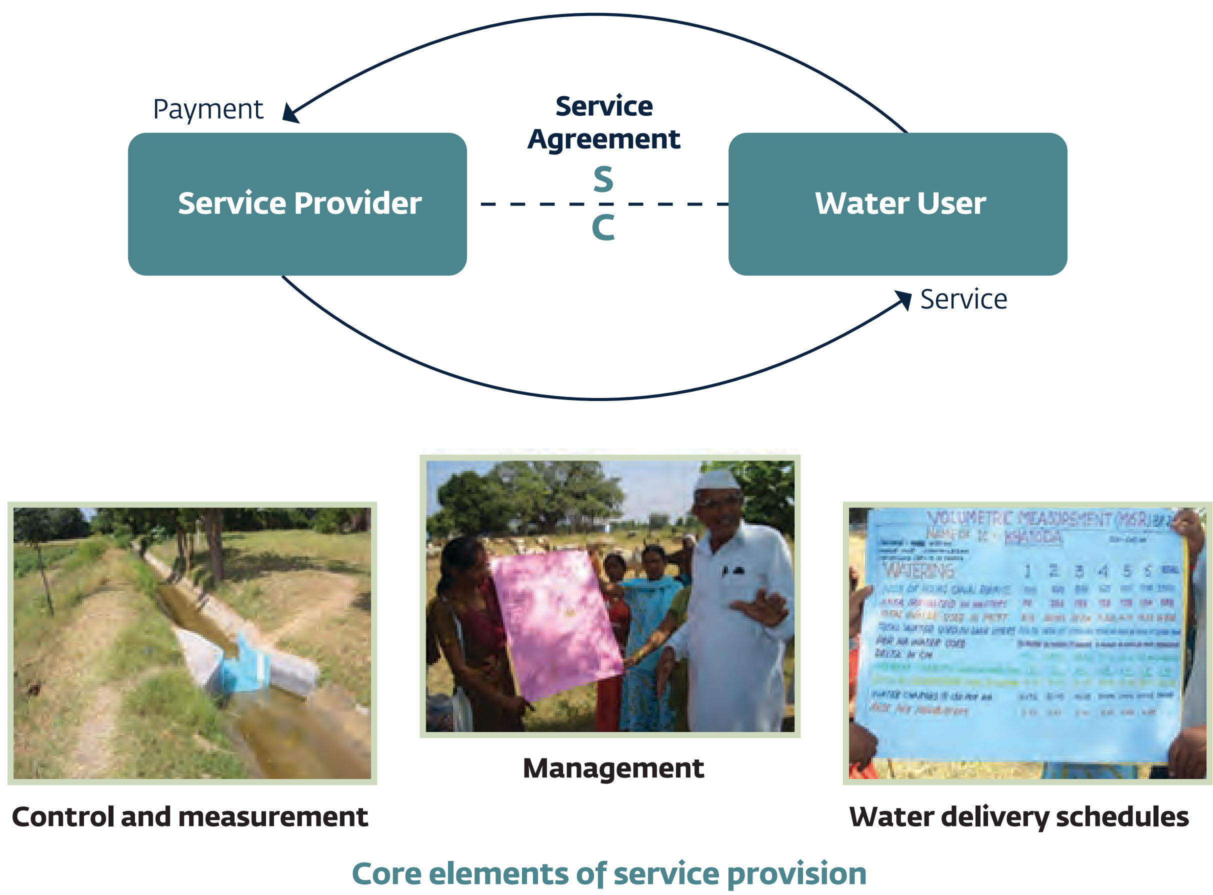
Performance of the I&D system is evaluated through:

- field surveys to assess the condition and performance of the physical assets
- surveys of water users (WUAs and farmers)
- surveys of irrigation agency staff
- analysis of records (e.g., crop data, discharge data)

AGREEMENT ON STANDARDS AND DESIRED LEVEL OF SERVICE PROVISION

Part of the AMP process is to specify the *desired* level of service, after which any performance shortfall can be determined by measuring the *current* levels the assets are providing (assuming there are no management constraints). Different types of irrigation systems will deliver different levels of service. In general, the higher the level of service required, the greater the capital and operational costs. Level of service should be discussed with farmers to establish what level they require and to raise their awareness of the cost implications and their commitment, particularly their commitment to pay the ISF. Once the level of service is agreed upon (Figure 8), the farmers and irrigation agency will need to sign a service delivery agreement.

Figure 8. Key components of service delivery



Source: After Huppert and Urban 1998; Burton 2020

ASSESSMENT OF WATER USERS' ABILITY AND WILLINGNESS TO PAY FOR DEFINED LEVEL OF SERVICE

A component of performance assessment is analysis of farmers' crops and farm budgets to assess their ability to cover the MOM costs of the I&D system. In some cases, a requested level of service cannot be provided because the costs of service provision are too high, and the farmers are unable to contribute financially. Such situations include where farmers have small landholdings and are growing subsistence crops, meaning that farmers will have limited funds available to cover the MOM costs. In these cases, subsidies may be required from the government. Use of the AMP process provides a transparent and accountable mechanism for identifying the total MOM costs for a given system, the ability of farmers to contribute to these costs, and the proportion of the costs that the government will bear through a subsidy.

PREPARATION OF THE AMP

The information generated as part of the AMP enables the level of investment required for the MOM of the assets over time to be determined. For larger systems, this calculation may be used to formulate a long-term investment plan (15-20 years) that can be separated into 5-year implementation blocks. For smaller systems, the time frame may be 5 to 10 years, with periodic reassessments every 3 to 5 years. The process should be kept simple for several reasons:

- **Time:** WUA staff are busy during the irrigation season, so time available to attend to tasks other than water management is limited.
- **Technical skills:** People with limited technical skills (in particular, WUA staff and members) must understand the process.
- **Physical resources:** Many WUAs are not equipped with computers, so the process must be operated and maintained through nonelectronic means.

CLASSIFICATION OF WORK IN THE AMP

WUA staff and farmers may perceive any work performed on the assets as "routine maintenance" to repair accrued damage rather than "preventative maintenance" to delay or prevent damage and complete "renewal" to replace damaged and non-functional assets. As a result, work should be implemented and reported in the following categories, because different stakeholders may be involved in each:

- Preventive maintenance:
  - Routine maintenance of irrigation equipment and assets such as greasing gates, minor de-silting and weed clearing, cleaning, oiling
  - Seasonal maintenance of water channels and pipe delivery systems such as removal of vegetation, silt, or other obstacles to water flow
  - Annual maintenance of irrigation equipment such as pump, motor, and electrical fittings and maintenance under the warranty and annual maintenance contract services
  - Emergency maintenance that may be required in cases of breakage and damage, leaks in pipe distribution system to maintain the irrigation system's good condition
- Repair or occasional work such as repairs of gate spindles, head walls, and culvert pipes
- Renewal of assets that may need to be entirely rebuilt
- Improvement, which involves acquiring new assets where none currently exist

ESTABLISHMENT AND COLLECTION OF ISFS

To finance and fully recover the expenses of MOM activities for irrigation systems, the stakeholder operating the system must establish and collect appropriate ISFs from farmers. ISFs may be based on irrigated area, crop area, or hours of water supplied.

DATABASE MAINTENANCE

The asset database should be updated as the AMP is implemented, in terms not only of asset inventory, but also of asset condition, performance, serviceability, investment planning, cost budgeting, and preparation of the implementation plan. Maintenance work and cost expenditures will also need to be recorded.

MONITORING IMPLEMENTATION OF AMP AND SERVICE LEVEL PROVISION

During development of the AMP, key sectors are identified, and key performance indicators are developed. Procedures must also be established to ensure that the data generated are shared regularly with water users, which allows users to see the returns they are receiving from their ISF payments.

OPERATING METRICS

A range of methods may be used to calculate or charge for the ISF. These are typically based on the size of the membership, the area served, and the homogeneity of the system.

- Metrics used for charging the ISF may include:
  - $ per member per year
  - $ per hectare per year
  - $ per cubic meter ofwater supplied
  - $ per irrigation
- ISF must also be assessed periodically to ensure that they meet the changing needs of the system but do not create an unsupportable burden. This requires that system operators create a transparent reporting system so that users can identify the causes, severity, and impacts of shortfalls reported.
- Metrics used for demonstrating the sufficiency or burden of the ISF include:
  - percentage of operating expenses recovered
  - percentage of operating expenses plus replacement recovered
  - percentage of farmers paying ISF
  - ISF as a percentage of farm income

PRACTICAL CONSIDERATIONS

The processes, guidelines, and training must be appropriate for the skills and knowledge of WUA staff and members. For example,

- Computers and reliable access to the internet may not be available to all staff or the farmers, and need for a paper-based system should be determined.
- WUA staff must be capable of using AMP as part of their normal work. Therefore, a process should not be designed that requires additional resources and should build on existing maintenance procedures.
- The AMP time frame should be realistic from the WUA's perspective. In the case above, 5 years was chosen.
- Local staff and skills should be used as much as practicably possible for preparing the inventory, defect surveys, and AMP.
- The WUA should appoint a senior sponsor to promote buy-in to AMP.
- The process of administering the surveys should be well thought through. Surveyors should be identified and trained using written guidelines, be mentored during the ongoing survey work, field check the results early, and review and modify the survey forms.
- Preparing an example or trial asset management plan will help avoid pitfalls. WUA staff should review results in the field (not only in the office), review and modify the AMP process as necessary, and use the example of the plan as part of the trainings.

Case studies

The case studies below from Central and South Asia demonstrate the importance of empowering smallholder farmers. The cases from the Kyrgyz Republic and India show that having asset management procedures in place is key and that they can be adapted to suit farmers' understanding, knowledge, and capabilities, even for smaller irrigation systems. Having WUAs manage these systems can lead to significant benefits.


Photo Credit - Richard Colback, IFC

CASE STUDY 5: Asset Management Plan by WUA in the Kyrgyz Republic: Improving Irrigation and Drainage Systems

Country:	Years:	Organization involved:	Crops:	Irrigation systems:
Kyrgyz Republic	**2011-2012**	**World Bank**	**n/a**	**On-farm I&D systems**

From May 2011 to November 2012, the Kyrgyz Republic developed asset management procedures and integrated them into management of its on-farm I&D systems. The World Bank then funded the Second On-Farm Irrigation Project, which adopted and implemented these on-farm I&D systems. The asset management procedures were initially applied to systems that the government formally owned and managed on state and collective farms before the country's independence in 1991.

The World Bank had funded several projects from 2003 to 2015 that established and supported WUAs. A typical WUA has a command area of 1,500 to 3,000 hectares, serves four to eight villages, and employs a management team of six to 10 staff members who report to an elected WUA board of 10 to 12 members. The WUA board in turn reports to a general or representative assembly of members. By January 2013, 481 WUAs had been established over a total area of 737,400 hectares, covering 73 percent of the country's irrigated land area. WUAs now manage these I&D systems since the successful implementation of a World Bank–supported irrigation management transfer program under which the physical assets and their MOM were transferred from the government to WUAs.

Developing the asset management procedures was an iterative process; various drafts were tested and refined based on a sample of WUAs before guidelines and training materials were prepared for wider use. The stakeholders identified the costs associated with short-, medium-, and long-term maintenance and the significant cost associated with renewal of some assets. The detailed costings demonstrated that the ISF needed to be tripled or even quadrupled to cover the long-term costs. This increased cost represented 4 percent to 15 percent of net farm income.

AMP had several key benefits: It encouraged WUA management to quantify and create an inventory of their assets; enabled them to identify and quantify maintenance and repair costs; clearly identified costs associated with replacement of assets; highlighted the need for timely preventative maintenance to prolong the life of assets, particularly structures and lined canals; and facilitated prioritization of maintenance and repair work based on loss of performance of the asset.

Key metrics

- Metrics for charging: $ per hectare per year
- Sufficiency: ISF as a % of farm income

Key results

- The results from the trial WUAs in the Kyrgyz Republic suggested that the ISF needed to be **tripled** or even **quadrupled** when calculated on a per hectare per year basis.
- Annual net farm income after paying for all crop production costs (but before paying the ISF and repaying rehabilitation costs) was estimated to be $156 to **$533** per hectare
- The ISF, without paying for asset renewal, is between **4** percent and **15** percent of net farm income
- If the cost of asset renewal is added, the ISF would need to increase by a factor of 2.5 to between 11 percent and 38 percent of net farm income, leaving the farmer with $100 to **$475** per hectare

Lessons learned

- The difference between the condition of an irrigation system and its performance in transporting and applying water must be understood so that farmers can fully support the costs, timing, and priorities of an asset management program.
- WUA staff and members should be involved in developing the AMP process from the outset. Staff should identify what needs to be done, understand what the benefits will be, and identify the WUA's priorities.
- The ISF resulting from AMP may be higher than what WUA members are prepared to pay. In such cases, members should have a way to decrease the amount being spent and to increase the fees temporarily when individual maintenance tasks must be performed.
- The AMP process and reports must be public to raise awareness of WUA members of the true cost of owning, operating, and maintaining the I&D assets.

CASE STUDY 6: Transferring Irrigation Assets for Service Delivery to Water User Association in West Bengal

Country:	Years:	Organizations involved:	Crops:	Irrigation systems:
India	**2012-2019**	**World Bank; West Bengal state government**	**Various**	Various types of irrigation schemes

The Accelerated Development of Minor Irrigation Projects program, implemented between 2012 and 2019 in the Indian state of West Bengal with financial and technical support from the World Bank, used the asset management approach of identifying the asset database, determining asset maintenance and operation costs, and setting the ISF to cover these costs.

The Water Resources Investigation and Development Department of the state government of West Bengal implemented the project, with the objective of enhancing agricultural production for smallholder and marginal farmers. The department achieved this objective by making irrigation water available to smallholder and marginal farmers through new SSI schemes, increasing the sustainability of irrigation services through farmer-managed irrigation schemes, and helping farmers diversify their production systems to grow more-remunerative crops and incomes. The project installed 2,291 SSI schemes covering 67,594 hectares of irrigated land and formed 2,277 WUAs to manage the schemes. The project reached 124,700 beneficiaries, 89 percent of whom were smallholder and marginal farmers and sharecroppers.

Implementation of the Accelerated Development of Minor Irrigation Projects began with irrigation scheme site selection based on a hydrological assessment by the project's engineers. Once the site was selected, the project team organized the farmers into WUAs for the irrigation scheme's MOM. With the farmers' participation, project staff planned and designed the irrigation scheme by preparing its scheme development and management plan. Installation of the irrigation scheme was tendered out to a contractor under the joint supervision and monitoring of the project engineer and the WUAs. Once the irrigation scheme was constructed, responsibility for its management was transferred to the WUAs through a memorandum of understanding between the Water Resources Investigation and Development Department and the WUA that made the latter responsible for the irrigation scheme's MOM. Upon taking charge of their irrigation scheme, the WUAs provided irrigation services to their members by preparing seasonal crop and irrigation plans with them. The WUAs collected ISFs from the farmers based on agreed-upon rates for the operation of the irrigation scheme and maintenance of the assets. The project also provided agricultural information, training, and extension services to farmers, such as crop demonstrations, introduction of new agronomic practices, and market information. At project closing, targeted water users successfully received new or improved I&D services. The project also supported social inclusion by ensuring representation of marginalized groups among beneficiaries.

Key metrics

- Irrigated land: hectares
- Beneficiaries: % of smallholder farmers in scheme
- Number of WUAs established and duration of operation
- ISF as % of operating costs

Key results

- Agricultural production value increased in multiple ways, including
  - **27** percent increase in cropped areas
  - **67,594**-hectare increase in areas equipped with new irrigation services
  - **192** percent increase in cropping intensity
- The project ultimately reached **124,700** beneficiaries
  - **111,203** (89 percent) were smallholder and marginal farmers and sharecroppers
  - **17,099** were women (which surpassed the target of 12,000).
- More than half of the 2,277 WUAs have been operational for longer than 3 years and have performed well in managing delivery of irrigation water to their members.
- 73 percent of the WUAs were generating at least 80 percent of the resources required to manage, operate, and maintain their irrigation schemes.

Lessons learned

- An integrated design of structural measures (irrigation infrastructure) and nonstructural measures (management institution development and agricultural support) is essential for a successful irrigated agriculture operation.
- The project invested in infrastructure to increase water availability, but agricultural support services and institution building were cornerstones of the project outcomes.
- Complex projects with many subprojects scattered over large areas require active learning and adaptive change management with innovations.
- AMP must delineate the roles and responsibilities with funding arrangements. This inbuilt system was instrumental to the sustainability of irrigation schemes and contributed to the low proportion of dysfunctional schemes after handover.

Call to action

All private sector actors involved in implementing irrigation systems should adopt AMP as part of their responsibilities. Owners and managers of infrastructure, public and private companies, and groups of farmers can all use AMP. Water users and irrigation service providers would benefit from adopting AMP to collect ISFs and provide services. Smallholder farmers should be involved in the process as well to establish the level of service required for their irrigation system and to be aware of its cost implications. Irrigation planners, managers, and users have the largest role to play in adopting AMP, including conducting performance evaluations of I&D systems and establishing and collecting ISFs. Because I&D systems will require maintenance and upkeep, stakeholders should invest in maintenance, repair, and renewal of infrastructure. The development community can fund and support irrigation projects that use AMP as part of their implementation process and as an incentive to enhance long-term sustainability.

Table 6. Role of Stakeholders in Managing Assets

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
PRIVATE SECTOR		
WUAs, farmer groups	• Use asset management planning to calculate level of shared costs • Share information on asset management plan timelines, priorities, and costs • Collect member payments, provide services on time • Ensure routine maintenance is performed on the system, including preventive maintenance, repair work	• Achieve optimal cost-benefit ratio, avoid large replacement costs through regular asset assessment • Build confidence that costs and benefits are appropriate, prepare for repairs, and set expectations for timelines • Ensure that sufficient funding is available to run and operate irrigation systems • Improve longevity of irrigation systems
Smallholder farmers	• Adapt asset management procedures to suit smaller assets in SSI system	• Improve reliability and adequacy of system, reduce replacement costs
Irrigation system service providers	• Evaluate system performance, including field surveys, water user surveys • Establish and collect ISF based on an irrigated area, crop-area basis, or hours of water supplied • Develop key performance indicators and put procedures in place to ensure that data collected are regularly shared with water users	• Provides an assessment of overall scheme performance in terms of output and outcomes • Ensures that management, operation, and maintenance expenses are fully recovered • Users see the returns they are receiving from their ISF payments and payment rates are maintained

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
PUBLIC SECTOR		
National government	• Build capacity of public sector staff to evaluate performance and sustainability of large-scale strategic assets • Create asset registry and budget for long-term asset management • Use AMP process across a broad range of infrastructure • Use AMP process to assess subsidy support requirements for smallholder farmers growing subsistence crops	• Reduce cycle of build, operate, rehabilitate, replace to improve longevity and performance; reduce budget demands for infrastructure replacement • Secure funding and improve performance independent of political cycles • Build supportive infrastructure – roads, power, markets, and information to increase food production and security • Systems remain efficient and operational with farmer contribution supported by an appropriate proportion of the costs through a subsidy
DEVELOPMENT SECTOR		
Development institutions	• Fund and support irrigation projects that use AMP as part of their implementation process	• Improve sustainable operation of systems and project development effectiveness
Donors	• Require AMP as part of funding requests	• Increase system lifespan

Photo Credit: IFAD/Sarah Morgan

Chapter 4: Irrigation Operating Models

Key messages

- Operating models should be context specific and adaptive.
- Sustainable use of water resources can be supported by increasing irrigation efficiency, using less water to produce food, and exploring alternative water sources, including water reuse.
- Many countries that once promoted government involvement in irrigation management are shifting their policies to create incentives for farmers to take over some part of the management of operations and maintenance while government agencies focus on improving water management at the bulk water level and on regulating water use.
- Increased profits from irrigation must exceed the additional costs required to repay the capital, operating, and replacement costs of irrigation equipment, which may vary according to operating model.
- Accountability of billing agents, WUAs, and irrigation districts to their members or clients is a critical component of the bulk water supply irrigation operating model.
- Sustainable use of water resources should be supported by making irrigation systems efficient and rewarding users for reducing losses and waste.
- Equity, fairness, and inclusion are critical in governing irrigation resources. All rightful users are equally entitled to access land and water.
- High-quality, targeted capacity building should be ongoing for an irrigation project to be sustainable. Intergenerational learning programs can be adopted and adapted for youth to ensure succession in irrigated farming.

Summary

SSI operating models are highly varied, from lone private farmers to various types of aggregators such as producer organizations, contract farming, agro-input dealers, and collectors. Organizations delivering services within irrigation systems differ in day-to-day management, governance, payment mechanisms, and land ownership arrangements, but those that are successful and sustainable share several characteristics that set them apart from unsustainable models. This chapter highlights what has worked in different contexts and outlines governance-related determinants of success for SSI models. These include what are normally considered to be the softer elements of governance but are often the most difficult to implement:

- accountability
- conflict management
- transparency and customer orientation
- equity, fairness, and inclusion
- sustainable use of water resources
- consistent policy, legal, and regulatory frameworks
- youth involvement and intergenerational learning
- capacity strengthening

The chapter considers these factors in relation to various functional and operating drivers such as water resource availability and hydraulic infrastructure functionality, socio-politics, land-water tenure, market access, affordable and participatory financial services, climate-smart agricultural adoption, and how these will influence (and be influenced by) governance-related determinants of success.

Determinants of success in operating models

ACCOUNTABILITY

Accountability of irrigation unit leadership is a determinant of success for irrigation management. In collective models, WUAs are held accountable to their members, with clear procedures and rights of appeal, and must take responsibility for delivering the agreed-upon irrigation services. This is accomplished by forming unit committees or electing leaders of WUAs. Regardless of the form it takes, leadership must show commitment to its responsibilities by enforcing agreements and licenses, providing operational accountability, and communicating results and information. When a scheme is well managed and led, users will be encouraged to adopt best practices for sustainable productivity increases.

CONFLICT MANAGEMENT

Conflicts in irrigation schemes often occur between users over direct extraction of water from canals and regulations covering use of the facility. Conflicts may also arise from land and water allocation, tensions in leadership, price negotiations, and expenditures. Disputes over use of financial resources are common reasons for WUAs to become dormant. Being able to manage conflicts between water users is important in successfully governing irrigation facilities. Rules regarding conflicts must be established, as well as a step-by-step process to sanction those who break the rules regarding use of common resources.

TRANSPARENCY AND CUSTOMER ORIENTATION

An organizational culture at the irrigation unit level that embeds trust, ensures ease of communication (within and with outside parties), and exchanges information effectively will improve relations between partners. A business-oriented perspective also requires alignment with consumer orientation—one that places the customer first. Assessing a service provider's transparency and customer orientation provides insights into its base culture and working styles. Transparency is needed at all levels of information, procedures, finances, and distribution of water based on an agreed-upon schedule.

EQUITY, FAIRNESS, AND INCLUSION

All legitimate users have the right to land and water, but tensions sometimes arise because of disparities in allocating land and water to users. Men and women, as well as youth, are treated differently in some traditional settings, which affects their rights to economic resources such as land and water. In Sub-Saharan Africa, most farming populations are women and youth, but the composition of WUA executive and leadership members does not necessarily reflect that.

SUSTAINABLE USE OF WATER RESOURCES

Sustainable use of water resources can be supported by increasing irrigation efficiency, using less water to produce food, and exploring alternative water sources, including water reuse. Deliberate, transparent methods should be used to reward sustainable use. In the governance of irrigation facilities under water scarcity, care must be taken that strong competition for water does not lead to accelerated consumption of the limited supply of water. Sustainable use of irrigation resources at the community level requires cooperation between water users.

CONSISTENT POLICY, LEGAL, AND REGULATORY FRAMEWORKS

Consistent policy, legal, and regulatory frameworks create an enabling environment for sustainable resource management, service orientation, and accountability for service provision. In many cases, SSI governance is characterized by legal pluralism, with multiple agencies engaged in the governance of water, which often leads to legal contradictions, gaps, and overlaps. This disconnect calls for adoption of a hybrid water-use rights system in which a range of regulatory tools is used that is most appropriate for the context and most likely to result in the intended outcome of water-use regulation. For example, a hybrid water-use rights system may use strictly enforced permits for high-impact users while using other instruments to support legal water use of small-scale users, including legal recognition of customary law, collective permits administered through local water management institutions, and exemptions of domestic and small-scale productive uses of water with prioritized legal status. Assessing the impact of these inefficiencies in the policy, legal, and regulatory frameworks can increase understanding of the core barriers to improving service-delivery performance and can help governments implement institutional hybrid policy frameworks that acknowledge statutory and customary land and water tenure and take a flexible approach that does not marginalize the most vulnerable.

YOUTH INVOLVEMENT AND INTERGENERATIONAL LEARNING

Programs such as female farmer of the year competitions, introduced in rainfed production systems in eSwatini, can be adopted and adapted for youth in irrigated farming to ensure that succession in irrigated farming remains a viable option for the next generation of farmers. Deliberate efforts by governments would help ensure sustainability of projects.

CAPACITY STRENGTHENING

Capacity strengthening must be ongoing for a project to be sustainable. One of the identified causes of poor yields and low productivity of schemes in small-grower sugarcane farming in eSwatini, for example, is lack of technical capacity of farmers. It is recommended that the range of government ministries engaged in agriculture, energy, water, and rural development intensify small-grower technical services to increase productivity.

The practical framework for understanding determinants of success of operating models goes beyond infrastructure or technical performance-specific areas (Waalewijn et al. 2020) covering three thematic areas comprising groups of functions (Table 7). These cover the physical and technical aspects of water service delivery, the organization, and the governance boundaries related to irrigation scheme MOM.


Photo Credit: IFAD/Susan Beccio

Table 7. Determinants of success in irrigation management

FUNCTIONAL THEME	DETERMINANTS OF SUCCESS	DESCRIPTION
Water service delivery	Adequacy	• Typically describes performance at the system level, often relating to physical infrastructure
	Reliability	• Technical and well-defined and -documented parameters (e.g., Bos, Burton, and Molden 2005; Malano and Burton 2001)
	Equity	• Numerical and finite indicators (e.g., ratios, percentages, finite numbers)
	Flexibility	• Attributed as a performance measure for project outputs (e.g., increased equity caused by introduction of command area channels)
	Quality	• Linked to a pricing policy (or tariff) that reflects the performance of service
	Multiple-use services	
	Productivity	
	Sustainable use of water resources	• Can be encouraged through improved irrigation efficiencies (using less water to produce food, exploring alternative water sources including water reuse). Deliberate and transparent methods should be used to reward sustainable use. In the governance of irrigation facilities under water scarcity, care must be taken so that strong competition for water does not worsen the limiting resource for agriculture. Sustainable use of irrigation resources at the community level particularly requires cooperation between water users.
Organizational resources	Financial sustainability	• Overall service provider ability to deliver quality and sustainable I&D services
	Asset management	• Service provider human resources (e.g., skills, capacities, diversity), financial resources (cost recovery and effectiveness), management, process, and sustainability
	Internal and external accountability	• Communication and ways of executing processes, including systems operations
	Process management	• Service provider accountability in MOM and recovery of service fees

Source: Adapted from Waalewijn et al. (2020).

Threats to sustainability of operating models

The vulnerability of an irrigation model can be seen as its sensitivity to being positively or negatively affected by changes in irrigation operations. Vulnerability goes beyond the confines of water for crops and includes consideration of larger-scale water management. Some of the wider aspects of water management that define how vulnerable the sustainability of operating models are include:

- Ability to respond to poor implementation of the model
- Rigidity of model to change according to demand
- Lack of constructive engagement with stakeholders
- Reluctance of stakeholders to pay for services

WATER QUALITY AND QUANTITY

Modern agricultural methods and unpredictable freshwater resource renewals through normal patterns of seasonal rainfall result in irrigation delivering water loaded with chemicals (pesticides, nutrients) and other pollutants. Declining water quality is one of the main challenges for irrigated agriculture, resulting from poor surface and groundwater resource management. In addition to agricultural uses, many shallow aquifers are important for domestic supply. These often receive some recharge from dry season percolation from areas under irrigation, representing simultaneously a benefit from a larger resource of water for households and a threat from the risk of chemical and biological pollution. In situations like this, irrigation system operation models must consider both domestic and agricultural user bases and arrive at an effective compromise.

- **Recycling of irrigation water:** Drainage flows from irrigated areas can be important assets in irrigation operations. Losses in one place become inputs in other areas. Such recycling can substantially ease the upstream operation problem by allowing less precision in distribution, knowing that any surplus will not be lost entirely. In operating models that account for return-flow systems, the drainage water and surplus irrigation are channeled back as a source of water for use in another part of the irrigation network, often to the benefit of a broader group of farmers.

- **Water harvesting and conjunctive management:** Water harvesting during rainfall is an important source of water for operating models, which may be designed to maximize harvesting in areas with excess beyond the soil water-holding capacity while preventing flooding of those fields. Conjunctive use of water (surface, groundwater, rainfall) can provide additional flexibility for operating models designed to benefit from a variety of sources across the season and combined surface area of the system. Groundwater is frequently used to compensate for rigidity or low performance in the surface water delivery system. Areas lacking access to additional supplies from groundwater require greater attention than areas where pumping facilities can compensate for inadequate or unreliable deliveries.

- **Soil and water salinity and water logging:** The rise in soil and water salinity and the increase in waterlogged areas are environmental hazards of great importance in arid regions. They pose a severe threat to irrigation schemes due to poor operation of the system. The operating model of irrigation systems must consider the distribution of these hazards to ensure that a cause in one part of a system does not lead to an impact in another. In practice, solutions are relatively site specific, and generic guidelines are difficult to devise, but as a principle, irrigated area should be partitioned to distinguish areas where freshwater must be provided from areas in which excessive percolation should be avoided to prevent saline groundwater from rising.

- **Multiple uses of water:** In many irrigation schemes, water is used not only for crops, but also for many other purposes, including domestic water supply, environmental uses, fisheries, perennial vegetation, and hydropower. Operating models for multipurpose systems are complex because of potential conflicts in setting rules and targets for the different uses and, on occasion, the lack of suitable accounting procedures. A first step in management of multiple uses is to define consistent water and productivity accounting procedures.

- **Water rights, equity, and priorities in distribution:** Water distribution priorities in a model may be based on land rights and prior established uses, but in systems experiencing water shortages, these priorities should define a policy to share limited water among shareholders. Priorities may be defined based on such things as the value of crops (high/low) and soil water-holding capacity. As the mission of irrigated agriculture changes from subsistence to more highly productive, it may be necessary sometimes to revise previous policies to avoid penalizing highly sensitive or high-value crops in case of shortage. In many cases, distribution policies should be rethought and, where appropriate, changed to enable new operational strategies in the model.

- **Health impact:** Despite the positive effects of irrigation on the economy and income of farmers, in some circumstances, it also harms the health of communities through vector-borne diseases. Maintaining water in canals for long periods can affect the reproductive cycle of disease vectors. The link between system operations and community health can be strong. The recommendations of health experts are converging on greater variability in canal flow regimes—for example, to reduce the number of mosquitoes, although there is a clear conflict between the requirements of the health sector for fluctuations in water depths and the irrigation management objective of stable water profiles. New techniques of operation may be required where mosquito breeding is linked directly to irrigation practices.

- **Position within the system:** The impact of operations on the command area is greater for structures located toward the head of the canal system, where larger volumes of water are controlled and inaccuracy has a greater impact, than lower down the system, where flows are already reduced.

Photo Credit: Liudmila Pestun, IFC

SOCIOECONOMIC FACTORS

It is also important to note the following factors that should be carefully considered to ensure sustainability of the model (Table 8).

Table 8.

FACTORS AFFECTING SUSTAINABILITY	IMPACT TO SUSTAINABILITY	SIGNIFICANCE
Effective facilitation (private sector, government, nongovernmental organization)	Lack of guidance, support, and facilitation	Critical
Buy-in from members	Lack of buy in	Critical
Working capital credit and credit worthiness	Indebtedness after losses	Critical
Input availability, including water	Input shortages	Important
Effective conflict-resolution mechanisms	Social conflicts	Important
Sustained skill to perform activities	Accidents, illness, death	Important
Time to invest in an activity	Demands on time (other activities given priority)	Important
Critical: Schemes would not run without the factor or in the face of a threat, there is no mitigation by operators or owners.		
Important: Scheme owners or operators can mitigate the factor, albeit with effort and difficulty.		

TRANSITIONING OPERATIONS FROM PUBLIC TO PRIVATE

Most countries that once promoted government involvement in irrigation management are shifting their policies to ones that create incentives for farmers to take over some part of the operation and maintenance while government agencies focus on improving water management at the bulk water level and on regulating water use. Farmers whose livelihoods depend on the water resource have the strongest incentive to manage those resources carefully.

The role of beneficiaries could be at the national, irrigation district, or WUA level, although introduction of participatory irrigation management and WUAs is complex and slow. There is a need for continuous, genuine political will for it to succeed, and patience and perseverance are required. Governments may need to provide incentives to farmers to assume responsibility for managing their water supply.

This is an alternative to the traditional approach whereby external funders, implementers, engineers, and technical experts lead prefeasibility and feasibility studies, design systems, and lead procurement of materials and construction before transferring the finalized infrastructure to communities for their use. Communities are often expected to take partial or full responsibility for system operation and maintenance.

COMMUNITY PARTICIPATION

In operating models that transition to participatory irrigation operations, beneficiaries are involved during all stages, including planning, designing, and installing an irrigation system. Participation during the initial planning phase sets clear expectations of the level of ownership that will transition during the project. Farmers normally have local knowledge, which is useful in the design and development process. Early engagement in the operational model enables beneficiaries to better understand how they will be expected to operate the irrigation system efficiently and to learn certain aspects of maintenance activities (e.g., pipe fitting, irrigation infrastructure maintenance and repair). Consequently, irrigation projects planned with beneficiaries are more sustainable than those designed for them, although supervision of installation and quality control remain the responsibility of the public sector irrigation planner or engineer.

Figure 9. Community participation in planning and installing

Photo Credit: EU/ECHO/Martin Karimi

Three key steps for participatory engagement include:

1. Planning
   - initiating collaboration (agreeing on goals and creating a community structure)
   - diagnosing problems
   - envisioning solutions
   - determining the budget
2. Implementing the system
   - procuring materials
   - recruiting workers
   - constructing
   - commissioning
3. Operating and maintaining the system
   - operating common infrastructure
   - maintaining quality of systems
   - replacing worn or defective infrastructure
   - refining and improving future irrigation systems

SSI Operating Models

SSI operating models can be considered in two categories (Molden 2007) —individual and collective—within which several types of systems exist based on system size and how it is owned. These range from individual private farmers to various types of aggregators, such as producer organizations, contract farmers, agro-input dealers, and collectors (Table 9).

1. **Collective** irrigation occurs when a group of irrigators shares the hydraulic infrastructure. These include large-scale public schemes (Type 1); for example, rice production in humid areas and staples and cash crops in dry areas and small- and medium-scale community-managed schemes (Type 2) (Molden 2007, Waalewijn et al. 2020). Collectively managed schemes can be autonomously managed or co-managed with operators or agencies.

   - **Autonomous** management includes, for example, village-owned schemes operated by voluntary farmer labor and private sector service organizations owned or contracted by irrigators. Autonomous management models, in all their varieties, usually do not have a government irrigation agency involved in the operation and maintenance of the infrastructure or water resource and fit the definition of a small irrigation scheme (Lankford et al. 2016, Waalewijn et al. 2020).

   - **Co-managed** schemes are mostly the result of transfer of management responsibilities for part of the irrigation infrastructure from the public sector irrigation agency to water user organizations and are often classified as large-scale schemes (Lankford et al. 2016).

2. **Individual** irrigation management occurs when farmers have independent control over their irrigation system but share a source (river, reservoir, aquifer) with other adjacent irrigators. These can be individually owned (Type 3) or company owned (Type 4).


Photo Credit: Liudmila Pestun

Table 9. Small-Scale Irrigation Ownership Models

	COLLECTIVE OWNERSHIP MODELS		INDIVIDUAL OWNERSHIP MODELS	
Definition and management arrangement	*A group of irrigators share the hydraulic infrastructure*		*Farmers have independent control over their irrigation system but may share a source (river, reservoir, aquifer) with other adjacent irrigators*	
	Type 1: small- to large-scale public irrigation systems	*Type 2: small- and medium-scale community-managed systems*	*Type 3: individually managed systems*	*Type 4: corporate irrigation systems*
Ownership	Government-owned, tenants have usage rights	Owned by community	Owned by individual	Private sector owned and leased
Day-to-day management	Co-managed	Autonomous management (e.g., trust or cooperative; operated by voluntary farmer labor or private sector service organizations owned or contracted by irrigators)	Autonomous management or co-managed	Autonomous management or co-managed (e.g., private sector service organizations contracted by irrigators)
Private sector role	Functioning input and output markets (seeds, agro-chemicals, irrigation equipment) Capacity building (technology, use and maintenance of equipment), finance service providers (loans, guarantees) Service providers (design, install, maintain) Market offtakers (providing secure market demand and stable pricing)			
Public-private partnership	Private sector bulk-water-supply operator, joint venture	Bulk water supply, irrigation service providers	Community as water infrastructure contractor	Private sector irrigation operators, agricultural service providers in outgrower roles or other strategic alliances; joint ventures
Governance	Distribution of land rights to water user associations, water user organizations, and irrigation and drainage agencies	Public-private associations	Multiple-use water services forums; community arrangements	Consolidation of land and technical, outgrower, or financial services relationships. The private sector can also provide agricultural support, extension, or financial services, irrigation operational support in exchange for secure access to irrigated land or produce (e.g., for processing facilities).

	COLLECTIVE OWNERSHIP MODELS		INDIVIDUAL OWNERSHIP MODELS	
Determinants of success	Participatory management; capacity; access to markets	Transparency and customer orientation; availability and sustainable use of water resources; access to markets and technology	Equity, fairness, and inclusion; consistent policy, legal, and regulatory frameworks; capacity; availability and sustainable use of water resources; access to markets and technology	Sustainable use of water resources; equity, fairness, and inclusion

Irrigation is managed collectively when a group of irrigators shares the same hydraulic infrastructure. Examples of collective management include large-scale public schemes (Type 1) and small- and medium-scale community-managed schemes (Type 2). Farmers can manage collectively managed schemes themselves or manage them collectively with operators or agencies. Autonomous management includes village-owned schemes operated by volunteer farmer labor and private sector service organizations owned or contracted by irrigators. Autonomous management models are often considered SSI schemes and are generally do not involve a government irrigation agency in operating and maintaining the infrastructure or water resource. Co-managed schemes are largely the result of transfer of management responsibilities for part of the irrigation infrastructure from the public irrigation agency to water user organizations and are often classified as large-scale schemes.

Case studies

The case studies below from Sub-Saharan Africa showcase some successful approaches that illustrate different operating models and include examples of governance-related determinants of success. The first case presents a success story of the collective ownership model in Ethiopia (Type 1), the second case discusses how a participatory approach benefited operationalization of a multiple-use water services project in South Africa (Type 3), and the third case discusses how outgrower models have evolved in southern Africa's sugarcane industry (Type 4).

Photo Credit: Nana Kofi Acquah. IWMI

Photo Credit: Richard Colback, IFC

CASE STUDY 7: Effective, Sustainable Investments in Water for Poverty Reduction: Enhancing the Quality of Agricultural Water Management Investments

Countries:	Years:	Organizations involved:	Crops:	Irrigation systems:
Ethiopia, Madagascar, Mali, Niger, Rwanda, Tanzania	**2014-2018**	**IFAD, Food and Agriculture Organization, International Water Management Institute, Consultative Group on International Agricultural Research**	**Various**	**Various**

More Effective and Sustainable Investments in Water for Poverty Reduction, a project implemented in six African countries (Ethiopia, Madagascar, Mali, Niger, Rwanda, Tanzania), developed new models of planning and implementing agricultural water management (AWM) investments. The project's goal was to increase food security and reduce poverty among smallholder farmers by providing guidance and technical support to enhance the quality, effectiveness, and sustainability of AWM investments. Specifically, the project sought to increase knowledge and assess the potential for designing and expanding innovative AWM solutions and business models; increase the capacity of AWM by providing capacity-building, mentoring, and support services; and improve AWM investment planning by enhancing existing dialogue platforms.

The project recognized the diversity and complexity of the country contexts and priorities and tailored its interventions accordingly. Any rural water development strategy must manage diversified livelihood systems with limited capacities for agricultural investment, emphasizing strategies to mitigate risks.

Any effort to enhance and expand farmer-led irrigation requires taking a gender perspective, which was done throughout the project. Wealthier male farmers often adopt labor-saving, motorized technologies, whereas women and poorer farmers are limited to labor-intensive, manual technologies. In Kenya and Tanzania, for example, women accounted for only 10 percent of all buyers of motor pumps (Njuki et al. 2014). Men are also likely to earn higher incomes from irrigation, not least because women tend to have access to smaller land portions, less access to money, and less farming and marketing information (Lefore et al. 2019). The project considered gender when defining the farmer types in each of the livelihood zones. It also analyzed the gender gap in technology adoption when assessing the suitability and potential of selected AWM solutions according to livelihood zone to ensure equitable benefits for women and men from investments and development support. In addition, the project's business models considered challenges and benefits related to gender, notably in considering potential financing mechanisms that could enhance gender equity.

The project offered a set of concrete, evidence-based recommendations and tools for donors, policy makers, the private sector, communities, and individual farmers in prioritizing and planning water-related interventions that support smallholder farmers. A continuous consultative process with stakeholders—farmers, investors, policy makers—led to development of recommendations on AWM technologies. For example, a series of iterative stakeholder analyses, workshops, interviews, and field visits resulted in development of a tailor-made methodology to assess countries' needs in AWM, including the relevance of, potential for, and opportunities for increasing the impact and effectiveness of AWM investments. The participatory nature of the mapping and consultation exercise, which involved policy makers at the dialogue stage, helped create solid ownership of the process and the selected AWM technologies in each country and ensure that the approach was sustainable. Representatives from Côte d'Ivoire and The Gambia, countries that were not part of the program, participated in some of the meetings and expressed interest in replicating the approach.


Photo Credit: Richard Colback, IFC

Key metrics

- Number of maps developed
- Number of countries with needs assessment reports and priority AWM solutions
- Number of business models developed
- Number of research papers published
- Number of practice guidelines and manuals
- Number of stakeholders trained
- Number of national dialogue teams established

Key results

- Twenty-three maps assessing potential and suitability of AWM solutions in four countries (Madagascar, Mali, Niger, Rwanda)
- Update of livelihood and suitability maps to better account for climate
- Six country reports assessing need for investment in research, technical assistance, training, and policy support in AWM following the livelihood and suitability mapping approach
- Priority AWM solutions identified for each country
- Two business models and nine research papers developed for priority AWM solutions identified: solar pumping for irrigation (Ethiopia, Mali) and small reservoirs
- Evaluation of irrigation WUAs and publication of practice guidelines to address challenges identified
- National dialogue teams established in four countries to prepare national master plans guiding investments at country level on SSI

Lessons learned

- The livelihood and suitability approach to investment planning should consider biophysical suitability, socioeconomic context, and diversity of livelihoods, including poverty and gender aspects. The maps allow the relationships between people and water to be analyzed and the extent to which and how water can boost development and reduce poverty to be understood.
    - Livelihood maps provide a good basis for planning to target beneficiaries, considering the diversity of livelihood systems. Livelihood maps can help guide water investments because they identify key needs and opportunities of smallholder family farmers.
    - The methodology allows for development of priorities for investment (in this case, reducing poverty) and an understanding of the potential for expansion.
- A range of community engagement approaches should be used systematically to ensure participation of various stakeholders in investment planning.
- Achieving gender equity is crucial. Any effort to enhance and expand farmer-led irrigation requires a focus on gender equity. For example, in Ethiopia, women preferred solar pumps over other irrigation technologies when the pumps were located nearby and could be used for multiple purposes because they saved them significant time and effort on domestic chores and provided them with the opportunity to earn additional income.

Sources: Njuki et al. 2014; Lefore et al. 2019.

Photo Credit: John Hogg, World Bank

CASE STUDY 8: Adopting a Participatory Approach: Key to Success in Tanzania's Participatory Irrigation Development Programme

Country: **Tanzania**	Years: **1999-2006**	Organizations involved: **IFAD; World Food Programme; Irish Development Aid; government of Tanzania**	Crops: **Cotton, sorghum, millet, maize, rice**	Irrigation systems: **Diversion of flood water and in-field application through surface irrigation**

Tanzania's Participatory Irrigation Development Programme was designed to increase crop productivity sustainably by expanding and improving well-managed farmer-initiated SSI systems with the following outputs:

- Improvement in water management systems in program areas
- Improvement in services for agricultural development
- Construction or improvement of market access roads in program areas
- Greater capacity of local institutions (farmers, districts, private sector)
- Greater participation, equity, and sustainability
- Establishment of coordinated program activities

By rehabilitating existing irrigation schemes and designing new ones, the Participatory Irrigation Development Programme implemented 56 schemes, bringing more than 14,000 hectares under irrigated cropping and reaching more than 25,400 beneficiaries—including 10,400 women and 8,400 youth.

The Participatory Irrigation Development Programme was created and implemented through a partnership involving international financing agencies, the government of Tanzania, and other beneficiaries. The roles and responsibilities of the partners were clearly outlined, including financing and co-financing, government counterpart financing, and contribution of beneficiaries.

The program's irrigation systems were designed after consultation with beneficiary communities, village leaders, and local government authorities. The systems were planned, implemented, and operated using a demand-driven, participatory approach. After the awareness of community members was raised, the planning process began with logical planning incorporating problem and solution tree analyses, well-being analyses, and logical framework and activity planning. The stakeholders reached an agreement on their roles in developing and maintaining the irrigation infrastructure, feeder roads, buildings, and wells.

In line with this participatory approach at the project design phase, beneficiaries actively contributed labor and materials to build the infrastructure, such as collecting stones and digging canals. Through their WUAs and village leaders, beneficiaries and government engineers supervised contractors.

Developing and managing the infrastructure included a public-private approach. The program trained and equipped local contractors and artisans, who took an active role in construction and later maintenance of the irrigation systems.

The participatory approach of the program was effective in managing water in these SSI schemes and increasing ownership and sustainability. There is evidence that Participatory Irrigation Development Programme interventions sustainably reduced poverty; improved physical assets; increased food security and incomes; enhanced human assets; and empowered and increased the knowledge, innovation adoption, and skills of beneficiaries, although this was limited to areas where water availability and reliability had increased.

Photo Credit: Neil Palmer / IWMI

Key metrics

- Yield: tons/hectares
- Physical assets: percent

Key results

- Rice yield increased from a baseline of **0.2** to an endline of **2.0** tons per hectare.
- **41** percent of farmers improved the quality of their houses. Farmers showed evidence of better quality of life through better houses and ownership of assets such as ox carts, bicycles, and cattle.

Lessons learned

- A participatory approach is effective in ensuring sustainability, gender equality, and inclusion of disadvantaged populations. Participation is a process that takes time to yield results but should be adopted when considering future SSI designs. The challenge is to combine development and expansion of irrigation, water harvesting, and agricultural productivity with community participation and capacity enhancement to yield effective, demand-driven schemes with appropriate physical structures.
- Experience from the Participatory Irrigation Development Programme shows that developing irrigation and water harvesting can reduce poverty, albeit not universally. The proposed irrigation plan must assess availability of water and timing to determine what can be achieved before a final decision is made. Various possible irrigation and water harvesting technologies should be discussed with future users in the context of each potential scheme.
- A holistic approach to developing water resource management is necessary to avoid irrigation development plans that may not be feasible or sustainable. The most pertinent development challenges related to irrigation and water harvesting go beyond the technical challenges of applying water to crops and increasing productivity.

Photo Credit: IFAD/Susan Beccio

VOICE OF A FARMER: How a Nepalese Community's Construction of an Irrigation Pond Solved Their Water Crisis

None of the residents of Nepal's Ghodadhauna village, including 60-year-old Umadevi Lamsal, had a kitchen garden to grow vegetables because of the lack of an irrigation facility. Nepal's National Adaptation Plan for Action district vulnerability ranking ranked the Dailekh District, where the village is located, as one of Nepal's most vulnerable districts to climate change. Umadevi recounted having to walk about an hour for her cattle to drink water. Without monsoon rain, cultivation of major crops was almost impossible. About 10 families left the village, unable to manage such problems.

To address the water shortage, the community banded together to form Kalika Farmer Group and registered it with the local authority. The group comprised 21 households—15 percent headed by women and 20 percent dalit (so-called lower caste) households. The farmer group prepared a proposal for a small irrigation system with the support of its ward committee (the lowest administrative unit) and the Adaptation for Smallholders in Hilly Areas project.[10] After assessing the proposal and a feasibility study, the district project coordination unit contracted Kalika Farmer Group for irrigation pond construction, which was deemed a priority based on the village's annual work plan. The project's technical team designed the pond and provided technical support to the farmer group to ensure that the pond was constructed according to those designs. Each household in the group participated in the 5-month construction process to complete a permanent 50-m^3 pond. The water source of the pond is only 2 kilometers away. The total cost of the project was $7,575 (NPR 878,700); the community's labor contribution was equivalent to $1,549, and the government of Nepal's was $1,565.

10 The Adaptation for Smallholders in Hilly Areas project is an undertaking of the Ministry of Forests and Environment in Nepal, with financial support from IFAD. The project is designed to support vulnerable smallholders to increase their climate resilience by disbursing grants to communities and households, disseminating climate-centric knowledge, and developing capacity.


Photo Credit: IFAD/Sanjit Das/Panos

Umadevi, along with other women in the village, benefited from the pond construction. She no longer had to spend 3 hours to fetch a bucket of water or suffer physical injuries, which were common among women. Life is easier for her now, and she has more time to complete household chores. She recounted that almost every household has access to tap water now.

Bhadra Bhadhur Thapa, a 76-year-old farmer from the same village, recounted facing increasing difficulties when the monsoon rains were delayed, massive floods occurred, newly emerged pests destroyed crops, and many more challenges arose. The volume of crops produced started to drop, but all that changed with the construction of the irrigation pond.

Call to action

The determinants of success discussed in this chapter are pillars that form the foundation for sustainable operating models. The models of the past were based on the environment that prevailed, including different socioeconomic factors, coupled with the role that governments played. Delegation of water management by governments, for example, comes with its own set of skills and operational requirements. The new environment of scarcity of resources dictates that detailed farm records be kept that detail practices so that they form lessons that can be used as models evolve.

Lessons from other countries must also be learned and modified to suit where a need arises. Governments must encourage collaboration at all levels, including at the farmer level, to learn from each other even across irrigation system boundaries.

Operating models should ensure:

1. Clear understanding of the mode of operation and clarity of roles and responsibilities of all parties. The levels to which government is involved must be clear and understood by farmers, noting that stakeholder consultation is not an event but a continuous process. Models must be sensitive to external and internal disturbances that may surface, even when everything is going well.

2. Transparency regarding the kind of data that needs to be collected to assist in monitoring performance of the model and provide timely interventions when required. Capacity building in this area is required because monitoring is important in ensuring that departure from intended practices is detected early and corrected.

3. Periodic audits (technical and financial) conducted and farmers taught how to perform them.

4. Awareness of environmental and climatic factors that are critical to production, including the micro-climate that they operate under. Rainfall and river flow records should be kept and analyzed against weather and climate projections for monthly or seasonal forecasts. Artificial intelligence tools for water management are now commonly used; the model should require that the water management agency use such tools in scenario playing and forecasts.

5. Active involvement in WUA meetings where water use patterns are discussed, balances for users are reconciled in the system, and results are publicized. In such meetings, water orders are placed for future releases according to user requirements. During periods of scarcity, users agree to rationing as advised by the water management agency, which becomes implemented and monitored, giving feedback to all water users in the affected area. Government representatives attend these meetings in a regulatory role because operations and management of water are delegated to the water management agency. Consideration of the changing needs of nonagricultural water users and the impact of updated water rights during times of scarcity will affect the remaining water availability for farming.

Beneficiary groups have an important role to play in ensuring accountability of their members, taking on a prominent role in water management, managing conflicts over water resources, and adopting an inclusive approach that involves women and youth within their leadership structures. Service providers should focus on policing water use, maintaining the irrigation infrastructure, and promoting transparency in interactions with customers.

The public sector has a critical role to play in large-scale infrastructure development and management, as well as setting policy and financial support mechanisms that enable operating models to remain sustainable when facing climatic shocks or for more vulnerable small farmers. National agencies should ensure consistency of policy, legal, and regulatory frameworks and adopt and promote intergenerational learning programs for youth in irrigated farming. Local government agencies can focus on increasing the technical capacity of farmers, ensuring equal access to land and water, and creating incentives for farmers to take over management of operations and maintenance of the irrigation system.

The private sector role in operating or supporting the operation of models of SSI systems is increasingly key as the public and development sectors seek to accelerate scale-up of irrigation. Climate change, an increasing need for reliability of crop supply by large off-take organizations, and an interest of equipment suppliers in entering this largely untapped market create several opportunities. The private sector may participate as intermediaries with financial organizations; as aggregators of smallholders to create greater economies of scale in developing these irrigation systems; and as service providers to deliver design, technical training, access to financing and equipment, and after-sales support to the in-field component of bulk water supply-based systems.

Table 10. Role of Stakeholders in Operating Irrigation Systems

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
PRIVATE SECTOR		
WUAs, farmer groups	• Make transparent operational decisions and minimize administrative costs • Require farmer representation on all committees • Use and share weather information to adjust water delivery schedules • Promote timely irrigation as part of integrated input program	• Increase participation in WUAs and improve return on investment to provide greater incentives to remain involved • Increase equity of water access and distribution, particularly at ends of canals or pipelines • Efficient use of bulk water supply, with water provided as required, not on a fixed plan • Improve input efficiency to optimize agricultural production
Financial institutions	• Provide pre-harvest and operations loans at end of season to ensure late-season irrigations are applied	• Increase yields of crops that are sensitive to water deficits because late-season irrigations are often not applied because of cash shortages
Equipment manufacturers and distributors	• Stock commonly required spares to expedite replacement, with focus on pumps	• Reduce downtime during critical periods of peak irrigation demand, improve overall system performance
Smallholder Farmers	• Schedule irrigation according to weather, crop growth and development stage, and soil water-holding capacity • Optimize use of equipment by matching capacity to crop area, use portable assets to provide irrigation as a service or rental for use to other farmers	• Match irrigation with crop water requirements to reduce costs and maximize water use efficiency • Maximize return on investment and additional cash flows from portable assets and maximize cash flow for faster repayment of loans
PUBLIC SECTOR		
National government	• Improve data and communications infrastructure, including radio, internet and wireless for mobile devices; provide low-cost data access in rural areas • Adapt and promote inter-generational learning and succession programs to promote youth engagement in irrigated farming	• Increase knowledge transfer, training, and support, including weather alerts; irrigation scheduled with field-based sensors; provision of remote technical support • Ensure knowledge transfer and ongoing growth of irrigated farming community and leverage technology skills and awareness of younger generation to improve efficiency
Local government	• Develop policy to require equity, fairness, and inclusion in use of irrigation resources • Create incentives for farmers to take over irrigation system operations and maintenance of bulk water supply component • Promote and supply financial support to successful local operating models	• Protect vulnerable communities, including female farmers, and ensure equal access to water resources • Allow public resources to focus on managing sustainability of water resources • Leverage perspective of government to improve match of operating model (collective or individual) to culture, climate, and commercial factors to improve outcomes for all stakeholders

Chapter 5: Irrigation Financing: Lessons from Practice and Emerging Innovations

Key messages

- Investment in SSI is needed to meet growing demand for food, but lack of financing has consistently been a constraint on expansion of irrigation investments.
- Effective irrigation financing requires consideration of the full lifecycle of costs, including capital costs, operating costs, replacement costs, and some measure of the environmental resource availability required to ensure the system's sustainable access to water.
- A substantial proportion of the 500 million smallholder farmers could increase irrigated production, as well as their incomes, if financially viable projects could be identified and implemented.
- Many smallholder farmers, particularly women, youth, and marginalized groups, face even greater barriers to accessing financing for agricultural inputs and for irrigation technology investments.
- Emerging innovations to strengthen standard approaches show promise for enhanced inclusion of smallholder farmers in irrigation through information and communications technology (ICT) and by bundling financial and technical solutions.
- Demand for private sector solutions, to commercialize payment schemes or combine them with public finance, are rising rapidly around the world as other priorities (including pandemics such as COVID-19) overtake public spending programs.
- Digital innovations are helping make current food systems more productive, cost efficient, transparent, and agile. Digitization of value chains enables tracking and building transaction records of farmers that were not available before, increasing the likelihood of financing.

Summary

Farmers and financial institutions face several related challenges in the context of irrigation financing. The first challenge is for smallholder farmers to leverage their access to labor and land to produce cash crops under irrigation within a commercial supply chain. This may require loans from the supply chain off-taker; crop sales revenues could be used to secure those loans. This is a supply chain–anchored model.

Farmers who do not sell their crops in a market-linked supply chain, operating at a subsistence level with rainfed agricultural production, and who wish to improve their incomes and quality of life by increasing their productivity with irrigated agriculture face a more complex challenge. These farmers operate in

an unanchored model because no guaranteed market exists, and repayment of loans relies on sales of crops in informal markets. In such cases, farmers may not initially be able to repay loans through sales of crops. Addressing the need for financing during the transition to a sustainable quality of life may require development assistance from external parties who can provide grants, insurance, first-loss guarantees, or similar risk-reduction measures while access to credit and reliable cashflows are established.

The final challenge is to design financing that meets the needs of the complete lifecycle of use of irrigation, including capital, operating, and replacement costs (lifecycle costs). This requires a structure of financing that varies significantly between high capital loans with low ongoing operating costs and low capital cost loans with high ongoing operating costs. Where systems are equally available, accounting for these trade-offs may be complex. For example, the high capital cost and low operating cost of longer lifespan technologies such as solar-powered irrigation pumps would be analyzed against the low capital cost and operating, maintenance, and replacement costs of fuel-powered pumps. Or the high capital costs of drip irrigation, which offers accuracy, lower overall water use, minimal labor, and higher potential yields, can be compared versus low-capital-cost furrow irrigation, with high operating costs in the form of labor, greater use of water, and lower potential yields.

This chapter outlines the constraints of limited access to financing; identifies roles and opportunities for actors in irrigation financing; presents the business case for financing different types of irrigation assets, including land development costs; and identifies the need for a combination of asset purchase, operating, and maintenance capital during the life of an irrigation system. The cases presented are not intended to highlight any particular solution, but rather to discuss different financing models to address different types of irrigation needs, from large-scale national energy and irrigation infrastructure to commercial farmers to smallholder farm-level enterprise. The chapter seeks to fill the gap in practice-oriented guidance for decision-making on financing different irrigation investments.

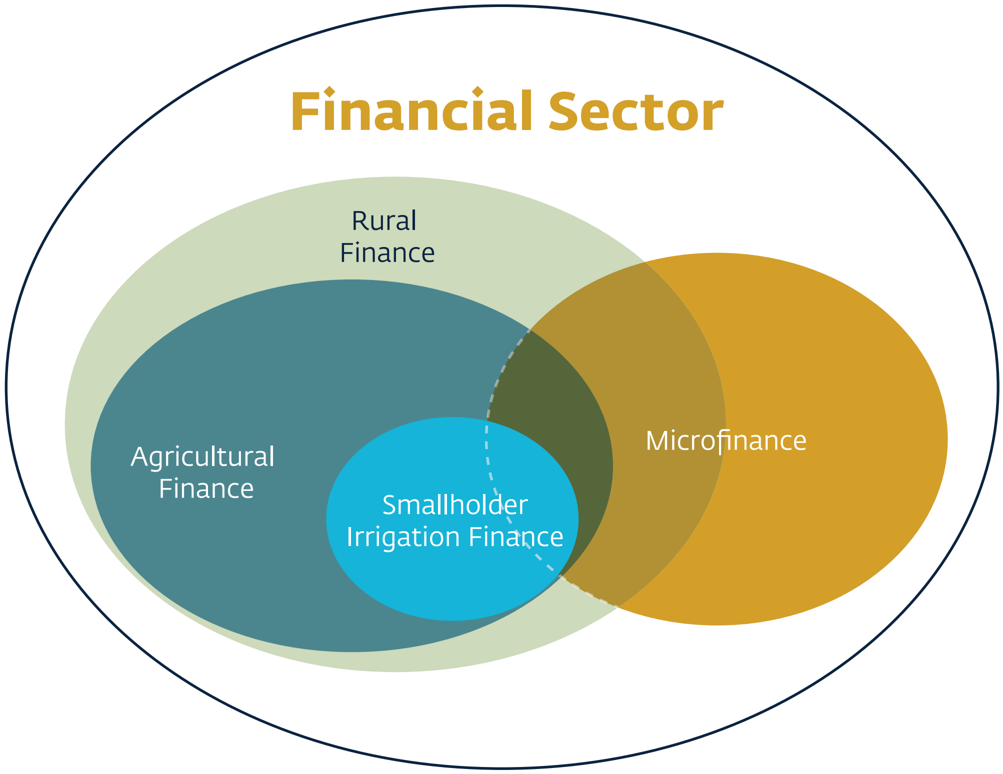
The case for investment in SSI

Agriculture accounts for more than 30 percent of GDP in Sub-Saharan Africa and 15 percent in Southeast Asia, employing up to 60 percent of the workforce in some Sub-Saharan African countries and about 40 percent in Southeast Asia. Additional investments in agriculture can provide a pathway out of poverty for many poor people in these regions. The World Bank estimates that investing in agriculture is up to four times as effective in reducing poverty as investing in other sectors (World Bank 2015).

Additional food demand could provide an opportunity for market-based agricultural growth. Food production may need to increase by up to 70 percent between 2005 and 2050 to meet the growth in food demand for an expected global population of more than 9 billion by 2050. Investment in SSI is needed to meet this growing demand for food, as well as animal feed, fiber, and biofuel. Financing has consistently been a primary constraint on expanding irrigation investments.

The financing gap for long-term funding for SSI is estimated to be more than $26 billion annually. Historically, international and bilateral development partners and national governments considered irrigation to be a strategic investment that warranted public funding. Recently, demand for private sector solutions, to commercialize payment schemes or combine them with public finance, are rising rapidly around the world as other priorities (including pandemics such as COVID-19) overtake public spending programs.

Figure 10. Smallholder irrigation finance nested in agricultural finance



(Adapted from Grimm and Richter 2006)

The need for irrigation finance

After decades of focus on serving other market segments and client bases, financial service providers are now being encouraged to seek opportunities to expand into rural markets to address the financial needs of smallholder farmers. The financing gap for SSI is significant, but it is expected that a substantial proportion of the 500 million-person global market represented by smallholder farmers could benefit from introducing irrigated crop production and increase their net incomes if financially viable projects can be developed. The challenge is to present a compelling business case to financial institutions that encourages development of a competitive market and products designed to provide SSI financing. This is likely to include risk-sharing mechanisms and innovative insurance solutions, given the dependence of the agricultural sector on external factors. Encouraging donors and governments to provide market development support is also important where a low initial level of demand does not provide the critical mass to meet fixed costs of deploying products and establishing risk profiles or credit ratings for farmers. At the producer level, the focus will by necessity be on farms that can produce surpluses to increase profitability and provide income for repayment of loans and savings for future investments.

Supply-side factors in SSI financing

A combination of commercial or public sector banks, development agencies, nongovernmental organizations and nonbank financial institutions typically provide supply-side SSI financing. In the case of banks and nonbank financial institutions, understanding the objectives and methodologies of calculating their costs and target returns provides insight into the necessary criteria to create an effective market for financial products that support farmers' investment in irrigation. Several key factors are illustrated in Box 1.

Box 1: Supply-side factors

Investment objective: Maximize bank and nonbank financial institution profit from lending for SSI

Profit from SSI lending: Repayment of SSI loan—interest charge, based on interest rate that covers all costs determined using risk-based pricing

Interest rate: Cost of funds + risk premium + transaction cost + profit margin if there is no interest rate ceiling policy and lenders are allowed to use risk-based pricing.

Based on the relationship above, banks will lend to small-scale farmers if the profit from the transaction is the same or greater than that earned from other borrower categories.

Probability of default: Probability of default depends on farmer income (yield x price – costs), size of loan, interest rate, collateral, insurance, access to other sources of income, and willingness to pay. Because default causes economic losses, it is a cost, like all other categories of cost. Risk of default is always positive because of the option of voluntary default that the borrower can exercise any time. Ignoring transaction costs affects default probability, as shown below.

Information asymmetry: A bank facing a pool of SSI farmers is unable to distinguish between the farmers and therefore cannot determine which of the three categories a farmer falls within:

1. Farmers who pay their loans in full with interest as agreed and on time
2. Farmers who pay their loans with significant amounts of costly monitoring and supervision
3. Farmers who default on their loans

Farmers know more about the business risks and opportunities from purchasing irrigation systems, with significant insights that affect the performance of the loan based on their level of farming skill and experience, the quality of their farms, their level of effort, and their intentions for the equipment. SSI farmers are also very different in these attribute types. The uncertainties that this variability creates gives rise to a reluctance by financial institutions to enter the market or expand their products to a broader base of smallholders.

Collateral: Banks use collateral to mitigate the risk of farmers not repaying loans and adverse selection risks. Farmers without collateral may be rationed credit or excluded from the market entirely. The need for collateral arises from imperfect information because it is costly to try to distinguish large numbers of heterogeneous borrowers (Bester 1987). Where collateralized lending is the dominant form, the value of available collateral limits the amount of credit available for SSI. For example, a bank may have a policy of lending up to 80 percent of collateral value, which sets the upper limit of credit available. This can pose a problem given the indivisibility of SSI investments. That is, there is a minimum investment needed for irrigation assets, which may be less than the credit limit set according to the collateral available.

Lending process

In many cases, the accuracy of data that smallholder farmers suppy to qualify for a loan fails to meet the standards to assess risks and price the loan efficiently. These challenges are often because of the informality of business records available from many small farms and lack of experience of banks and farmers with the full capital, operating, and replacement costs of different systems. This requirement for accurate data on farms' financial performance may therefore require a prerequisite stage of establishing a data collection and management system during which smallholder farmers transition to operating their farms and collecting records suitable for lenders' needs. These records may be established at a group or cooperative level or at an individual farmer's level. Legal rights to land holdings require accessible, robust land registries, and full lifecycle costs must be established for each system. The typical process for lending to farmers entails a series of steps in common with all other lending products.

1. Collect information on prospective SSI financing
2. Evaluate all observable information
3. Sort and screen borrowers
4. Select borrowers with low probability of default, adequate collateral, and high income potential
5. Monitor, collect, and supervise loans: Because monitoring and supervision are costly, lenders prefer borrowers who do not require close monitoring and supervision.

The impact of digital innovation

Digital innovations are helping make current food systems more productive, cost efficient, transparent, and agile. Digitization of value chains is also enabling tracking and analysis of transaction records of farmers that were not available before. Over the last 10 years, these innovations have come a long way to helping understand farmers' capacity to produce and their creditworthiness. Furthermore, different financial technology, agritech, e-commerce, and digital platforms are helping increase the reach of new financial and nonfinancial services for farmers. Below is a list of innovators that are contributing to this trend.

1. Access to Services
   - Digital Advisory services: agri Good Agricultural Practices, Climate Smart Advisory, weather information, pest and disease management, product verification, digital record keeping
   - Agri digital financial services: Credit scoring, input financing, crowdfunding, insurance, digital agri wallets, digital savings, accountability tools
2. Access to Markets:
   - Digital Procurement: Digital records with payments, with traceability, with payment and traceability
   - Agri e-commerce: Digital platforms offering high-quality access to inputs, e-commerce platforms sourcing agricultural products, digital platforms offering inputs and access to markets
3. Access to Assets
   - Smart farming equipment
   - Smart shared assets
   - Equipment monitoring (Internet of Things, sensors)
   - Livestock and fishery management

As highlighted above, the traditional lending cycle, which has been labor intensive, can now transition to a high-tech and low-touch model in which banks must collaborate with different partners, agri-tech, e-commerce platforms, and financial technology to use the digital information they are generating to issue, manage, and recover loans. Building those partnerships will still require a significant level of effort from banks, agri-tech, and digital platforms (Table 11).


Photo Credit: Richard Colback, IFC

Table 11. Digital innovation in the loan cycle

LOAN STAGE	ACTIVITY	DIGITAL SOLUTION
Farmer onboarding	Farmer Know your Customer—land ownership, type of farmer (sharecropper, tenant farmer, lessee)	Digital advisory services Digital procurement companies Agri e-commerce companies
Creditworthiness & risk assessment	Estimation of assets, income, and farmers' credit behavior	Asset access companies Digital advisory services Agri-digital financial services
Linking credit to inputs sales	Farmers' profile, location, input needs, creditworthiness	Agri e-commerce companies Agri-digital financial services
Post disbursement monitoring	Risk monitoring and risk mitigation	Digital advisory services: Drone and satellite imagery monitoring Access to assets: Sensor / IoT-based start-ups
Loan recovery	Settlement of loan and loan collection through buyers	Access to markets: e-commerce platforms Agri-digital financial services

Demand-side factors in SSI financing

The demand side of SSI financing includes investors seeking to purchase irrigation equipment for use by others, such as off-takers or farmer groups who are promoting increased yields, reliability of crop production, and improved quality of crops. These investors can play the role of intermediary between banks and farmers. The farmers themselves provide the ultimate demand and responsibility to repay the cost of financing. Several key factors are illustrated in Box 2.

Demand-side investor: Smallholder household, farmer company, off-taker WUA

Investment objectives: Maximize net income, enhance food and nutrition security, create wealth, manage risk

Investment opportunity: Increase in food demand from population growth and urbanization and decrease in rainfall reliability because of climate change

Box 2: Demand side factors

I. Farmer resource endowments for SSI

Land: Owned or documented communal leasehold land, L (hectares), is currently used for subsistence agriculture—low-risk reserve activity that generates income of $RI—that is to be replaced by high-risk irrigated crop production that generates income $NI. Boucher et al. (2008) explain the concept of a low-risk reserve subsistence activity that represents the opportunity cost of investing in SSI.

Access to water right: Water allocation through a permit adequate to irrigate (L) above

Labor: Own family or hired labor

Capital: Own equity financing from savings ($E), grants and subsidies ($G), loan from bank and nonbank financial institutions at interest rate (r) with loan repayment ($R). If land is owned, it can be used to access loans. Otherwise, availability of collateral substitutes limits access to financing.

Access to inputs: Fertilizer, machinery, seeds, electricity, diesel, and crop chemicals are from factor markets. All these inputs are divisible, meaning that the farmer can use amounts determined according to budget constraints.

Technical assistance: Available from government and donor agencies, crop buyers, and input suppliers

II. Crop production economics

Access to market: Outgrower contract, forward contract, local domestic market to supply produce (Q tons = yield per hectare x L). Market is sufficiently insulated from gluts.

Price: Price ($P per ton) is determined externally from market (international or domestic).

Total cost ($TC): Crop production costs per hectare + marketing costs

Revenue ($R): Price ($P) x crop quantity (Q tons)—Yield per hectare depends on uncontrollable weather variables and level of input use and timing, which depend on availability of working capital, managerial expertise, and experience. Each smallholder farm will have its own yield distribution, which will determine repayment capacity over time.

Irrigation system cost ($I) = L hectares x irrigation system cost per hectare determined by irrigation technology selected and design. Amount $\mathbf{I_i}$ is indivisible given the need for irrigation equipment to cover the whole area. If amount **I** is not available, the investment in SSI will not go ahead.

Demand for credit ($C) = Ii – E – G, when E is less than the investment amount and otherwise 0 if E is greater than I and the farmer wishes to self-finance fully. In some cases, C = Ii – aE, where a is a fraction from 0 to 1.

Net farmer income ($NI) = R – TC – R is a random variable affected by prevailing prices and yield achieved

- Investment in irrigation is worthwhile if NI > RI (reserve/subsistence activity income).

Challenges and constraints

All stakeholders must address four key constraints though a coordinated approach to develop access to finance:

- **Lack of, or short-term, land tenure and long repayment periods:** Lack of security of land tenure significantly reduces the incentive for farmers to invest in irrigation systems that require several years to repay. Farmers and off-takers may focus irrigation on higher-value crops, which allow for shorter repayment periods; short-term returns will match the time frame of the short-term land tenure.
- **Improvements in land ownership such as registries:** Land assets may be used to provide longer timeframes for repayment by allowing collateralization of loans, which reduces risk, increases access to financing, and therefore increases adoption of irrigation.
- **Risk aversion:** Farmers face a wide range of natural and market-based risks and thus tend to favor diversification to reduce their exposure. This includes rotating higher value irrigated crops that are sensitive to water shortages with rainfed crops that are more drought tolerant and limiting debt by irrigating a smaller area to ensure that potential debts do not exceed assets. Public sector and development project promotion targeting expansion from pilot to broad adoption across the whole area may require additional risk-sharing options targeting farmers and banks, who carry most of the risk. Mechanisms include crop insurance and payment default (first loss) insurance.
- **Limited access to financing:** Irrigation systems can be installed on small pilot areas with limited amounts of equipment that can be easily supplied through existing agribusiness retailers using farmers' own funds or development partner funds, but expansion from these initial pilot areas often requires access to finance throughout the supply chain, which is often beyond the savings of famers and includes a need for low-cost capital to invest in infrastructure plus working finance for operating costs and maintenance. For equipment retailers, the additional cost of purchasing equipment from manufacturers and carrying related spares requires a significant increase in working capital. The leap from pilot to scale may thus require additional financial support to develop the market ecosystem while demand and supply are brought into balance.

Access to finance should also be designed to address specific inefficiencies occurring at a farmer level in relation to agricultural inputs and irrigation technology investments (Table 12).

Photo Credit: IFAD/Horst Wagner

Table 12. Constraints on Accessing Financing

CONSTRAINT	DESCRIPTION
Production risk	• A wide range of external factors such as poor weather conditions affect irrigated crops, making yield uncertain, which can make financiers hesitant to lend to farmers because these risks are difficult to control.
Market and price risk	• Agricultural commodity prices are typically volatile, creating uncertainty for farmers. In many cases, the price of harvested output is not known at the time of planting, when production decisions are made.
Savings, collateral, and credit history	• Lenders often require borrowers to make equity contributions of 10 percent to 25 percent. In most cases, smallholder farmers lack savings and equity. • Smallholder farmers may lack assets that can be pledged as security for loans and often lack a credit history.
Legal and institutional constraints	• Poor legal frameworks and lack of enforcement capacity increase risks for lenders, who are often unable to sell collateral after borrowers default.
Limited skills and knowledge	• Smallholder farmers often have low levels of education, which limits their financial literacy. They also have limited access to high-quality inputs or lack awareness of options. This can contribute to highly variable yields and revenues, reducing their capacity to service their loans.
SUPPLY-SIDE CONSTRAINTS (BANK AND NONBANK FINANCIAL INSTITUTIONS)	
Cost to serve	• Low population density increases cost per customer served. • High transaction costs are incurred because of the fixed costs of loan origination, collection, and supervision, which are independent of loan size.
Expected returns	• Highly volatile income and high probability of default reduce bank, expected returns.
Limited knowledge and experience of financial institutions	• Some banks and nonbank financial institutions do not have experience lending to agriculture and irrigation. • Information on small-scale irrigation is scanty and not available to banks.
Long-term financing	• Banks that are capitalized largely from deposits by clients are not well equipped to lend for irrigation, which requires loan tenors ranging from 3 to 7 years.
ECOSYSTEM CONSTRAINTS	
Political constraints	• Smallholder farmers are an important constituency for politicians in developing countries as voters and through their role in ensuring food security. • This political interest often results in interventions such as interest rate ceilings, price controls, loan write-offs, bailouts using donor funding, and policy changes that can significantly increase risk for lenders. • These political interventions result in donor funding crowding out commercial funding and are a moral hazard because smallholder farmers know there will be loan write-offs, food aid, and bailouts if they do not pay their loans.
Poor infrastructure	• Lack of transport, electricity, information and communications technology, warehouses, and cold rooms increases costs for smallholder farmers and their banks.

Inclusive financing

Women, youth, and marginalized groups face additional barriers to accessing financing for agricultural inputs and irrigation technology investments. Lack of access to financing from formal credit providers can prevent marginalized farmers included in irrigation systems from obtaining and using inputs to achieve high yields.

In addition, although studies suggest that women can benefit from microfinance, which can be used for agricultural inputs and irrigation services, microfinance is often insufficient for the purchase of irrigation equipment, and the terms and conditions often make it an expensive form of credit for smallholders.

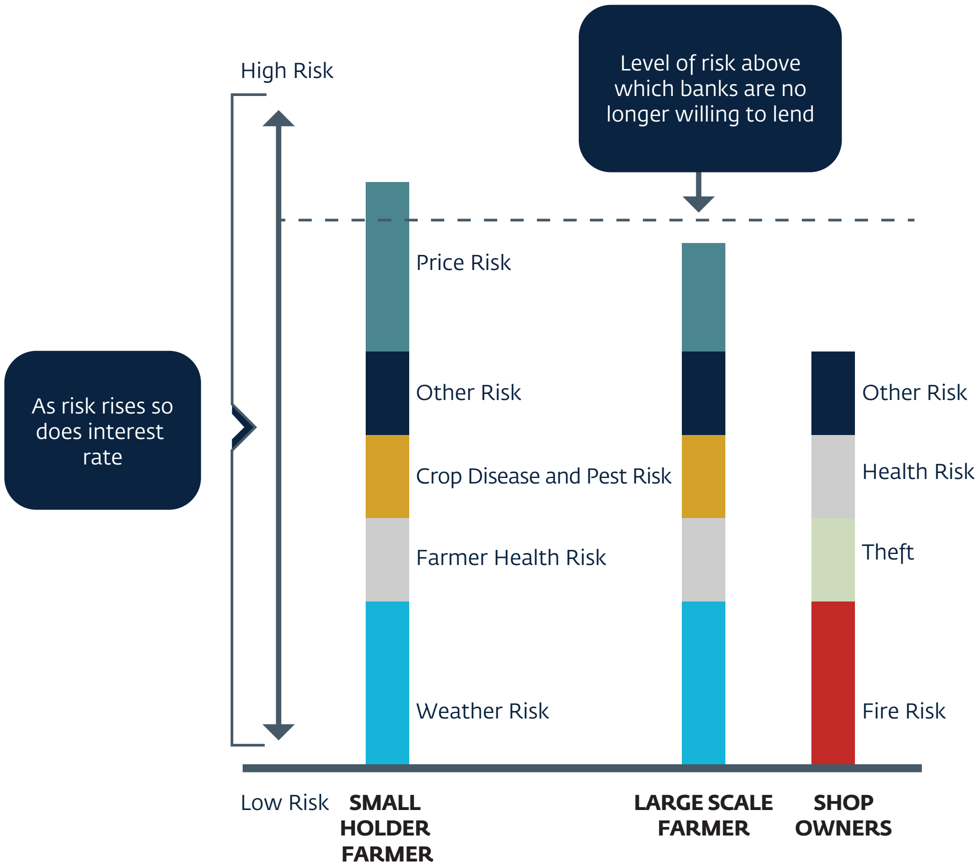
Table 13 outlines the characteristics of individual urban borrowers, large-scale farmers, and SSI farmers and how banks discriminate against SSI farmers when the banks use the characteristics of large-scale farmers as an imperfect indicator of desired individual farm characteristics. Consequently, SSI farmers are offered less credit and on terms that differ from those offered to large-scale farmers with similar risk and productivity levels.

Table 13. How Banks Compare Small-Scale Irrigation (SSI) Farmers with Other Borrowers

INDIVIDUAL URBAN BORROWERS	LARGE-SCALE FARMERS	SSI FARMERS
• Limited to no exposure to covariant risk such as extreme weather or locust swarms • Regular certain income • Short-term loans • Track record of borrowing and repaying loans • Low information asymmetry • Defined location • Unsecured small loans	• Potential for uninsured exposure to covariant risk (some are insured) • Uncertain income (low variation) • Higher repayment capacity from low yield variation • Medium- to long-term loans for irrigation • Track record of borrowing and repayment reduces information asymmetry • Low transaction costs because of high loan amount and small number of borrowers • Size diversification and economies of scale • Own land and assets that can be used as collateral • Farming and managerial expertise • Commercial-scale use of modern farming techniques • Record keeping • Adequate working capital for inputs	• Uninsured exposure to covariant risk • Uncertain income (high variation) • Higher probability of default because of high yield variation • Medium- to long-term loans for irrigation • No track record of borrowing and repaying loans • High information asymmetry • Lack of diversification and economies of scale • High transaction costs because of larger numbers and smaller loans than large-scale growers • No record keeping • Limited farming and managerial expertise • Limited use of modern farming techniques • Highly variable use of inputs at each farm

(Source: Publication: Agribusiness and Commodity Risk: Strategies and Management (2003). Authors: Varangis, Bryla)

Figure 11. How banks look at risk



Irrigation financing constraints and recommended solutions

Although there are some common constraints on SSI financing, there are also some recommended solutions. Exposure to production and price risks can be addressed with index- and area-based yield insurance and price risk management instruments (e.g., outgrower contracts, forward contracts, futures contracts). To address information asymmetry, information can be gathered through credit bureaus, information databases on SSI, partnerships with value chain players working with the same farmers, and tied and interlinked contracts. Irrigation investment comes as a large investment in several components at the same time (pumps, canals, pipelines, in-field distribution), although stakeholders providing financing should explore investing in irrigation that is designed for small farms, such as micro-drip kits and small solar pumps, which allow for greater flexibility in timing and scale-up of investment in infrastructure. Because of the large numbers of farmers requiring access to small individual loans and high transaction costs to process and serve the loans, smallholder farmers should be aggregated into group associations and use mobile banking platforms and payment systems to keep transaction costs low. SSI financing also has lumpy or seasonal income for which farmers should opt for loans with repayment schedules that are tied to cash flows and allow repayments from nonfarm income.

SSI financing also faces challenges from lack of land ownership or formal rights in many rural communities and undocumented use of leaseholds from tenant farmers. This constraint could be overcome by mapping all irrigable smallholder farms, which could also reduce information asymmetry. Land titles should be issued to facilitate leasing and sales; smallholder farmers could create transferrable leaseholds to facilitate secure leasing. To overcome the constraint of lack of collateral, the financial sector should help identify and support passage of legislation that would facilitate land ownership, such as creating land title registries. The financial sector may also develop loan guarantee processes that rely on substitutes such as credit guarantees and insurance and use of nonland durable assets. Another means of building collateral could be comprehensive savings mobilization to facilitate farmer equity financing.

Lack of secure access to water, another common constraint, can be addressed by obtaining water permits, building dams or diversion weirs, harvesting water, drilling boreholes, and improving the electricity supply to allow motorized pumps to be installed. Financial institutions can gain access to more-structured groups of farmers such as outgrower networks that enter predictable financial arrangements that can indicate how much cash will be generated from the sale of their crops, including sales contracts, forward contracts, and grower quotas. In addition to irrigation systems, supporting infrastructure that is deployed off the farm, including transport infrastructure, warehouses, and cold rooms to store produce, can allow smallholder farmers to receive better prices for their crops, increasing farmers' incomes and improving their quality of life.

Training and technical assistance provided by government agencies, crop buyers, and input suppliers, as well as farmer experiential learning, can strengthen smallholder farmers' knowledge of good agricultural practices and expertise, increasing quantity and quality of production as well as sustainability. Investing in ICT to facilitate its use in reducing transaction costs through mobile banking platforms and payment systems and enhancing information processing capabilities of financial institutions to reduce information asymmetry can increase smallholder farmers' familiarity with information technology.

Green and blended financing

Accessing financial services for irrigation remains a key challenge in emerging markets. Beyond access, maturity mismatch is a structural challenge of the financial system because of the preference of financial institutions to offer relatively short-term financing instead of the longer-term repayment periods required to allow for the high capital and installation costs of irrigation equipment. Green bonds could provide a way to bridge this gap. A green bond is like any other fund-raising instrument except that the money that the issuer raises is earmarked for financing green projects that benefit the environment and society by reducing pollution or addressing climate change, and the bond typically has a longer maturity. Green bonds could serve as a low-cost source of funding for long-term green credits and investments to solve the maturity mismatch in irrigation financing and other green projects. Achieving this will require collaboration of the government and private sector. Institutional investors such as insurance companies, pension funds, mutual funds, and unit trusts that contribute to development of capital markets could mobilize the capital needed to invest in fundable green projects. Governments could encourage these companies to invest in green bonds and make funds available for green projects such as subsidies for solar-powered pumps used for irrigation or in technologies such as drip irrigation that increase water and fertilizer efficiency and reduce greenhouse gas emissions.

Blended financing combines funds focused on addressing the social (public good) needs of the recipient with profit-based (private good) interests of the investor, thereby providing a financing package combining concessional funding provided by development partners and commercial funding. Blended financing solutions can provide financial support to high-impact projects that would not attract funding on strictly commercial terms because the risks are considered too high and the returns are unproven or not commensurate with the level of risk. For example, by blending donor funds that focus on food security and nutrition from sources such as the Global Agricultural Food Security Program with more commercially priced funds from IFC, interest rates can be adjusted to allow for shorter payback periods, first-loss guarantees can be established to share the risks that lenders take on, and technical assistance can be provided to increase the effectiveness of irrigation on small farm.

Emerging innovations

Emerging innovations to strengthen standard approaches to financing or reduce loan default risks in the agricultural sector show promise for greater inclusion of smallholder farmers in irrigation, in particular the use of ICT and bundling of insurance and loan instruments. Although not exhaustive, the following list offers tools that finance institutions may consider and that development partners and public institutions can support:

- Social lending and grant financing seek a near economic return and development impact when funding is not paid back. These grants are useful for projects that seek food security and humanitarian assistance and stimulate economic activity in underdeveloped areas with potential. These financial tools should be coordinated with other types of financing because they can create disincentives for market mechanisms in the overall finance ecosystem.

- There is a wide range of subsidies for all types and sizes of irrigation investments. Subsidies can increase market size and density, draw more suppliers into a market, increase competition, reduce prices, and increase tax revenue over time, although the few studies available on subsidies suggest that most are not well designed and ultimately fail to achieve their goal. Nevertheless, subsidies can be an effective way to create equity and inclusivity in irrigation investments. Robust mechanisms are needed for subsidies to be implemented transparently and to ensure they are coordinated across investments to reach their intended beneficiaries.

- Financial institutions mainly lend to commercial farmers, most of whom are located near each other. This increases localized density of retailers and service providers who support irrigation and limits collection points of markets whereby smallholders can sell crops. Development partners have improved commercial lending to agriculture by developing capacity of bank and nonbank financial institutions, providing credit lines for short- and long-term lending, establishing guarantee funds, co-developing suitable financial instruments and products for agriculture, and off-setting risks of pilot projects.

- Structured financing uses risk mitigation by sharing, pooling, transferring, and diversifying risk. Structured financing segments risks into different types and tranches and then allocates and places each risk with the party most equipped to manage that risk. Structured financial products include credit portfolio guarantees, structured funds, securitization, contract farming-based financing, receivables-backed financing, warehouse receipt financing, and vouchers such as warehouse receipts.

- Value chain financing can be adapted to a specific context by considering the collective set of actors, processes, and markets of the chain, including market demand, as opposed to an individual lender–borrower system.

- Micro-entrepreneurs who own pumps provide irrigation as a service, renting them out or offering pumping services. Irrigation companies that offer direct, asset-based financing are piloting how to operationalize irrigation services as part of their business model.[11]

- Many equipment suppliers, especially pump suppliers, provide direct financing to farmers on asset-based financial terms (sometimes referred to pay-as-you-go). Some of the irrigation systems supplied have Bluetooth-enabled shut-off tools so that suppliers can simply turn equipment off for nonpayment rather than having to come take it back.

- Systemic and covariant risks (e.g., weather, pests and disease, price volatility) reveal the need for a combination of risk-management instruments, such as partial credit guarantees, and first-loss guarantees with insurance solutions.

- ICT is opening up ways to reduce transaction costs associated with lack of infrastructure, market fragmentation, and heterogeneity. Mobile money is enabling companies and financial institutions to reduce transaction costs, acquire smallholder customers, improve payment collection efficiency and reliability, set up down payments through e-wallets, and obtain data on individual financial activity for credit scoring.

- Although aggregation of farmers is not a financial instrument, bringing smallholder farmers together to form a group can reduce risks and costs to financers while achieving economies of scale and creating value through access to markets and access to information.

Case studies

The case studies below showcase the importance of securing irrigation financing for development of irrigation systems, along with the challenges. The case studies discuss how the use of value-chain financing, financial institution loan product development, and public subsidies can be combined to bring commercial irrigated agriculture to underdeveloped areas.

11 https://claroenergy.in/, https: //www.agrirain.com/

Photo credit: Kathryn Faith/University of Illinois

CASE STUDY 9: eSwatini's Lower Usuthu Small-Scale Irrigation Project

Country: **eSwatini**	Years: **2001-2013**	Organizations involved: **Government of eSwatini; IFAD**	Crop: **Sugar**	Irrigation system: **Bulk water supply**

The Usuthu River basin forms a part of the Maputo basin and is shared with Mozambique and South Africa. The Lower Usuthu Smallholder Irrigation Project (LUSIP) delivered an irrigation infrastructure that enabled production of high-value crops by smallholders in eSwatini by giving them sustainable access to water resources. Phase 1 of the project targeted an area of 6,500 hectares of irrigated sugarcane under smallholder production. The government of Swaziland, IFAD, farmer beneficiaries, and seven additional co-financiers financed the project. The IFAD program consisted of four components: Upstream irrigation project and distribution system, downstream irrigation development and agriculture commercialization, environmental mitigation, and project coordination and management. The Swaziland Water and Agricultural Development Enterprise (SWADE), a government agency responsible for facilitating the planning and implementation of large agricultural development projects, implemented the project. At commencement of the project, the SWADE project team consisted of a multidisciplinary team of international consultants, advisers, and trainers that adjusted after the midterm review, at which time SWADE was empowered to directly employ (local) staff and acquire associated resources.

Lending was highly concessional, with four types of lending terms used across the consortium:

- special loans on highly concessional terms, free of interest but bearing a service charge of 0.75 percent per annum and having a maturity period of 40 years, including a grace period of 10 years
- loans on hardened terms, bearing a service charge of 0.75 percent per annum and having a maturity period of 20 years, including a grace period of 10 years
- loans on intermediate terms, with a rate of interest per annum equivalent to 50 percent of the variable reference interest rate and a maturity period of 20 years
- including a grace period of 5 years for the loans, after which ordinary terms followed, with a rate of interest per annum equivalent to 100 percent of the variable reference interest rate and a maturity period of 15–18 years, including a grace period of 3 years

The project was complex, with the co-financiers targeting to differing degrees the two development objectives of promoting irrigation of smallholder cash crop production and poverty alleviation. There were also several government agencies involved in water policy and regulation. Nevertheless, nine of the 12 required WUAs were established successfully and ensured water delivery from balancing dams to farmers' fields on time. The project has played a significant role in increasing the standard of living. The project was originally supposed to be completed in 2011 but was extended to 2013, and the cost soared from an estimate of USD 119 million at appraisal to almost USD 253 million, with a fivefold increase in the government of Swaziland's contribution and with the beneficiaries, IFAD, and the European Union making up the difference.

The cost per beneficiary at closure was an increase of 227 percent (USD 4,133 at appraisal to USD 13,521 at closure) and the IFAD-supported downstream component cost per hectare increased from USD 6,138 to USD 30,390, an increase of 257 percent. The impact on the local economy was strong, with the unemployment rate falling from 71 percent in 2005 to 46 percent in 2013. Approximately 5,101 people benefited from employment in the infrastructure and agricultural construction work, including seasonal and permanent workers, providing a community benefit beyond direct farmer beneficiaries.

A second phase of the project was launched in 2016 to build upon these initial successes (LUSIP II) by transforming the existing subsistence farmers into commercial farmers on irrigated lands. Infrastructure was expanded to include new areas served by a siphon, lined main canal, bulk storage reservoirs, and a supervisory control and data acquisition system that provides centralized data and management of water in the system. This phase is expected to be completed in mid-2022.

Key metrics

- Land under irrigation: Hectares
- Area under crops: % of targeted diversification of irrigated production
- Beneficiaries reached
- Increase in profits
- WUAs: Number reaching target performance
- Cost per beneficiary: USD / % of target cost
- Unemployment: Percentage
- Number of new jobs

Key results

- **6,500** hectares of land under irrigation, of which 3,000 hectares were converted to grow alternative crops because of soil conditions and distance from the sugar mills
- **17** percent of the target for alternative cash crops, **35** percent for commercial gardens, **50** percent of the target for livestock activities
- **1,184** households (46 percent of targeted households)
- Each household saw an average of USD **1,525** increase in profit.
- **9** of the **12** WUAs ensured water delivery from balancing dams to farmers' fields on time.
- Cost per beneficiary at closure increased **227** percent (USD 4,133 at appraisal to USD 13,521 at closure), and the IFAD-supported downstream component cost per hectare increased 257 percent, from USD 6,138 to USD 30,390.
- The unemployment rate fell from **71** percent in 2005 to 46 percent in 2013.
- Approximately **5,101** people benefited from employment in the infrastructure and agricultural construction work, including seasonal and permanent workers.

Lessons learned

- The project invested in building the capacity of the farmers from their formation into groups to land development, planting, and crop production, although one-third of the members are not literate, and the concept of being a shareholder in the farmer company was not clear to them.
- The project design was ambitious and complex given that the public sector, farmer groups, and eight co-financiers were involved, leading to cost overruns and conflicting objectives.
- Despite the principle that promotion of irrigated cash crop production should not jeopardize food security, farmers made crop selection choices based on maximization of profit. The number of households growing maize fell from 85 percent in 2005 to 43 percent in 2013 mainly because of conversion of arable, high-quality land to sugarcane cultivation, although 90 percent of households reported consuming three meals each day, up from 58 percent at baseline.
- Two critical areas for sustainability of the irrigation scheme were ongoing guidance to farmer groups and operationalizing water user associations and water governance institutions.
- Two major challenges regarding the sustainability of the farmer groups were the need to prevent the membership from accepting new shareholders for traditional influence reasons and to establish a sustainable business mentoring mechanism.

Photo Credit: Richard Colback, IFC

CASE STUDY 10: SunCulture

Country: **Kenya**	Years: **2012-2022**	Organizations involved: **Distribution partners, smallholder farmers, government**	Crop: **Mixed crops and dairy farming**	Irrigation system: **Smallholder solar irrigation pump**

Off-grid solar technology has emerged as a leading way to provide farmers with reliable access to water, irrigation, lighting, and mobile charging without the restrictions imposed by the need for access to an electrical grid or a fuel supply. SunCulture has developed a range of systems designed to meet the financial, commercial, and technical needs of smallholder farmers and has developed a market that they serve directly within Kenya. In other countries, they operate through partnerships (Uganda, Ethiopia, Togo, Ivory Coast). Their most popular products combine solar water pumping technology with high-efficiency drip irrigation to lower operating costs and provide significantly greater crop productivity than rainfed production.

Despite significant benefits from the use of solar-powered irrigation systems, their use is still limited in Kenya because there are a range of obstacles to reaching smallholders with the technology, including affordability and awareness. To solve the affordability problem, SunCulture has implemented a pay-as-you-go financing solution allowing farmers to pay costs through monthly fees. Raising awareness remains a costly challenge and is addressed through donor-funded marketing campaigns and market engagement via regional sales and support centers. Access to credit from banks for SSIT in Kenya remains limited and costly. To support use of its systems by farmers unable to purchase outright, SunCulture provides financing through loans that are held on their own balance sheet using funds provided by impact investors.

Three systems and loan types are available in Kenya, with typical systems capable of irrigating 2 acres with pressures up to 60 m and flow rates up to 3000 liters per hour:

ClimateSmart Battery with RainMaker 2 System

- Deposit USD 90, $40 per month for 30 months
- Cash: USD 950

ClimateSmart Direct with RainMaker 2 System

- Deposit USD 55, USD 30 per month for 24 months
- Cash: USD 570

ClimateSmart Battery with RainMaker 2 and Direct Drip

- Deposit USD 95, USD 40 per month for 36 months
- Cash: USD 1,130

The reliability and durability of these systems is key and requires that SunCulture deliver and install the system and provide a 36-month warranty to reduce risk of failure. The financing models vary when operating through a partner; for example, in Togo, SunCulture entered into an agreement to sell solar irrigation systems to smallholder farmers at a subsidized price targeted to promote off-season and higher-value agriculture.

To reach a larger market, donor-funded initiatives should ensure that solar-powered water pumps are accessible and affordable to end-users by

- Providing results-based financing and subsidies to stimulate uptake
- Supporting local banks to lend, potentially with bank guarantees to lower risk
- Seeking to remove value-added taxes and duties on irrigation system components and accessories

Photo Credit: Liudmila Pestun

Key metrics

- Farmers: % reporting increased production, % revenue increase
- Jobs created: Number
- Labor savings: Hours

Key results

- **90** percent reported an increase in agricultural production, an average revenue increase of **44** percent per season
- An estimated average of **1.5** local jobs created per solar irrigation system in nonirrigation-related activities
- Up to **17** hours of irrigation labor time saved each week

Lessons learned

- Demand-side financial incentives to reduce cost for farmers will drive market growth by reaching more financially constrained farmers.
- The potential for solar-powered irrigation systems is large, which is likely to require dozens more solar-powered water pump companies and involvement of local banks.
- An International Water Management Institute assessment found that more than 100 million solar-powered water pumps could be installed in Africa without creating groundwater scarcity, including 700,000 in Kenya alone.

Photo Credit: Laurent Stravato

CASE STUDY 11: iDE Nepal - Water and Irrigation

Country: **Nepal**	Years: **2009 - present**	Organizations involved: **iDE, USAID, UKAid, EU, MCIC, Big Lottery Fund UK**	Crop: **Various, primarily vegetables**	Irrigation system: **Various**

In Nepal, smallholder farmers constitute the largest segment of the rural poor. A critical limitation given Nepal's challenging terrain is access to water, and many of the most marginalized communities are situated on steep slopes above their water sources. To improve water access and increase agricultural productivity, iDE developed a multiple-use water systems (MUS) approach adapted with solar power to pump water to a protected tank above the community, with excess directed to a separate reservoir for agriculture and other productive uses. The water is then piped directly to houses and fields. Water is the entry point for farmers to turn their subsistence farms into farm businesses, and accompanied by agronomic training, connections to reliable markets, and access to quality seeds and inputs such as micro-irrigation, farmers' income increase on average by approximately USD 350 annually within the first year after the intervention.

The 31 solar MUS constructed to date in Nepal have been funded through public-private partnerships. On average, 35 percent of the design and construction cost is funded by a development project, 30 percent by the community (in-kind labor and resources), 21 percent by local government agencies, 7 percent by a local nongovernmental or community-based organization, and 7 percent by the community in financial contributions by future users. Co-investment across stakeholders is critical to the long-term use and sustainability of the system.

In 2018, solar MUS cost on average USD 19,000 to build (approximately USD 128 per community member), with a USD 6,500 investment from the community and USD 52 each from user households. On average, it can take a community as little as 3 years to recoup its investment in a solar MUS, and the estimated lifespan is 20 years. The average cost is declining every year, as pumping designs and photovoltaic solar panels become more efficient. On average, solar MUS pump 11,329 liters of water per day, lifting the water 105 meters, and using about 2.47 kilowatts peak.

Elected user committees build and manage MUS, and users pay a small monthly fee for a manager and maintenance fund. Increased agricultural income is key for their sustainability, providing farmers with access to the resources and training they need to be more productive while connecting them to reliable markets that increase their income. A MUS study by the International Water MWI found high sustainability, with an 11 to 1 return for the farmer from increased agricultural income alone.

Key metrics

- Land under irrigation: Hectares
- Area under crops: % of targeted diversification of irrigated production
- Beneficiaries reached
- Increase in profits
- WUAs: Number reaching target performance
- Cost per beneficiary: USD / % of target cost
- Unemployment: %
- Number of new jobs

Key results

- Average increase in annual household income: **USD 614**
- Average construction cost per user household: **USD 578**
- More than **500** MUS developed
- More than **82,000** people served by improved water and irrigation systems
- More than **300,000** micro-irrigation units (sprinklers, treadle pumps, drip kits) sold

Lessons learned

- The MUS approach has proven to be an essential strategy for rural communities to develop and manage their water resources effectively and sustainably, aligning with the key principles of community-based adaptation.
- Designs can be adapted to address different water-source and water-use scenarios.
- Typical communities benefiting from solar MUS use point water sources that are marginal, threatened by environmental stresses, or located at an altitude below or a long distance from the users' village.
- MUS have high returns to communities when intentionally coupled with productive uses. Efficient micro-irrigation technology combined with a reliable supply of water from MUS allows communities to irrigate limited land areas on which high-value vegetable crops can be grown year-round, ensuring income for maintenance.
- Nepal, like most countries, has historically maintained separate institutions regulating drinking water and water for productive use. Institutionalizing the MUS approach and securing recognition across government was one of the greatest challenges to achieving scale.

Photo Credit: Sylvain Lanau

VOICE OF A FARMER: How a Drip Irrigation Public-Private Partnership Eased Lives for Moroccan Farmers

As Youssef Jebha walks past the lush citrus groves surrounding the town of Guerdane in central Morocco, he remembers the long period when the land was bare. Until a few years ago, the region's severe water shortages drove residents from their homes and orchards. "Many people, especially farmers, left the region because they couldn't make a living," says Jebha, who heads the Guerdane farmers' cooperative.

Citrus farming is water intensive, and generations of farmers had been depleting vital groundwater faster than nature could replace it. As local aquifers dried up, farmers were forced to dig wells up to 200 meters deep, reducing groundwater levels by more than 3 meters every year. As thriving farms withered, residents and workers abandoned more than 3,000 hectares of land. It was an environmental, social, and economic disaster—in the Guerdane area alone, more than 100,000 people earn their living directly or indirectly from citrus farming.

"The situation was catastrophic," says Ahmed El Bouari, Director of Morocco's Ministry of Agriculture. "Farmers were digging their wells deeper, but the situation was not improving. The loss of production and jobs resulted in social and environmental distress."

To confront the growing environmental damage and help farmers like Youssef achieve sustainable growth, Moroccan officials hired IFC in 2004 to design the world's first irrigation public-private partnership. IFC structured a project introducing drip irrigation that brought nearly USD 40 million in private investment into the region and created hundreds of local jobs.

The project transformed the land and the economy; by 2009, farmers could drip irrigate 10,000 hectares of land without worrying about droughts or further depleting their groundwater, and in 2017, Moroccan citrus production reached 2 million tons—82 percent more than before the project began.

Guerdane is in the heart of Morocco's citrus industry, producing half of the country's citrus fruit, which is a major export crop. Agriculture generates 40 percent of jobs nationwide and is one of Morocco's core sectors, but that is only part of the reason Guerdane's transformation is so important. The irrigation project has gone beyond restoring local farms to their former fertile glory; it has revitalized a community. Producing more and better fruit generated profits that allowed the Guerdane cooperative to invest USD 13.5 million in upgrading its citrus processing factory. This boosted efficiency, increased revenues from USD 5 million to USD 25 million per year, and created 350 new jobs.

The ripple effect of this single irrigation public-private partnership helped the Guerdane cooperative establish the El Guerdane Foundation, which trains young farmers in the region, providing them with the technical and agricultural skills they need to maintain their farming heritage and manage future climate challenges. The foundation also used its increased revenue to build an elementary school.

Amensouss, Morocco's first domestic infrastructure operator for irrigation projects, won the contract to supply 45 million cubic meters of surface water to nearly 2,000 Guerdane farms from a dam 90 kilometers away. The transaction is structured as a 30-year concession to build, co-finance, and manage an irrigation network to channel water from the dam complex and distribute it to farmers in Guerdane. At the end of the concession, the infrastructure will be returned to the government.

"In the past, we suffered a lot economically," says Ahmed Bounit of the El Guerdane Foundation. "We are now on solid footing thanks to this project, and we are in a position to make a positive, lasting impact on society."

Photo Credit: EU/ECHO/Martin Karimi

Call to action

Given the fragility and uncertainties of smallholder farming systems, a fully commerical model has not yet emerged to supply the financing required to scale up the irrigation market and its use in the short term, but a blended approach that allows the public sector donors and the private sector to share the risk has proven successful. Widely available, low-cost financial solutions are a fundamental requirement to scale up access to and use of irrigation by smallholder farmers. This will require an integrated approach from all stakeholders, and distinct roles and opportunities have become clear, particularly for the private sector.

Smallholders are the central stakeholders and must build their commerical skills and establish their credit profiles through formal banking systems to be a stronger client base for commercial loans. To serve a rural market, financial institutions must develop highly efficient systems that can evaluate, approve, disburse, and manage loans so that costs remain low and access to finance is rapid and simplified. Equipment providers should be prepared to provide guarantees for their equipment that match the tenor of loans, typically around 3 years, so that equipment costs can be repaid before systems need to be replaced. Commerical off-takers and crop transformation agribusinesses in irrigated value chains may be required to finance crop inputs and production expenses in advance of harvests for outgrowers and contract farmers, providing loan terms equivalent to those of financial institutions. In addition to developing and delivering support through policies, institutions, and regulations, the public sector should continue to finance communal goods within the irrigation system, such as bulk water supply in communal schemes and equipment subsidies for low-income farmers. Where subsidies are provided, they should be designed to support rather than compete with commerical loans by reducing the capital costs only to a level that enables repayment of commerical loans for the complete irrigation system within a maximum 3-year time frame. Governments must also enforce policy and regulatory measures that control the use of water in areas where it is limited and may fall below levels that would also allow individual farmers to continue to access water for irrigation. A combination of donors, development agencies, and the public sector can provide life and weather-linked insurance, first-loss guarantees, output-based aid, access to technical training, and credit guarantees that all of these stakeholders, who must confront the risks that climate change and fragility pose, may all support.

Overall, the flow of information between stakeholders, in particular donors and their public sector partners, must become more effective, allowing for cost and operational efficiencies to be realized. The demand for financing for loans and supplying of irrigation equipment must be predictable in terms of timing, location, and volume to attract the sustained presence of the private sector. This must replace the current model of irrigation support that largely delivers isolated, costly, unsustainable pilot schemes and projects.

Table 14. Role of Key Stakeholders in Financing Irrigation

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
PRIVATE SECTOR		
WUAs, farmer groups	• Collect funds from members for down payments on shared equipment and infrastructure • Provide loan security for individually owned field irrigation systems • Help members secure a market for crops and address legal or institutional requirements • Ensure that full lifecycle costs are calculated and provided for in calculating the need for financing	• Enable investment in equipment and payment for large pumps, canals, water storage, etc. to improve access to bulk water • Benefit from economies of scale in securing finance for farm-level equipment • Reduce risks of loan repayment default and access larger markets for crop sales • Secure adequate financing for purchase, operation, and replacement to provide access to irrigation services
Smallholder producers	• Participate in training to increase financial literacy and farming business skills • Establish account with financial institution and leverage mobile banking for ease of repayment	• Increase access to finance with certification of financial literacy and commercial efficiency • Build credit to access loans, reduce loan balances rapidly, and reduce cash transactions
Offtakers	• Develop risk-share mechanisms with other stakeholders (e.g., equipment providers, banks) • Provide preseason and late-season financing for inputs to supply chain farmers • Contract with farmers, banks, and equipment providers to directly repay partial proceeds of crop delivery against loans	• Allow farmers in supply chain to access lower-cost loans and increase production quantity and quality though irrigation • Partially fund costs of improved inputs and operational costs that directly increase yields and volumes • Provide direct financial access to crop collateral for use in securing loans by farmers from equipment and finance providers
Financial institutions	• Define a set of approved equipment and crops for irrigation equipment loans that accounts for lifecycle financial needs • Combine insurance policy and equipment costs in irrigation loan product • Leverage equipment manufacturers' training on target equipment types • Establish risk-share agreements with off-takers, equipment providers, public sector, and donors to enable lower interest rate loan products • Provide funds directly to equipment providers on an output-based loan basis	• Streamline application approvals and ensure that equipment costs are aligned with best value options • Mitigate risks of repayment default from key factors including natural disaster (drought, flood), life insurance, pests and diseases • Build technical awareness of loan officers to evaluate and disperse loans for equipment, including output-based loan model • Tailor more financial products to agricultural sector and increase amount dedicated to agriculture • Ensure loans are applied to verified and functioning irrigation systems

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
Irrigation equipment providers	• Pilot and implement finance products directly to farmers (e.g., pay-as-you-go asset-based finance) • Extend warranties for small-scale irrigation systems	• Market growth for irrigation equipment, agricultural inputs, machinery, services • Ensure that they are operated for longer time period
PUBLIC SECTOR		
National government	• Provide adjustable smart subsidies to enable private sector financing to meet demand • Develop multiple forms of funding (e.g., results-based, insurance, and guarantee mechanisms) • Provide credit guarantees for public and state-owned irrigated agriculture • Provide investment guarantees and support for infrastructure development	• Reduce burden on public funds, provide broader access to funding, leverage public finances for markets and transforming cropping systems • Adapt funding to maximize uptake and sustainability of irrigation systems; use of multiple forms of funding allows financial resources to be used to meet greatest market needs • Reduce cost of financing for public entities that support use of irrigation • Build better market infrastructure to support sales of higher-value irrigated crops
DEVELOPMENT SECTOR		
Multilateral financial institutions and bilateral aid	• Offer risk-sharing instruments that allow lower interest rates for irrigation loans • Provide working capital loans to distributors to develop commercial markets • Finance distributors and retailer networks to provide equipment performance guarantees and extended warranties • Provide access and support through green finance and climate funds	• Enhance market growth for longer-term loans with greater risks by reducing first loss or underwriting insurance premiums • Expand ability to order larger quantities of equipment, hold inventory or spares, and extend load terms directly to farmers from distributors • Increase operational life of equipment and ensure that it remains operational with smallholders who may lack maintenance funds • Reduce cost of finance through access to blended rates that combine commercial and subsidized interest rates

Chapter 6: Future Outlook

Key messages

- It is estimated that expanding irrigation and increasing irrigated cropland productivity in LMICs could cost between USD 26 billion and USD 50 billion per year over the next 20 years, enabling between 70 million and 150 million hectares to be added, or a 32 percent increase in irrigated areas in developing countries.
- The irrigation sector in Sub-Saharan Africa offers the greatest potential for change and may learn from Asia's experience by intensifying agriculture in areas of cultivated land that are currently unproductive by bringing them under irrigation. This is critical to address the supply-demand gap in food production.
- Implementing irrigation at scale must start from considering a farmer's perspective. Farming remains a key source of livelihood, but its demanding physical nature and riskiness make it a less attractive option for youth. Technology can be used to bridge the generational gap that is emerging in agriculture.
- Ensuring that women benefit from access and support would vastly increase the area of land under irrigation, productivity of water through multi-use systems, and labor savings from collection of water in dry seasons and improve nutritional outcomes.
- The private sector, including financial institutions, equipment providers, and off-takers, typically fails to support expansion of SSI unless demand is predictable and of sufficient scale to support establishment of a long-term market-based service and support infrastructure.
- Key innovations required in future irrigation systems include low-cost precision irrigation technologies, labor- and energy-saving technologies, and information technology–assisted irrigation scheduling tools.
- The decreasing cost of technologies has already enabled irrigation systems to be more water efficient, with advanced systems capable of providing precise amounts of water and nutrients to the rootzone, without extensive labor, to meet crop water demand.
- Irrigation benefits can only be maximized if other inputs and practices are delivered at optimal levels. For example, farmers who irrigate during the dry season encounter different pests and diseases and therefore require additional crop protection products or integrated pest management approaches.
- The people, tools, and practices of the irrigation sector must evolve continually to meet challenges arising from growing competition for water resources driven by climate change and growing demand for irrigated crops.
- Expansion of SSI is also expected to bring a need for stronger guidelines and procedures, led by the public sector, to monitor the environmental impact, particularly on water quality and soil health, and for investment to increase the national capacity of agricultural experts to guide policy makers and support farmers.
- Although there are technical solutions, capacity for environmental management in many countries remains limited, and cooperation with the international community will be needed.

Summary

The people, tools, and practices of the irrigation sector must evolve rapidly to meet challenges arising from growing competition for water resources driven by climate change and increasing demand for irrigated crops. Whereas in the past the main goal of agricultural production in many parts of the world was food security, future use of irrigation must contribute to other Sustainable Development Goals, including sustainable land use and biodiversity, minimal greenhouse gas emissions, sustainable water use, pollution control, adaptation to climate change and climate variability, peace and security, job and income creation, and better nutrition and health outcomes.

The key components of future irrigation include continued innovation in precision irrigation technologies, labor-saving technologies, and information technology–assisted irrigation scheduling tools. These will also allow for targeted development of agricultural intensification packages, which combine irrigation with advanced seed technologies and judicious use of other agricultural inputs. Despite the challenges, the potential for smallholder irrigation systems is high. As climate change affects the world, there has been a shift from lower cost and reliability surface sources of water for crops, such as rainfall, to higher cost and reliability sources stored underground in aquifers. An alternative exists in the form of groundwater stored beneath the land. Irrigation development projects and financial support for farmers to promote the adoption of irrigation should be focused in areas where these groundwater resources are also being renewed and are therefore suitable for sustainable use by agriculture. As costs of water and energy efficient technologies such as drip irrigation and solar powered pumps decline, a balance between costs, sustainability, and benefits is bringing irrigation within reach of a vast number of smallholder farmers.

Addressing Barriers

Despite apparent advantages of irrigation, it has not been expanded to all areas where it would be beneficial and where sustainable groundwater resources would allow for further SSI system development particularly in Africa (Figure 12). This can be attributed to a range of structural barriers that should be addressed using a holistic approach, which requires a coordinated approach between the public, private, and farming sectors to improve information exchange and address a range of key factors.

- **Changes in climate, food security, and population growth:** Extreme weather events, international supply chain disruptions, and growth in populations have made development agencies, off-takers, and the public sector aware of the need for SSI to address large-scale food security risks, although, from the farmer's perspective, climate and demographic changes are slow, taking years to become noticeable, and may not overcome their reluctance to change from traditional rainfed production systems. Occasional extreme weather events such as droughts and floods can increase awareness of the need for change and accelerate the pace of adoption of SSI, but the difference in time scales between long climate change and short-term weather patterns causes uncertainty regarding the need for irrigation systems on a year-to-year basis. This affects willingness to change from a long-term, proven, rainfed crop production model to SSI models that are adapted to the changing circumstances.
- **New technologies such as low-cost solar-powered irrigation pumps:** The recent cost reduction of solar-powered technologies now provides an affordable solution without high operating costs,

Photo Credit: Richard Colback, IFC

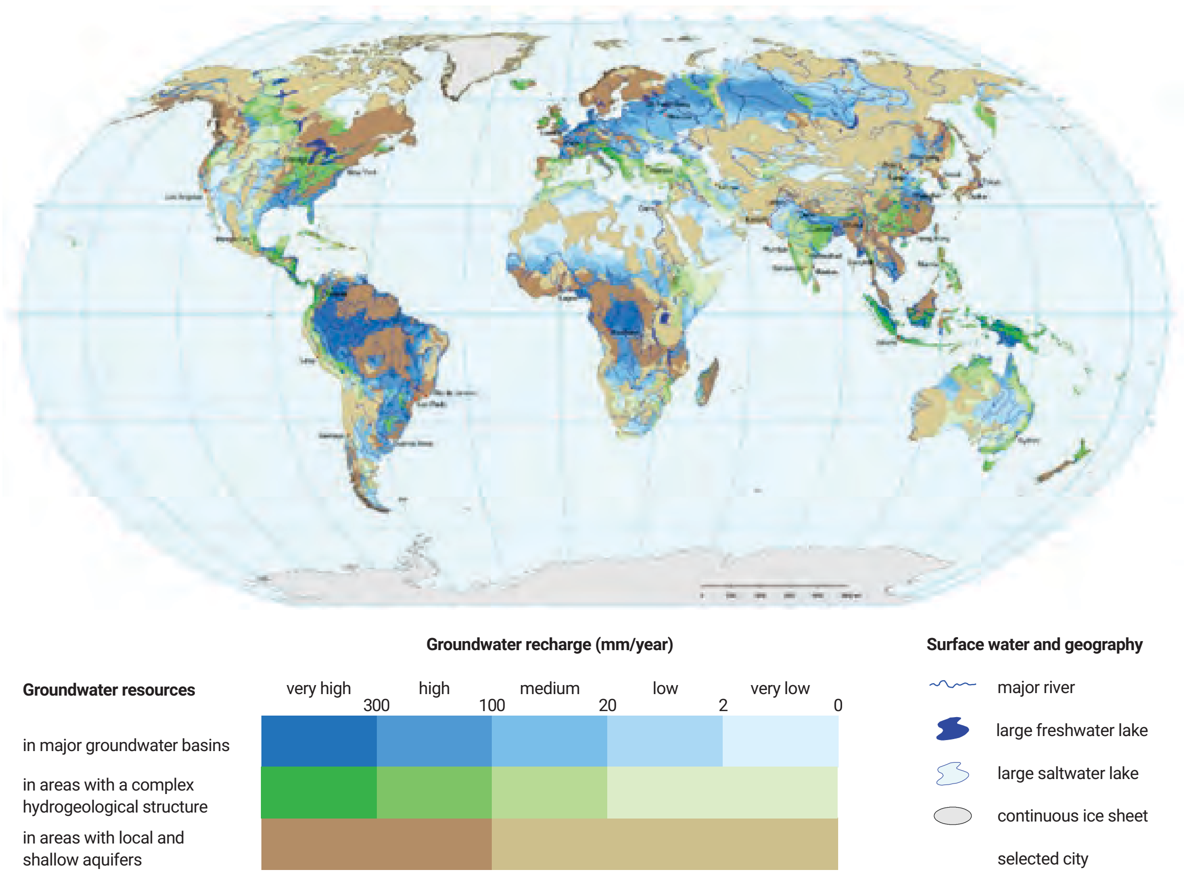
but the need for technical training to operate and maintain this equipment, suitable configurations of equipment for use in SSI, and the lack of locally stocked spares to ensure sustained operation of equipment currently limit the use of these technologies. There are opportunities for the public sector to support expansion by reducing or eliminating import tariffs and sales taxes to promote imports of targeted technologies and for development agencies to design projects using a common set of successful technologies to develop a critical mass of demand and local capacity to provide technical services. Many private sector successes with SSI rely on an anchor off-taker to provide a secure way to convert crops to cash for repayment of the cost of equipment. These models are not effective for smallholder farmers who operate outside of the supply chains, but public and development agencies should adapt successful models to support alternative anchor models such as farmer cooperatives and similar groups of smallholders taking the role of aggregators.

- **Streamlining development projects and eliminating competing initiatives:** Streamlining development projects and eliminating competing initiatives is an area where rapid improvements can be made. Poorly functioning, unfunded, or oversubscribed public sector subsidies limit market growth by discouraging adoption of irrigation on commercial terms. Farmers will be slow to purchase, operate, or maintain equipment using their own savings or with commercially available loans when the offer or availability of full subsidies favors delaying the purchase. Smart subsidies designed to taper off the percentage of costs that the public sector pays to reach a level at which the breakeven period on the farmer-paid component is within 2 years are optimal. Public subsidies may then be used effectively to generate demand for SSI systems, demonstrate a positive return on investment, validate the expected duration of payback periods, and reduce the risks of adopting technologies.
    - The private sector, including financial institutions, equipment providers, and off-takers, typically fails to support expansion of SSI unless demand is predictable and of sufficient scale to support establishment of a long-term market-based service and support infrastructure.

- Donor- and development institution–supported SSI projects often rely on unsustainable and unscalable equipment grants that crowd out private sector investment. In some cases, grants may be required to overcome risk aversion, lack of technical capacity, financial fragility, and limited access to irrigation equipment, particularly for bulk water supply, but these do not translate into broader uptake of SSI. Grants increase the number of SSI systems installed but prevent broader market development outside the project area. Expansion requires coordinated public, private, and smallholder adherence to a financing, training, and equipment support model that can transfer from one project outward to a broader community or be supported sequentially as new projects commence or government funds are released with a design for longer-term, widely available smart subsidies to replace short-term grants.

- **Expansion of SSI:** Stronger guidelines and procedures will be required to monitor the environmental impact, particularly on water quality and soil health, and for investment to increase the national capacity of irrigated agricultural experts to guide policy makers and extension officers in supporting farmers. Although there are technical solutions, capacity for environmental management in many countries remains limited, and cooperation with the international community will be needed.

Figure 12. Global ground water resources



Source: United Nations 2022.

Irrigation sector forecast needs and impacts

It is estimated that expanding irrigation and increasing irrigated cropland productivity in LMICs could cost between USD 26 million and USD 50 billion per year over the next 20 years. This budget would be required for bulk water and on -farm capital costs to be heavily subsidized, enabling between 70 million and 150 million hectares to be added, or a 32 percent increase in irrigated areas in developing countries, making notable improvements in food security. Asia has bridged the gap between supply and demand of food by intensifying irrigation efforts, and Sub-Saharan Africa has increased the area of cultivated land, which has increased agricultural production in absolute terms, albeit not enough to address the supply-demand gap. As a result of low productivity and high population growth, about 30 of 48 Sub-Saharan African countries produce less food per capita today than they did in the early 1960s.

Transforming smallholder agriculture contributes significantly to most of the development objectives of LMICs, particularly in Sub-Saharan Africa. GDP originating from agricultural growth was found to be five times as effective at reducing poverty as nonagricultural GDP in low-income countries and 11 times as effective in Sub-Saharan Africa. Despite this, the region lags in irrigation and drainage development (FAO n.d.).

This lag provides an opportunity for rapid, effective expansion, because African governments have had the opportunity to learn from the experience of other LMICs and can therefore avoid costly institutional, social, environmental, and technical experimentation, although expanding irrigation has its own set of challenges:

- To ensure that all (including domestic and industrial) water demands are met, governments generally identify irrigation systems as a first target to reduce water abstractions.
- Irrigation expansion must be limited to areas where environmental damage can be avoided, water can be used with maximum efficiency (e.g., by applying drip technology), agricultural and economic growth can be supported, and smallholder farmers can benefit.
- Irrigation has been a major source of agricultural water pollution through runoff of agricultural chemicals. Future irrigation systems must drastically reduce pollution to avoid contributing to a growing public health threat and damage to fish populations, other aquatic life, and ecosystems in general.
- Governments should identify and implement interventions that lead to real water savings, coupled with enforceable water allocation systems, but despite local irrigation inefficiencies, reuse of return flows elsewhere or potential recharging of aquifers limits the scope for greater efficiency at the subbasin or basin level.

Photo Credit: Richard Colback, IFC

Farmer perspectives

When considering how to improve SSI, it is important to "put oneself in a farmer's shoes," carefully considering a farmer's perspective. Farming remains a key source of livelihood, but its demanding physical nature and riskiness make it a less attractive option for youth, who may prefer to seek opportunities elsewhere. The demand for food is rising, and it is therefore important to consider the farmer's perspective carefully and seek ways to increase the retention of a future generation of farmers in the sector when considering how to improve SSI. Choices that farmers make may depend on several factors:

- **Increased income:** If yield tonnage, quality, or alternative high-value crops will increase farmers' income to a level where they can pay for investment, they will have an incentive to improve the SSI system.
- **Risk aversion and food security:** Farmers may shift from rainfed agriculture to irrigation to reduce uncertainties associated with variable rainfall patterns.
- **Convenience:** Time is a key constraint for farmers, particularly female farmers, who often juggle many domestic and care responsibilities. Female farmers also often find it difficult to recruit external labor. Thus, irrigation technologies should always be designed to reduce time spent on productive activities.
- **Reduced costs:** Farmers may save on pumping costs if delivery losses are reduced. They may also save on labor costs by installing equipment that does not require constant field presence or equipment that is not subject to theft if fields are from the homestead.
- **Non-water-related motivations:** Saving on labor and other costs; growing higher-value crops; reducing uncertainty regarding water availability; availability of credit, extension advice, and technical support; and land leveling, among others, all factor into the final decision on whether and how to use or improve SSI.
- **Alternatives:** If there are other sources of income in the dry season, irrigation may not be the best option for employment at that time, especially if rainy-season production covers nutritional and food security needs at the household level.
- **Financing:** If there are grant or subsidy programs, farmers may wait until they are available in their area, even if they could benefit sooner by purchasing irrigation technology using their own funds.

Gender equity in irrigation

Irrigation development favors owners of agricultural land, who are more often men. Men tend to provide knowledge about irrigation that is directed toward male farmers. Male farmers also have more access to credit to purchase irrigation technology than women. Ensuring that women benefit from access and support as irrigators would vastly increase the area of land under irrigation, productivity of water through multi-use systems, and labor savings from collection of water in dry seasons and improve nutritional outcomes. Women's and men's concerns and experiences must be taken fully into account in the design, implementation, and monitoring and evaluation of all development activities, including irrigation. The aim is to develop interventions that overcome barriers to equal access of men and women to the resources and services they need to improve their lifestyle. Recent guidance on engendering small-scale irrigation (Theis et al. 2018) suggests the following steps.

- **Design:** Women's preferences regarding design of irrigated areas and technologies 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, social acceptability of use, and upfront and operational costs.
- **Dissemination:** There is evidence that traditional channels providing information about irrigation technology do not reach female farmers. Channels that can effectively reach women and thus support adoption and use of irrigation technology include female community leaders, savings groups, frontline health workers, and women-led farmer and producer groups.
- **Adoption:** Women face many barriers to adoption of irrigation technologies, including lack of or limited access to irrigable land, water, labor, credit, and markets to buy inputs and sell produce. Women also often need their husbands' consent to purchase technology, including irrigation technology.
- **Use:** Ownership of irrigation technology by women does not guarantee access, and varying workloads, decision-making authority regarding plots on which to use the technology, and control over income from irrigated produce can influence use.

Technical and Operational Innovations

A combination of technical and operational innovations is reducing the labor burden, increasing water-use efficiency, and enabling sustainable scale-up. These include:

Photo Credit: Richard Colback, IFC

PUMPS

Labor time and costs associated with manual water lifting and low flow rate generally prevent commercialization of irrigated produce and limit irrigation to households with sufficient labor, whereas motorized pumps have a much higher flow capacity, making it possible to expand irrigated areas.

Over the last several decades, water lifting has advanced from manual lifting of water from shallow, hand-dug wells with buckets to shallow and deep tube wells with individual motorized pumps, including diesel, electric, and solar-powered pumps. In particular, the emerging diffusion of affordable solar-powered pump technologies in Asia and Africa may enable access to irrigation in locations that are not linked to the electric grid, such as two-thirds of Africa's rural areas, democratizing access to energy and water for various uses.

IRRIGATION WATER APPLICATION TECHNOLOGIES

Key advanced irrigation technologies include drip and sprinkler irrigation and innovations that focus on hardware (e.g., precision application drip irrigation and software, irrigation scheduling tools). These technologies are useful on uneven land and sandy soils. Using pipes to transport water allows supply lines to be buried underground or placed above ground and ensures minimum water loss during transport.

Recent advances in drip irrigation have made the process even more efficient. For example, drip tape is responsive to crop demand for water and uses half the water of most other drip technologies. Although it is unaffordable for smallholders and outside greenhouses (USD 0.75 per meter vs. USD 0.04-0.07 for regular drip), its use will expand once costs decrease.

ON-FARM WATER MANAGEMENT

On-farm technical interventions include mulching (plastic, soil, straw), deficit irrigation at appropriate crop growth stages, changing planting density, weed control and fertilizer application, cultivation selection, growth enhancers (polyamines: putrescine, spermidine), tillage practices, and terracing.

Several approaches used to improve the efficiency of large-scale irrigation rely on computer models and data integration. These approaches have now also become financially feasible for smaller scale irrigation systems, given the lowering costs of computing power and sensors. These approaches may take advantage of ground-based systems installed on each farm, remote sensing using satellite or aerial imagery that measures water and crops, or computer-based models that collect data and calculate the impact of weather and crops on water balances to increase sustainability of water supply in water-stressed areas. As artificial intelligence gains broader application in agriculture, it is expected to speed up calculations and control application of water with highly precise, optimized use of resources.

GROUND-BASED SENSORS

Automated irrigation systems can reduce water use by combining data on weather, soil moisture levels, and specific plants to calculate optimal irrigation water application levels, as well as optimal timing of

Photo Credit: Richard Colback, IFC

water applications, with the goal of replenishing root zone moisture before water stress limits plant growth. They often rely on a combination of sensors to control water supply and monitor plant growth using computer systems or smartphones. All of these systems require full water control and will mostly be applied to high-value crops and high-end commercial operations.

REMOTE SENSING

Remotely sensed data can help optimize water applications through advanced technologies and can measure water evaporation and biomass generated in irrigated areas. Drones and thermal imagery data can be used to calculate irrigation water demand and use over small areas.

COMPUTER MODELING FOR WATER RESOURCE MANAGEMENT

Computer-based models that simulate conditions based on algorithms and some data collection inputs, such as the Food and Agriculture Organization Water Productivity Open-Access Portal, provide near-real-time satellite-generated data on the amount of water consumed through crop evapotranspiration. This tool can be used in combination with other measurement tools to determine whether changes in irrigation systems reduce or increase crop water use and whether aquifer withdrawals exceed recharge.

NONCONVENTIONAL SOURCES OF WATER

Nonconventional sources of water such as desalinated and treated wastewater could expand irrigation water availability provided they are affordable and safe. For example, desalination could be an alternative water source for irrigation and other uses, especially for Middle Eastern and African countries with coastal territories. Currently, at least 20 million hectares in 50 countries are irrigated with untreated, partially treated, or partially diluted wastewater. Although the benefits of wastewater use in agriculture are multiple, there are also disadvantages of this practice, including public health challenges from contact with pathogens in the wastewater by farmers and consumers and accumulation of heavy metals, salts, antibiotics, growth hormones, and other hazardous substances in soil and water. These energy and quality challenges must be resolved, but as food prices and technology costs drop, reuse of water is becoming increasingly viable.

MULTISCALE INNOVATION

Key irrigation innovations include measures to increase availability of irrigation water at the right time, in the right quantity, and of the right quality. New business and financing models are also needed to reach a broader set of potential irrigators. This includes expansion of the public-led and nongovernmental organization–led irrigation delivery model, with more private sector and farmer-driven development of irrigation (known as farmer-led irrigation development).

Photo Credit: IWMI/Jeffery M Walcott / IWMI

Reducing water pollution

Governments are most often called upon to lead the effort to regulate, monitor, and enforce water-quality standards so that land and water remain accessible, productive, and safe. Although there are technical solutions, capacity for environmental management in many countries remains limited, and cooperation with the international community will be needed. There are various ways to expand or implement irrigation systems:

- Higher nutrient-use efficiency, a plant trait under development that can substantially reduce pollution loads
- Promotion of better agricultural practices for fertilizer management, which can also dramatically reduce pollution

- Fertigation, the process of applying irrigation water with diluted fertilizer directly at the plant or root zone, generally via drip or sprinkler
- Deep placement of urea where appropriate
- Crop rotation with nitrogen-fixing (cover) crops
- No-till or reduced-tillage and other conservation measures that can dramatically reduce erosion and thus protect water bodies from chemical runoff
- Precision agricultural methods such as (variable rate) yield monitors that direct application of fertilizers where most needed to generate the highest yields
- Buffer strips alongside fragile water systems to reduce direct runoff

Broadening the impact of irrigation

OPTIMIZING IRRIGATION SYSTEMS FOR A BROADER SET OF AGRICULTURAL OUTPUTS

Optimizing irrigation systems for a broader set of agricultural outputs could include integration of fisheries with SSI systems through, for example, development of fish ponds. This could be done jointly with several smallholder irrigators, but farmers would first need to assess the tradeoffs if both fish and irrigated crops are produced, including the quantity and quality of water. Farmers would also need to assess the broader impact of SSI on natural water bodies that are sources of fisheries.

CONSIDERING MULTIPLE USES FOR WATER AND IRRIGATION INFRASTRUCTURE

Water systems that are designed for multiple purposes and that consider health and environmental outcomes may reduce the overall time that farmers spend collecting water, freeing up their time for other productive uses and caregiving. Calculation of return on investment and business models should consider irrigation as the primary use of SSI development but one that supports multiple uses of irrigation investment to multiply its benefits.

INCREASING THE NUTRITION SENSITIVITY OF IRRIGATION

Greater crop productivity and greater and more-stable food production can support food security, nutrition, and resilience. Investments in SSI development should focus on areas with an unstable food supply to proactively support nutrition. These investments would need to be complemented by nutrition training focused on nutrient-dense crops. Specific entry points include:

- Incorporating nutritional considerations into irrigation project design at the concept stage
- Equipping cooperatives, agricultural extension systems, and other relevant organizations with information on nutrition and diets


Photo Credit: Richard Colback, IFC

- Leveraging community platforms to deliver nutrition messages
- Engaging women in irrigation interventions
- Promoting nutrient-dense crops and incorporating home gardening into irrigation projects
- Designing formal, culturally appropriate, safe multiple-use water systems
- Incorporating irrigation into larger rural service delivery programs

REHABILITATING AND MODERNIZING POORLY FUNCTIONING SMALL-SCALE SYSTEMS

Many systems require rehabilitation and modernization to provide on-demand irrigation services that are suited to a large number of small fields, as typically found in Africa and Asia. Providing irrigation services to beneficiaries on demand enables supply of sufficient water quantities at least at a minimum operating pressure in the most distant fields. When this type of service is provided, each farmer may retrieve water at the desired time. This type of system helps avoid problems such as excessive use at the start of a system and lack of water at the end that occur in water rotation. Monitoring of water supply and amount of water used is automatic and controlled in real time to forestall problems. This also enables water to be appropriately priced to encourage water stewardship.

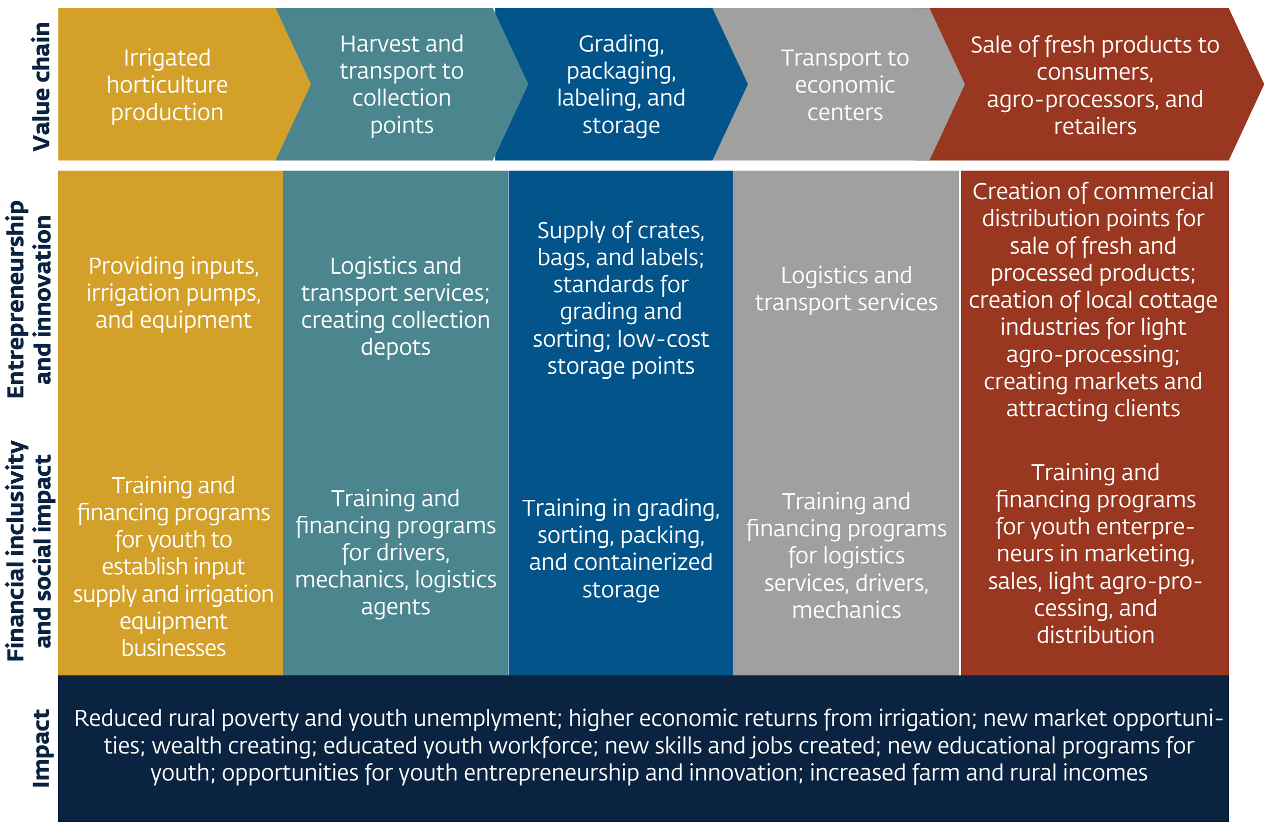
ADJUSTING TO CONDITIONS OF LOW WATER AVAILABILITY

Limited availability of water that prevents full-time irrigation or restricts production may constrain demand for irrigation. In these circumstances, use of irrigation (frequency or duration) is typically reduced by focusing on adjusting crop type and inputs. For example, reducing the use of water while increasing other agricultural inputs could be considered for high-value crops, although irrigation water should be increased proportionally with inputs for low-value crops.

CREATING AN ENABLING ENVIRONMENT

An enabling framework that supports farmers to procure complementary inputs as well as to sell the much larger volume of irrigated produce will be required. To address this, many business models around irrigated value chains have been developed, including by Madramootoo (2017) for IFAD (Figure 13).

Figure 13. Value chains across irrigated production and supportive services



Source: Madramootoo 2017.

Conclusion

As described in this chapter, future irrigation systems must be water efficient, providing water to a plant based on its needs rather than a torrent to soak the soil. These efficient systems provide precise drops of water and fertilizer to the rootzone to meet crop water demand and, as a result, consume less energy. Although farmers have struggled to obtain efficient irrigation technologies because of lack of financial resources, market demand from smallholder farmers has created an opportunity for development of new commercial financing products suitable to fund irrigation technologies. At the same time, securing a reliable source of water is increasingly possible as solar power and low-cost fuel pumps enable farmers to reach the depths at which water is located beneath the ground or to transport it longer distances from the source. Irrigation systems also require a combination of immediate capital investment and longer-term working capital to ensure that they can be installed, maintained, and operated sustainably.

Financial, technical, and legal support to improve water source development, including development of various types of water storage (surface, soil, groundwater) that are accessible to farmers, can help farmers decide whether to invest in their own systems to apply water to crops in their fields.

For irrigation to be profitable for farmers, initiatives are needed in continued innovation in precision irrigation technologies, labor-saving computer-assisted irrigation scheduling tools, and targeted development of agricultural intensification packages that combine irrigation with advanced seed technologies and other agricultural inputs.

These initiatives will require not only strong support to farmers on irrigation management, including after-sale services for irrigation technology, but also better support of the appropriate combination of irrigation and complementary inputs (e.g., pest management). To reach more farmers, including female farmers, stakeholders must try harder to identify how women can access information on irrigation technologies and benefit from such technologies.

The future of irrigation also requires innovations in irrigation institutions with stronger community-based management of natural resources, aided by remotely sensed and other advanced ICT systems. Although farmers are increasingly driving new irrigation development, governments must still enable and regulate the financial and economic environment to help ensure property rights to water, increase equity, and reduce overexploitation of increasingly scarce water resources. Finally, for irrigation to increase food security and improve nutrition, health, and quality of life, irrigation investors must work closely with women and men in rural communities and with the agencies and programs providing support for health and nutrition.

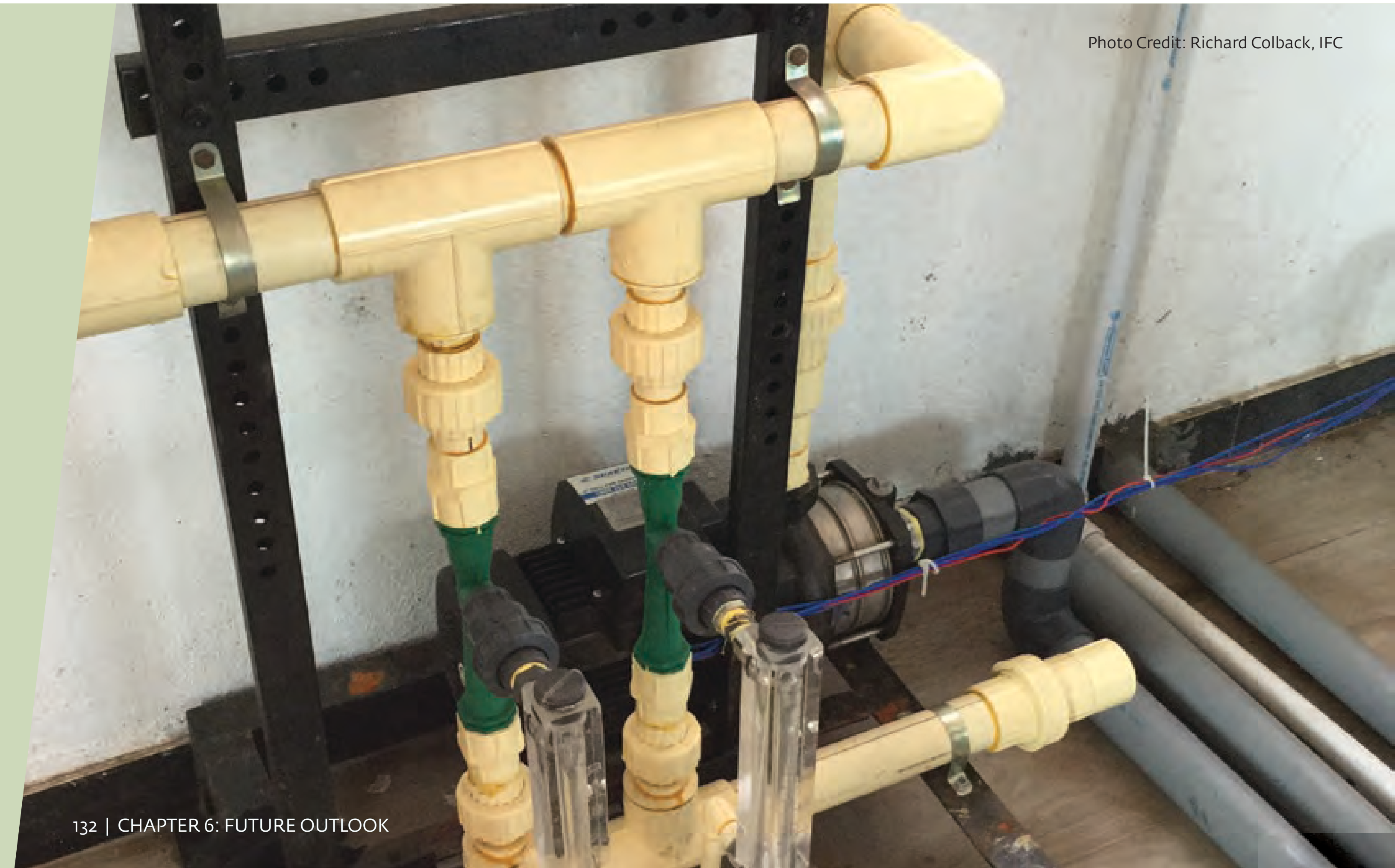


Photo Credit: Richard Colback, IFC

CASE STUDY 12: Effective Model for a Private Sector–Led Community Drip Irrigation Scheme

Country:	Years:	Organization involved:	Crops:	Irrigation systems:
India	**2017**	**Government of Karnataka, Netafim, Jain Irrigation Systems**	**Orchard crops such as grapes, bananas, and pomegranates; vegetables such as tomatoes, cauliflower, and spinach; cash crops such as sugarcane and cotton**	**Drip irrigation**

The Ramthal Drip Irrigation project in the Bagalkot district of Karnataka, India, created to alleviate water scarcity, is the largest community drip irrigation project in Asia. The project demonstrates an alternative to traditional methods of canal network and flow irrigation that lose 60 percent of water through conveyance, evaporation, percolation, and seepage. Other advantages of the project include equitable, adequate delivery of water to farmers at the end of the system, strengthening the benefits of a community approach; less buildup of salinity that typically occurs with uncontrolled or excess irrigation, extending the commercial sustainability of the system; installation of measuring devices and control structures to track water allocations throughout the community accurately and increase transparency; greater water and fertilizer application uniformity, leading to more-even crop growth and yield, allowing for greater equity in the community; and better soil condition at the canal head due to reduced waterlogging and poor drainage.

Through the project, bulk water is supplied to farmland communities through fully automated drip irrigation systems, with water channeled through installed cylinders to mix fertilizers and pesticides. This increases water-use efficiency, reduces pesticide and fertilizer use, and increases crop yield and uniformity.

The project is a joint venture of several public and private partners. A consortium of equipment providers and construction companies developed the system under a build, own, operate, transfer model, with private parties responsible for creation of water-use boards and operation and management of the system for 5 years.

In addition to paying the infrastructure costs, the government of Karnataka established market linkages with 14 agri-companies for offtake of produce. To facilitate expansion of the drip irrigation technology, the Drip-to-Market Agro Corridor was established to promote market-based mechanisms, with eight private agricultural firms agreeing to procure the farm produce.

Key technical features of the project:

- Water is taken from the Narayanpur reservoir and distributed to fields using high-density polyethylene and polyvinylchloride pipes.
- Self-cleaning automatic filters ensure clean water for drip systems and reduce clogging, a typical point of failure in poorly managed drip irrigation systems.
- Field outlets are fitted with automated valves controlled from a wireless remote monitoring station to regulate water flow. The automated system uses field sensors with data stored in a central server for access by project engineers, field technicians, and farmers. Automated alerts are sent by text to farmers regarding on–off schedules, crop alerts, and other agronomic practices.
- Pressure regulation and opening and controlling of pumps are automated based on predefined, preset water levels in the system, with data secured on cloud servers to allow remote monitoring.

As adoption of piped distribution networks gains traction, private sector involvement in construction, operations, and management of such systems is expected to increase.


Photo Credit: Richard Colback, IFC

Key metrics

- Area under irrigation: Hectares
- Number of beneficiaries
- Net income: U.S. dollars
- Water productivity: kg crop produced per cubic meter of water

Key results

- **90** percent additional area coverage using the same quantity of water (12,571 hectares in first stage covered by flood irrigation through canals vs 24,000 hectares in second stage covered by integrated drip irrigation); in both stages, the water requirement remained the same (78 million cubic meters)
- Twice as many beneficiaries reached using the same resources (more than **15,000** farmers in **30** villages)
- Net income, **USD 160**/hectare
- **1.41** kilograms of crops harvested per cubic meter of water supplied by drip irrigation (compared with 0.28 kilograms per cubic meter from conventional canal systems, or more than 500 percent increase)
- Water equitably distributed irrespective of topography and distance of farm from water source
- Improved standard of living of project beneficiaries
- Improved crop quality

Lessons learned

- Similar integrated micro-irrigation projects can be adopted in other states of India where canals or other irrigation sources are available. The government of Haryana is planning for a similar project powered by solar energy.
- Operation and management by a third party, participatory irrigation management by water boards, and marketing linkages will be helpful in maintaining the sustainability of future projects.

Call to action

As climate change continues to affect vulnerable communities, institutions, including nongovernmental organizations, must find innovations that will enable stronger community-based management of natural resources, aided by remotely sensed and other advanced ICT systems. For example, irrigation system designers must ensure that future irrigation systems reduce pollution, and service providers must find ways to use irrigation water for multiple purposes.

Although farmers are increasingly driving new irrigation development, governments must still support financial and economic environments and regulations that protect resources for future generations. This will entail addressing weaknesses in property rights to water, increasing equity, and reducing overexploitation of increasingly scarce water resources. Governments should also identify and implement interventions that lead to real water savings, coupled with enforceable water allocation systems. Development institutions can focus on financing innovative irrigation technologies and improving nutrition by investing in SSI in areas that have an unstable food supply.

Photo Credit: Richard Colback, IFC

Table 15. Role of Key Stakeholders in Creating Future Markets

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
PRIVATE SECTOR		
Private sector	• Scale up field-based testing and monitoring for inputs (seeds, agrochemicals, irrigation) • Provide open access to web-based training on improved practices and technologies (technology and commerce) • Use participatory processes to design improved irrigation services and water delivery systems	• Farmers receive targeted information on soil and water status to improve results from use of irrigation and inputs; increased farmer knowledge of improved varieties and agrochemical formulations for local context • Increase skills and outcomes in remote locations that lack access to in-person training and extension • Increase use, support, and efficiency of service and water delivery systems
Smallholder farmers	• Transition from rainfed systems to partial or full irrigation • Grow high-value dry season crops	• Increase yield productivity and incomes and give farmers greater control over time of sowing • Improve land productivity, reduce soil fertility loss, and farmers' ability to access higher-value markets during dry seasons
Irrigation equipment providers	• Develop low-cost precision irrigation and labor-saving, and information technology-assisted irrigation scheduling and delivery equipment • Ensure that future irrigation systems reduce pollution and support greenhouse gas emission reductions • Adapt equipment to local context, including sources of water • Design irrigation systems based on farmer needs, including needs of women and youth	• Irrigation systems are better suited for farmers' needs and address growing resource deficits • Contribute to public health and sustainability of ecosystems; access green funds • Increase area of land under irrigation; increase water productivity through multiple-use systems; increase food security; reduce need for labor collection of water not needed • Practical and profitable equipment that allows a wider range of people to benefit
Data providers	• Improve access to short-term weather and bulk water availability forecasting through mobile alerts and on-demand channels • Provide transparency of water use and availability to integrated user bases	• Optimize use of irrigation water resources by farmers based on weather conditions, water availability, and crop water requirements • Allow farmers, commercial users, and domestic users of water to allocate, share, and plan water use at a community level
PUBLIC SECTOR		

STAKEHOLDER	RECOMMENDED ACTIONS	IMPACT OF ACTIONS
National government	• Address weaknesses in water rights through changes in financial and economic regulations • Identify and implement interventions that lead to water savings coupled with enforceable water allocation systems • Regulate, monitor, and enforce water quality standards	• Increase equitable use and protect resources for future generations • Reduce overexploitation of increasingly scarce water resources • Ensure accessibility of water for productive and safe use
DEVELOPMENT SECTOR		
Multilateral financial institutions	• Adapt irrigation interventions to specific implementation context (national, subnational) and consider local context, including availability of water, labor, and markets • Assist with scaling up of irrigation systems by providing low-cost loans and incentives for low-emission technologies • Fund technology demonstration sites at cooperatives and other farmer centers • Finance innovative irrigation technologies, such as solar-powered pumps • Invest in small-scale irrigation in areas with an insecure food supply; provide training on nutrition to improve workforce and household nutrition	• Increase crop productivity and farmer incomes • More sustainable use of water and reduced greenhouse gas emissions • Greater visibility and adoption of resource saving technologies • Improve sustainability of projects • Reduce water use–related conflicts between different user groups • Access to irrigation in locations that are not yet linked to the electric grid; reduce greenhouse gas emissions • Improve household nutrition and increase resilience
Nongovernmental organizations and foundations	• Adopt innovations that will enable stronger community-based management of natural resources, aided by remotely sensed and other advanced ICT systems	• Help combat negative effects of climate change

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