



ICID•CIID

EAU,
AGRICULTURE
ET TERRITOIRES



26th INTERNATIONAL CONGRESS ON IRRIGATION AND DRAINAGE

12-17 October 2026, Marseille, France



Proceedings of the
**ICID International Symposium on
Future Proofing Irrigation: Modernisation and
IWRM, Finance, Policies, and Institutions**

INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE
COMMISSION INTERNATIONALE DES IRRIGATIONS ET DU DRAINAGE



ICID•CIID

The International Commission on Irrigation and Drainage (ICID), established in 1950 is the leading scientific, technical and not-for-profit Non-Governmental Organization (NGO). The Commission through its network of professionals spread across more than a hundred countries, has facilitated sharing of experiences and transfer of water management technology for over six decades. ICID supports capacity development, stimulates research and innovation and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework.



VISION

Water secure World, free of poverty and hunger achieved through sustainable rural development.

MISSION

To work together towards sustainable agriculture water management through inter-disciplinary approaches to economically viable, socially acceptable and environmentally sound irrigation, drainage and flood management.



Organizational Goals to realise the ICID Vision 2030

A

Enable Higher Crop Productivity with Less Water and Energy

B

Be a Catalyst for a Change in Policies and Practices

C

Facilitate Exchange of Information, Knowledge and Technology

D

Enable Cross-Disciplinary and Inter-Sectoral Engagement

E

Encourage Research and Support Development of Tools to Extend Innovation into Field Practices

F

Facilitate Capacity Development

For more information on ICID Vision 2030, please access document on 'A Road Map to ICID Vision 2030' available on ICID website - http://www.icid.org/icid_vision2030.pdf

Proceedings of the

**ICID International Symposium on
Future Proofing Irrigation: Modernisation
and IWRM, Finance, Policies, and
Institutions**

Presented at:

26th ICID International Congress and 77th IEC Meeting

12-17 October 2026, Marseille, France

ICID accepts no responsibility for the statements made, opinions expressed, maps included and accuracy of URLs for external or third-party Internet Web sites in these transactions.

La CIID se degage de toute responsabilité pour les déclarations faites, les opinions formulées, les cartes reproduites et l'exactitude de l'URL des sites web externes ou tiers dans ces Actes

© International Commission on Irrigation and Drainage (ICID), 2026

ISBN: 978-81-89610-56-2

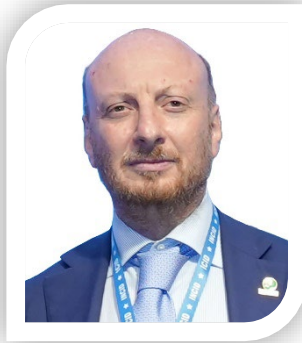
CONTENT

Preface

(v)

Paper No.	Title of the paper	Page No.
1	THE DEVELOPMENT OF FUTURE PROOFING IRRIGATION IN CHINA: PRACTICES, CHALLENGES, AND THE PATH TO MODERNIZATION – CHINA	1
2.	AGROECOLOGICAL REINGENIERING OF IRRIGATED SCHEMES: FROM THEORY TO CASE STUDIES – FRANCE <i>N. Urruty, E. Dressayre, C. Hello, J. Lecollinet, S. Sauviat, B. Vennat</i>	13
3.	INTRODUCTION IN THE CONTEXT OF IRRIGATION IN THE HUNGARY <i>Attila Nagy, Andrea Szabó, Éva Nikolett Kiss, István Szamosvári</i>	25
4.	IRRIGATION MODERNIZATION AND WATER RESOURCES MANAGEMENT IN IRAQ: SYSTEM PERFORMANCE, CLIMATE CHALLENGES, AND SUSTAINABLE PATHWAYS – IRAQ Eng. Rafat Nael Abdul Ghani, and Eng. Nisreen Sami Tarkhan	37
5.	ICID INTERNATIONAL SYMPOSIUM IN ASSOCIATION WITH UN-FAO ON “FUTURE PROOFING IRRIGATION: MODERNISATION AND IWRM, FINANCE, POLICIES, AND INSTITUTIONS” – JAPAN	55
6.	IRRIGATION MODERNISATION IN SOUTH AFRICA: A NOVEL PATHWAY TOWARDS FUTURE PROOFING AND RESILIENCE – SOUTH AFRICA <i>Luxon Nhamo, Cuthbert Taguta, Sylvester Mpandeli, Tinashe Dirwai, Stanley Liphadzi, and Tafadzwanashe Mabhaudhi</i>	69
7.	INTRODUCTION TO THE IRRIGATION STATUS OF THE REPUBLIC OF KOREA <i>Dr. Sung-Hee Lee</i>	85
8.	IRRIGATION IN UKRAINE: BACKGROUND, REALITY, AND PERSPECTIVES – UKRAINE	99

FOREWORD



It is my great honour and a real privilege to present these Proceedings of the ICID International Symposium on “**Future Proofing Irrigation: Modernisation and IWRM, Finance, Policies, and Institutions,**” organised by ICID in association with the Food and Agriculture Organization of the United Nations (FAO). The Symposium will be held on 12 October 2026 in Marseille, France, as an integral part of the 26th ICID International Congress and the 77th Meeting of the International Executive Council.

The Congress theme — *Water and Agricultural Resilience in the Face of Climate Change* — frames three questions that will occupy us throughout the week: how irrigation and drainage can serve the agro-ecological transition; where we stand with innovative technologies and practices for water-use efficiency; and whether non-conventional water can loosen the grip on scarce resources, and for what uses. This Symposium is the institutional companion to those questions. It asks how modernisation can be financed, governed and sustained — not only how it can be engineered. I have said it before, and I repeat it here with conviction: there can be no improvement or resilience of agrifood systems without the support of modern, well-governed irrigation.

Irrigated agriculture occupies only about one-fifth of the world’s cultivated land, yet it produces close to 40 percent of global food and accounts for some 70 percent of freshwater withdrawals. Climate variability, ageing infrastructure, groundwater stress and constrained public budgets are now testing the systems on which food security depends. Future-proofing irrigation therefore means more than lining canals or installing gates. It means placing infrastructure, IWRM, finance, policies and institutions on the same drawing board.

Eight National Committees have contributed country papers to this volume. Together they offer a rare, comparative view of how different societies are attempting that task.

China sets out the scale of a national modernisation programme: some 73 million hectares of irrigated land producing more than four-fifths of the country’s grain; digital twin districts and smart scheduling; agricultural water-pricing reform; and the still-unfinished work of groundwater recovery and last-mile delivery.

France proposes an analytical framework for the agroecological re-engineering of large collective schemes, applied to case studies in Senegal and Cambodia, and reminds us that inflexible hydraulic infrastructure can itself become an obstacle to ecological transition.

Hungary describes irrigation as a climate-adaptation service on the Great Plain, where only part of the area permitted for irrigation is actually watered, and where new sustainable water-management communities, water retention and digital metering must close the gap between installed capacity and reliable service.

Iraq traces a pathway from rehabilitation to IWRM and participatory irrigation management, with Water User Associations, closed-pipe systems, solar pumping and remote-sensing tools such as WaPOR, while being frank about financing gaps and the limits of cost recovery.

Japan presents two millennia of paddy irrigation now managed through some 4,000 Land Improvement Districts, and addresses the twin pressures of ageing facilities and an ageing farming population with ICT, pipeline conversion, “paddy-field dams” and a renewed Basic Law that places food security and eco-friendly systems at its core.

South Africa argues for a shift from area expansion to performance and equity: revitalising smallholder schemes, farmer-led irrigation, data-driven scheduling and the “soft” investments in tenure, training and markets without which hardware does not last.

The Republic of Korea reviews the smart water-management systems of the Korea Rural Community Corporation, stronger drainage standards for upland and horticultural crops, and the unfinished debate on farmer participation after irrigation fees were abolished.

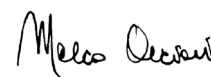
Ukraine sets out background, present reality and perspectives: the Irrigation and Drainage Strategy to 2030, water user organisations, and a Long-term Development Plan to 2050, against the severe loss of irrigation potential following damage to infrastructure, including the Kakhovka reservoir. Restoration is framed as a matter of national food security and of Ukraine's role as a global food donor.

What, then, do we expect from the deliberations in Marseille? First, that participants will compare these experiences without seeking a single model. Pathways must fit hydrology, history and institutions. Second, that finance will be discussed as a system — public investment, fair cost recovery, blended capital and the chronic underfunding of operation and maintenance — not merely as a project budget. Third, that IWRM will be treated as daily practice: conjunctive use, ecological flows, basin coordination and genuine roles for water users. Fourth, that digital tools will be judged by the quality of service they deliver to the last farm, not by the sophistication of the dashboard. Fifth, that capacity development — of managers, of associations, of young professionals and of women in water governance — will be recognised as infrastructure in its own right.

I thank the authors and National Committees who prepared these papers, often under demanding conditions; FAO for associating itself with this Symposium; Eau, Agriculture et Territoires, the French National Committee and our host, for welcoming us so generously in Marseille; and the Secretary General and staff of the ICID Central Office for bringing these Proceedings to print.

May the discussions of during this International Symposium be elaborate, practical, and useful. May they help National Committees, FAO and our partners turn diagnosis into investment, policy into practice, and modernisation into resilience. I wish the International Symposium every success.

The journey of a thousand miles begins with one step. Let this Symposium be a good one.



Dr. Marco Arcieri
President

International Commission on Irrigation and Drainage

CHINA'S FUTURE-ORIENTED RESILIENT IRRIGATION: PRACTICES, CHALLENGES, AND PATHWAYS TO MODERNIZATION — (CHINA)

Introduction

With 6% of the world's freshwater resources and 9% of its cultivated land, China has ensured food security for about 17% of the global population, and irrigation has played an irreplaceable role in this. By the end of 2025, China's irrigated cultivated land area had reached 73 million ha, accounting for 56.8% of the country's cultivated land, and a relatively complete irrigation and drainage system had taken shape. In 2025, 80.76% of China's total grain output was produced on irrigated cultivated land. In recent years, in response to multiple challenges — including intensifying climate change, localized imbalances between agricultural water supply and demand, and aging infrastructure—China has continued to advance the modernization of irrigation. It has integrated the concept of resilience into the entire chain of engineering construction, scheduling management, and institutional governance; established and improved the institutional and policy system for agricultural water conservation and efficiency enhancement; and steadily improved the reliability of agricultural water supply, the operational reliability of systems, and irrigation efficiency.

I. Irrigation Overview and System Efficiency

1.1 Irrigation Methods

China's agricultural production is characterized by diverse climatic conditions, complex water source conditions, and a rich variety of crops, and its irrigation technology development has distinct regional features. By the end of 2025, the national irrigated cultivated land area was 73 million ha. This included 6,924 large and medium-sized irrigation districts with a designed irrigation area of 41.8 million ha, providing basic support for stable and high grain yields. At the same time, "five small" water conservancy projects — small water cellars, small cisterns, small ponds, small pumping stations, and small canals — were built according to local conditions to serve scattered plots. Major grain-producing areas in northern China rely mainly on surface-water canal irrigation and well irrigation, while rice-producing areas in southern China rely mainly on water diversion and pumping from rivers and lakes and gravity irrigation from reservoirs and ponds. By 2025, the national area equipped for water-saving irrigation had reached 43.5 million ha, accounting for 59.4% of irrigated cultivated land, about 15 percentage points higher than in 2020; among this, drip irrigation and micro-sprinkler irrigation exceeded.

6.67 million ha. Over the past five years, with a focus on major grain-producing areas, China built 30 major water diversion and key water source projects, constructed 191 supporting irrigation districts, modernized 1,959 large and medium-sized irrigation districts, and added, restored, or improved more than 13.33 million ha of irrigated area.

1.2 Water Sources

China's irrigation water sources have formed a diversified supply pattern "dominated by surface water, supplemented by groundwater, and complemented by unconventional water." National agricultural water use is 368.38 billion m³, accounting for 62% of total water use. In terms of irrigation water, surface water remains the main source for large and medium-sized irrigation districts. It relies mainly on river runoff, reservoir regulation and storage, and pond/small-dam storage to provide basic security for rice-producing areas in both the south and north, the Huang-Huai-Hai Plain, and oasis irrigation districts in the northwest. Inter-basin water transfer projects, such as the eastern and middle routes of the South-to-North Water Diversion Project and the Yellow River-to-Hebei water diversion project to replenish Baiyangdian, have continued to optimize water source allocation in northern China, substituting for surface water previously used for agriculture and enhancing the supply capacity of key irrigation districts. North China and the northwest coordinate surface water and groundwater resources, scientifically developing well-irrigation districts and well-canal combined irrigation districts to support stable grain production and yield increases. The use of unconventional water sources has been steadily expanded.

In some water-scarce areas, reclaimed water, rainwater, mine water, and other unconventional sources are used for urban greening irrigation, ecological water replenishment, and as alternative water sources, becoming a supplementary factor in strengthening the resilience of irrigation systems.

1.3 Irrigation Efficiency

The national effective utilization coefficient of irrigation water rose from 0.536 in 2015 to 0.583 in 2025. Average irrigation water use per ha of cultivated land fell to 5,130 m³, down 4% from the end of 2020. Grain productivity per cubic meter of irrigation water remained above 1.8 kg, and agricultural water use efficiency has improved steadily for 10 consecutive years. In 2025, the national irrigated cultivated land area increased by more than 3.87 million ha compared with the end of 2020, and grain output on irrigated area accounted for 80.76% of the national total, giving full play to its role as the main force in grain production. From 2000 to 2025, China's irrigated cultivated land area increased from 53.8 million ha to 73 million ha, while national total grain output rose from 462 million tonnes to 715 million tonnes, an increase of 54.7%. According to years of tracking analysis, the average yield per unit area in large and medium-sized irrigation districts is 1.5 times the national average yield per unit area and 2.7 times that of rainfed cultivated land. Irrigation plays a prominent role in enhancing the drought resistance and harvest security of cultivated land, stabilizing grain output, and withstanding extreme climate, thereby consolidating the water conservancy foundation for national food security.

II. Major Risks and Challenges

2.1 Climate Change and Its Risks

In 2025, China experienced numerous extreme weather events of high intensity, frequent heavy rainfall events, heavy precipitation during the autumn flood season, and frequent flooding on small and medium-sized rivers. A total of 913 rivers experienced floods exceeding warning levels, and 42 rivers experienced floods exceeding historical observed records. In addition, China experienced successive drought episodes, including spring drought in the southwest, spring-summer drought in the northern winter wheat region and other areas, and summer droughts in the Huang-Huai and Jiang-Huai regions; extreme low-water conditions occurred in the Han River basin. According to statistics, in 2025, floods affected 2.59 million ha of crops nationwide, and droughts affected 1.86 million ha. Over the past decade, the areas affected by floods and droughts have generally trended downward, indicating that the effective measures China has taken in irrigation and drainage to respond to extreme climate have achieved remarkable results. In 2025, the areas affected by floods and droughts were 56.7% and 71.2% lower, respectively, than the average of the past 10 years.

2.2 Infrastructure Bottlenecks

The early construction standards of China's large and medium-sized irrigation districts were relatively low. After long-term operation, some projects have aged and fallen into disrepair, and the efficiency and capacity of canal water conveyance and distribution in irrigation districts have declined. The renovation of irrigation districts has lacked sufficient integration and systematic planning, and benefits have not been fully realized. In some irrigation districts undergoing renovation, supporting renovations focused on serious hazardous defects and key sections, while the construction and renovation of main works and on-farm works were not synchronized, lacking integration and systematic coordination. In irrigation districts in remote mountainous areas, land is relatively scattered, and the supply capacity of water source projects cannot be fully utilized. Interregional water resource allocation capacity remains insufficient, and the mismatch between water and land resources in the south and north remains prominent.

2.3 Groundwater Overexploitation and Available Water Volume

Since 2014, China has strengthened comprehensive governance of groundwater overexploitation areas, and the situation has improved markedly. Compared with the end of 2020, in the Beijing-Tianjin-Hebei treatment areas, shallow groundwater levels rose by an average of 3.76 m and deep groundwater

levels by an average of 7.65 m; groundwater overexploitation in the other 10 key areas improved overall. In 2025, China's groundwater resources totaled 810.56 billion m³, 1.2% above the multi-year average for 2001–2016 and 6.6% lower than in 2024.

2.4 Institutional and Funding Constraints

Grassroots irrigation management agencies generally face a shortage of professional staff and weak professional capacity. In some irrigation districts, funding for operation and maintenance is insufficiently guaranteed, and in some areas the operation and maintenance of projects have not yet received sufficient attention. At the funding level, the investment demand for modernizing irrigation districts is enormous, and relying solely on public financial investment creates considerable pressure. The return mechanism for private capital participation in irrigation is unclear, and profit models are immature, limiting the scale and scope of private capital attracted. The overall collection rate of agricultural water fees is low, cost recovery mechanisms are incomplete, and irrigation districts lack the capacity for self-maintenance and self-development, making it difficult to support long-term sustainable operation.

III. Climate Resilience and Environmental Sustainability

3.1 Irrigation System Response Measures

Climate change can easily trigger disaster risks such as high-temperature drought, extreme rainstorms, and rapid transitions between drought and flood. China has continuously optimized and built a resilient prevention and control system at the irrigation district scale, field scale, and system management and control levels.

In terms of enhancing irrigation district resilience, China coordinates the construction and renovation of water sources, water conveyance and distribution canal systems, and drainage systems with the development of smart management and control systems. It carries out the renewal of old pumping stations, seepage prevention in main and branch canals, and multi-water-source connectivity and regulation projects, and builds supporting small water-storage ponds and small dams, emergency water source wells, and other facilities. This enhances water source security capacity and water conveyance and distribution efficiency, ensuring that irrigation is possible in drought and drainage is possible in flooding.

In terms of enhancing field-level resilience, China strengthens the upgrading and renovation of existing surface irrigation systems, vigorously develops high-efficiency water-saving irrigation models such as drip irrigation, micro-sprinkler irrigation, and piped water conveyance, and supports technologies such as integrated water and fertilizer application, regulated deficit irrigation, rainwater harvesting and storage, and subsurface pipe drainage. Relying on field soil moisture and meteorological monitoring data to provide precise water supply on demand, it improves field irrigation water use efficiency and benefits, effectively addressing risks such as drought and water shortage, secondary soil salinization, and waterlogging-induced yield reduction.

In terms of enhancing system resilience, China builds digital twin irrigation district platforms, deploys perception terminals across the entire area for meteorology, water conditions, engineering conditions, soil moisture, and crop conditions, and realizes integrated intelligent regulation covering rainfall and water regime forecasting, drought and flood risk early warning, water scheduling rehearsal, and emergency response plans. Through the linkage of engineering resilience enhancement and digital scheduling, it strengthens the comprehensive safeguard capacity of irrigation and drainage systems to withstand extreme climate fluctuations, allocate water resources across time periods, and respond rapidly to alternating drought and flood disasters.

3.2 Drought Resistance and Early Warning

China continues to improve its flood and drought disaster prevention work system, strengthening mechanisms for responsibility implementation, decision support, and scheduling command. It consolidates territorial and sectoral responsibilities in all links, including plan preparation, monitoring and early warning, engineering scheduling, and emergency support, standardizes the scheduling, command mechanism, and handling procedures for major drought events, and systematically enhances the level of comprehensive drought prevention and control. It comprehensively strengthens the work measures of forecasting, early warning, rehearsal, and contingency planning, precisely implements drought resistance scheduling of water projects and emergency water scheduling, and continuously improves comprehensive drought disaster prevention capacity. It strengthens management of drought warning water levels (flows) for rivers, lakes, and reservoirs, optimizes monitoring stations, scientifically sets warning thresholds, and achieves full coverage of all provincial-level administrative regions. Based on conditions below drought warning levels, it assesses drought situations to provide support for issuing drought warnings and initiating emergency responses. It organizes the formulation of emergency water scheduling plans for rivers, lakes, and important water projects, completes the revision and development of technical standards such as Hydrological Drought Grades and Regional Drought Grades, and builds a complete system of plans, contingency schemes, and technical specifications. It improves the national comprehensive drought monitoring and early warning platform to support scientific drought resistance decision-making.

3.3 Soil and Water Environment Governance and Protection

In response to soil and water environmental problems arising from irrigation, China implements systematic governance. In terms of salinization control, through coordinated irrigation and drainage, subsurface pipe drainage, soil improvement, and promotion of salt-tolerant crops, it has cumulatively treated more than 100 million mu of saline-alkali cultivated land, and the degree of salinization in key areas such as the Hetao Irrigation District and the Huang-Huai-Hai Plain has continued to decrease. It advances the restoration and renovation of farmland ditches and canals and the governance of plain waterlogging areas. In Northeast China, the middle and lower reaches of the Yangtze River, the Huai River basin, and the southeast coastal areas, it implements upgrades of drainage pumping stations and renovation of field ditches and canals, generally raising farmland drainage standards and effectively alleviating the impact of waterlogging on crops. In addition, reform and innovation in soil and water conservation continue to advance. Taking small watersheds as units, it carries out comprehensive governance of soil and water loss and strengthens remote sensing supervision of soil and water conservation in production and construction projects. In 2025, the national area of soil and water loss decreased to 2,576,400 km², and the national soil and water conservation rate rose to 73.09%.

IV. Irrigation Modernization

4.1 Construction of Modern Irrigation Districts

China aims to build modern irrigation districts that are “well-equipped, water-saving and efficient, scientifically managed, and ecologically sound.” Taking the modernization and renovation of large and medium-sized irrigation districts as an opportunity, it is accelerating the improvement of scientific irrigation systems, water metering and monitoring systems, agricultural water pricing policies and institutions, water-saving market systems, and water-saving technology and market service systems, comprehensively improving the quality of irrigation services. It promotes standardized management of irrigation districts, clarifies the list of responsibilities and operating standards of management units, optimizes the entire process of water supply application, scheduling, and metering, fully implements water withdrawal permits, and promotes the “total volume control and quota management” water use model. Through farmer water user cooperative organizations and other entities, it assigns responsibility for the management and maintenance of terminal canal systems, improves the timeliness and fairness of end-of-system water supply services, and opens up the “last mile” of irrigation services.

4.2 Construction of Water-Saving Irrigation Projects

By 2025, the national area of water-saving irrigation projects had reached 43.47 million ha, an increase of 5.66 million ha from the end of 2020. China has now cumulatively built more than 66.67 million ha of high-standard farmland. By 2030, it will strive to cumulatively build 90 million ha of high-standard farmland and cumulatively renovate and upgrade 18.67 million ha. It will plan as a whole and simultaneously develop high-efficiency water-saving irrigation, adding 5.33 million ha of high-efficiency water-saving irrigation area.

4.3 Digital and Intelligent Irrigation Technologies

In recent years, China's digital and intelligent irrigation technologies have advanced rapidly. Relying on the deep integration of digital information technologies such as the Internet of Things, remote sensing monitoring, artificial intelligence, and digital twins with conventional irrigation and drainage engineering technologies, China has gradually built an integrated smart irrigation system of "perception–decision-making–control." In terms of water scarcity perception, it has developed water scarcity perception technology based on multi-source data fusion across space, air, ground, water, and engineering, generating daily water scarcity index maps. In terms of intelligent decision-making, it has developed an intelligent irrigation decision-making system driven by crop models, dynamically generating irrigation prescription maps. In terms of precise control, through data flow and driving, it achieves precise regulation of the entire process of water conveyance, distribution, and irrigation. Smart irrigation has significantly enhanced agricultural production's capacity for drought resistance, flood prevention, and disaster reduction. It can increase crop yields by more than 10% and improve water use efficiency by more than 15%, providing key scientific and technological support for safeguarding agricultural production and alleviating the contradiction between agricultural water supply and demand.

4.4 Agronomic Water-Saving Technologies

After long-term research and development and large-scale demonstration, China's agronomic water-saving technologies have formed a complete technical system covering moisture conservation through mulching, rainwater harvesting and storage, improved variety breeding, and water-fertilizer coordination. Evaporation suppression and rainwater harvesting technologies such as plastic film mulching and full-film double-ridge furrow sowing effectively reduce non-beneficial soil evaporation. Drought-resistant and water-saving crop varieties are continuously bred and promoted, enhancing crops' own water adaptability. Technologies such as field rainwater harvesting cellars and ridge-furrow rainwater harvesting effectively increase the utilization of natural rainfall resources on dryland. Integrated water-fertilizer technology achieves synchronous and precise supply of water and fertilizer, and fertilizer use efficiency is significantly higher than with traditional broadcasting. In 2025, Northeast China implemented conservation tillage on black soil on 7.47 million ha. In Xinjiang, the area under integrated water-fertilizer technology reached more than 4.67 million ha. Water-scarce areas continued to optimize planting structures, reduce the planting scale of high-water-consumption crops, promote rainfed agriculture and dryland farming technologies, and emphasize water-adaptive agricultural development. With synergy between agronomic and engineering water-saving measures and empowerment by digital and intelligent technologies, farmland irrigation water use efficiency and benefits have continued to improve.

4.5 Irrigation Management, Operation, and Maintenance

China is deepening reform of the management system for farmland water conservancy projects, clarifying project property rights, and implementing management and protection entities and responsibilities. Large and medium-sized irrigation districts in China promote the separation of management and maintenance. Management units are responsible for operation and scheduling, while professional teams are introduced through government purchase of services to undertake routine project maintenance, improving the professionalism of management and protection. For small farmland water conservancy projects, property rights system reform clarifies ownership, management rights, and use rights. Multiple models are adopted, such as trusteeship by village collective economic

organizations, management and protection by farmer water user cooperative organizations, and socialized services, to solve the problem of absent management and protection. A system of regular inspection and safety appraisal for irrigation projects has been established, and normalized monitoring and maintenance are carried out for key projects. Fiscal subsidies are provided for the maintenance and repair of farmland water conservancy facilities and, together with collected water fees, provide stable funding for routine project maintenance.

4.6 Joint Utilization of Water Resources

China actively promotes the optimal allocation and joint utilization of multiple water sources to enhance system resilience. Northern irrigation districts establish joint scheduling mechanisms for surface water and groundwater according to local conditions: in wet years, more surface water is used and groundwater is recharged; in dry years, groundwater is moderately extracted, achieving interannual regulation of water resources. In the water-receiving areas of the South-to-North Water Diversion Project, transferred water, local surface water, and groundwater are coordinated to optimize irrigation water source allocation and reduce groundwater extraction. The scale of unconventional water source utilization continues to expand. Urban reclaimed water, after advanced treatment, is used for urban greening irrigation and ecological water replenishment. In the northwest, southwest, south China, and other regions, rainwater harvesting and utilization projects are promoted, and rainwater harvesting supplementary irrigation is developed to enhance irrigation security capacity in hilly and mountainous areas.

4.7 Development of Clean Energy Irrigation

China's clean energy irrigation technology has developed steadily, forming a technology application system dominated by solar photovoltaic water-lifting irrigation, supplemented by wind-powered water lifting, and supported by wind-solar complementary solutions. Photovoltaic irrigation systems combine high-efficiency pumps, intelligent control equipment, and water-saving irrigation technologies such as integrated water-fertilizer management and subsurface drip irrigation. They have been promoted and applied in the northwest, north China, and other areas with weak grid coverage. Supporting energy storage and wind-solar complementary solutions are gradually solving the problem of intermittent solar power supply. Many places have carried out demonstrations integrating photovoltaic irrigation with irrigation decision-making systems, achieving coordinated optimization of solar energy utilization and water resource allocation.

V. Institutional and Policy System

5.1 Policy and Regulatory Framework

China has developed a relatively complete legal and policy system for irrigation development and governance. Laws and regulations such as the Water Law of the People's Republic of China, the Farmland Water Conservancy Regulations, the Groundwater Management Regulations, and the Water Conservation Regulations provide a solid legal basis for irrigation development planning, the construction of irrigation and drainage projects, the operation and management of irrigation districts, and the management and control of irrigation water resources. At the national level, documents including the National Water-Saving Action Plan, the Outline of the National Water Network Construction Plan, the 14th Five-Year Plan for Building a Water-Saving Society, the National Farmland Irrigation Development Plan, and the Opinions on Comprehensively Building an Institutional and Policy System for Water Conservation have been issued successively, clarifying the objectives, tasks, and implementation paths for irrigation modernization. The comprehensive reform of agricultural water pricing has been advanced across the board, establishing a water price formation mechanism based on "permitted cost plus reasonable return," implementing classified water pricing and a progressive surcharge system for water use exceeding quotas, and supporting it with precise subsidies and water-saving reward mechanisms. This not only safeguards farmers' reasonable water use burden but also

uses the price lever to promote water conservation and achieve sound operation of projects. The water withdrawal permit system and water resources demonstration system are strictly implemented, and total volume control and quota management are applied to irrigation water withdrawal, effectively promoting improvements in water use efficiency.

5.2 Institutional Arrangements and Intersectoral Coordination

In 2023, the Ministry of Water Resources systematically summarized useful experience and successful practices in the field of agricultural water conservation and proposed an institutional and policy system for agricultural water conservation and efficiency enhancement, covering scientific irrigation systems, water metering and monitoring, agricultural water pricing policies, water-saving markets, and water-saving technologies and services. China implements an irrigation management system featuring overall coordination and responsibility at different levels. The Ministry of Water Resources performs national irrigation industry management and overall planning functions. Basin management agencies are responsible for water use management in irrigation districts spanning provincial boundaries and for basin water resource scheduling. Local water administrative departments at all levels undertake responsibilities for the construction and operation management of key irrigation projects within their jurisdictions. Relevant sectors such as agriculture and rural affairs, development and reform, finance, and natural resources work in coordination according to their division of responsibilities, forming a work pattern featuring government leadership, multi-sectoral coordination, and broad social participation. Special intersectoral coordination mechanisms have been established around key tasks such as comprehensive governance of groundwater overexploitation, continuously improving the effectiveness of comprehensive governance.

5.3 Farmer Water User Self-Governance Organizations

China continues to cultivate various farmer water user self-governance organizations, with farmer water user cooperative organizations as the main body. As important vehicles for participation in irrigation management reform, they mainly undertake functions such as management and maintenance of terminal canal systems, coordination of water allocation, collection of water fees, and mediation of water use conflicts, realizing coordinated “specialized management plus group management” in irrigation management. All localities adhere to adapting measures to local conditions, combine the comprehensive reform of agricultural water pricing and the modernization and renovation of irrigation districts to improve the operating rules of self-governance organizations, guide farmers to independently participate in the entire process of irrigation management, effectively open up the “last mile” of farmland water conservancy management and protection, and promote agricultural water conservation. At present, all localities are actively promoting the upgrading of grassroots farmer water user self-governance organizations through government purchase of services, capacity training, and empowerment through digital management.

VI. Investment and Financing

6.1 Public and Private Financing Mechanisms

Public finance is the main source of funding for irrigation development. The central government has established dedicated funding channels to support tasks such as the modernization and renovation of large and medium-sized irrigation districts, high-efficiency water-saving irrigation, and comprehensive governance of groundwater overexploitation. From 2021 to 2025, under the active guidance of central government finance, local governments coordinated and increased fiscal support, raised funds through multiple channels, implemented the modernization and renovation of 2,150 large and medium-sized irrigation districts, developed more than 667,000 ha of high-efficiency water-saving irrigation area annually, and achieved overall improvement in groundwater overexploitation in key areas. Innovative investment and financing mechanisms have been adopted. Localities have attracted private capital to participate in the construction and operation of irrigation districts through concession operations, equity

cooperation, and other means. Some areas have introduced professional water utilities to take charge of irrigation district operation management and water-saving renovation, using water-saving benefits and water supply fees as return mechanisms. Development finance and policy-based finance have increased medium- and long-term credit support, reducing financing costs by extending loan terms, providing low-interest loans, and offering interest subsidy policies.

6.2 *Cost Recovery and Water Pricing Systems*

The comprehensive reform of agricultural water pricing and the development of an institutional and policy system for agricultural water conservation and efficiency enhancement have continued to advance. Since 2016, China has comprehensively advanced the comprehensive reform of agricultural water pricing. Using agricultural water pricing as a leverage point, it has gradually established an agricultural water price formation mechanism, a targeted subsidy and water-saving reward mechanism, a project construction and maintenance mechanism, and a water use management mechanism, effectively improving the level of agricultural water conservation and the management and protection of farmland water conservancy facilities. By the end of 2025, the cumulative area covered by the comprehensive reform of agricultural water pricing nationwide had reached 72.4 million ha, achieving the goal of reform wherever it is needed. In 2025, the Ministry of Water Resources and four other Ministries issued opinions on comprehensively building an institutional and policy system for water conservation, placing agricultural water conservation and efficiency enhancement first. On the basis of improving irrigation water quotas, metering facilities, and water rights allocation, all localities have continued to advance the agricultural water price formation mechanism based on “permitted cost plus reasonable return,” and have implemented classified water pricing, progressive surcharges for water use exceeding quotas, targeted subsidies, and water-saving reward systems according to local conditions. This has driven the operation and maintenance, water-saving renovation, and water use management of irrigation districts to shift from “engineering construction-driven” to “synergistically driven by institutional policy, pricing mechanisms, digital monitoring, and technical services,” providing long-term institutional support for the construction of modern irrigation districts and agricultural water conservation and efficiency enhancement.

6.3 *Investment Priorities and Funding Arrangements*

At present, China's irrigation investment priorities focus on four major directions: first, the modernization and renovation of large and medium-sized irrigation districts to consolidate the safeguarding capacity of key irrigation and drainage projects; second, in conjunction with high-standard farmland construction, improving field irrigation and drainage systems and developing high-efficiency water-saving irrigation to expand the coverage of advanced water-saving irrigation technologies; third, comprehensive governance of groundwater overexploitation and water source substitution to restore groundwater ecology; and fourth, the construction of digital irrigation districts and smart irrigation to empower management upgrading. Investment in irrigation projects is shifting from a single government investment path to a diversified investment and financing model guided by government fiscal investment, with active participation of local bond funds, bank loans, private capital, and other sources.

VII. **Capacity Building**

7.1 *Technical Training*

A tiered and categorized training system for irrigation talent has been established. For irrigation management professionals, online and offline training, technical exchanges, skills competitions, and job competency improvement programs are used to enhance the capacity of irrigation district management personnel in project operation and maintenance, digital scheduling, water resources management, and other areas. Since the 14th Five-Year Plan period, all localities have continued to increase efforts in talent cultivation, regularly organizing business training for grassroots irrigation district and farmland water conservancy management personnel. Through field schools, demonstration bases, cultivation of technical leaders, and other methods, combined with high-quality farmer cultivation and grassroots agricultural technology extension projects, training in water-saving irrigation, integrated water and

fertilizer management, dryland farming technologies, and other areas has been widely carried out. The exemplary and leading role of such training has been brought into play to enhance farmers' ability to apply advanced irrigation technologies.

7.2 *Technology Extension*

China has established a ministry-led, vertically coordinated irrigation technology extension system. Relying on the national irrigation experiment station network, it conducts long-term experiments and observations on crop water requirements, regional irrigation regimes, and new water-saving irrigation technologies, providing basic data support for technological upgrading and parameter localization. It has established a release system for new technologies and products, including the Guiding Catalog for Key Promotion of Advanced and Practical Water Conservancy Technologies, the Catalog of Advanced, Mature, and Applicable Water-Saving Technologies and Equipment, and the Catalog of Major Agricultural Technologies. It has built a national professional science and technology exhibition and exchange platform and mechanism to promote nationwide irrigation and drainage science and technology exchange and training. More than 100 advanced and practical technologies—such as smart water metering in irrigation districts, mulched drip irrigation, integrated water and fertilizer management, and dryland rainwater harvesting and moisture conservation—have been released and transformed, opening a fast track for the large-scale application of scientific research achievements. The timeliness of new water-saving irrigation technologies and products is increasingly improving, and results are becoming increasingly notable.

VIII. Countermeasures and Measures

8.1 *Development Achievements*

For a long time, China has consistently regarded the construction and improvement of irrigation and drainage facilities as an important foundation for effectively responding to climate change and enhancing the resilience of agricultural production. Since the beginning of the new century, under the guidance of the central government, all localities have continued to carry out the construction and renovation of irrigation and drainage facilities, vigorously develop water-saving irrigation, strengthen the allocation and control of water resources, and continuously improve the management systems and mechanisms for irrigation and drainage facilities. The proportion of irrigated cultivated land has continued to rise, and grain output per unit of water has steadily increased, providing a solid water conservancy foundation for grain output to remain stable above 700 million tonnes.

8.2 *Implementation Pathways for Irrigation Modernization*

With the establishment and improvement of the institutional and policy system for agricultural water conservation and efficiency enhancement as the core lever, China is systematically advancing the implementation of irrigation modernization. It focuses on the following priority actions to comprehensively build a resilient, efficient, smart, and sustainable modern irrigation development pattern:

First, vigorously implement the modernization and renovation of irrigation districts. Focusing on enhancing the capacity to guarantee the supply of grain and other important agricultural products, China will scientifically plan farmland irrigation development for the 15th Five-Year Plan period, accelerate the construction of large irrigation districts such as Jiayan in Guizhou, Yutan in Chongqing, and the Leizhou Peninsula in Guangdong, and comprehensively advance the modernization and renovation of large and medium-sized irrigation districts such as Dujiangyan in Sichuan and Qingtongxia in Ningxia. At the same time, it will strengthen intersectoral coordination and accelerate the construction of a complete irrigation and drainage engineering system from water sources to fields.

Second, accelerate the governance of key waterlogging areas. Adhering to overall planning, systematic governance, and comprehensive advancement, China will vigorously promote the integrated governance of rivers, lakes, ditches, and farmland, effectively connect main and field irrigation and drainage canal systems, improve the farmland ditch and canal network, reduce the risk of waterlogging on farmland, and continuously enhance agricultural disaster prevention and mitigation capacity.

Third, continuously improve the institutional and policy system for agricultural water conservation and efficiency enhancement. China will guide all localities to strengthen irrigation experiments and the application of results, revise irrigation water quotas in due course, build smart irrigation decision-making systems, and guide scientific irrigation. In conjunction with the modernization and renovation of large and medium-sized irrigation districts, it will improve water metering and monitoring facilities. It will issue relevant policies to consolidate and expand the results of the comprehensive reform of agricultural water pricing, making the results of the reform long-term and institutionalized. It will encourage local governments to adhere to the “two hands” approach for tapping both public and private capital, innovate investment and financing mechanisms for the construction and maintenance of irrigation districts, actively explore and standardize the promotion of water rights trading, and explore effective channels such as using the revenue from trading newly added cultivated land indicators in irrigation districts mainly for irrigation district construction, so as to mobilize the initiative and enthusiasm of private capital and agricultural water users to participate in irrigation district construction and management. It will promote the research, development, and application of high-efficiency water conveyance and distribution technologies in irrigation districts, and form systematic solutions for high-efficiency water conveyance and distribution in major grain-producing areas such as the Huang-Huai-Hai Plain, the Fen-Wei Plain, and the Northeast Plain. It will carry out pilot projects for digital twin irrigation districts, promote digital and intelligent transformation of irrigation districts, and continuously improve the efficiency of water resource utilization and the level of operation and management in irrigation districts.

8.3 Regional and Global Cooperation

As an important member of the International Commission on Irrigation and Drainage (ICID), China is deeply involved in global irrigation governance and practical regional and global cooperation in the field of irrigation and drainage, comprehensively sharing China's experience, solutions, and wisdom in irrigation and drainage. At the capacity-building level, relying on the ICID cooperation platform, it regularly carries out technical seminars, international academic conferences, expert mutual visits, and exchanges among young professionals, contributing to the cultivation of professional and managerial talent in irrigation and drainage. At the technology extension level, it summarizes mature equipment and complete solutions for external sharing, such as variable-rate sprinkler irrigation, large-scale drip irrigation, and digital and intelligent irrigation technologies, and actively leads and participates in the formulation and revision of international standards for the irrigation and drainage industry. At the knowledge dissemination level, it organizes renowned Chinese experts to compile and publish a series of books on irrigation and drainage, continuously sharing with the world localized practical experience in irrigation district modernization and renovation, high-efficiency water-saving irrigation, and rainwater harvesting and utilization in arid areas, and providing solutions for the efficient use of global agricultural water resources and food security.

References

- [1] Ministry of Water Resources of the People's Republic of China. (2026). 2025 Statistic Bulletin on China Water Activities. Beijing: China Water & Power Press.
- [2] Wang, H. (2025, December 30). National irrigated farmland area exceeds 1.09 billion mu. People's Daily, p. 4.
- [3] Ministry of Water Resources of the People's Republic of China. (2021). 2020 Statistic Bulletin on China Water Activities. Beijing: China Water & Power Press.

- [4] Wang, H. (2025, September 23). National irrigated farmland area reaches 1.086 billion mu. People's Daily, p. 2.
- [5] State Council Information Office of the People's Republic of China. (2025, September 29). Press conference on the high-quality completion of the 14th Five-Year Plan: Achievements in high-quality water conservancy development during the 14th Five-Year Plan period [Press conference transcript]. <http://www.scio.gov.cn/live/2025/37487/index.html>
- [6] Ministry of Water Resources of the People's Republic of China. (2026). China Water Resources Bulletin 2025. Beijing: China Water & Power Press.
- [7] Ministry of Water Resources of the People's Republic of China. (2016). China Water Resources Bulletin 2015. Beijing: China Water & Power Press.
- [8] State Council Information Office of the People's Republic of China. (2026, January 9). The State Council Information Office holds a press conference to introduce progress in accelerating the construction of the national water network [Press conference transcript]. <http://www.mwr.gov.cn/hd/zxft/2026/fbh20260109/index.html>
- [9] National Bureau of Statistics of China. (2025). China Statistical Yearbook 2025. Beijing: China Statistics Press.
- [10] Ministry of Water Resources of the People's Republic of China. (2026). China Flood and Drought Disaster Prevention Bulletin 2025. Beijing: China Water & Power Press.
- [11] Ministry of Water Resources of the People's Republic of China. (2026). China Soil and Water Conservation Bulletin (2025).
- [12] General Office of the Communist Party of China Central Committee & General Office of the State Council. (2025, March 30). The General Office of the CPC Central Committee and the General Office of the State Council issue the Implementation Plan for Gradually Building Permanent Basic Farmland into High-Standard Farmland. https://www.gov.cn/zhengce/202503/content_7016421.htm
- [13] Departments of Agriculture and Rural Affairs of Heilongjiang, Jilin, Liaoning, and Inner Mongolia. (2026, April 27). Cultivating black soil together to stabilize grain and revitalize the nation: Three northeast provinces and one autonomous region focus on food security to consolidate the foundation for comprehensive revitalization. https://qys.moa.gov.cn/gdxw/202604/t20260427_6483675.htm
- [14] Department of Natural Resources of Xinjiang Uygur Autonomous Region. (2025, October 22). Safeguarding every inch of grain-producing farmland north and south of the Tianshan Mountains: A review of farmland protection work in Xinjiang since the 14th Five-Year Plan. <https://zrzyt.xinjiang.gov.cn/xjgtzy/mtxc/202510/bea1ddd9f250409296e7a2c392b714cb.shtml>
- [15] Ministry of Water Resources of the People's Republic of China et al. (2025, April 10). Five Ministries, including the Ministry of Water Resources, comprehensively build an institutional and policy system for water conservation. http://www.mwr.gov.cn/xw/slyw/202510/t20251001_2047101.html
- [16] Ministry of Water Resources of the People's Republic of China. (2026, April 10). Press conference on progress and achievements in water infrastructure construction in the first quarter of 2026 [Press conference transcript]. <http://www.mwr.gov.cn/hd/zxft/2026/fbh20260410/>

AGROECOLOGICAL REINGENIERING OF IRRIGATED SCHEMES: FROM THEORY TO CASE STUDIES – FRANCE

N. Urruty¹, E. Dressayre², C. Hello², J. Lecollinet¹, S. Sauviat¹, B. Vennat²

ABSTRACT

Irrigated agriculture remains a cornerstone of global food security (20% of cultivated land that produce 40% of total food). However, large-scale collective irrigation schemes are most often characterized by intensive agricultural practices and their associated drawbacks, such as biodiversity reduction, soil degradation, water pollution and greenhouse gas emissions. Among the alternative ways to reconcile environmental, sustainability and production goals, agroecology is now receiving increasing attention by emphasizing the application of ecological concepts and principles to the design and management of agricultural systems. However, recent work by COSTEA³ has shown that few agroecological innovations are present in large-scale irrigation schemes, which could be partly explained by the inflexibility of the associated hydro-agricultural infrastructures and their management. To explore this avenue, a study conducted by BRLi & SCP and commissioned by COSTEA aimed to examine various reengineering options to promote the adoption of agroecological principles in large-scale irrigated areas. A framework (multi-input analysis grid) was established to analyze these irrigated areas according to various agroecological criteria. The adopted agroecological principles are based on an integrated approach which considers the interactions between water, energy and food. This grid was applied to various collective irrigation projects in Senegal and Cambodia to assess the level of commitment to agroecology. Results of this study revealed that: i) agroecology principles are often cited in design and rehabilitation studies but they rarely cover all the dimensions mentioned above, ii) the shift from gravity-fed to modern irrigation infrastructures are highly limited by various factors (e.g. availability of water resources, budget constraints, technical skills of users and maintenance services...), which leave little room for technical innovation, and iii) the proposed changes are multifaceted and therefore require long time for concertation and adaptation.

1. INTRODUCTION

During the 20th century, agricultural modernization was largely driven by processes of homogenization and standardization of production systems. This paradigm relied on the widespread use of improved crop varieties and animal breeds, combined with uniform management practices, mechanization, and the intensive use of external inputs such as fertilizers and pesticides. By maximizing the genetic potential of a limited range of plant and animal species under controlled and optimized conditions, this model enabled substantial increases in agricultural productivity and contributed significantly to global food security (Gollin *et al.*, 2021).

Following a similar trajectory, large-scale irrigation schemes have been developed worldwide through the construction and expansion of hydraulic infrastructures and increasingly sophisticated water management systems. These schemes rely mainly on collective organization, enabling the coordinated allocation and distribution of water resources across extensive agricultural areas. By ensuring more reliable water supply, reducing dependence on rainfall variability, and supporting the intensification of agricultural practices, such systems have significantly enhanced crop productivity and stability of yields. In many regions, they have facilitated the adoption of high-yielding varieties and input-intensive farming systems, thereby amplifying the overall gains of agricultural modernization. As a result, collective irrigation schemes have contributed substantially to increases in agricultural output and have played a

¹ Société du Canal de Provence, LE THOLONET, France

² BRL Ingénierie, NÎMES, France

³ Comité Scientifique et Technique de l'Eau Agricole

critical role in meeting the food demands of a rapidly growing global population, which has nearly quadrupled over the past century (FAO, 2020).

However, these developments have also raised important challenges related to water resource sustainability, equity in access, and environmental impacts. Moreover, a recent work by COSTEA has shown that few agroecological innovations are present in large-scale irrigation systems, which could be partly explained by the inflexibility of the associated hydro-agricultural infrastructure and management (Roesch et al., 2022).

This process of agricultural modernization and intensification is now approaching its limits within an increasingly unfavorable context, characterized by rising climatic, economic, and sociopolitical uncertainties, mounting constraints on critical inputs such as water, and stagnating system performance dynamics that call into question the continued acceptability of the significant environmental externalities it produces (Leauthaud et al., 2025).

Accordingly, this situation calls for the emergence of a new paradigm commonly framed as the agroecological transition (Gliessman, 2018) structured around several core principles:

- a shift from yield maximization towards multi-functional and water efficient use of irrigation water (e.g. irrigation of cover crops, agroforestry, soil and water conservation);
- a decentralization of governance with strengthened roles for farmers and stakeholder coordination;
- and the pursuit of flexible and modular water access systems to support more autonomous and adaptive farming practices.

In this paper, we propose an analytical framework aimed at facilitating both the diagnosis and the design of irrigated schemes within an agroecological perspective. This framework aims to illustrate the links between the various components of irrigated schemes and their agroecological performance. After outlining the core principles of this conceptual framework, we demonstrate its applicability through two irrigated case-studies in Senegal and Cambodia.

2. PRESENTATION OF THE CONCEPTUAL FRAMEWORK

The conceptual framework is based on the intersection between, on the one hand, the core components of irrigated schemes and, on the other, the various agroecological objectives pursued.

The seven dimensions of irrigated schemes

While the implementation of irrigated systems may solve the challenges related to insufficient available water resources for rainfed cultivation, it also radically increases the diversity of skills and expertise required of farmers, governance systems and policy makers. We have identified seven dimensions that reflect the complexity of collective irrigated systems and their integration into different spatial, economic, and political levels. (**Figure 1**).

Dimension 1: Governance. The governance of irrigated systems encompasses the institutional frameworks, policies, and decision-making processes that shape how water resources are allocated, managed, and monitored within irrigation schemes. It involves multiple stakeholders, including public authorities, water user associations, farmers, and private actors, whose interactions determine the performance and sustainability of the system.

Dimension 2: Infrastructure design. It refers to the physical and technical components that enable water storage, conveyance, distribution, and application within irrigation schemes. It includes both large-scale hydraulic structures (e.g., dams, reservoirs, diversion weirs) and distribution networks (e.g., canals, pipelines, control gates), as well as on-farm irrigation technologies (e.g., drip, sprinkler, or surface irrigation systems).

Dimension 3: Spatial organization. This aspect relates to the internal spatial configuration of plots and the different areas within the perimeter. It also emphasizes the interactions between irrigation systems and the broader landscape, including land use patterns, agricultural and livestock practices, rural development dynamics, and ecosystem functions.

Dimension 4: Support and capacity building. It refers to the set of institutional, technical, and human processes that aim to strengthen stakeholders' capacities to effectively manage, operate, and adapt irrigation systems. It encompasses advisory services, technical experimentations, knowledge transfer, training, technical assistance, and facilitation mechanisms provided to farmers, farmers organisations, water user associations, and other actors.

Dimension 5: Agro-economic strategy. This dimension examines the interactions between agricultural production, economic performance, and institutional-economic arrangements that shape farmers' decisions. It extends beyond farm-level production to include the influence of agricultural value chains (e.g., processors, cooperatives, distributors), public policies (e.g. subsidies, pricing), and market structures that structure demand and influence production choices.

Dimension 6: Organization and maintenance. It refers to the structures, arrangements, and coordination mechanisms through which actors involved in irrigation collectively organize the operation, management, and use of water resources and infrastructure. It focuses on how responsibilities, roles, and interactions are structured among stakeholders at different levels.

Dimension 7: Territorial integration. This dimension refers to the relationship between the irrigated scheme and the territory in which it is embedded. It encompasses the relationships between irrigation and other water uses (e.g., domestic, industrial, environmental flows), as well as the integration of irrigation into regional development strategies.

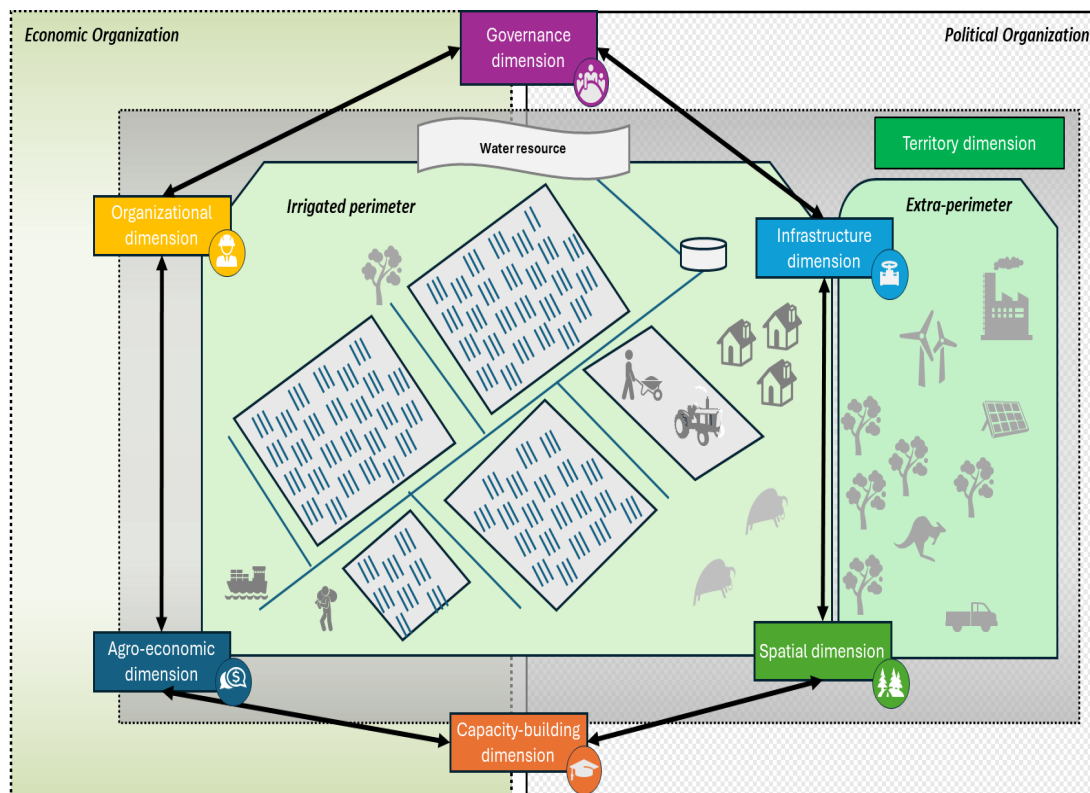


Figure 1. Schematic representation of the seven dimensions of irrigated schemes

Key challenges associated with agroecological redesign of irrigated schemes

The major challenges and objectives associated with the agroecological transition of irrigated schemes encompass water, agri-food, socio-economic, energy, and environmental dimensions. This type of categorization is inspired by the Water–Energy–Food (WEF) Nexus approach, to which economic and environmental considerations have been added. **Table 1** below illustrates the diversity of these challenges, while highlighting the different spatial scales at which they occur.

Table 1: Examples of agroecological issues and success drivers at local, irrigated scheme and territory scales

Agroecological issues	Local scale --> (farm, field)	<-- Irrigated Scheme --> scale	<-- Territory Scale (> irrigated scheme)
Water management	- Enhance water-use efficiency and water productivity at the field scale - Promote flexible access to water resources	- Minimize water losses between abstraction and farm distribution - Design infrastructure according to actual water demand - Deploy a soil and plant sensor network for early warning of water stress risks	- Reduce pressure on water resources under conditions of scarcity - Mitigate conflicts over water use with other stakeholders in the territory - Ensure adequate drainage of excess water
Food supply	- Increase crop productivity and sustainability	- Promote food-oriented production and supply to local markets - Support collective organization among farmers	- Support the organization of supply chains (e.g. storage, commercialization systems, transport infrastructure)
Rural Livelihoods	- Enhance income per crop and per household - Improve access to land resources - Promote the establishment of young farmers	- Reduce poverty among farming households - Improve the association of crop and livestock systems - Promote gender equity and youth inclusion in collective organizations	- Promote the integration of neighbouring communities (e.g. livestock keepers) - Encourage the interactions with agricultural extension and R&D services
Energy supply	- Reduce the use of fossil-based inputs (e.g. mineral fertilizers, diesel) by farmers	- Enhance the integration and use of renewable energy for water pumping - Reduce operational costs and dependency on external energy inputs	- Promote the transfer of renewable energy solutions into irrigated schemes
Environmental protection	- Encourage the adoption of agroecological farming practices (e.g. agroforestry, soil and water conservation, biological pest control...)	- Preserve ecological continuity in the design of the irrigated scheme (e.g. trees, wetlands, etc.) - Implement sustainable canal maintenance practices (e.g. mechanical weed removal)	- Reduce the risk of downstream pollution from irrigated scheme

Presentation of the analytical framework

The analytical framework ultimately consists of a cross-analysis between the seven dimensions of irrigated schemes and the main agroecological transition challenges. **Table 2** below provides an illustration of this framework, highlighting some agroecological redesign options.

Table 2. Analytical framework and examples of agroecological redesign options in collective irrigated schemes

	Governance	Infrastructure design	Spatial organization	Support and capacity-building	Agro-economic paradigm	Organization and maintenance	Territorial integration
Water management		Modernization with pressurized systems to allow the use of drip irrigation systems					Establishment of a resource monitoring center
Food supply			Areas dedicated to crop and livestock associations (e.g. rice and fish).		Subsidies to encourage the purchase of materials suited to agroecological practices.		
Rural Livelihoods				Training programmes to support farmers in adopting agroecological practices			
Energy supply		Use of renewable energies to offset increased carbon emissions and energy requirements					
Environmental protection	Integration of environmental stakeholders into the governance					Sustainable maintenance with mechanically weeding canals).	

3. USE OF THE ANALYTICAL FRAMEWORK IN TWO CASE STUDIES

3.1 Overview of the case studies

3.1.1 DELTA project in Senegal

The DELTA programme operates across 13 municipalities in the Senegal River Valley —eight in the Saint-Louis region (Dagana and Saint-Louis) and five in the Louga region (Louga and Linguère)—with planned expansion toward Podor and Matam. Aligned with Senegal's national agricultural development strategy and the 2021–2025 mandate of SAED, the programme supports territorial planning and rural development through an integrated approach combining land-use management, irrigation development, and value chain strengthening.

DELTA aims to address key structural challenges, including land saturation, limitations in territorial planning, and the need for professionalization of agricultural value chains, while also integrating cross-cutting issues such as climate change, environmental impacts, social inclusion, nutrition, and gender equality. It builds on a long-standing partnership with SAED to enhance institutional resilience and capitalize on previous interventions.

Based on preliminary design studies (APS), the programme focuses on two main investment pillars:

1. the rehabilitation of approximately 2,700 ha of irrigated rice schemes and three village irrigation schemes (PIVs) in Dagana, and
2. the development of around 2,200 ha of new irrigated areas in the Lake Guiers zone, with the objective of sustainably improving agricultural productivity and resource management.

However, the targeted irrigated schemes face significant structural and organizational constraints. Ageing hydraulic infrastructure (levees, drainage networks), largely dating from the 1960s–1980s, requires substantial rehabilitation to restore functionality and ensure long-term sustainability. In addition, collective governance arrangements, primarily involving SAED and farmer organizations (GIEs), combined with flat-rate water pricing, limit the flexibility and efficiency of irrigation practices relative to farmers' needs. Finally, the system is characterized by weak integration between crop and livestock systems and a high dependence on diesel for pumping, increasing vulnerability to energy price volatility and environmental pressures.

3.1.2 Sway Chek project in Cambodia

The Sway Chek River Basin, located at the transboundary interface between Thailand and Cambodia, is subject to significant environmental and hydro-climatic pressures, including deforestation, soil erosion, biodiversity loss, and increasing variability in water availability, characterized by recurrent flooding during the wet season and droughts in the dry season. These constraints are further exacerbated by degraded hydraulic infrastructure and limited integration of governance frameworks across sectors and national boundaries.

In this context, Sway Chek project adopts an integrated water resources management (IWRM) approach, combined with the deployment of nature-based solutions (NbS), to improve rural livelihoods while enhancing the sustainability and resilience of agro-ecosystems.

Main objectives include the rehabilitation of water storage systems, restoration of river ecological connectivity (e.g. fish passages and reforestation), and the implementation of integrated flood risk management strategies. The project also promotes the transition toward sustainable agricultural systems through capacity building of farmer water user communities, the dissemination of agroecological practices, and investments in resilient infrastructure such as solar-powered irrigation systems, storage facilities, and rural access roads.

In parallel, efforts are made to strengthen water governance through the establishment of basin-level coordination mechanisms, the development of integrated management plans, and the use of modelling tools to assess water resources and ecosystem services, complemented by early warning systems. Particular attention is given to climate vulnerability, recognizing the high sensitivity of agricultural systems to hydro-climatic hazards and the need to enhance adaptive capacity through diversification, improved water management, and institutional strengthening.

By combining infrastructure investments, governance reforms, and ecosystem-based approaches, the project seeks to foster a more resilient, inclusive, and ecologically sustainable socio-agricultural system at the basin scale.

3.2 Overview of the reviewed documents

The adopted methodology relies on the analysis of available documentation from the two case studies (**Table 3**) and the identification of agroecological elements aligned with the analytical framework previously detailed.

In the case of Senegal, the availability of multiple project phases enabled the analysis of how agroecological challenges were addressed and evolved over time.

Table 3. List of the reviewed documents for each project

Project	List of the reviewed documents
DELTA project (Senegal)	• Project formulation report • Pre-feasibility and feasibility studies (APS) • Environmental and Social Impact Assessment (ESIA) • Terms of Reference (ToR) and Detailed Design Reports (APD) • Climate change vulnerability assessment
Sway Chek project (Cambodia)	• Baseline study • Full feasibility study report • Gender action plan • Stakeholder engagement plan • Vulnerability to climate change

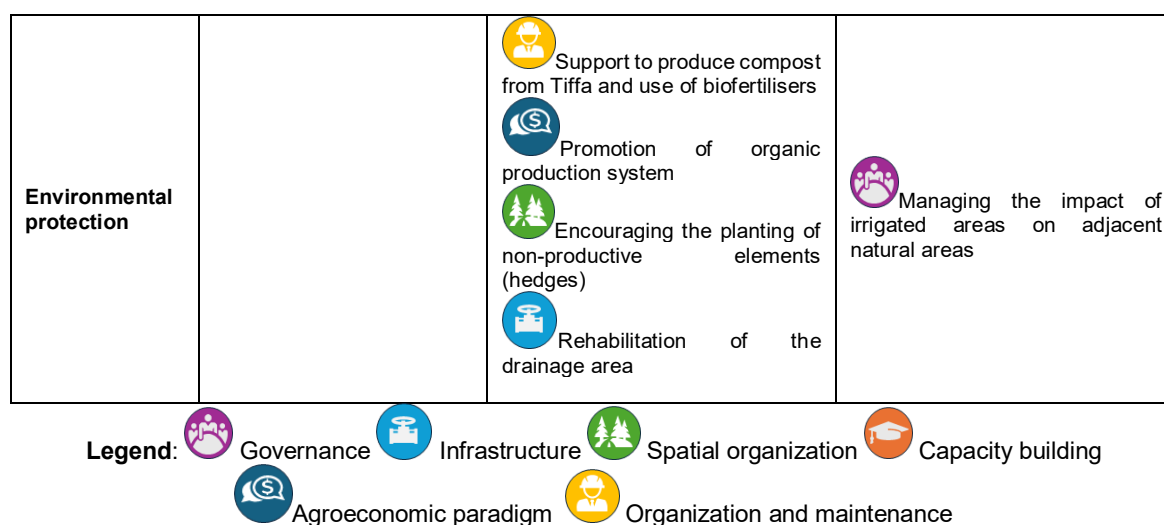
3.3 Key findings from the document analysis

3.3.1 Agroecological assessment of DELTA project

The analysis of the DELTA project documents through the analytical framework revealed the strengths and weaknesses of the project design in agro ecological terms. **Table 4** presents the results of this analysis at different spatial scales, highlighting the proposed actions for each dimension of the irrigated schemes.

Table 4. Inventory of proposed actions in DELTA project documents and cross-checking with the analytical framework criteria

Agroecological issues	Local scale --> (farm, parcel)	<-- Irrigated Scheme --> scale	<-- Territory Scale (> irrigated scheme)
Water management	 Field-scale irrigation mode adapted to local pedo-climatic conditions	 Improvements to drainage and earthworks on the plots  Lining of canal  Weeding the non-lining canal and ridges  Availability of a weather station for appropriate climate monitoring	 Establishment of a resource monitoring center
Food supply	 Capacity building of farmers	 Promoting interaction between the irrigation system and livestock farming  Certified seed producer	 Development of local initiatives such as DYTAEL (Dynamique pour la Transition Agroécologique Locale)  Improvement of roads and tracks  Existence of advisory bodies and research center in agroecology (ISRA)
Rural Livelihoods		 Renovation (or design) that considers non-agricultural uses of infrastructure  Promoting of areas designated for women and young people  Gender representation in the governing bodies of the group  Rules/allowances for livestock farmers and other users/Existence of a dispute resolution body  Availability of a demonstration plot, educational farm, or pilot farm	 Encourage women and young people to participate in training programs  Promotion of activities aimed at women and young people  Development of downstream production sectors to promote value-added processing
Energy supply		 Promotion and used Solar-powered water pumping systems	



The cross-analysis of DELTA project documents against the agroecological assessment framework shows that agroecological considerations are incorporated to varying degrees across different scales, with a strong emphasis on water management, infrastructure development, and capacity building:

- Strong focus on water management, with actions including improved irrigation and drainage systems, canal rehabilitation, weather stations, and resource monitoring tools to enhance water-use efficiency and climate resilience.
- Support for sustainable agricultural production, through farmer training, seed production initiatives, crop–livestock integration, and local agroecological initiatives such as DYTAE.
- Attention to rural livelihoods and inclusion, with measures promoting the participation of women and youth, conflict-resolution mechanisms, demonstration farms, and the development of value-added agricultural value chains.
- Environmental and energy considerations are addressed through solar-powered irrigation, compost production from *Typha*, biofertilisers, organic farming promotion, hedge planting, and the management of impacts on surrounding ecosystems.

Overall, the DELTA project incorporates several agroecological principles, particularly regarding natural resource management, capacity building, and governance. However, it remains primarily focused on irrigation infrastructure and productivity improvements, while more transformative agroecological dimensions such as biodiversity enhancement and farming system diversification are less explicitly addressed.

3.3.2 Agroecological assessment of Svay Chek project

The same analysis was performed for Svay Chek project documents. **Table 5** presents the results of this analysis at different spatial scales, highlighting the proposed actions for each dimension of the irrigated schemes.

Table 5. Inventory of proposed actions in Svay Chek project documents and cross-checking with the analytical framework criteria

Agroecological issues	Local scale --> (farm, parcel)	<-- Irrigated Scheme --> scale	<-- Territory Scale (> irrigated scheme)
Water management		 Upgrading of network infrastructure, canal regulation and drainage  Capacity strengthening of Water User Associations (WUAs)  Strengthening the operation and maintenance (O&M) of hydraulic structures	 Strengthening of the Watershed Management Committee and development of a risk prevention plan  Enhanced coordination with Thailand
Food supply	 Capacity building of farmers	 Lotus cultivation in reservoirs  Promotion of vegetable cultivation in raised areas  Improvement of roads and tracks	 Establishment of modern cooperatives  Strengthening agricultural strategies across 15 municipalities  Promotion of off-soil activities (beekeeping, mushroom cultivation)
Rural Livelihoods	 Promotion of crop insurance		 Promotion of gender equity and youth inclusion in agriculture
Energy supply		 Carbon footprint analysis of the project  Solar-powered water pumping systems for high-elevation areas  Promotion of subsidies for solar-powered pumps	
Environmental protection	 Support for on-farm waste recycling	 Bank stabilization and revegetation  Implementation of an agricultural input management plan  Training of 15 municipal staff in agroecology	 Establishment of flow allocation rules  Protection of buffer zones  Removal of in-stream obstacles

Legend:  Governance  Infrastructure  Spatial organization  Capacity building
 Agroeconomic paradigm  Organization and maintenance

The analysis of this cross-referenced information highlights the following key aspects:

- The irrigation scheme and territorial scales are particularly well addressed in the analyzed documents, whereas the local scale of the plot or farm is treated more superficially;
- The most prominently addressed dimensions are governance (6 actions), stakeholder support (6 actions), infrastructure (4 actions) and spatial organization (4 actions), whereas the agro-economic (2 actions) and organizational (1 action) dimensions are comparatively less represented.
- The most prioritized agroecological issues identified through the analysis include water management (5 actions), food systems (7 actions), and environmental protection (7 actions), whereas energy-related issues (3 actions) and livelihood improvement (2 actions) appear to be of lower priority in this development project.

DISCUSSION AND CONCLUSION

Strengths and limitations of the analytical framework

The application of this analytical framework to two case studies highlighted its usefulness in identifying gaps or, conversely, the prominence of certain agroecological issues. This analytical framework can cover at least four main uses for the design or rehabilitation of irrigated schemes:

- Scoping and formulation: it can facilitate the project design by identifying the key elements to be considered from the initial stages;
- Diagnosis: it can be used to assess the initial state of an irrigated scheme and the main agroecological challenges
- Techno-economic sizing: it allows the project to be aligned with technical and financial realities, and helps define intervention priorities.
- Monitoring and evaluation: it supports the project over time by measuring progress and assessing results before and after implementation.
- In summary, the framework is a cross-cutting tool that can be used to design, assess, size, and monitor irrigation and agroecological projects.
- However, some limitations were identified during the use of the analytical framework:
- The high number of dimensions and agroecological issues, that may not always fit with the nature and context of the project.
- The ambiguity of certain indicators (e.g., canal lining, which enhances efficiency but negatively affects environmental outcomes and groundwater recharge).
- In the case of an ongoing project, assessing the level of completion of the framework is challenging: whether it should be evaluated based on the initial objectives (project design phase) or on tangible results.

This analytical approach can be viewed as complementary to the multicriteria evaluations already used in project and scenario assessments. It should also be noted that project owners and consulting firms are themselves constrained by several factors: i) agroecology principles are often cited in design and rehabilitation studies but they rarely cover all the dimensions mentioned above, ii) infrastructure choices towards a greater flexibility are highly limited by various factors (e.g. availability of water resources, budget constraints...), which leave little room for technical innovation, and iii) the proposed changes are multifaceted and therefore require more time for concertation and adaptation.

Perspectives

This analytical framework was developed as part of the COSTEA 3 initiative on the agroecological re-engineering of irrigated schemes. Beyond its ex-post application to already completed studies, COSTEA members intend to use this approach in new pilot schemes to define agroecological transformation and adaptation options for hydraulic infrastructure, productive areas and collective management arrangements.

In this regard, a study is currently underway, led by BRLi and SCP with the support of CIRAD, to define the most appropriate agroecological re-engineering options in several irrigation schemes in Senegal and Cambodia. A side event will be organized on this topic at the ICID conference.

REFERENCES

- FAO. 2020. The State of Food and Agriculture 2020. Overcoming water challenges in agriculture. Rome. <https://doi.org/10.4060/cb1447en>
- Gliessman, S. (2018). Defining agroecology. *Agroecology and sustainable food systems*, 42(6), 599-600.
- Gollin, D., Hansen, C. W., Wingender, A. M. (2021). Two blades of grass: The impact of the green revolution. *Journal of Political Economy*, 129(8), 2344-2384.
- Leauthaud, C., Ameer, F., & Leenhardt, D. (2025). Irrigation and agroecology: a scientific mismatch? A literature review. *Agroecology and Sustainable Food Systems*, 1-28.
- Levrard, L., Mathieu, B., Masse, P., Berton, S., Blanchart, E., et al. (2019). Mémento pour l'évaluation de l'agroécologie : méthodes pour évaluer ses effets et les conditions de son développement. GTAE-GRET, 131 p.
- Roesch K, Scopel E, Scholle J, Ducrot R, Leauthaud, C. 2022. Action Structurante COSTEA « Transitions Agroécologiques en périmètres irrigués », Rapport final de synthèse et de recommandations. 16 p.

INTRODUCTION IN THE CONTEXT OF IRRIGATION IN THE HUNGARY

Attila Nagy¹, Andrea Szabó¹, Éva Nikolett Kiss¹, and István Szamosvári²

The role of irrigation in Hungary is increasingly becoming a strategic issue, as agriculture is simultaneously facing more frequent summer droughts, higher evaporation losses, and an increasingly unpredictable water supply. This is particularly true for the Great Hungarian Plain and the Danube–Tisza Interfluvium, where drought is no longer a temporary problem but a persistent process. According to 2022 data, the area legally permitted for irrigation in Hungary was 211.21 thousand hectares, of which only 141.6 thousand hectares were actually irrigated. Agricultural water use amounted to 0.55 km³, and sprinkler irrigation systems continued to dominate among the applied technologies, although site-specific and more water-saving solutions are gaining increasing importance (Demeter, 2022) (Figure 1).

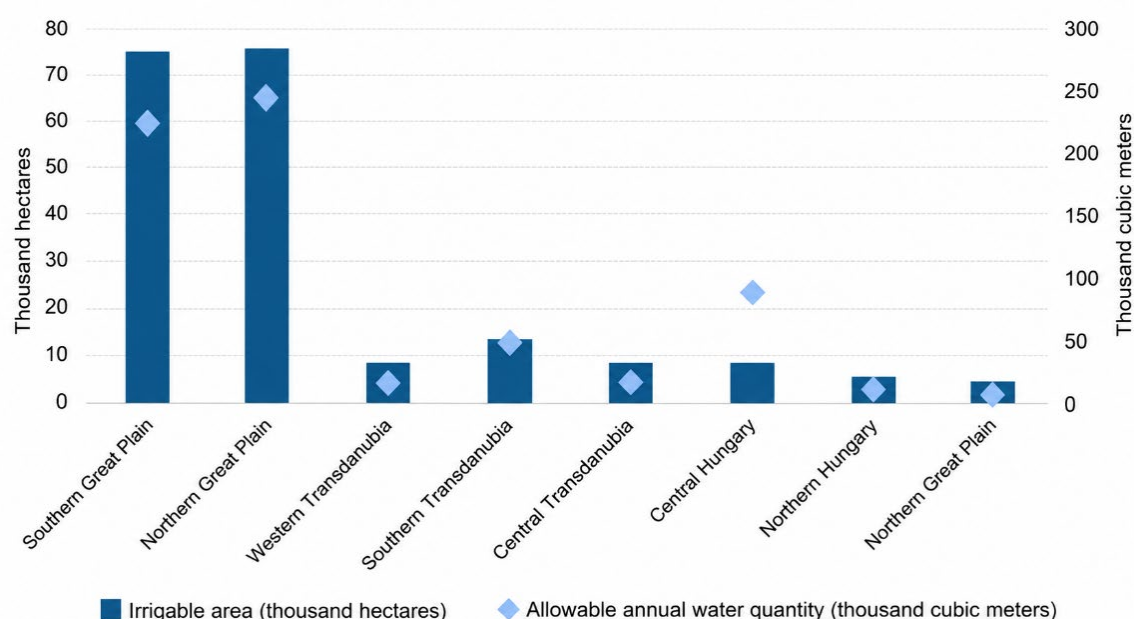


Figure 1: Data on water rights permits by region 2022 (Demeter, 2022)

In recent years, the regulatory environment has also changed substantially. In addition to the general principles of water management, Act CXIII of 2019 introduced a new framework for irrigation development, including irrigation development areas, various planning instruments and district-level systems, irrigation easements, as well as organisational forms based on cooperation. After 2023, the former irrigation communities were transformed into sustainable water management communities. Despite these changes, it is still evident that although a significant share of the technical capacity is available, the area actually irrigated remains considerably smaller. This indicates that the limitations are not only technical in nature: the availability of water resources, the organisational background, financing, and the lack of professional knowledge also play an important role. The severity of the 2022 drought is clearly illustrated by the fact that it caused approximately HUF 1,000 billion in damage to Hungarian agriculture. In 2024, according to Reuters reports (Fenyő and Komuves, 2024; Fenyő and Than, 2024),

¹ University of Debrecen Faculty of Agricultural and Food Sciences and Environmental Management Institute of Water and Environmental Management 138. Böszörményi str. Debrecen 4032, Hungary, e-mail: attilanagy@agr.unideb.hu

² General Directorate of Water Management, Department of Water Management and Irrigation 1012 Budapest, Márvány u. 1/D. Hungary, szamosvari.istvan@ovf.hu

more than 80% of the country was affected by moderate or severe drought, and the summer dry period caused crop losses on approximately 390 thousand hectares. By 2025, the situation in the Danube–Tisza Interfluvium remained critical, mainly due to the persistent decline in soil moisture and shallow water resources. All this indicates that, in the future, irrigation will not simply mean capacity expansion, but a much more complex adaptation task: water retention, reliable supply, regional-level coordination, digital metering, and environmental constraints will all become increasingly important (Magyar Mezőgazdaság, 2026).

Ultimately, irrigation in Hungary is not only an agricultural issue, but also a matter of climate adaptation and water management. The total area of the country is 9.303 million hectares, of which 4.30471 million hectares were used for agricultural cultivation in 2022. The average annual precipitation is 589 mm, while the total renewable water resource is 104 km³ per year, the vast majority of which — 94.23% — originates from external sources. At first glance, this might suggest that the country is rich in water resources; however, in reality, the temporal and spatial distribution of agricultural water supply is highly vulnerable (Figure 2).

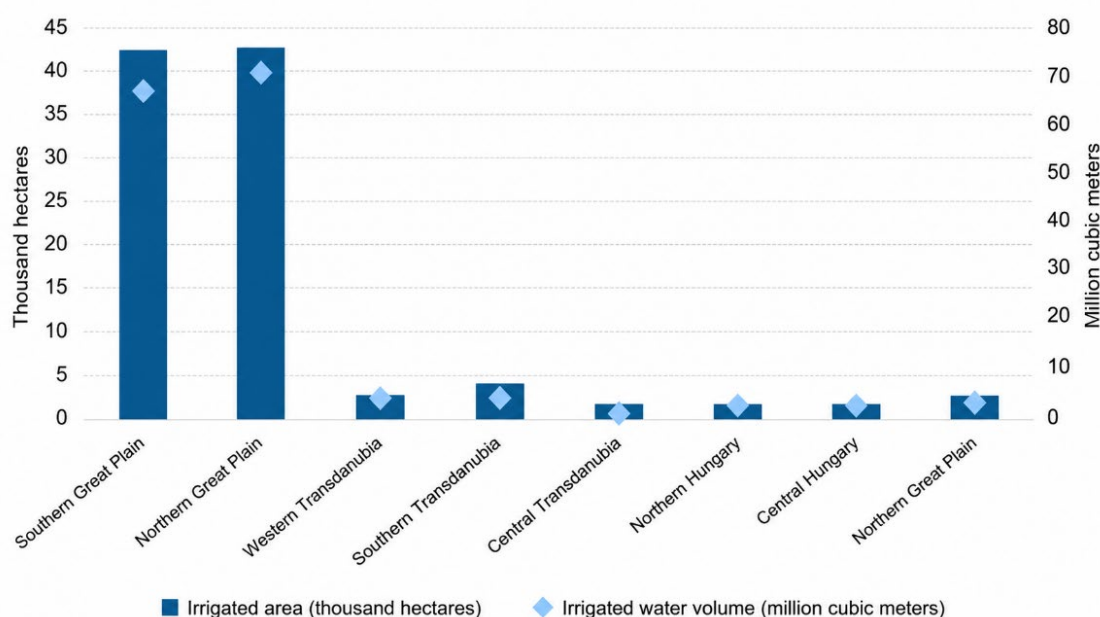


Figure 2: Irrigated area and volume of water applied by region 2022 (DEMETER., 2022)

The role of irrigation, therefore, is not to “solve” national water scarcity, but rather to reduce production risks, stabilise yields, and maintain the competitiveness of higher-value crops. The Great Hungarian Plain and the Danube–Tisza Interfluvium clearly demonstrate that declining precipitation, summer heat stress, and falling groundwater levels are no longer exceptional events, but long-term structural challenges. For this reason, irrigation should not be assessed merely in terms of the number of irrigated hectares, but as part of a complex water service and regional adaptation system. Developments can only be considered truly successful if they involve not only the expansion of infrastructure, but also the strengthening of water retention, the integration of ecological considerations, reliable operation, and the effective access of farmers to these services. This perspective is also well aligned with the FAO–ICID approach to irrigation revitalization and modernization, which emphasises reliable water service delivery, improved system performance, and adaptation to changing climatic and production conditions.

IRRIGATION SYSTEM PERFORMANCE

Based on the most recent internationally harmonised data, the area equipped for irrigation in Hungary was 226.91 thousand hectares in 2022, representing approximately 5.27% of the total cultivated area. Of this, 141.6 thousand hectares were actually irrigated, meaning that only about 62.4% of the installed capacity was used in practice. In the same year, agricultural water use amounted to 0.55 km³, accounting for roughly one tenth of the country's total water abstraction. From these data, a simplified national average can also be calculated: when related to the actually irrigated area, irrigation water use was approximately in the order of 4.1 thousand m³ per hectare in 2022. However, this should not be interpreted as a technological efficiency indicator, but rather as a highly aggregated national-level estimate.

The technological structure shows that irrigation in Hungary is no longer uniform, but operates as a mixed system. Of the approximately 214 thousand hectares covered by controlled irrigation in 2022, around 138 thousand hectares were equipped with sprinkler systems, 68 thousand hectares with localised, or micro-irrigation, solutions, and approximately 8 thousand hectares with surface irrigation. This clearly indicates that the simpler gravity-based or surface irrigation systems that were previously more common have declined in importance and are gradually being replaced by a more modern, intensive, and water-saving technological mix. Sprinkler systems continue to dominate in arable crop production, while precision-based, localised solutions are becoming increasingly important in horticulture and plantation sectors (Figure 3).

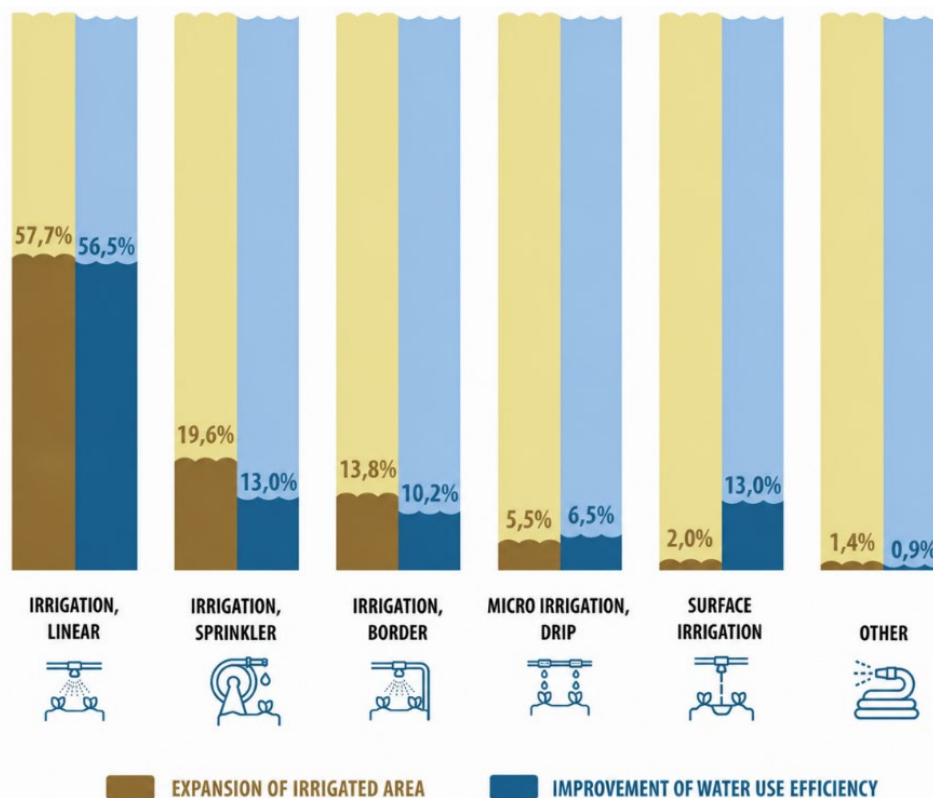


Figure 3: Distribution of irrigated areas and water volume by irrigation method (DEMETER., 2022)

At the same time, comparability is an important issue when interpreting the data. For example, based on earlier data submitted by the National Directorate General for Water Management (OVF) to the Hungarian Central Statistical Office (KSH), the area with water rights permits in 2014 was reported as 222.75 thousand hectares, while the actually irrigated area was 130.4 thousand hectares, which differs

considerably from the harmonised values for 2022. This difference most likely does not indicate a real decline or increase, but rather results from methodological differences, changes in definitions, or the harmonisation of data collection. Therefore, when interpreting long-term trends, it is advisable to rely on a single time series, preferably a national one based on KSH data, while FAO data should rather be treated as a background source for international comparison (KSH).

At the system level, the main lesson remains that there is a considerable gap between the irrigation infrastructure already in place and the capacity actually used. This “underutilisation gap” indicates that the operation of irrigation cannot be treated merely as a technical issue. Actual performance is influenced simultaneously by water availability, energy and operating costs, the organisational background, the return on investments, and farmers’ practical knowledge and adaptive capacity. It is therefore no coincidence that the ICID–FAO approach also emphasises the joint assessment of service quality, reliability, equity, and productivity.

CHALLENGES AND RISKS ASSOCIATED WITH IRRIGATION SYSTEM IN THE COUNTRY

Hungarian agriculture is increasingly exposed to weather extremes, particularly frequent droughts and the uneven distribution of precipitation. The development of irrigation systems is therefore of key importance; however, it also involves several challenges and risks.

One of the most important problems is the limited and uneven availability of water resources. In some regions, the pressure on both surface water and groundwater resources is significant, raising long-term sustainability concerns. In addition, drainage and irrigation infrastructure is outdated in many areas, leading to efficiency losses and high maintenance costs (Figure 4, Figure 5).

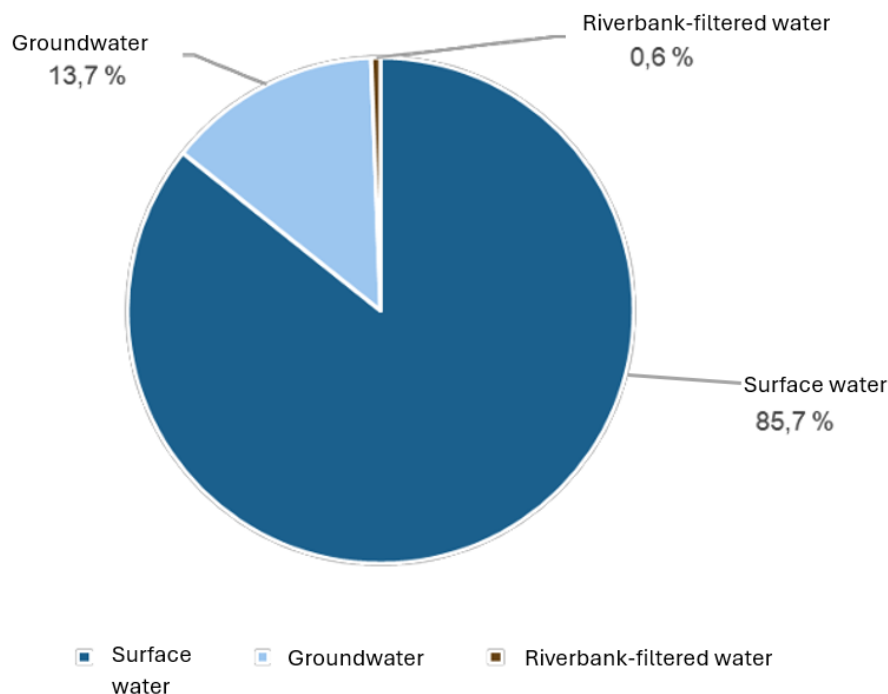


Figure 4: Percentage of irrigated area by source of irrigation water 2022 (DEMETER,, 2022)

SURFACE WATER IRRIGATION OPPORTUNITIES (VGT3)

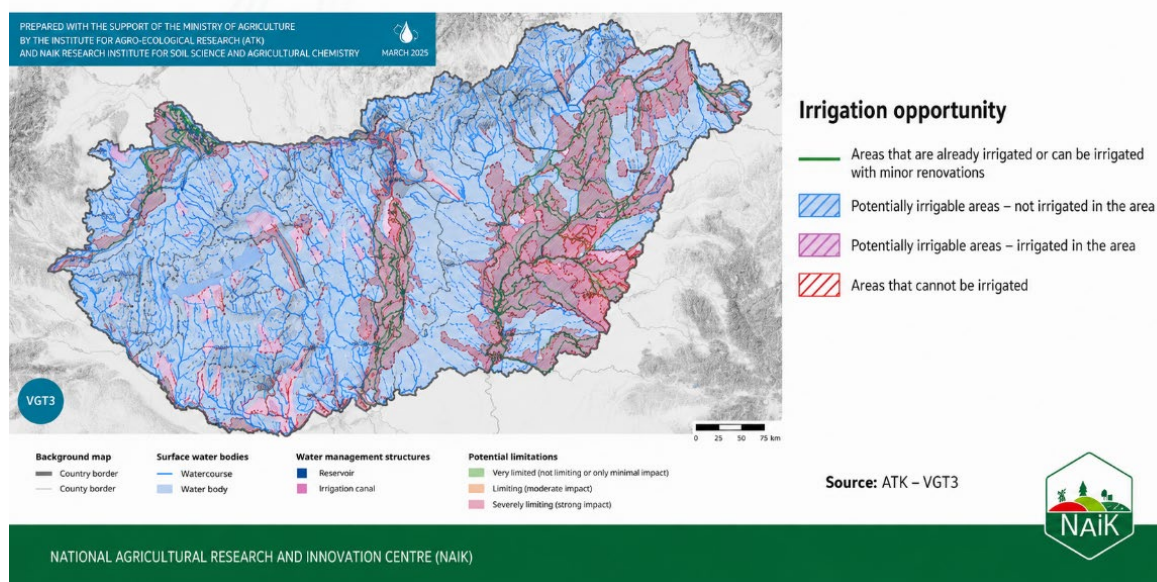


Figure 5: Surface water irrigation opportunities (VGT3) (OVF-VGT3 and Gabriella Tasnádi presentation)

A further challenge is the energy demand associated with irrigation, as well as the high cost of investments, which may represent a particular barrier for smaller farms. The impacts of climate change — increasingly extreme and frequent heatwaves — further increase irrigation demand, while the pressure on water resources also intensifies.

Another risk is that poorly planned or excessive irrigation may lead to soil degradation, salinisation, and a decline in the quality of agricultural land. In addition, regulatory and water allocation issues may also cause conflicts among agricultural, industrial, and residential water users (Lakatos, 2020; Tóth, 2021). Overall, the development of irrigation systems in Hungary is essential for the stability of agricultural production; however, it can only be successful in the long term if combined with sustainable water management and modern technological solutions.

MODERNISATION PATHWAYS

The future of irrigation in Hungary can increasingly no longer be treated merely as a question of “more irrigation equipment”. The focus is shifting much more towards how well the existing system functions, how predictable it is, and how capable it is of adapting to increasingly extreme weather conditions. Accordingly, the first and most obvious direction of modernisation is not the rapid expansion of new capacities, but the better utilisation of the infrastructure already in place. At present, actual irrigation takes place on only approximately 58.67% of the equipped areas, which in itself indicates that significant reserves lie not in development alone, but in operational efficiency. This includes improving access to water, managing energy and operating costs, strengthening organisational operation, and improving the maintenance background.

The second important direction is technological renewal. The structure of irrigation in Hungary already shows a mixed pattern: sprinkler and localised systems are jointly dominant, providing a good basis for the wider adoption of more precise, data-driven solutions. Legislative changes in recent years have also pointed in this direction, for example through the introduction of digital well water meters. The next stage of development can build on this, where irrigation is no longer operated according to a fixed schedule, but on the basis of real-time data: soil moisture sensing, remote monitoring, and parcel-level decision-support systems can assist farm management (Nagy et al. 2025). Particular attention should be given

to the wider adoption of Variable Rate Irrigation (VRI), which enables irrigation depth to be adjusted according to within-field variability in soil properties, crop water demand, and topographic conditions. By applying water only where and when it is needed, VRI can improve water-use efficiency (Szabó et al. 2023), reduce energy consumption and nutrient leaching, minimise environmental impacts, and contribute to more stable crop yields under increasingly variable climatic conditions. Overall, this points towards a much more finely regulated, “precision” irrigation practice (Radics, 2022).

The third direction is the reconsideration of water resource management. The regulatory environment increasingly encourages water to be interpreted not only from the perspective of abstraction, but also from the perspective of retention and storage. Legislation already treats the retention of excess water and its use during dry periods as separate issues, which essentially indicates that the future will not be about continuous water abstraction, but about seasonally stored and targeted water use. In this logic, the modernisation of irrigation does not simply mean “using more water”, but rather distributing and timing water use more intelligently.

Using reclaimed water in irrigation has a significant potential. In Europe, the agricultural reuse of reclaimed water is regulated by Regulation (EU) 2020/741 on minimum requirements for water reuse, which entered into force on 26 June 2020 and has been applicable since 26 June 2023. The direct agricultural use of raw, untreated domestic wastewater cannot be considered safe. Regulation (EU) 2020/741 establishes the minimum quality requirements for water reuse in agricultural irrigation, including reclaimed water quality classes (A–D), monitoring requirements, and the mandatory implementation of a Water Reuse Risk Management Plan. Furthermore, the Regulation explicitly requires that, where appropriate, risk assessments extend beyond microbiological parameters to include heavy metals, pesticides, disinfection by-products, pharmaceutical residues, contaminants of emerging concern, microplastics, and antimicrobial resistance. Consequently, the use of reclaimed wastewater for irrigation is permitted only within a strictly regulated, risk-managed, and authorised framework for specific agricultural applications. The amount of waste water produced annually is 0.595 km³, which equals to the agricultural water use in Hungary, which, following appropriate treatment, has the potential to become a strategic irrigation water resource at the national level. Especially where surface water bodies are scarce and not available.

There are good examples already in Hungary where alternative water resources are used for irrigation, applying VRI. At the site there is no available surface water at the case study site, alternative water resources are used. The basis of the alternative water resources are

- excess water ,
- treated wastewater,
- fermentation sludge

which are collected in a water reservoir with 114000 m³ capacity (Figure 6).

The water is irrigated by a lateral moving variable rate irrigation (VRI) system, which can work in pivoting mode as well at the end of the field (Nagy et al., 2021).

The fourth direction is the strengthening of nature-based solutions and landscape-level water management. An increasing number of examples show that, alongside conventional engineering solutions, rewetting the landscape, retaining water within the area, and improving the microclimate may also play a role. In the Danube–Tisza Interfluve, for example, local initiatives have emerged that aim to improve groundwater conditions and the water balance through the use of thermal waters and shallow inundation. These solutions do not replace irrigation, but complement it, and highlight that in regions affected by increasing drought, water management is no longer only a matter of infrastructure, but also of landscape shaping (Qadir, 2018; Tóth, 2021; Bogárdi, 2023).

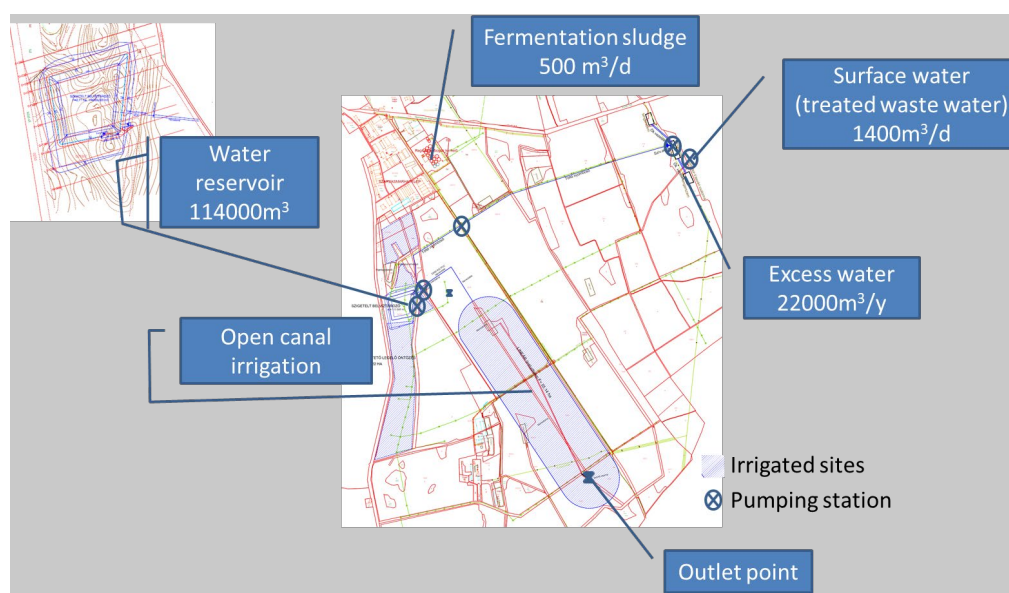


Figure 6. Alternative water resource management at the case study site

GOVERNANCE AND INSTITUTIONS

The institutional framework of irrigation in Hungary is fundamentally defined by Act LVII of 1995 on Water Management. This legislation interprets state responsibilities related to water in a relatively broad sense: these include the formulation of national water management directions, the operation of regulatory and administrative tasks, the management of state-owned water infrastructure, hydrological monitoring, the quantitative and qualitative registration of water resources, and river basin-level planning. Within this framework, irrigation does not appear as an independent agricultural policy field, but rather as one element of the overall water management system.

This is complemented by Act CXIII of 2019, which focuses specifically on irrigation and strengthens the logic of development and spatial planning. This regulation established the role of the irrigation administration body, introduced the system of irrigation development areas and plans, and regulated the issues of irrigation easements and connection to tertiary infrastructure. It also prescribed district-level planning in cases where no approved development plan exists, or where a deviation from such a plan is intended. All this clearly shows that the legislator embedded the expansion of irrigation into a strongly area- and environment-based planning system.

Community-based cooperation is also an important pillar of the system. After 2023, the previously recognised irrigation communities were gradually replaced by sustainable water management communities. These are recognised, registered, and supervised by the agricultural administration, while the designation of irrigation districts is also carried out centrally, under ministerial authority, based on professional proposals. In practice, these communities can function effectively only if they represent not merely a legal form, but also real cooperation: joint operation, maintenance, data sharing, and coordinated water-use interests.

The institutional system is also increasingly moving towards a data-driven direction. Legislation allows water management bodies to transfer technical data and, in certain cases, land parcel and ownership information to irrigation administration bodies, agricultural research institutes, and professional chambers. This may provide an important basis for a future unified performance assessment system, in which not only the extent of irrigation matters, but also the associated water-use efficiency, crop performance, and environmental impacts (Magyar Mezőgazdaság, 2025).

FINANCING

The financing of irrigation in Hungary is fundamentally based on three interconnected pillars. The first is the tariff system for water services. Under the current regulation, agricultural water users pay a fee for the service, consisting of a basic fee and a variable fee adjusted to the actual volume of water used. At the same time, the legislation also allows the state to partially or fully cover the water service costs of certain agricultural water uses, particularly irrigation, rice production, and fish farming. This indicates that the regulation does not place the costs exclusively on users, but treats irrigation as an activity of strategic importance.

The second element of financing is the system of allowances related to the water resource fee. In several cases, the law exempts agricultural producers from paying this charge. Up to a certain quantitative threshold, no water resource fee is payable for irrigation water use; in addition, allowances may also be applied during periods of persistent water scarcity and when water resources originating from the retention and storage of late-winter excess waters are utilised. These measures not only reduce producers' costs, but also encourage water retention and adaptation to climate change.

The third financing element is related to the maintenance and development of irrigation infrastructure. The Irrigation Act allows the state to take over the management of tertiary water infrastructure owned by municipalities. The irrigation administration body acting on behalf of the state may operate these facilities itself, or may transfer their operation to other organisations. The aim of this regulation is to ensure that the burdens of infrastructure operation do not arise exclusively at the local level, but that a more coordinated and flexible system can be established at the national level (Ruttkay, 1998; Illés, 2001; Nagy, 2018; Burja et al., 2020).

With regard to the financing system, the main issue today is no longer primarily the existence of legal frameworks, but rather their long-term sustainability. A comprehensive assessment of the topic would also require a detailed examination of the CAP and national support programmes for the 2024–2026 period, the payments made by the Hungarian State Treasury, and the actual investment resources. Since programme-level verification of these elements could not be carried out directly in all cases, the financing section in its present form primarily presents the legal and institutional frameworks, while a full assessment of the financial programmes requires further research.

CAPACITY DEVELOPMENT

In professional and policy debates on the development of irrigation in Hungary, technical investments often come to the forefront, while the importance of capacity development is frequently pushed into the background. However, international experience shows that the construction of infrastructure alone is not sufficient for the successful operation of modern irrigation systems. An appropriate institutional background, the professional preparedness of farmers, and the use of digital and decision-support tools that enable the efficient use of water resources are equally important. In the Hungarian context, this is particularly necessary, as the gap between installed irrigation capacities and actually irrigated areas indicates that investments have not always been accompanied by adequate operational, organisational, and knowledge-based development (Zhu et al., 2019).

At the same time, the national regulatory framework already contains elements that point towards knowledge sharing and data-based decision-making. The Irrigation Act adopted in 2019 creates opportunities for cooperation and data exchange between the irrigation administration body, agricultural research institutions, and the Hungarian Chamber of Agriculture. This provides a basis for linking research results, water management information, and farmer advisory services more closely. The next step, however, could be the development of a transparent and performance-oriented knowledge system from the collected data, capable of simultaneously assessing irrigation intensity, water-use efficiency, energy demand, crop performance, soil condition, and environmental risks (Csizmadia, 2018).

For farmers, practical knowledge required for the efficient operation of irrigation systems is expected to become increasingly important in the future. This includes, for example, the use of water meters and digital registration systems, the timing of irrigation based on soil moisture and meteorological data, as well as knowledge related to the maintenance, pressure regulation, and filtration of equipment. In addition, understanding the different water requirements of various crops is also becoming increasingly important. At the institutional level, strengthening cooperation between water management and agricultural professional actors is similarly decisive. The long-term success of irrigation in Hungary is determined not only by the available water resources or the condition of infrastructure, but also by the extent to which water management, land use, production, nature conservation, and energy-related considerations can be integrated into a common planning and decision-making system (Albert and Dávid, 2023).

LESSONS LEARNED AND RECOMMENDATIONS

The experience of recent years has clearly shown that the development of irrigation in Hungary cannot be reduced to the construction of new wells or the installation of more modern irrigation equipment. The agricultural losses caused by the severe drought of 2022, the recurrence of nationwide water scarcity in 2024, and the persistent water supply problems of the Danube–Tisza Interfluve indicate that irrigation is a far more complex issue than can be addressed simply by increasing water abstraction. Water retention, reliable water service delivery, and landscape-scale adaptation are, in fact, different dimensions of the same challenge. Accordingly, future irrigation strategy should not focus on maximising water abstraction, but rather on an approach that equally considers retaining water locally, ensuring predictable service delivery, applying water precisely, and maintaining environmental sustainability (MACROMETO.HU). The need for water retention has been present in the water management administration for many years, and earlier practices, such as the unconditional drainage of excess inland water, were already discontinued in 2020. However, the extreme weather events caused by climate change in recent years have presented the sector with numerous challenges that still need to be addressed.

In light of the above, the “Water into the Landscape!” programme was launched in February 2025. Within this programme, 8.6 million m³ of water was retained on the offered areas in 2025. In addition, during the autumn–winter period of 2025/26, the water directorates operated their channels according to a new operational regime. Water control structures were kept closed in order to support water retention, and the majority of irrigation systems also remained 50–100% filled during this period.

The regulatory background of irrigation has developed more rapidly in recent years than the measurability of system performance. The current legal framework is significantly more complex and modern than it was a decade ago: irrigation development areas, environmental planning instruments, community-based cooperation forms, differentiated fee and contribution rules, and requirements related to digital metering have all been introduced. For this reason, the revision of the regulatory environment is still ongoing. By contrast, data describing the actual operation of irrigation are still not always consistent or easily accessible. The differing results of various statistical and administrative databases suggest that the monitoring of irrigation performance cannot yet be considered fully mature. Therefore, in future analyses, it is advisable to clearly distinguish between areas equipped for irrigation, areas with water rights permits, actually irrigated areas, and areas determined on the basis of actual water use (OVF.HU).

The third important conclusion is that the social and economic impacts of irrigation development do not appear equally across different types of farms. The introduction of modern technologies is expected to be rapid and successful primarily in holdings that have sufficient capital strength and are engaged in higher value-added or horticultural production. For smaller farms, however, the cost of adaptation may often remain a significant barrier. For them, shared infrastructure, water management cooperation, and targeted professional support may play a particularly important role. Policy interventions can therefore be truly effective if they focus not only on supporting investments, but also on improving access to services and long-term operational capacities (AGRÁRIUM7.HU).

Based on the results of the study, several development directions can be identified that may become decisive in the coming years. First, it is necessary to establish a unified national data platform capable of managing, within a single system, information on irrigated areas, the volume of water used, water sources, applied technologies, and environmental constraints. In addition, the retention of late-winter excess waters and the expansion of storage capacities deserve particular attention, as these may form one of the most important foundations of future water security. It is also justified to improve the energy and water efficiency of existing irrigation systems and to accelerate the spread of localised irrigation technologies and digital decision-support systems in horticultural regions. Strengthening sustainable water management communities is likewise an important task, particularly in the fields of operation and data provision. In addition to all these aspects, environmental considerations such as the protection of groundwater resources, the preservation of soil condition, water quality, and the interests of Natura 2000 areas must be taken into account with the same weight as irrigation development objectives.

REFERENCES

- Act LVII of 1995 on Water Management.
Act CXIII of 2019 on Irrigation Management.
Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse. EUR-Lex.
AGRÁRIUM7.HU. Irrigation development is not just an economic issue.(Nem csak gazdasági kérdés az öntözésfejlesztés). Available at: <https://agrarium7.hu/cikkek/2324-nem-csak-gazdasagi-kerdes-az-ontozesfejlesztes>
Albert, F., & Dávid, B. (2023). Interpersonal relationships in Hungary – an overview. *Metszetek*, 7(2). <https://doi.org/10.18392/metsz/2018/2/6>
Bogárdi, J. J. (2023). More than 50 Years of Water Management and Mismanagement: Lessons from Major International River Basins (50+ év vízgazdálkodása és vízgarázdálkodása, nemzetközi nagy folyók példán). *Hidrológiai Közöny*, 103(3), 4–20. <https://doi.org/10.59258/hk.12330>
Burja, V., Tamas-Szora, A., & Dobra, I. B. (2020). Land concentration, land grabbing and sustainable development of agriculture in Romania. *Sustainability*, 12(5), 2137. <https://doi.org/10.3390/su12052137>
Csizmadia, E. (2018). Time Perspective and Political Science: Alternating Governance Cycles Between Present-Centered and Historical Approaches (Időszemlélet és politikatudomány. Váltógazdálkodási ciklusok a jelen-centrikus és a történelmi szemléletmód között.) *Metszetek*. 7(2): 94-130 <https://doi.org/10.59258/hk.12330>
Demeter, E. (2023). Statistical Reports. Irrigation Report (Statistikai jelentések. Öntözésjelentés). 2022. év. XXVI. évfolyam, 1. szám. Agrárközgazdasági Intézet, Budapest. ISSN 1418-2130. Available at: <https://www.aki.gov.hu/termek/ontozesjelent-es-2022-ev/>
FAO & ICID. (2013). *Irrigation revitalization in the Asia-Pacific region*. Food and Agriculture Organization of the United Nations and International Commission on Irrigation and Drainage. Available at: <https://www.fao.org/fileadmin/templates/rap/files/meetings/2013/130228-report.pdf>
Fenyő, K., & Komuves, A. (2024). Hungarian farmers lead camels through Budapest to highlight climate change. Reuters, 1 August 2024. Available at: <https://www.reuters.com/world/europe/hungarian-farmers-lead-camels-through-budapest-highlight-climate-change-2024-08-01/>
Fenyő, K., & Than, K. (2024). Hungarian lawmakers, NGOs meet in dried-out riverbed to sound alarm over drought. Reuters, 11 September 2024. Available at: <https://www.reuters.com/world/europe/hungarian-lawmakers-ngos-meet-dried-out-riverbed-sound-alarm-over-drought-2024-09-11/>
Hungarian Central Statistical Office. (2026). Irrigation by county and region, 2004–2025. STADAT table 19.1.2.26. Available at: <https://www.ksh.hu/stadat?lang=en&theme=mez>
Illés, I. (2001). Regions and Regionalization. (Régiók és regionalizáció.) *Tér és Társadalom*, 15(1), 1–23. <https://doi.org/10.17649/tet.15.1.785>
Lakatos, B. O. (2020). Water Security – Establishment of Water Retention Facilities for Municipal and Local Climate Adaptation (Vízbiztonság – önkormányzati/települési éghajlati adaptációs célú vízmegtartó objektumok létesítése). *Műszaki Katonai Közöny*, 30(2), 57–76. <https://doi.org/10.32562/mkk.2020.2.5>
MACROMETO.HU. Planning an Irrigation Strategy (Öntözési stratégia tervezése). Available at: <https://www.macrometeo.hu/ontozesi-strategia-tervezese/>

- Magyar Mezőgazdaság. (2025). Irrigation Communities Without Water (Öntözési közösségek víz nélkül.) Available at: <https://magyarmezogazdasag.hu/2025/10/07/ontozesi-kozossegek-viz-nelkul/>
- Magyar Mezőgazdaság. (2026). This Year's Water Shortage May Reach a Record Level (Rekordot dönthet az idei vízhiány). Available at: <https://magyarmezogazdasag.hu/2026/04/30/rekordot-donthet-az-idei-vizhiany/>
- Nagy, A., Szabó, A., Fehér, Z. Z., Tamás, J.: (2025). Precision irrigation solutions for drought management in Central and Eastern Europe. In: 4th World Irrigation Forum, Is irrigation a sunset industry. Ed.: Marco Arcieri, Ir Yuslina binti Hj Mohd Sani, R.K. Gupta, International Commission of Irrigation and Drainage, Kuala Lumpur, Malaysia, 1-10.
- Nagy, A., Szabó, A., Gálya, B., Tamás, J.: (2021). Real-time spectral information to measure crop water stress for variable rate irrigation scheduling. In: Precision agriculture '21. Ed.: John V. Stafford, Wageningen Academic Publishers, Wageningen, 427-433, ISBN: 9789086863631
- Nagy, Z. (2018). The regulation of financial support in particular for agricultural support. Journal of Agricultural and Environmental Law = Agrár- és Környezetjog, 24, 135–162. <https://doi.org/10.21029/jael.2018.24.135>
- National Directorate General for Water Management. OVF information on water rights permitting. Available at: <https://www.ovf.hu/del-dunantuli/kozerdeku/kozszolgaltatasok/tajekoztatas-a-vizjogi-engedelyezesrol-es-az-ahhoz-szukseges-igazgatosagi-vagyonkezeloi-hozzajarulasrol-es-objektumazonositasi-nyilatkozat-megkeresrol>
- Qadir, M. (2018). Policy note: Addressing trade-offs to promote safely managed wastewater in developing countries. Water Economics and Policy, 4(2), 1871002. <https://doi.org/10.1142/s2382624x18710029>
- Radics, Z. (2022). Complex Study of the Effects of Irrigation, Organic Mulching and Artificial Soil Compaction on the Earthworm Community. PhD dissertation, Hungarian University of Agriculture and Life Sciences <https://doi.org/10.54598/002250>
- Ruttkay, É. (1998). The Financing System of Regional Development in the Context of EU Accession (A területfejlesztés finanszírozási rendszere az EU csatlakozás tükrében). Tér és Társadalom, 12(1–2), 13–37. <https://doi.org/10.17649/tet.12.1-2.459>
- Szabó, A., Tamás, J., Kövesdi, Á., Nagy, A.: Evaluation of new pivoting linear-move precision irrigation machine. Irrig. Drain. 72 (4), 922-933, 2023. <https://doi.org/10.1002/ird.2850>
- Tóth, T. (2021). Integrating the Circular Economy Concept into Irrigation Development in Hungary (A körforgásos gazdaság koncepciójának integrálása a magyarországi öntözésfejlesztésbe). Hadmérnök, 16(2), 157–168. <https://doi.org/10.32567/hm.2021.2.11>
- Zhu, T., Ringler, C., & Rosegrant, M. W. (2019). Viewing agricultural water management through a systems analysis lens. Water Resources Research, 55(3), 1778–1791. <https://doi.org/10.1029/2017wr021007>

IRRIGATION MODERNIZATION AND WATER RESOURCES MANAGEMENT IN IRAQ: SYSTEM PERFORMANCE, CLIMATE CHALLENGES, AND SUSTAINABLE PATHWAYS – IRAQ

Eng. Rafat Nael Abdul Ghani¹, and Eng. Nisreen Sami Tarkhan²

1. Water Resources in Iraq

1.1 Introduction

Water resources constitute the cornerstone of agricultural sustainability and food security in Iraq. The country relies primarily on the waters of the Tigris and Euphrates Rivers and their tributaries, in addition to groundwater resources and other non-conventional water resources.

These resources facing increasing challenges resulting from climate change, declining transboundary water inflows, the expansion of dam and reservoir construction in upstream countries, the continuous increase in water demand, and the relatively low efficiency of traditional irrigation systems.

Despite these challenges, water resources remain the principal driver for expanding cultivated areas and achieving sustainable agricultural development.

During recent decades, Iraq has experienced a significant decline in the discharges of the Tigris and Euphrates Rivers within its territory due to recurrent drought events and the construction of dams and reservoirs in Turkey, the Syrian Arab Republic, and the Islamic Republic of Iran. This situation has directly affected cultivated land areas and agricultural production levels.

In this context, strategic crops—particularly wheat, barley, rice (paddy), and sunflower—serve as key indicators for evaluating water resource utilization, irrigation system performance, agricultural production stability, and the equity of water distribution among agricultural regions.

1.2 Current Water Situation in Iraq

Iraq's water resources depend primarily on the Tigris and Euphrates Rivers and their tributaries, Groundwater resources, Surface water storage in dams and reservoirs. However, more than 70% of Iraq's water resources originate outside its national borders, making the country one of the most vulnerable states in the region to political and climatic changes affecting transboundary water resources. Furthermore, the absence of legally binding water-sharing agreements with upstream countries represents one of the most serious current and future challenges facing Iraq's water security. Table 1 and the accompanying map present Iraq's principal water resources.

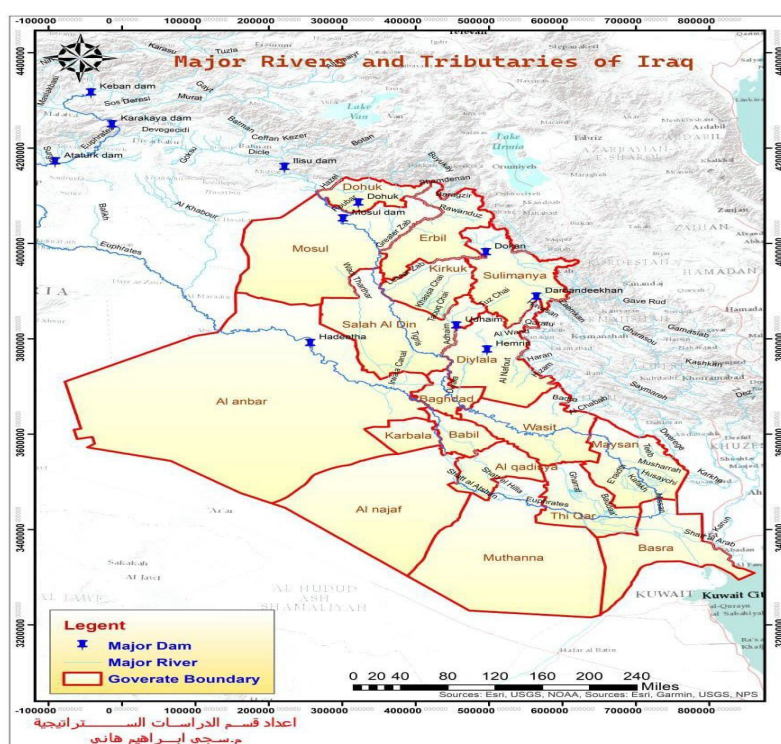
The International Symposium of the International Commission on Irrigation and Drainage (ICID) in cooperation With the Food and Agriculture Organization of the United Nations (FAO)

¹ National Center for Water Resources Management Ministry of Water Resources, Republic of Iraq

² Planning and Follow-up Directorate Ministry of Water Resources, Republic of Iraq

Table 1. The Main Rivers and Tributaries in Iraq.

River /Tributary	Source	Entry Point into Iraq	Governorates Traversed	Water Significance
Tigris River	Taurus Mountains, Turkey	Faysh Khabur	Duhok, Nineveh, Salah Al-Din, Baghdad, Wasit, Maysan, Basra	Main source of surface water in Iraq
Euphrates River	Taurus Mountains, Turkey	Al-Qaim	Al-Anbar, Babylon, Karbala, Al-Najaf, Al-Qadisiyah, Al-Muthanna, Dhi Qar	Primary irrigation source for central and southern Iraq
Greater Zab	Turkey	Northern Iraq	Erbil, Kirkuk, Nineveh	One of the major tributaries of the Tigris River
Lesser Zab	Iran and Iraq	Northeastern Iraq	Sulaymaniyah, Kirkuk	Supplies Dokan Dam
Diyala River	Zagros Mountains, Iran	Eastern Iraq	Diyala, Baghdad	Supplies Hamrin Dam
Al-Adhaim River	Hamrin Mountains (Iraq)	Within Iraq	Salah Al-Din, Diyala	Important seasonal tributary
Khabur River	Turkey	Northern Iraq	Duhok	Tributary of the Tigris River
Karun River	Iran	Southern Iraq / Shatt Al-Arab	Basra	Influences water quality and salinity
Karkheh River	Iran	Southern Marshlands	Maysan	Supplies the southern marshes
Sirwan River	Iran	Kurdistan Region	Sulaymaniyah, Diyala	Supplies Darbandikhan Dam



Map 1. The Main Rivers and Tributaries in Iraq.

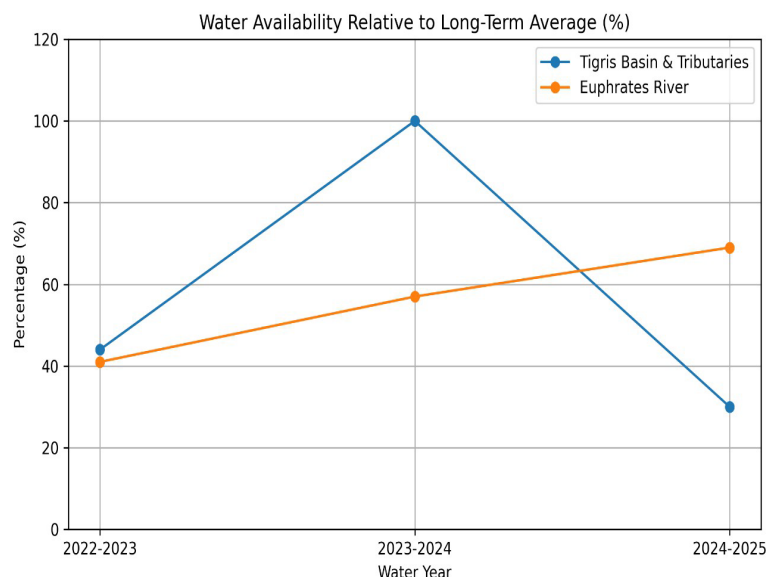
Groundwater represents a strategic water resource in Iraq and ranks second only to surface water in terms of importance and utilization, particularly in light of the growing challenges affecting surface water resources as a result of climate change and the continuous decline in transboundary water inflows. Water demand in Iraq continues to increase due to population growth, agricultural expansion, and economic development. Hydrogeological studies have classified Iraq into seven major groundwater zones, each characterized by distinct geological formations, groundwater quality, recharge rates, and aquifer characteristics. These zones include the mountainous region, the high and low folded zones, the

Jazira region, the western desert plateau, and the Mesopotamian alluvial plain. The northern mountainous regions generally contain relatively fresh groundwater owing to continuous recharge from rainfall and snowmelt. In contrast, groundwater within the alluvial plain is affected by elevated salinity resulting from irrigation return flows and drainage water. The western desert region also contains extensive groundwater aquifers; however, these aquifers exhibit limited natural recharge and depend primarily on seasonal rainfall and flash floods. Groundwater has become an essential supplementary resource for maintaining water and agricultural security during periods of drought and water scarcity. Nevertheless, ensuring the long-term sustainability of this resource requires an integrated scientific management approach, including regulation of groundwater abstraction, continuous updating of hydrogeological investigations, systematic monitoring of groundwater quantity and quality, and strengthening the integration of surface water and groundwater management within the framework of Integrated Water Resources Management (IWRM).

1.3 Water Inflows and Storage Conditions

In recent years, Iraq has experienced a substantial decline in water inflows, particularly throughout the period 2020–2025. This decline has resulted from reduced precipitation, upstream dam operations, and the expansion of irrigation projects outside Iraq. Consequently, the 2025 water year was considered one of the driest years in recent history, requiring the Ministry of Water Resources to implement strict operational scenarios in order to preserve the country's strategic water storage. Conversely, the 2025–2026 water year witnessed a relative improvement following increased rainfall. By 30 May 2026, the cumulative inflows to the Tigris and Euphrates River basins had reached approximately 116% of the long-term average, contributing significantly to increased storage levels in Mosul, Dokan, and Darbandikhan Dams.

Figure (2) illustrates the considerable fluctuations in water inflows during recent years. The inflows to the Tigris River Basin and its tributaries declined to 44% of the long-term average during the 2022–2023 water year, recovered to 100% during 2023–2024, and subsequently dropped sharply to only 30% during 2024–2025. Similarly, inflows to the Euphrates River fluctuated between 41% and 69% of the long-term average over the same period. These fluctuations clearly demonstrate the increasing uncertainty associated with Iraq's water resources and highlight the combined impacts of climate change and upstream reservoir operations on the reliability and stability of irrigation systems throughout the country.



1.4 Performance of Irrigation Systems in Iraq

Irrigation systems in Iraq are among the oldest in the world. The civilizations of Mesopotamia flourished through use of the Tigris and Euphrates Rivers waters and the extensive irrigation networks associated with them. At Currently, Iraq's agricultural sector relies primarily on traditional surface irrigation supplied by the Tigris and Euphrates Rivers and their tributaries, supplemented by groundwater and other non-conventional water sources. Irrigation projects are distributed across all governorates through an extensive network of dams, reservoirs, main and secondary canals, pumping stations, and drainage systems, which collectively constitute the backbone of agricultural production and national food security. However, during recent years the performance of these irrigation systems has become increasingly affected by mounting water and environmental challenges. Climate change, declining precipitation and snowfall, rising temperatures, and increasing evaporation rates, together with reduced transboundary inflows from upstream countries, have placed unprecedented pressure on Iraq's available water resources. These circumstances have directly affected the operation of irrigation schemes and their capacity to satisfy agricultural, environmental, municipal, and industrial water requirements.

1.4.1 *Reliability*

Reliability refers to the ability of an irrigation system to provide water in the required quantities and at the appropriate time on a regular and dependable basis. Data from the Ministry of Water Resources indicate considerable fluctuations in water inflows during recent years. These fluctuations have significantly influenced the stability of irrigation system operations and the implementation of seasonal agricultural plans. During periods of severe water scarcity, the relevant authorities are often required to reduce cultivated areas or reprioritize water allocation among competing sectors, thereby affecting the regularity and reliability of water deliveries to agricultural irrigation projects.

1.4.2 *Efficiency*

Efficiency reflects the ability of an irrigation system to convey water to agricultural fields while minimizing conveyance and operational losses. Traditional surface irrigation remains the dominant irrigation practice across most agricultural areas in Iraq. Consequently, significant water losses occur due to evaporation, seepage, and, in some cases, inefficient water distribution. In addition, continuous rehabilitation and modernization of irrigation infrastructure remain essential. In recent years, the Ministry of Water Resources has implemented several irrigation modernization programs, including the expanding the use of sprinkler and drip irrigation systems, canal lining projects, improved water distribution management, and the use of modern monitoring and operational technologies. These measures are intended to increase water productivity, reduce water losses, and improve the efficiency of utilizing limited water resources. Despite the progress achieved, irrigation efficiency remains below the targeted level because conventional surface irrigation continues to dominate a substantial proportion of Iraq's cultivated land.

1.4.3 *Equity in Water Distribution*

Equity in water distribution represents one of the principal indicators used to evaluate irrigation system performance. It reflects the ability of water institutions to deliver irrigation water and related services fairly and equitably among different regions and water users. In Iraq, this indicator has gained increasing importance during recent years because of declining water inflows and growing pressure on available water resources. To ensure equitable water distribution among governorates and irrigation projects, the Ministry of Water

Resources has implemented numerous administrative and operational measures. One of the most significant initiatives has been the nationwide campaign to remove encroachments on rivers, canals, and irrigation infrastructure. This campaign has included the removal of unlicensed pumps, illegal water outlets, unlicensed fishponds, and other unauthorized activities that adversely affect officially allocated water shares. Thousands of violations have been identified and removed throughout Iraq with the

objective of protecting legally established water rights and ensuring that water reaches downstream irrigation schemes and tail-end users.

Furthermore, the Ministry has carried out extensive river dredging, canal cleaning, sediment removal, aquatic weed control, and the elimination of flow bottlenecks. These measures have contributed to improving water conveyance efficiency, reducing operational losses, and enhancing the likelihood of delivering water more equitably across agricultural areas. Collectively, these efforts demonstrate the Government's continued efforts to improving irrigation system performance and promoting a more equitable distribution of water among governorates and economic sectors.

1.4.4 Agricultural Productivity

Agricultural productivity represents the ultimate and most comprehensive indicator of irrigation system performance, as it reflects the capacity of both land and water resources to sustain agricultural production, support food security, and support economic development. In Iraq, agricultural productivity is closely associated with the reliability of water supplies and the efficiency of irrigation management, as agricultural production depends predominantly on surface irrigation derived from the Tigris and Euphrates Rivers and their tributaries. Statistics published by the Central Statistical Organization and the Directorate of Agricultural Statistics indicate that the productivity of Iraq's major strategic crops responds significantly to the availability and reliability of irrigation water. Among these crops, wheat has consistently achieved substantially higher yields under irrigated conditions than under rain-fed agriculture. During the 2020 growing season, irrigated wheat recorded an average yield of approximately 840 kg/dunum, compared with only 470 kg/dunum under rain fed conditions. Consequently, wheat productivity in irrigated areas was nearly twice that of rain fed agriculture, clearly demonstrating the direct contribution of reliable irrigation to improving agricultural productivity and crop stability. Barley, which is generally more tolerant of drought conditions than wheat, has demonstrated greater resilience during periods of water scarcity. Nevertheless, its average productivity has remained lower than that of wheat throughout most growing seasons. Rice (Paddy) is among the most water-intensive crops cultivated in Iraq and relies heavily on reliable irrigation throughout the summer season. Rice production is concentrated primarily in the central and southern governorates where sufficient water releases are available, particularly in Al-Najaf, Al-Qadisiyah, Wasit, and Dhi Qar. Comparative analyses covering the period 2015–2020 indicate that both the cultivated area and total rice production are directly influenced by annual water allocation decisions and the national agricultural plan. During years of water scarcity, rice cultivation areas declined considerably, whereas both cultivated areas and production increased during years characterized by improved water availability. Sunflower, by contrast, represents a crop with relatively lower water requirements. Statistical data for the period 2015–2020 indicate comparatively stable yields relative to several other crops, suggesting higher water-use efficiency and a greater capacity to adapt to water scarcity. Accordingly, sunflower is increasingly regarded as one of the strategic crops capable of supporting sustainable water use and climate change adaptation strategies while contributing to improved agricultural water management. Overall agricultural production trends observed during recent years demonstrate a strong correlation between agricultural productivity and annual water availability. Years characterized by improved inflows to the Tigris and Euphrates Rivers have generally resulted in larger cultivated areas and increased production of most strategic crops, whereas drought years have required reductions in agricultural plans and significant decreases in the cultivation of water-intensive summer crops. Consequently, increasing water productivity has become a fundamental objective of Iraq's agricultural and water policies through irrigation modernization, the adoption of modern irrigation technologies, and improved water management at both farm and irrigation project levels. Overall, the performance of Iraq's strategic crops confirms that agricultural productivity remains highly dependent upon the reliability of water supplies and the efficiency of irrigation systems. The experience of wheat, barley, rice, and sunflower demonstrates that improving water-use efficiency not only increases agricultural production but also strengthens the sustainability of water resources and enhances the resilience of the agricultural sector to climate change and future water-related challenges.

1.4.5 Overall Performance Assessment

Based on the current performance indicators, Iraq's irrigation systems possess extensive infrastructure and benefit from decades of operational experience. However, they are facing increasing pressure resulting from limited water resources, rising water demand, and the growing impacts of climate change. Accordingly, irrigation modernization, improved water-use efficiency, and enhanced operational management of irrigation projects constitute strategic priorities for ensuring the long-term sustainability of water resources, ensuring the sustainability of water resources and achieving food security and agricultural development.

2. Key Challenges and Risk Drivers

2.1 Climate Risks and Climate Variability

Climate change is one of the major challenges facing Iraq's water resources and irrigation sector. Over recent decades, the country has experienced an increasing frequency of drought events, accompanied by substantial declines in precipitation and snowfall, as well as rising air temperatures and evaporation rates. Iraq experienced several major drought periods during 1999–2001, 2007–2008, 2017–2018, and 2020–2025, all of which significantly reduced available water resources and intensified pressure on the country's limited water supplies. Recent hydrological records further demonstrate considerable inter annual variability in water inflows. The cumulative inflows to the Tigris River Basin and its tributaries declined to approximately 44% of the long-term average during the 2022–2023 water year, before falling further to only 30% during 2024–2025. Likewise, inflows to the Euphrates River fluctuated between 41% and 69% of their long-term average over the same period. These fluctuations have directly affected on agricultural planning, irrigation system operation, and the stability of agricultural production. Moreover, these climatic conditions have increased the risk of desertification, increased the frequency and intensity of dust storms, and contributed to the degradation of ecosystems, including the Iraqi Marshlands. These conditions also increase crop water requirements owing to rising temperatures.

2.2 Infrastructure Challenges and Operational Constraints

Although Iraq possesses an extensive network of dams, reservoirs, primary and secondary canals, and drainage systems, an important part of this infrastructure was constructed several decades ago and requires continuous rehabilitation, modernization, and maintenance. Traditional surface irrigation remains the dominant irrigation practice throughout most agricultural regions, resulting in considerable water losses through evaporation, seepage, and inefficient distribution. Accordingly, there is a continuing need to expand irrigation modernization programs, including canal lining, infrastructure rehabilitation, and the adoption of advanced monitoring and operational technologies aimed at improving conveyance efficiency and minimizing water losses.

2.3 Groundwater Pressures and Water Availability

Groundwater has become an important strategic resource for compensating for declining surface water supplies. However, this resource is itself subject to significant challenges. As surface water availability has diminished, dependence on groundwater abstraction has increased across many agricultural regions, leading to higher extraction rates from groundwater aquifers. Hydrogeological investigations reveal considerable variation in groundwater characteristics among Iraq's different aquifer systems. The northern and mountainous regions generally possess groundwater of relatively good quality, whereas extensive areas within the Mesopotamian alluvial plain and parts of the western desert suffer from elevated salinity and limited natural recharge. Furthermore, the limited information regarding exploitable groundwater reserves remains an additional challenge for sustainable groundwater management. Despite its growing importance in strengthening water and agricultural security during drought periods, ensuring the long-term sustainability of groundwater resources requires regulating groundwater abstraction, strengthening monitoring programs, expanding hydrogeological databases, and implementing integrated management of surface water and groundwater.

2.4 Institutional and Financial Challenges

Iraq's water resources and irrigation sector face a range of institutional and financial challenges associated with the implementation of modern water resources management. Expanding irrigation modernization programs, upgrading infrastructure, and rehabilitating water facilities require substantial and sustained financial investments. At the same time, government institutions are under increasing pressure due to the extensive irrigation infrastructure requiring continuous operation and maintenance. Effective water resources management also requires stronger coordination among institutions responsible for water resources, agriculture, environmental protection, planning, and other related sectors. Furthermore, there is a continuing need to strengthen regulatory and legislative frameworks governing water demand management and monitoring of water use across all sectors. Additional priorities include institutional capacity building, wider adoption of advanced technologies, and the expansion of water information systems capable of supporting planning and decision-making. Given the growing imbalance between limited water availability and increasing demand, the implementation of Integrated Water Resources Management (IWRM), the development of sustainable financing mechanisms, and improved investment efficiency in water infrastructure have become fundamental requirements for ensuring the long-term sustainability of irrigation services and achieving water and food security in Iraq.

3. Climate Resilience and Environmental Sustainability

Iraq is facing growing challenges resulting from climate change, including declining rainfall, more frequent drought years, rising temperatures, increased evaporation rates, and the continuous reduction in water inflows from upstream countries. These challenges have directly affected water resources, agricultural production, and ecosystems. In response, the Ministry of Water Resources has adopted a range of measures aimed at enhancing climate resilience and achieving environmental sustainability within the framework of integrated water resources management (IWRM).

3.1 Adaptation Measures in Irrigation Systems

The Ministry of Water Resources has adopted a comprehensive set of measures aimed at improving water use efficiency and enhancing the agricultural sector's capacity to adapt to changing climatic conditions. One of the key measures is the expansion of irrigation modernization and agricultural land rehabilitation projects through the implementation of closed irrigation systems, which aim to reduce water losses and improve the efficiency of water delivery to agricultural fields. The Ministry is also introducing advanced technologies into water resources management through automation and digital transformation projects, as well as the application of remote sensing technologies and artificial intelligence to support decision-making and enhance the management of both surface water and groundwater resources. Within this framework, the Ministry of Water Resources is developing and implementing specialized digital platforms to monitor agricultural plans and manage water allocations. These include a platform for monitoring the implementation of agricultural plans and analyzing water-related data, as well as a platform for managing water allocation requests and matching cultivated areas with available water releases. These digital tools contribute significantly to improving water management efficiency and enhancing the operational flexibility of irrigation systems, particularly under the increasing variability of water inflows resulting from climate change.

3.2. Drought Management and Early Warning Systems

Drought management has become one of the main components of Iraq's water policy due to the increasing frequency of water scarcity over the past two decades. The Ministry of Water Resources operates an integrated monitoring system to assess water resources, monitor inflows to the Tigris and Euphrates River basins, track water storage levels in dams and reservoirs, and continuously observe climatic and hydrological indicators. The Ministry also utilizes remote sensing technologies, Geographic Information Systems (GIS), and national water databases to support early warning, forecasting, and proactive drought management. These systems contribute to the preparation of annual agricultural plans, the prioritization of water allocation, the management of strategic water storage, and the

mitigation of drought impacts on the agricultural and environmental sectors. As part of its long-term climate change adaptation strategy, the Ministry of Water Resources is incorporating a number of projects into the National Climate Investment Plan, including initiatives for the assessment and sustainable development of groundwater resources to enhance resilience to drought and desertification. In addition, the Ministry, in cooperation with several international organizations and Iraqi government institutions, is implementing strategic projects aimed at strengthening sustainable water resources management and enhancing resilience to climate change and water scarcity in Iraq. Among the most prominent is the MURUNA Project, funded by the Government of Canada and implemented in partnership with the International Center for Bio saline Agriculture (ICBA) and the World Food Program (WFP). The project focuses on improving integrated water resources management, promoting climate-smart agriculture, supporting local communities and Water User Associations, and establishing demonstration sites for salt- and drought-tolerant crops. The Ministry is also implementing, in cooperation with the German Agency for International Cooperation (GIZ), the Climate-Resilient Water Resources Management Project within the Shatt Al-Hillah system. The project aims to strengthen water resources information systems, improve water balancing and distribution, enhance institutional capacities, and conduct studies on the reuse of drainage water, thereby improving the efficiency of water resources management and increasing resilience to climate change.

3.3 Environmental Safeguards and Ecosystem Protection

The Ministry of Water Resources places increasing emphasis on the environmental dimensions of water resources management, particularly addressing salinity, waterlogging, and ecosystem degradation. Iraq faces significant environmental challenges due to the characteristics of its alluvial plain, high temperatures, declining river discharges, and the long-term expansion of irrigated agriculture.

3.3.1 Salinity Management

Soil salinity is one of the most critical environmental challenges affecting Iraq's agricultural lands, particularly in the central and southern regions. To mitigate its impacts, the Ministry continues to operate and upgrade the main and secondary drainage networks, carry out regular maintenance of drainage canals, and improve the efficiency of excess water disposal from agricultural lands. In addition, irrigation modernization projects and the reduction of excessive surface irrigation contribute to limiting salt accumulation and enhancing soil fertility over the long term.

3.3.2 Waterlogging Control

The problem of rising groundwater levels and waterlogging is addressed through the development of drainage systems and the routine maintenance of drainage canals and irrigation channels. These efforts also include the removal of sediment deposits and aquatic vegetation that obstruct water flow. Collectively, these measures improve soil aeration, preserve agricultural productivity, and reduce the risk of land degradation.

3.3.3 Ecosystem Protection

The Iraqi Marshes constitute one of the region's most important ecosystems. Accordingly, the Ministry allocates environmental water releases to support their sustainability and conserve their rich biodiversity. In addition, innovative environmental projects are being implemented to treat and reuse wastewater using environmentally friendly approaches. One notable example is the wastewater treatment project in Maysan Governorate, which utilizes native reed (*Phragmites australis*) and bulrush (*Typha* spp.) plants in cooperation with the World Food Program (WFP). This initiative represents a practical example of a nature-based solution for water management, contributing to improved water quality and the protection of wetland ecosystems.

4. Irrigation Modernization Pathways in Iraq

4.1 Provision of Services and Improvements in System Operation

The modernization of irrigation services and the improvement of water system operation constitute one of the principal pillars of the strategy of the Iraqi Ministry of Water Resources to address the challenges arising from declining water inflows and climate change. The Ministry is undertaking the rehabilitation of irrigation and drainage infrastructure and enhancing the operational efficiency of water networks through the modernization of hydraulic structures and control outlets, improved management of water releases, and the development of more effective water distribution procedures to ensure equitable allocation among water users. In parallel, the Ministry is strengthening the role of Water User Associations (WUAs) in the operation and management of irrigation projects, thereby promoting sustainable service delivery, increasing local participation, and enhancing the adaptability of irrigation systems to changing hydrological conditions. Furthermore, the Ministry aims to gradually increase overall irrigation efficiency from its current level of approximately 30–40% to around 60% by 2035 through the modernization of operational infrastructure, reduction of conveyance and operational water losses, and implementation of improved water demand management practices.

4.2 Digitalization, Remote Sensing, the Internet of Things (IoT), and Smart Irrigation Systems

The Ministry of Water Resources has adopted a clear digital transformation pathway for the management of irrigation and water resources, in line with international trends toward smart water management. The Ministry has initiated the development of specialized digital platforms to support agricultural planning and water allocation management. These include a platform for monitoring the implementation of agricultural plans and analyzing water-related data, a platform for managing water allocation requests and matching cultivated areas with available water releases, as well as the development of interactive mapping systems and decision-support dashboards to enhance planning and informed decision-making. In addition, remote sensing technologies and satellite imagery are being utilized to monitor cultivated areas, assess water consumption, and evaluate the efficiency of water resource utilization. The Ministry is also expanding the deployment of smart metering devices and real-time remote water level monitoring systems to improve operational monitoring and water distribution management. International organizations, development partners, and organizations supporting digital transformation and water resources management projects have contributed to the adoption of smart solutions and digital systems for water management, as well as to monitoring the operational performance of water projects.

4.3 Decision Support Systems

The Ministry of Water Resources is developing Decision Support Systems (DSS) to improve water resources management and enhance the efficiency of planning and operational management in the face of increasing climate- and water-related challenges. These efforts include the development of digital platforms and national databases that support decision-making processes at various administrative and technical levels. Among the most prominent systems are the Agricultural Plan Monitoring Platform, which tracks the implementation of agricultural plans and analyzes spatial and agricultural data, the Water Allocation Management Platform which links water allocations with the agricultural plan, and remote sensing applications used to monitor land use and water productivity. These systems contribute to improving water management, optimizing water allocation, monitoring the implementation of agricultural plans, supporting climate change adaptation measures, and enhancing water use efficiency.

4.4 Agricultural Improvements to Increase Water Productivity

The modernization strategy focuses on increasing water productivity rather than merely increasing the volume of water used. Accordingly, the Ministry, in cooperation with the Ministry of Agriculture and development partners, has adopted a range of measures, including restructuring cropping patterns in accordance with crop water requirements, expanding the cultivation of low water-demand crops; reducing dependence on water-intensive crops in critical areas; promoting modern irrigation

technologies (drip and sprinkler irrigation); improving on-farm management and irrigation scheduling based on actual crop water requirements, and increasing cropping intensity from 85% to 115%, in line with the targets of the Strategic Study. According to the

Strategic Study, these measures could increase irrigated areas by approximately 17% compared with the current irrigated area while reducing water use by approximately 30%, owing to improved irrigation efficiency and better agricultural management.

4.5 Irrigation Asset Management and Maintenance Practices

The Ministry of Water Resources places great importance on the operation and maintenance of water infrastructure, recognizing it as a fundamental requirement for ensuring the sustainability of irrigation services and improving water use efficiency. These activities include river dredging, cleaning primary and secondary canals, removing sediment and aquatic vegetation, maintaining drainage networks and hydraulic structures, and eliminating bottlenecks that impede water flow. The Ministry also seeks to improve the efficiency of water conveyance and distribution networks through canal lining projects, expanding the application of closed irrigation systems, and rehabilitating existing irrigation and drainage networks, thereby reducing water losses and improving water delivery efficiency to end users. Annual project implementation reports indicate the continued execution of maintenance and rehabilitation programs across all governorates, contributing to greater operational reliability of irrigation projects and improved performance of Iraq's irrigation and drainage system at the national level.

4.6 Integrated Water Resources (Surface Water, Groundwater, and Water Reuse)

The Ministry of Water Resources adopts an Integrated Water Resources Management (IWRM) approach by promoting coordinated utilization of different water sources to achieve their optimal use. The principal measures include the conjunctive management of surface water and groundwater; the development of groundwater investment projects in drought- and desertification-affected areas; the reuse of treated wastewater for agricultural and industrial purposes, and the reuse of agricultural drainage water after appropriate treatment or blending in accordance with environmental standards. The Ministry also promotes the utilization of non-conventional water resources to strengthen water security and supports wastewater treatment projects based on Nature-Based Solutions (NbS), including constructed wetland treatment systems implemented with support from the World Food Program (WFP). This approach represents one of the key pillars for adapting to limited water resources and achieving *long-term sustainability*.

4.7 Energy Use and the Development of Solar-Powered Irrigation

The Iraqi Ministry of Water Resources adopts an integrated approach within the Water-Energy-Food-Ecosystems (WEFE) Nexus framework, aiming to improve the efficiency of water and energy use in the agricultural sector while reducing operational costs and carbon emissions. The transition toward renewable energy sources, particularly solar energy, constitutes one of the main pillars of irrigation modernization and climate change adaptation programs. Within this framework, the Ministry, in cooperation with international organizations and development partners, has implemented several pilot initiatives and projects integrating modern irrigation technologies with renewable energy. The United Nations Development Programme (UNDP) has supported the provision of solar-powered systems to a number of Water User Associations benefiting farmers in the governorates of Karbala, Najaf, Al-Qadisiyah, Al-Muthanna, Maysan, Dhi Qar, and Basra, in addition to supporting drip irrigation systems over various agricultural areas. Several associations have also been equipped with laser land-leveling equipment to improve water distribution efficiency and minimize water losses. Similarly, the International Organization for Migration (IOM) has implemented closed irrigation projects, including a solar-powered closed irrigation scheme covering approximately 525 dunums in Al-Duwaib Sub-district, Dhi Qar Governorate, in addition to water harvesting projects and small dams implemented in coordination with Water User Associations in areas affected by water scarcity. The Food and Agriculture Organization of the United Nations (FAO) has also supported closed irrigation projects in several agricultural associations, thereby improving both water and energy use efficiency. Modernization efforts also

encourage replacing conventional fuel- or electricity-powered pumping systems with solar-powered pumping systems, reducing operation and maintenance costs while lowering carbon dioxide emissions. Furthermore, the Ministry is expanding the adoption of localized irrigation, sprinkler irrigation, and smart irrigation systems integrated with renewable energy to simultaneously enhance water and energy productivity. Through water extension programs and awareness campaigns, the Ministry promotes the gradual transition toward climate-smart agriculture and the adoption of advanced technologies that combine efficient irrigation with clean energy, including closed irrigation systems, laser land leveling, irrigation scheduling, and digital agriculture applications. These measures are regarded as essential components of Iraq's irrigation modernization vision, which seeks to achieve water sustainability, clean energy, and enhanced resilience to climate change and water scarcity.

4.8 Comprehensive Modernization Vision

With the support of international organizations and development partners, the Iraqi Ministry of Water Resources is pursuing a comprehensive transformation of the irrigation sector based on the transition from traditional open irrigation systems to modern closed irrigation systems, canal lining, digitalization, remote sensing, smart water management, water reuse, and renewable energy technologies. This transformation aims to increase water use efficiency, strengthen water and food security, and enhance the resilience of the agricultural sector to climate change and future challenges associated with water scarcity.

5 Policy and Regulatory Frameworks

Water governance in Iraq is based on a set of policies, strategies, and legislative frameworks aimed at achieving Integrated Water Resources Management (IWRM) and improving water use efficiency in response to declining water inflows, climate change, and increasing water demand. The Strategic Study for Water and Land Resources in Iraq (2015–2035) serves as the principal national reference for the development of the water sector. The study recommends the rehabilitation of water infrastructure, improving irrigation efficiency from the current levels of approximately 30–40% to around 60%, expanding the use of modern irrigation technologies and closed irrigation systems, promoting the reuse of treated wastewater, and strengthening integrated water resources management at both basin and project levels. The Ministry of Water Resources has also adopted a set of legislative instruments regulating beneficiary participation in water management. Foremost among these is the Fourth Amendment to Law No. (12) of 1995 (Irrigation Network Maintenance Law), which authorizes beneficiaries sharing a common water source to establish Water Users Associations (WUAs) responsible for the management, operation, and maintenance of secondary irrigation and drainage infrastructure within their agricultural areas. The law defines the objectives of establishing these associations as improving water use efficiency, reducing water losses, contributing to the resolution of disputes among water users, preserving irrigation and drainage infrastructure, and strengthening community participation in water resources management. Furthermore, the law authorizes the Ministry of Water Resources to issue regulations governing the establishment, organization, and management of these associations. The most recent amendment, issued in 2025, aims to broaden community participation, strengthen decentralization in water management, transfer selected operational responsibilities to water users, improve on-farm water distribution efficiency, and develop sustainable financing and maintenance mechanisms. The Ministry is currently working to align the regulatory framework with irrigation modernization programs by supporting the transition from open-channel irrigation systems to closed irrigation systems, regulating groundwater abstraction, promoting the use of non-conventional water resources (treated wastewater and drainage water), encouraging the adoption of modern irrigation technologies and solar energy, and integrating digital transformation and remote sensing technologies into water management processes. Consequently, Iraq's regulatory framework has evolved beyond the traditional management of water resources to encompass infrastructure sustainability, enhanced water use efficiency, and strengthened community participation in water governance.

5.1 Institutional Arrangements and Coordination

Water management in Iraq is based on a multi-level institutional framework that encompasses government agencies, local authorities, end users, and international partners. The Ministry of Water Resources serves as the principal national authority responsible for the management of surface water and groundwater resources, the operation of dams, reservoirs, and hydraulic structures, the management of the main irrigation and drainage networks, the preparation of national plans and strategies, the regulation of water allocation among governorates and different sectors, and the technical and administrative supervision of Water User Associations (WUAs). The Strategic Study for Water and Land Resources in Iraq also emphasized the importance of coordination among the Ministries of Water Resources, Agriculture, Planning, Environment, and Electricity, as well as local governments and the Kurdistan Regional Government, to ensure the integration of water, agricultural, energy, and environmental policies and to achieve national water and food security objectives. In addition, several joint committees and technical working groups have been established to coordinate the operation of irrigation projects, prepare seasonal agricultural plans, monitor the implementation of modernization programs, manage water scarcity conditions, and support the application of participatory water management. International organizations have also made significant contributions to strengthening the institutional framework. The Japan International Cooperation Agency (JICA) has supported the establishment and expansion of Water User Associations, strengthened institutional and technical capacities, developed participatory management models, and provided training for WUA management teams. The Food and Agriculture Organization of the United Nations (FAO) has supported closed-pipe irrigation projects, capacity building in integrated water resources management, and initiatives aimed at improving on-farm water use efficiency. The United Nations Development Program (UNDP) has contributed to the implementation of solar-powered irrigation and modern irrigation projects, supported Water User Associations in the southern governorates, and promoted climate change adaptation. The International Organization for Migration (IOM) has implemented water harvesting projects, supported closed-pipe irrigation initiatives, and rehabilitated water infrastructure in conflict-affected areas. The World Food Programme (WFP) has assisted farmers by providing modern irrigation equipment and technologies and by implementing water management training and extension programs. These partnerships have played a vital role in strengthening institutional capacities and providing the financial resources, technical expertise, and capacity-building support required for the modernization of Iraq's irrigation sector.

5.2 Role of Water User Associations and Stakeholders

Water User Associations (WUAs) represent one of the most significant pillars of institutional reform in Iraq's irrigation sector. They have evolved from a pilot initiative supported by JICA into a nationally recognized model under the country's Participatory Irrigation Management (PIM) policy, which is based on the direct involvement of farmers in the management and operation of secondary irrigation networks. Their responsibilities include organizing water distribution among beneficiaries, maintaining local irrigation infrastructure, monitoring illegal water abstractions and water losses, and resolving local water-related disputes. This participatory approach has significantly improved management efficiency compared with the conventional centralized system. The Ministry of Water Resources, in cooperation with its international development partners, has facilitated the establishment of more than 200 Water User Associations across different governorates of Iraq. These associations now cover extensive agricultural areas, while thousands of farmers and members of their management committees have received technical and institutional training, thereby strengthening local participation in water resources management. WUAs play a pivotal role in implementing irrigation modernization programs by improving water conveyance efficiency, supervising canal cleaning and maintenance activities, reducing encroachments on irrigation canals, and contributing to the operation of closed-pipe irrigation networks. In addition, they support improvements in on-farm water-use efficiency by promoting drip and sprinkler irrigation systems, supporting irrigation scheduling, implementing water extension and awareness programs, contributing to field data collection, encouraging the use of solar energy for irrigation, managing water demand during drought and water-scarcity periods, and promoting water reuse wherever feasible.

5.3 Conclusion

Iraq is moving towards a modern water governance model based on Integrated Water Resources Management (IWRM) and Participatory Irrigation Management (PIM). The existing legal and regulatory frameworks provide the necessary foundation for transferring part of the operation and maintenance responsibilities to Water User Associations (WUAs), while maintaining the supervisory and regulatory role of the Ministry of Water Resources. Furthermore, cooperation among government institutions, international organizations, and farmers constitutes the cornerstone for the successful implementation of irrigation modernization programs, including canal lining, closed-pipe irrigation systems, solar energy applications, digital transformation, and improved water use efficiency at the national level.

6. Government Financing Mechanisms

Government financing constitutes the primary source of funding for water resources and irrigation projects in Iraq. The Ministry of Water Resources relies principally on the Federal General Budget to finance the construction and rehabilitation of dams, reservoirs, irrigation and drainage networks, pumping stations, and various hydraulic structures. The Strategic Study for Water and Land Resources in Iraq (SWLRI 2015–2035) confirms that the implementation of water sector projects requires long-term investments incorporated into the government's annual and medium-term investment plans. The study estimates that the total investment required to implement the strategic plan is approximately USD 175 billion over a twenty-year period. These investments cover the water resources sector, the municipal and industrial sectors, the construction of dams and other strategic water control infrastructure, the establishment of a national database for irrigation and agricultural projects, water monitoring systems, flood forecasting, and the enhancement of training and capacity building. This reflects the state's reliance on public financing as the principal driver for the development of Iraq's water infrastructure.

6.1 Cost Recovery and Tariff Systems

The irrigation sector in Iraq relies on an Irrigation Service Fee system administered by the Ministry of Water Resources and applied to beneficiaries of government irrigation services. This system constitutes the primary mechanism for recovering a portion of the costs associated with the operation and maintenance of irrigation and drainage networks and water infrastructure. In 2025, the Ministry strengthened its revenue collection procedures by introducing an electronic fee collection system using Point-of-Sale (POS) devices, while simultaneously updating beneficiary databases and integrating them with official land ownership and agricultural records. These measures have enhanced collection efficiency and reduced administrative errors. Fee collection is based on verifying farmers' information and the areas of agricultural land benefiting from irrigation services, with the data cross-checked against the decisions of agricultural committees and official land registry records. The Ministry of Water Resources is responsible for managing and supervising the collection process through its provincial directorates and local water units. Although a formal irrigation fee system is in place, cost recovery remains limited relative to the actual costs of constructing, operating, and maintaining water infrastructure. The government therefore continues to bear the majority of these expenditures through the national budget. Consequently, irrigation service fees primarily serve as a mechanism for partial cost recovery and for promoting the efficient and rational use of water, rather than as an instrument for achieving full financial cost recovery. Current policy directions focus on improving collection efficiency and strengthening financial governance through the transition to electronic fee collection, the standardization of beneficiary databases, the integration of fee collection with agricultural identification systems and land records, enhanced monitoring and auditing of collection procedures, and improved revenue tracking at the level of provincial water directorates.

6.2 Investment Priorities and Financing Gaps

Current public investment in Iraq's water resources sector is focused on addressing water scarcity challenges, improving water-use efficiency, and enhancing the reliability of irrigation services. The main investment priorities include modernizing conventional irrigation networks and gradually transitioning to closed-pipe irrigation systems; lining irrigation canals and drainage channels to reduce water losses;

expanding the adoption of modern irrigation technologies and pressurized irrigation systems; developing solar energy infrastructure for water pumping and irrigation; rehabilitating aging irrigation and drainage schemes; expanding water harvesting programs, including small dams and reservoirs; strengthening digital monitoring and hydrological measurement systems, supporting Water User Associations (WUAs) to promote participatory irrigation management, and enhancing farmers' capacity building and water extension services. Despite the continuation of government financing through the national state budget and the support provided by international organizations such as JICA, UNDP, FAO, IOM, and WFP, among others, investment needs substantially exceed the financial resources currently available. Financing gaps are particularly evident in completing the nationwide transition to closed-pipe irrigation systems; expanding the coverage of modern irrigation technologies across larger agricultural areas; rehabilitating deteriorated secondary and on-farm irrigation networks; ensuring sustainable financing for routine operation and maintenance; mainstreaming renewable energy systems in irrigation projects; expanding Water User Associations to cover all irrigation schemes, and further developing water measurement and water accounting systems at the farm level. In addition, the limited recovery of operation and maintenance costs through irrigation service fees leaves the sector heavily dependent on annual government budget allocations, which may slow the implementation of major investment projects whenever capital budget appropriations decline.

6.3 Conclusion

Iraq has a well-established institutional and legal framework for water resources management, supported by the Ministry of Water Resources through irrigation modernization programs, the development of Water User Associations (WUAs), the implementation of the irrigation service fee system, and the execution of extensive projects aimed at improving water use efficiency. Government funding through the national budget remains the primary source of investment in the sector, while international organizations contribute by supporting selected institutional and technical modernization initiatives. Nevertheless, the continued pressures arising from water scarcity and climate change require increased investment in irrigation modernization, the gradual and equitable strengthening of cost recovery mechanisms, the expansion of the role of Water User Associations in operation and maintenance, and improved efficiency in the allocation of financial resources. The success of Iraq's irrigation modernization pathway will ultimately depend on the ability of national institutions to combine sustainable government financing, international support, and participatory water management in order to enhance agricultural productivity and strengthen long-term water security.

7. Training Systems for Farmers and Personnel in the Irrigation Sector

Human and institutional capacity development constitutes one of the fundamental pillars of irrigation modernization in Iraq. The Ministry of Water Resources implements integrated training, capacity-building, and extension programs aimed at enhancing the competencies of water-sector personnel, farmers, and water users in support of sustainable water resources management and improved water-use efficiency. The Training and Development Department of the Ministry of Water Resources is responsible for strengthening the technical and administrative capacities of the Ministry's staff through the design and implementation of specialized training programs delivered both within Iraq and abroad. These programs cover a wide range of fields, including water resources management, operation and maintenance of irrigation and drainage infrastructure, dam and reservoir management, Geographic Information Systems (GIS) and remote sensing, digital transformation, project management, strategic planning, decision support systems, water crisis management, and climate change adaptation. The Department also implements Training of Trainers (TOT) programs and continuous professional development initiatives to enhance institutional capacity and improve the technical and administrative performance of the Ministry. At the farmer and beneficiary level, the Water Extension Division and the Water Users Associations Department, in coordination with the Training and Development Department, implement extensive training and awareness programs in collaboration with the Water Resources and Agriculture Directorates in the governorates. More than 120 training courses, workshops, seminars, conferences, and extension activities have been conducted, benefiting approximately 18,000 participants, including farmers, engineers, agricultural extension officers, and university students. These programs have focused on water conservation, on-farm and off-farm water management, modern

irrigation technologies, the use of sprinkler and drip irrigation systems, laser land leveling, and improving on-farm irrigation efficiency. Within the framework of the Water Users Associations (WUAs) Project, association members and management teams have received training in participatory water resources management, operation and maintenance of irrigation and drainage networks, improving equity in water distribution, enhancing water-use efficiency, and resolving conflicts related to shared water resources. Dedicated training, monitoring, and evaluation systems have also been developed for the associations to ensure the sustainability of local management of irrigation projects. These efforts have been further strengthened through technical assistance and capacity-building programs implemented by international organizations, particularly the Japan International Cooperation Agency (JICA), the United Nations Development Program (UNDP), the Food and

Agriculture Organization of the United Nations (FAO), the World Food Program (WFP), and the International Organization for Migration (IOM). These organizations have contributed to training farmers and Water Users Associations on modern irrigation technologies, solar energy applications, integrated water resources management, and the operation and maintenance of pilot irrigation projects. Despite the significant progress achieved, there remains a need to further strengthen specialized training programs in smart irrigation, digitalization, remote sensing, artificial intelligence, groundwater management, and the operation of closed-pipeline and pressurized irrigation systems. Expanding these areas of capacity development is essential to keeping pace with irrigation modernization requirements and ensuring the optimal and sustainable utilization of Iraq's water resources.

8. Lessons Learned from Previous and Ongoing Initiatives

Previous and ongoing initiatives in Iraq's irrigation and water management sector have demonstrated that irrigation modernization is not limited to the introduction of new technologies; rather, it requires an integrated approach that combines infrastructure rehabilitation, capacity building, strengthened local participation, and the use of modern data for informed decision-making. The rehabilitation of the Tal Al-Hawa Pumping Station under the North Al-Jazira Irrigation Project in Rabia Subdistrict, Nineveh Governorate, implemented in cooperation with the Food and Agriculture Organization of the United Nations (FAO) and financed by the European Union Regional Trust Fund, has demonstrated that rehabilitating critical irrigation infrastructure can restore irrigation services to more than 100,000 dunums, increase the irrigated area by at least 40%, improve farmers' incomes, and enhance food security in liberated areas. The WaPOR project for monitoring water productivity using remote sensing technologies has also demonstrated that satellite-based data can serve as an effective tool for measuring water-use efficiency and improving agricultural and water resources planning. The project highlights the importance of developing national databases and linking them with water and agricultural policies, in addition to training national technical staff in data analysis and its application to evidence-based decision-making. Ongoing projects in southern Iraq, funded by the Government of Canada and the Swedish International Development Cooperation Agency (Sida) and technically implemented by FAO, have further demonstrated that climate-smart agriculture, women's empowerment, the use of solar energy, modern irrigation technologies, and the improvement of agricultural value chains are essential components for strengthening the resilience of rural households to water scarcity and climate change. Likewise, the experience of converting selected sites from surface irrigation to closed-pipe irrigation—such as the Al-Ghadeer Water Users Association project in Al-Muthanna Governorate, covering an area of 160 dunums—has shown that small-scale pilot projects can provide a practical foundation for the gradual expansion of irrigation modernization. Another key lesson learned is that the success of irrigation modernization projects depends on effective partnerships among the Ministry of Water Resources, the Ministry of Agriculture, local governments, international organizations, and Water Users Associations (WUAs). Furthermore, field training, agricultural extension services, and capacity building are equally as important as investment in physical infrastructure, since the long-term sustainability of these projects depends on the ability of farmers and local institutions to operate, maintain, and manage modern irrigation systems efficiently.

8.1 Priority Actions for Scaling Up Irrigation Modernization

To scale up irrigation modernization in Iraq, a gradual and integrated approach should be adopted, beginning with successful pilot projects and progressively expanding to irrigation schemes and governorate-level implementation. The strategic priorities include the following:

- **First:** Rehabilitating critical irrigation infrastructure, particularly pumping stations, primary and secondary canals, and drainage networks, while prioritizing areas experiencing water scarcity or low water delivery efficiency.
- **Second:** Expanding the transition from traditional surface irrigation to closed-conduit and pressurized irrigation systems, including sprinkler irrigation, drip irrigation, and closed-pipe distribution networks, while providing farmers with technical and financial support to reduce the costs of this transition.
- **Third:** Mainstreaming the use of remote sensing technologies, Geographic Information Systems (GIS), and national water information databases, building on the experience of the WaPOR platform, to monitor water productivity, assess irrigation performance, and identify priorities for modernization.
- **Fourth:** Strengthening the role of Water User Associations (WUAs) in the management, operation, and maintenance of local irrigation systems, as participatory irrigation management enhances water distribution efficiency, reduces conflicts, and supports the long-term sustainability of irrigation infrastructure.
- **Fifth:** Promoting the use of solar energy in irrigation pumping and water supply projects, particularly in rural and vulnerable areas, to reduce operating costs and improve the reliability of water delivery.
- **Sixth:** Expanding training and extension programs for farmers, engineers, and technicians, with particular emphasis on modern irrigation management, irrigation scheduling, maintenance of closed irrigation systems, data analysis, and climate-smart agriculture.
- **Seventh:** Integrating women and youth into agricultural and water modernization programs, particularly in southern Iraq, where ongoing projects have demonstrated that women's empowerment enhances the resilience of rural households to water scarcity and climate change.

8.2 Regional and International Cooperation Opportunities

The Ministry of Water Resources has significant opportunities to expand regional and international cooperation in the fields of irrigation modernization and water resources management. Previous collaborations with the Food and Agriculture Organization (FAO), the European Union (EU), the Government of Canada, and the Swedish International Development Cooperation Agency (Sida) have demonstrated the success of partnership models between national institutions and international organizations in implementing practical projects that integrate infrastructure development, technological innovation, capacity building, and community empowerment. Iraq can further benefit from international cooperation in areas such as remote sensing, water productivity enhancement, climate-smart agriculture, the use of solar energy for irrigation, drought management, and the development of Water User Associations (WUAs). Cooperation with international organizations can also be expanded to facilitate the transfer of global expertise and its adaptation to Iraqi conditions. At the regional level, cooperation with the riparian countries of the Tigris and Euphrates River basins represents a strategic necessity for improving the exchange of hydrological data, enhancing drought and flood management, and promoting coordinated planning for transboundary water resources. Regional collaboration can also support the development of early warning systems, water quality monitoring, and the protection of shared ecosystems, particularly the Shatt Al-Arab and the Iraqi Marshes. Overall, Iraq's strategic priority

is to transform successful pilot initiatives into scalable national programs while strengthening regional and international partnerships to secure sustainable financing, facilitate technology transfer, build institutional and technical capacities, and achieve long-term water and food security under the challenges posed by climate change.

References

Ministry of Water Resources / Planning and Follow-up Directorate (Planning Department, Department of Operation and Maintenance for Irrigation Projects, International Water Department, Strategic Studies Department, Water User Associations Department, Environmental Policies Department, International Cooperation Division).

Legal and Contracts Directorate/ Investment Department.

General Commission for the Operation of Irrigation and Drainage Projects.

National Center for Water Resources Management (Water Control and Hydrological Analysis Department, Groundwater Studies Department).

Official website of Ministry of Planning / Central Statistical Organization (CSO).

ICID INTERNATIONAL SYMPOSIUM IN ASSOCIATION WITH UN-FAO ON “FUTURE PROOFING IRRIGATION: MODERNISATION AND IWRM, FINANCE, POLICIES, AND INSTITUTIONS” — JAPAN¹

1. Introduction in the context of irrigation in the country

1.1 Outline

About 70% of Japan's land area is mountainous and hilly, while plains cover 25% of the land area and farmland covers 13.5% of the land area. In addition, Japan has a series of mountains of a 2-3,000-meter range in the center of the islands. The rivers are short, whose gradients are quite steep, so rainwater runs off into the sea in a short period of time.

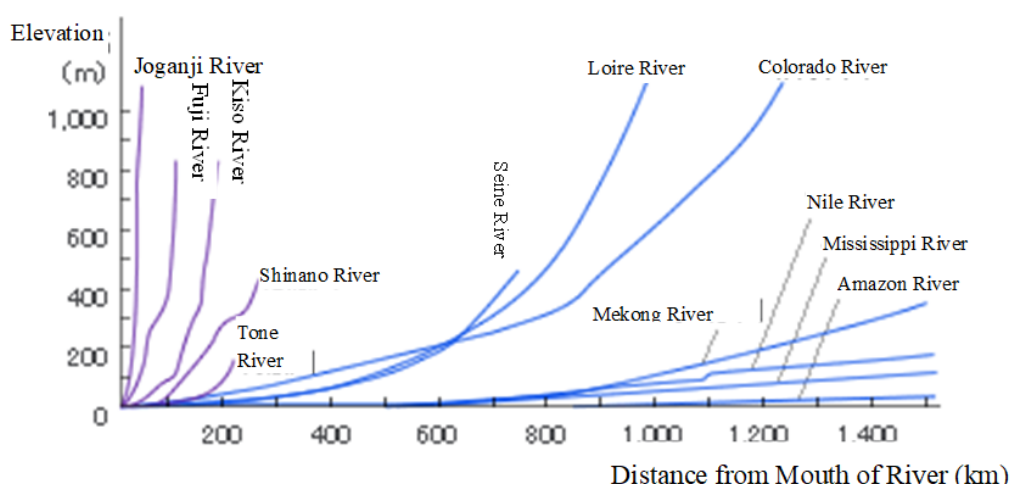


Figure 1. Longitudinal Sections of Rivers

Japan belongs to the Asian monsoon region and receives about 1,500 mm of annual rainfall, which is roughly twice as the world average. However, this rainfall is concentrated during the rainy and typhoon seasons, and there may be long stretches of time with almost no rain in the summer. Due to such natural conditions, rainfall alone is insufficient to supply water for rice paddies, and so for more than 2,000 years, Japan has been cultivating paddy rice with utilizing river water or reservoirs, and therefore developing irrigation facilities such as irrigation and drainage canals.

As of 2024, about 7,700 large-scale core facilities such as dams, water intake weirs, and irrigation and drainage pump stations have been installed to supply irrigation water for about 2.8 million hectares of farmland, or two-thirds of the nation's total farmland, and to protect the farmland and surrounding areas, including urban areas, from flood damage. There are 400,000 km of irrigation and drainage canals, including 50,000 km of main canals, which is equivalent to ten times the circumference of the earth.

1.2 History of Water Management

In Japan, a community-based consensus-building system has been formed in each village over a long history of rice cultivation, and a water management has also been carried out with villages as a basic unit. Since the Meiji era (beginning in 1868), the legal status of water management organizations has been gradually established alongside the development of various legal systems related to irrigation and drainage projects. Mergers of water management organizations have been promoted along with

¹ Japanese National Committee, ICID (JNC-ICID). E-mail: jncid@maff.go.jp

irrigation development projects for the integration of small-scale irrigation and drainage facilities in the modern era. Currently, irrigation and drainage management in Japan is carried out by groups of farmers, called Land Improvement Districts (LIDs), for each water use system.

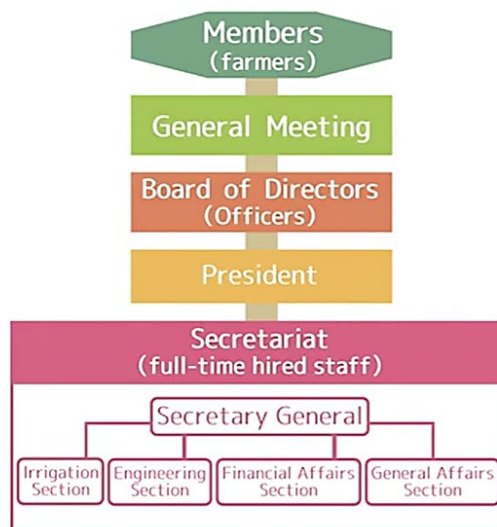


Figure 2. General LIDs organization chart

2. Irrigation system performance

In terms of management, LID is a farmer organization prescribed under the Land Improvement Act and established with the approval of the prefectural governor. Following the enactment of the Land Improvement Act, and in parallel with the implementation of land improvement projects, traditional village-based water management organizations and entities under the old laws were granted legal status as LIDs. Today, there are approximately 4,000 LIDs covering an area of about 2.4 million hectares, with a membership of about 3.3 million (as of 2025).

In terms of facilities, the asset value of large-scale core irrigation and drainage facilities—including 7,700 dams and water intake weirs—along with 50,000 km of core irrigation and drainage canals, is estimated at approximately 20 trillion yen (about 150 billion USD) based on replacement costs.

3. Challenges and risks associated with irrigation system in the country

3.1 Impact on Agricultural Production Activities and Rural Communities Due to the Decline in Farmers

The total population of Japan peaked in 2008 and has been declining. However, rural areas have experienced population decline ahead of urban centers, leading to a remarkable reduction and aging of the farming population. The number of core agricultural workers has halved, dropping from 2.4 million in 2000 to 1.2 million in 2021, with the peak of their age distribution now at 70 years or older. The cohort currently under 60 years old, who are expected to become the core agricultural workforce in 20 years, accounts for only about 20% of the total, standing at approximately 0.25 million individuals.

Furthermore, population decline and aging are progressing even more rapidly in rural areas, particularly in hilly and mountainous regions. This trend not only impacts agricultural production activities that have traditionally been supported by community-based collective actions, but also raises concerns that maintaining rural local societies themselves may become difficult.

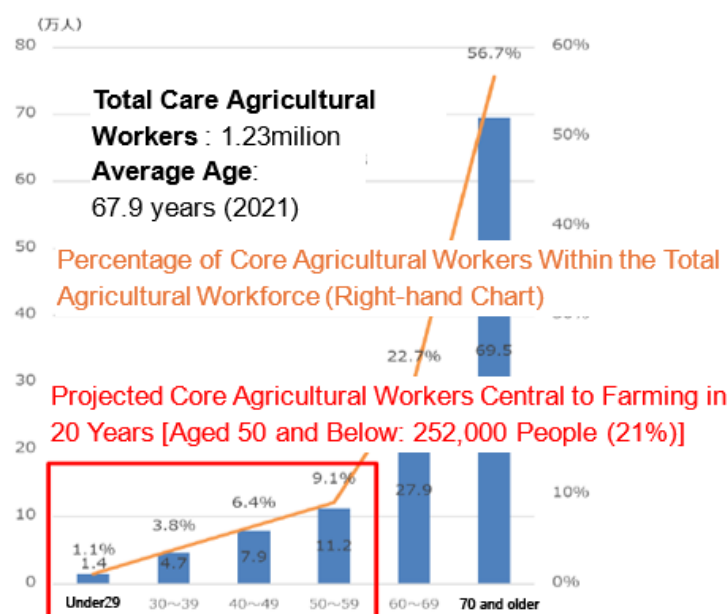


Figure 3. Age Distribution of Core Agricultural Workers (2021)

3.2 Vulnerability of the Agricultural Production Base and Infrastructure

Although the replacement and upgrading of core agricultural irrigation and drainage facilities are underway, the percentage of core facilities that have exceeded their standard useful life increased from 42% to 58% between 2007 and 2023. Similarly, the percentage of the total length of core canals exceeding their service life rose from 25% to 48% over the same period.

Core Agricultural Irrigation and Drainage Facility Category	2007 (H19)			2023年 (R5)		
	Number of Facilities with Extended Life	Standard Useful Life Exceeded	Ratio	Number of Facilities with Extended Life	Standard Useful Life Exceeded	Ratio
Core facilities (locations)	7,268	3,041	42%	7,763	4,535	58%
Reservoirs	1,237	104	70 and older	1,295	133	10%
Intake weirs	1,949	442	23%	1,976	897	45%
Agricultural drainage pump stations	2,801	1,801	65%	3,030	2,401	79%
Water gates, etc.	1,062	535	50%	1,138	862	76%
Management facilities	219	159	73%	324	242	75%
Main waterways (km)	48,570	12,033	25%	52,073	24,902	48%

Figure 4. Core Facilities Exceeding Standard Useful Life

As the aging of facilities progresses, it is often difficult to perform functional diagnosis and deterioration prediction, particularly for pipelines. In recent years, sudden accidents such as bursts and leaks have frequently occurred. The increasing frequency of these accidents not only destabilizes the food supply but also poses a risk of causing severe damage to daily life in rural communities.

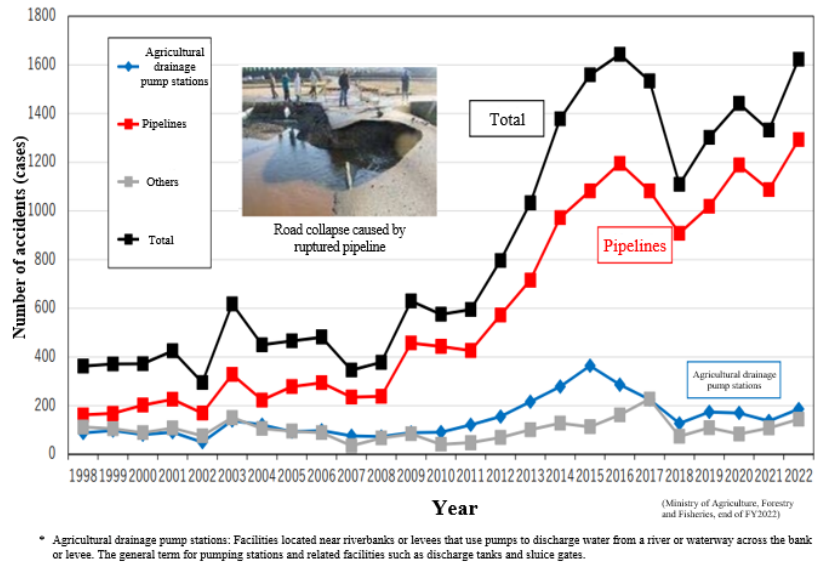


Figure 5. Sudden Accidents at Agricultural Irrigation and Drainage Facilities

3.3 Increasing Risk of Natural Disasters

In recent years, due to the effects of climate change, torrential rains have become more severe and frequent. The average annual number of occurrences with hourly rainfall of 50 mm or more was approximately 226 times during the period from 1976 to 1985; however, it has increased by about 1.5 times to approximately 330 times over the last ten years from 2014 to 2023. In the future, the increasing frequency of short-duration heavy rains and the growing scale of rainfall are expected to become even more pronounced, raising concerns about heightened flood risks and the risk of damage to aging agricultural water facilities.

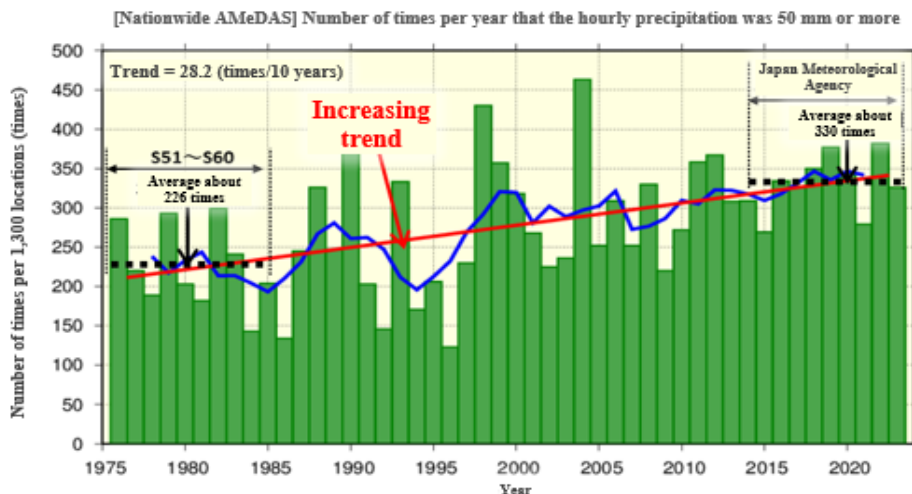


Figure 6. Annual Number of Times When Hourly Rainfall was 50 mm or More

4. Modernization pathways: it can cover more than one pathway described above

In Japan, a five-year “Land Improvement Plan” is formulated based on the Land Improvement Act, with the current plan established in 2025. To address various challenges surrounding agricultural infrastructure, including irrigation and drainage facilities, this plan sets quantitative performance targets for each policy objective. Through this approach, planned development is advanced while managing and verifying progress. The specific measures are as follows.

4.1 Strengthening the Production Base to Improve Productivity

4.1.1 Reducing Production Costs through Farmland Consolidation and Infrastructure Development for the Promotion of Smart Agriculture

In coordination with local plans, infrastructure development will be promoted, including the expansion of farmland into larger plots (which encompasses simplified development such as the removal of ridges), the leveling of farmland with an eye toward future larger-scale partitioning, and the conversion of irrigation and drainage canals into pipelines. These infrastructure improvements are designed to accelerate the accumulation and consolidation of farmland into the hands of core farmers, such as agricultural corporations. Furthermore, to facilitate the introduction of smart agricultural technologies such as automated agricultural machinery, developments such as farmland enlargement, land reallocation, gentle sloping of upland fields and orchards, and the widening of ridges will be promoted.

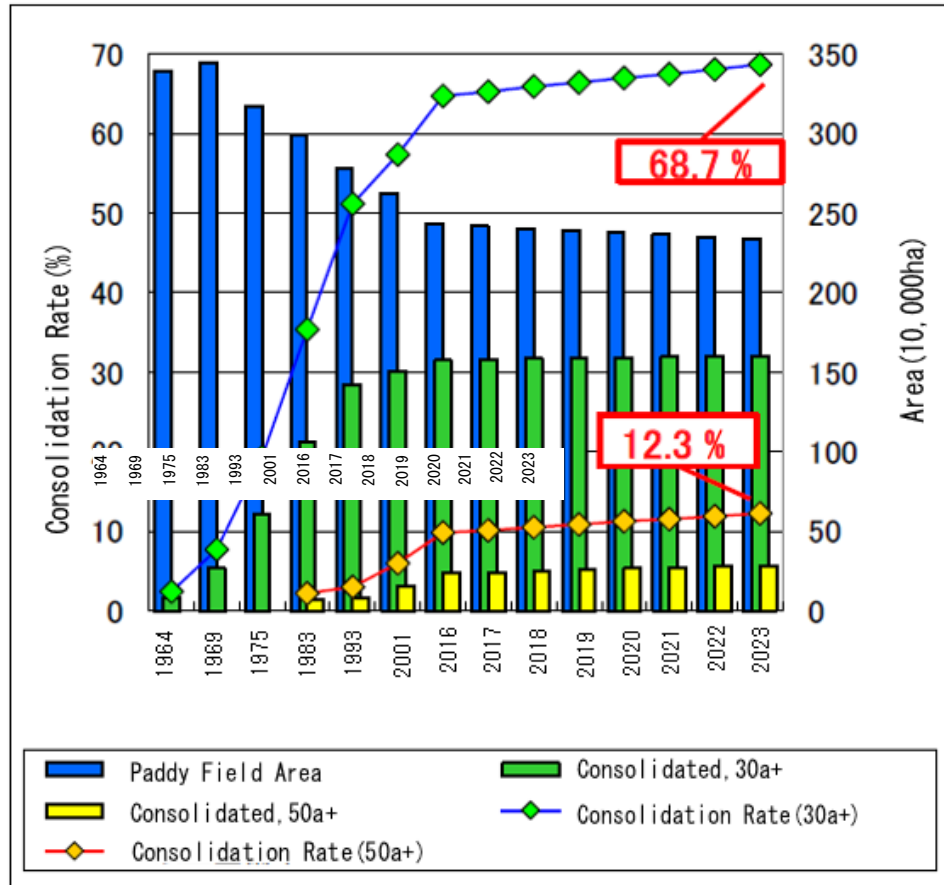


Figure 7. Trends in the Consolidation Status of Paddy Fields

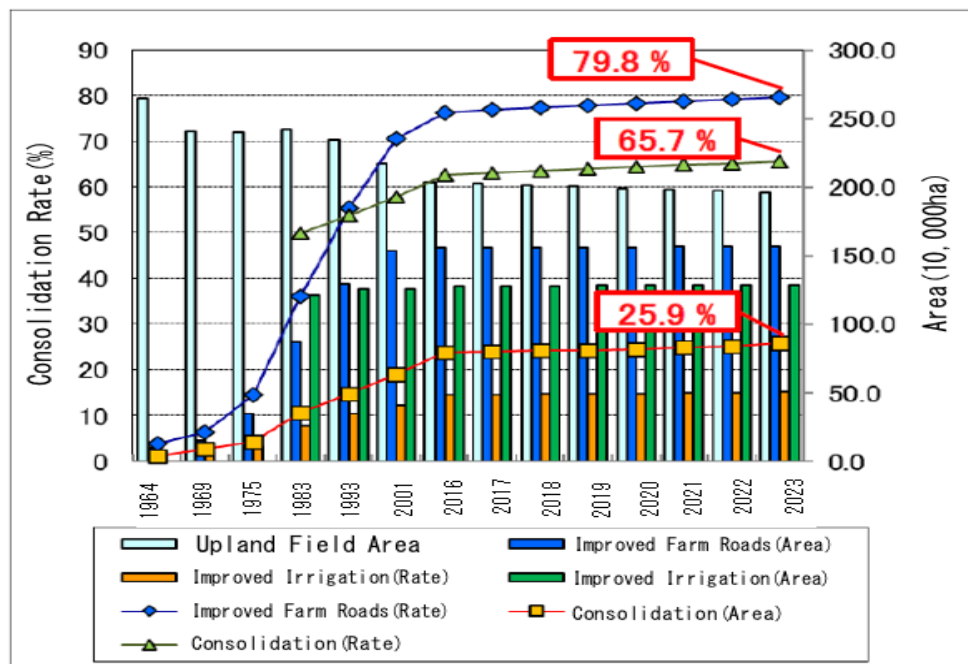
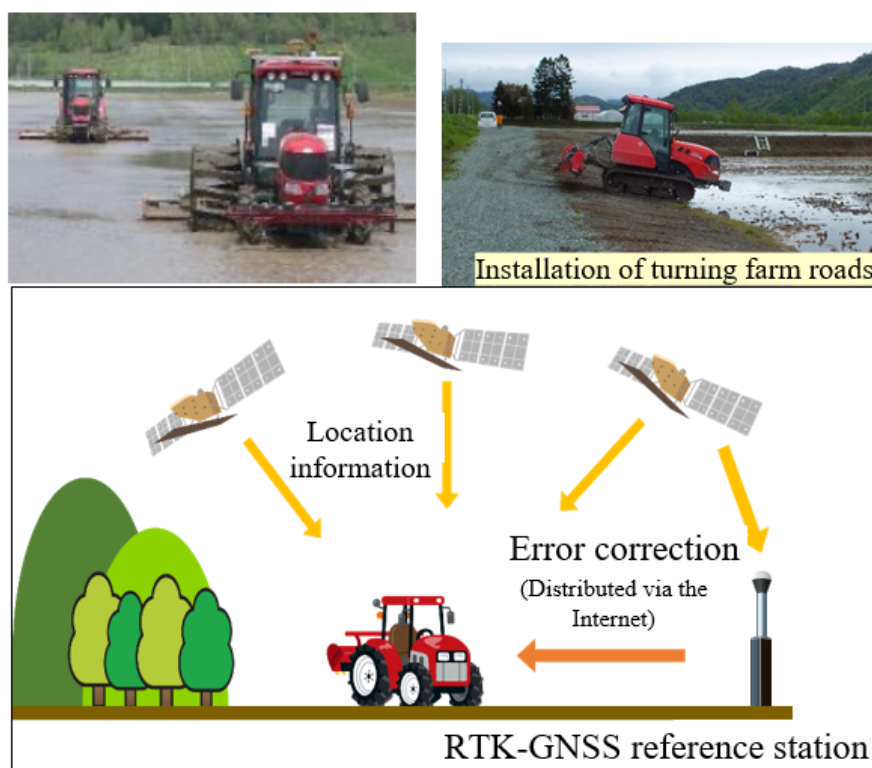


Figure 8. Trends in the Consolidation Status of Upland Fields



Figure 9. Enlarging Paddy Fields for Automated Machinery



RTK-GNSS reference stations installed to correct satellite positioning data and improve the accuracy of autonomous driving

Figure 10. Infrastructure Development for Smart Agriculture

4.1.2 Expansion of Production Based on Domestic Demand and Other Factors

To establish production areas for wheat, soybeans, vegetables, and horticultural crops like fruits, which have a high dependence on imports, high-functioning conversion of fields and orchards through drainage improvement will be promoted. This aims to ensure a stable supply of both volume and quality tailored to the specific uses required by consumers. In doing so, the introduction of water level control systems will be promoted to improve crop yields and quality by allowing the flexible regulation of underground water levels.



Figure 11. Block Rotation of Three Crops per Two Years: Rice, Wheat, and Soybeans

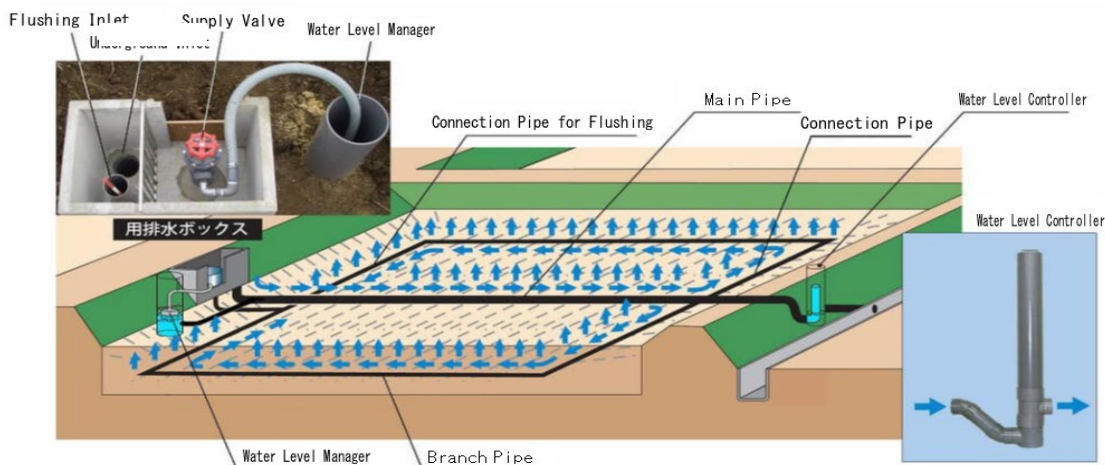


Figure 12. Overview of the Water Level Control System

4.2 Stabilizing Agricultural Water Supply and Drainage

For core agricultural irrigation and drainage facilities with wide-ranging benefits, a decline in functionality poses a risk of severely impacting the sustainable execution of local agricultural production activities. Therefore, planned renewals will be promoted not only through applications from farmers but also through the implementation of projects initiated by the national or prefectural governments based on the Land Improvement Act. To prevent incidents such as sudden accidents or water supply stoppages caused by a loss of functionality, several measures will be implemented through urgent projects. These include general measures to prevent similar damage implemented alongside recovery from sudden accidents, prompt reinforcement of agricultural irrigation and drainage facilities at risk of damage due to aging, and the construction of alternative facilities. In particular, responses for pipelines with a high risk of road subsidence will be prioritized and promoted.

In the maintenance and management of agricultural water infrastructure, while incorporating the latest technical knowledge, the utilization of robot technology for diagnosing the functionality of aging facilities will be promoted. Additionally, during facility renewals, the consolidation and reorganization of facilities, energy-saving measures for pumps, the utilization of renewable energy such as small-scale hydropower, and the introduction of ICT for labor-saving and automation of operations will be promoted. To reduce labor requirements for management tasks on canals around farmland, the conversion of irrigation and drainage canals into pipelines, the introduction and renewal of automatic water valves, the widening of ridges, and the covering of slope faces will be further promoted. Furthermore, technical support will be provided to facility managers to improve the efficiency and sophistication of maintenance and management based on the latest technical knowledge. In addition, to further enhance the efficiency and sophistication of maintenance and management, the digitalization of facility information will be pursued, and technology development in related fields, such as daily inspections and functional diagnosis utilizing AI, as well as renewable energy utilization, will be promoted.

4.3 Strengthening the Resilience of Agriculture and Rural Areas to Counter Increasing Disaster Risks

To respond to heavy rain disasters that are intensifying and becoming more frequent due to climate change, conventional plan formulation methods based on historical rainfall records will be reviewed. New planning methodologies incorporating future rainfall predictions will also be introduced to promote the development and improvement of drainage facilities adapted to climate change.

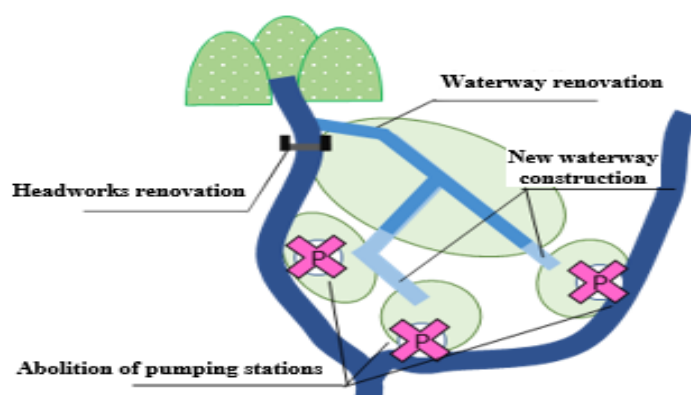


Figure 13. Consolidation and Reorganization of Facilities

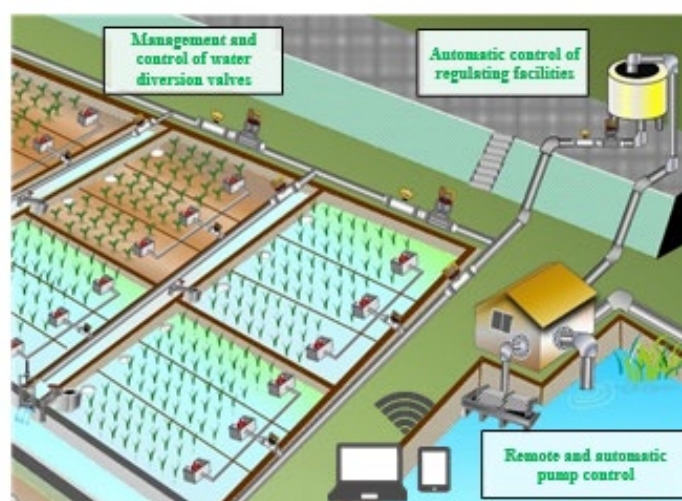


Figure 14. Introduction of New Technologies such as ICT(Remote and Automated Water Management)



Figure 15. Energy Saving in Irrigation and Drainage Facilities (Upgrading to High-Efficiency Motors)

To effectively and efficiently demonstrate and utilize the rainwater storage and flood control functions inherent in farmland and agricultural water infrastructure, the utilization of paddy fields as “Paddy Field Dams” will be promoted through the improvement of ridges, spillways, and drainage canals. Concurrently, the advance release of water and low-water-level management of agricultural dams and agricultural reservoirs will be promoted.

Furthermore, efforts will be made to develop and manage drainage facilities that also contribute to rainwater drainage for entire regions, including urban areas and local communities. In doing so, regarding these River Basin Disaster Resilience and Sustainability initiatives, information on the functions possessed by farmland and agricultural water infrastructure, as well as the roles played by farmers and facility managers, will be communicated to local residents and stakeholders.

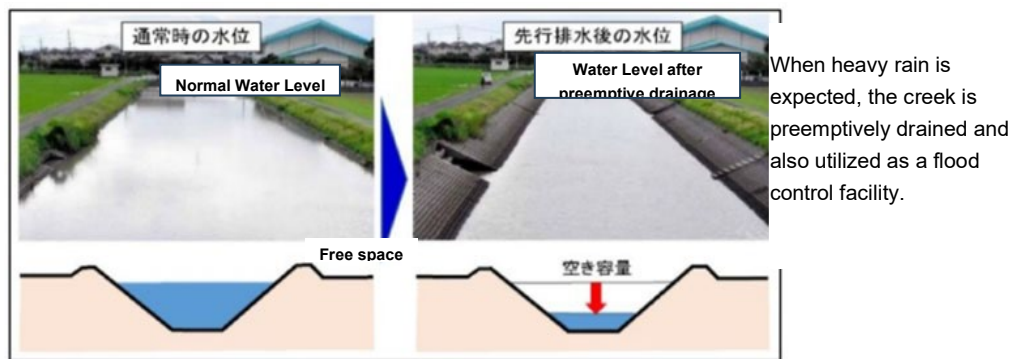


Figure 16. Approach to River Basin Resilience and Sustainability

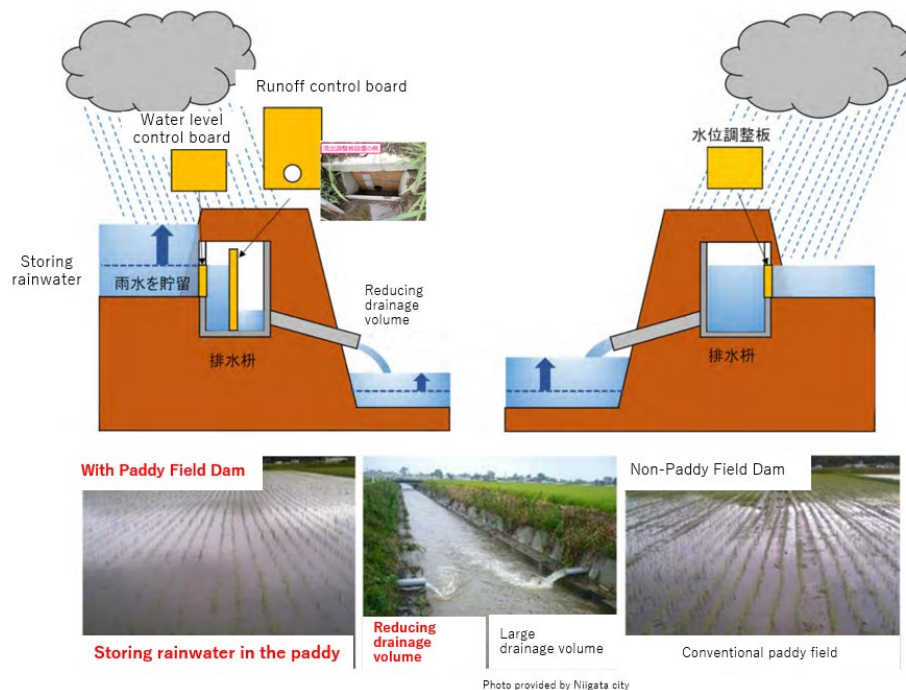


Figure 17. “Paddy Field Dam” Approach

4.4 Creation of Value and Appeal in Rural Areas

Rural areas, which occupy the majority of the national land, serve as the foundation for the stable supply of essential food. These areas are not only sites for industries such as agriculture and forestry but also serve as living spaces for diverse residents. Furthermore, they play multifunctional roles, including national land conservation, groundwater recharge, flood prevention, formation of beautiful and serene landscapes, biodiversity conservation, and the preservation of cultural heritage. To ensure that these multifunctional roles are fully realized for the benefit of urban residents as well, the revitalization of rural areas is essential.

In rural areas, including hilly and mountainous regions, farming operations that leverage local characteristics—such as horticulture utilizing cool climates and slopes—will be established. To achieve this, comprehensive development of production infrastructure, as well as facilities for production, sales, interaction, and lodging, will be promoted to improve incomes and create employment in rural areas. Furthermore, to enable continued residency in rural areas, including hilly and mountainous regions, the development of living infrastructure will be prioritized. This includes the preservation of rural community sewerage facilities and their consolidation and reorganization for efficient maintenance, the preservation of farm roads, and the improvement of information and communication environments.

In Land Improvement Districts (LIDs), activities will be vitalized by involving farmers of various management types and scales in operations. In collaboration with national and prefectural governments, the appointment of diverse talent—including women and young people—to board positions will be promoted in accordance with regional circumstances, thereby establishing sustainable long-term organizational management systems.

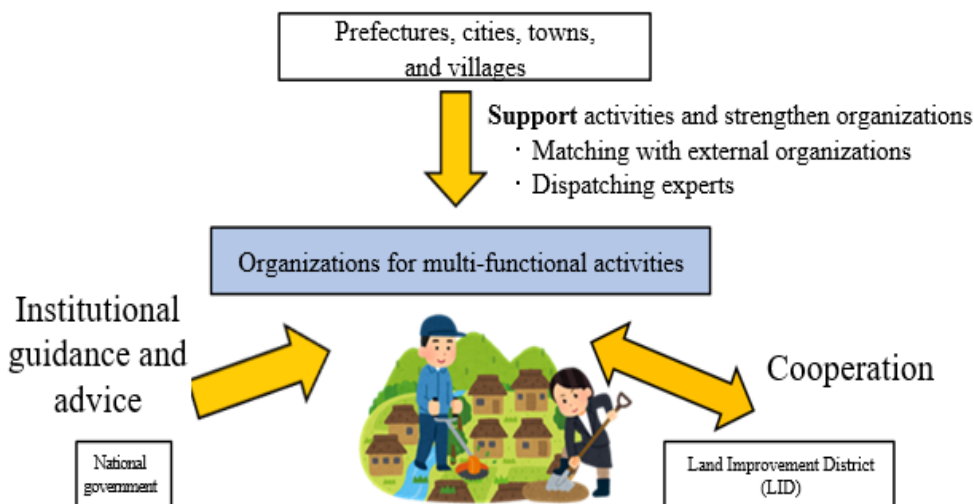


Figure 18. Strengthen the system to maintain joint activities in the region

5 Governance and institutions

5.1 The Basic Law on Food, Agriculture and Rural Areas

The Basic Law on Food, Agriculture and Rural Areas was enacted in 1999 as the fundamental policy framework aimed at ensuring a stable food supply for the public, promoting the sustainable development of agriculture, and advancing rural areas. Subsequently, to address shifting global food demand, advancing global warming, and rapid domestic population decline, the Law was revised in 2024 to position “ensuring food security” and “establishing an eco-friendly food system” as its new fundamental principles.

Through this amendment, provisions were legally established to ensure food security, secure food access and stable imports, promote the reduction of environmental burdens in agricultural production activities, and enhance productivity through the utilization of smart agriculture. Additionally, the revised Law mandates the promotion of collective activities that contribute to the preservation of farmland to maintain local communities.

5.2 Strategy for Sustainable Food Systems, MIDORI

The Ministry of Agriculture, Forestry and Fisheries has formulated the "Strategy for Sustainable Food Systems, MIDORI" (2021) to strengthen the response to SDGs and global warming, and will promote innovations, such as carbon neutrality, to reduce environmental burden in the medium to long term. The strategy sets 2050 as the target year and sequentially promotes the social implementation of technologies that are already being developed (by 2030), the development of innovative technologies and production systems (by 2040), and the social implementation of developed technologies (by 2050). In the irrigation sector, the strategy aims to introduce renewable energy sources, such as small-scale hydroelectric power generation, in order to achieve carbon neutrality by 2050.

5.3 The Land Improvement Act

The Land Improvement Act was enacted in 1949 with the objective of improving and developing the infrastructure for agricultural production, thereby contributing to increased agricultural productivity and food production. Subsequently, in response to growing disaster risks from recent climate change and rapid population decline in rural areas, and following the amendment of the Basic Law on Food, Agriculture and Rural Areas in 2024, this Act was revised in 2025 to explicitly mandate the proper implementation of the "conservation" of agricultural production infrastructure, in addition to its "improvement".

Through this revision, the phased construction of efficient conservation and management systems encompassing both structural and non-structural components is underway. These measures include the planned upgrading of core agricultural water infrastructure initiated by national and prefectural governments, the accumulation of funds by Land Improvement Districts (LIDs) for future facility renewals, and the promotion of formulating the "Midori Vision," a collaborative framework for regional stakeholders to collectively maintain and manage local infrastructure.

5.4 Water Management System

Land Improvement Districts (LIDs) typically manage irrigation and drainage facilities developed through Land Improvement Projects (LIPs), such as agricultural reservoirs, pumping stations, and major irrigation and drainage canals. However, large-scale facilities with high public interest developed by the national government require special technical considerations for their operation; therefore, the national government manages them directly.

The management responsibilities of LIDs include operating the gates of major irrigation canals, managing irrigation and drainage pumping stations, and overseeing water management in terminal canals. Sub-organizations, such as water users' associations, distribute water to farmland based on a rotation system. Safety inspections, weeding, and the cleaning of irrigation canals are frequently performed by farmers and local residents.

6 Financing

6.1 Land Improvement Projects (LIPs)

Construction and maintenance of irrigation and drainage facilities is carried out in accordance with the Land Improvement Act (LIA) (1949). In principle, LIPs under the LIA must be implemented with farmers' initiative and application with the consent of at least two-thirds of the beneficiary farmers in each project area. The project implementing bodies for LIPs are the national government, prefectures, and

organizations (LIDs, unions of LIDs municipalities, agricultural cooperatives, etc.), which is determined in consideration of a scale of projects, technical difficulty, etc. Project costs are borne by the national government, prefectures, municipalities, and beneficiary farmers in accordance with types and a scale of projects.

6.2 Collection of Levies by Land Improvement Districts (LIDs)

The operation and maintenance of irrigation and drainage facilities are conducted by Land Improvement Districts (LIDs), and the necessary costs are collected as levies from all benefiting members in proportion to the size of their farmland. Furthermore, the collection of these levies is mandated under the Land Improvement Act, carrying strong legally binding enforcement power.

7 Capacity development

To address changing circumstances and challenges—such as the decline and aging of farmers, the vulnerability of agricultural production infrastructure, and increasing disaster risks—and to contribute to achieving the policy targets set forth in this Plan, technical development will be promoted. This includes technical development related to smart agriculture, advanced facility conservation and management utilizing AI and other technologies, and systems for disaster risk prediction, information dissemination, and sharing in preparation for heavy rains and earthquakes. Furthermore, initiatives to ensure smooth introduction and dissemination will be promoted, including industry-academia-government collaboration, training, the dissemination and promotion of technical manuals, and on-site technical demonstrations.

In addition, the development of agricultural and rural engineering professionals will be promoted through collaboration among the national government, prefectural and municipal governments, educational institutions, research institutes, private companies, and the Federations of Land Improvement Districts. In this process, the focus will be on training personnel capable of utilizing the latest technologies on-site to improve the efficiency and sophistication of maintenance and management, as well as those capable of implementing measures tailored to regional characteristics through the accumulation of field experience. Concurrently, initiatives to secure talent from a wide range of fields and generations will be promoted.

8 Lessons learned and recommendations

Amid significant shifts in the circumstances surrounding agriculture and rural areas—such as the decline and aging of farmers, the vulnerability of agricultural production infrastructure, and increasing disaster risks—risks to food security have escalated to unprecedented levels in recent years. Furthermore, Japanese agriculture and rural communities are poised to confront an unprecedented challenge, with the number of core agricultural workers projected to plummet to approximately one-quarter of the current level in about 20 years. Anticipating this future outlook for agriculture and rural areas, it is essential to establish a foundation that enables highly productive farming by motivated next-generation farmers. This will ensure they can absorb abandoned farmlands, expand their scale of operations, and sustain national food production.

Under these circumstances, structural transformation in agriculture will be intensively driven during the initial five-year period.

To achieve thorough cost reductions, the consolidation and development of large-scale farmlands of 1 hectare or more will be accelerated. Concurrently, by sustainably securing the functions of agricultural water infrastructure, a foundation will be ensured that allows key farmers to expand efficient farming operations while improving productivity. In tandem, through the strengthening of agricultural and rural resilience to counter increasing disaster risks from climate change and other factors, continuous agricultural production activities and safe, secure living in rural areas will be realized. Furthermore, the maintenance of local communities will be pursued through the comprehensive development of production infrastructure alongside production and sales facilities, the improvement of living

infrastructure, and the vitalization of activities by reinforcing the organizational structures of Land Improvement Districts (LIDs) and activity organizations under the multifunctional payment system.

Through these measures, the improvement and conservation of agricultural production infrastructure, as well as the revitalization of rural areas, will be advanced, thereby contributing to securing food self-sufficiency potential. In doing so, the deployment of effective and efficient measures through the manifestation of "Rural Co-creative Power" and initiatives toward realizing "Sustainable agricultural production in harmony with the environment" will be promoted concurrently. Through these efforts, the "Water and Soil" that sustain the food and lives of the public will be passed down to future generations, aiming for the long-term assurance of food security and the realization of the multifunctional roles of agriculture.

IRRIGATION MODERNISATION IN SOUTH AFRICA: A NOVEL PATHWAY TOWARDS FUTURE PROOFING AND RESILIENCE — SOUTH AFRICA

Luxon Nhamo¹, Cuthbert Taguta², Sylvester Mpandeli³, Tinashe Dirwai⁴,
Stanley Liphadzi⁵, and Tafadzwanashe Mabhaudhi⁶

1. Irrigation Profile and System Performance in South Africa

South Africa is a water-scarce country whose food system relies heavily on both rainfed and irrigated agriculture (Nhamo, 2015; Stevens & van Koppen, 2015). The agriculture sector faces significant risks from worsening climate change, increasing water scarcity, ageing irrigation infrastructure, and deep structural inequalities (Nhemachena et al., 2020; van Koppen et al., 2017). Existing irrigation schemes and broader agricultural water management (AWM) systems perform far below their potential in terms of water productivity, inclusiveness, and resilience, particularly for smallholder and historically marginalised farming communities (van Koppen et al., 2017). Three cross-cutting mechanisms, namely wastewater recovery and reuse, water-energy-food (WEF) nexus implementation, and the mainstreaming of drought-tolerant and indigenous crops, implemented within the framework of the African Union's Irrigation Development and Agricultural Water Management AU-IDAWM pathways, present the most tractable entry points for improving productivity and resilience without requiring large-scale area expansion or additional freshwater allocation (Nhamo et al., 2025). This study highlights South Africa's irrigated agriculture performance and how to unlock its irrigation potential and transform existing systems to support equitable rural livelihoods, national food and nutrition security, and sustainable socio-economic growth under increasing water scarcity while also sustaining the natural base, with water security as the entry point.

Irrigation development and broader agricultural water management (AWM) play a critical role in stabilising production and enabling the cultivation of higher-value crops in South Africa, yet the performance and distribution of benefits are highly uneven (Dirwai et al., 2024). A relatively small share of irrigated land accounts for a substantial proportion of high-value output, while many smallholder and former homeland schemes struggle with unreliable water supply, deteriorating infrastructure, weak governance, and limited support services (Cai et al., 2017). At the same time, the majority of cultivated land remains rainfed, often in areas with poorer soils, high climate exposure, and limited alternative livelihoods, leaving many households exposed to climate and market shocks (Cai et al., 2017).

1.1. Status of irrigation development in South Africa

A combination of weather extremes and poor soil health leaves only 12% ha of the country's arable land suitable for rainfed crop production. Only 3% ha of the country's land is fertile for crop production (StatsSA, 2019). Approximately 1.3 million ha of land is irrigated, accounting for 1.5% of cultivated land and producing 30% of the country's crops, including 90% of fruit and wine exports (Cai et al., 2017; StatsSA, 2019). Significant growth potential exists in the Northern and Western Cape, though water scarcity and ageing infrastructure present challenges. Around 67% of the approximately 1.3 million small

¹ Water Research Commission (WRC), Lynnwood Manor, Pretoria, South Africa; E-mail: luxonn@wrc.org.za

² Centre for Transformative Agricultural and Food Systems, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, South Africa; E-mail 'tagutac@ukzn.ac.za

³ Senior Research Manager. Water Research Commission (WRC), Lynnwood Manor, Pretoria, South Africa; E-mail: sylvesterm@wrc.org.za

⁴ International Water Management Institute (IWMI), Harare, Zimbabwe; E-Mail t.dirwai@cgiar.org

⁵ Group Executive. Water Research Commission (WRC), Lynnwood Manor, Pretoria, South Africa; E-mail: stanleyl@wrc.org.za

⁶ Centre on Climate Change and Planetary Health, London School of Hygiene and Tropical Medicine (LSHTM), London, UK, E-mail: tafadzwanashe.mabhaudhi@lshtm.ac.uk

holder farmers in the country are women, cultivating approximately 14 million ha of cultivated land (NDP, 2013). Thus, most of the cultivated area is rainfed. About 45% ha of cultivated land is dedicated to maize production, the staple food. About 69% ha of the country's surface area is suitable for grazing, making livestock farming by far the largest agricultural sector (van Averbeke et al., 2011).

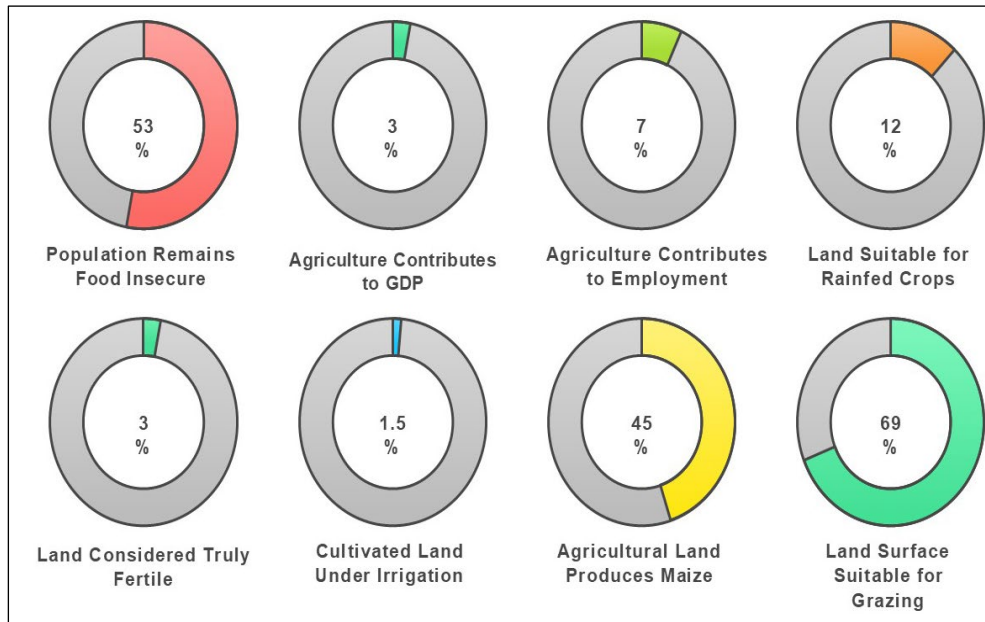


Figure 1. Agricultural statistical outlook in South Africa

In addition to its vast spatial area of 1.2 million km² and a diversified, most developed economy in Africa, South Africa has been significantly exposed to extreme weather events, with reported livestock deaths, widespread pests and diseases, escalating food prices, electricity load shedding, and water rationing in some municipalities (Masipa, 2017). Although the country is food-secure at the national level, there is a need to increase the area under irrigation to enhance crop-water productivity as the population continues to increase (StatsSA, 2019). However, irrigation expansion should consider water and energy availability, equally important sectors that support irrigation (Nhamo et al., 2025). The Western Cape, Northern Cape, Limpopo, and KwaZulu-Natal provinces have the highest proportion of agricultural land under irrigation (Meza et al., 2021). The other provinces have irrigated areas of less than 15%, most of which are located along an axis of regions with extreme dry conditions (Magidi et al., 2021). Most rainfed agriculture is practised in marginalised areas, under the control of smallholder farmers (Nhamo, Mpandeli, et al., 2022).

South Africa has a dual agricultural economy comprising a highly productive, export-oriented commercial sector (occupying ~87% of farmland) and a largely subsistence-based sector in former homeland regions (Vink et al., 2022). This structure drives significant food production, yet it highlights deep disparities in land ownership, technology, and market access (Nhamo, Mpandeli, et al., 2022; StatsSA, 2019). Commercial farmers generally have more resources to adapt to climate change and variability than smallholder farmers. The sector contributes about 3% to South Africa's gross domestic product (GDP) and about 10% to formal employment (Nhemachena et al., 2020; StatsSA, 2019). The combination of climate change and soil degradation leaves only 12% of the country's land suitable for rainfed agriculture (Fig. 1). Only 3% of South Africa's land is considered truly fertile. Almost 1.3 million hectares are under irrigation, accounting for 1.5% of the cultivated land, producing 30% of the country's crops. Around 1.3 million smallholder farmers cultivate approximately 14 million hectares of land. As a result, most of the cultivated area relies on rainfed agriculture (Mabhaudhi et al., 2018). Over 45% of the agricultural land is used to grow maize. However, around 69% of the country's land surface is suitable for grazing, making livestock farming the largest agricultural sector (StatsSA, 2019). Irrigation

is a key component of AWM and is fundamental for climate change adaptation and ensuring food and water security (Nhamo et al., 2023). Implementing innovative and efficient irrigation technologies helps smallholder farmers mitigate climate risks and enhance their resilience. Therefore, converting rainfed areas to irrigated land could enhance crop productivity year-round and create employment (Smith et al., 2024). However, irrigation expansion should be informed by transformative and circular approaches, including the WEF nexus (Nhamo et al., 2025).

South Africa has 4,632 dams, which collectively hold more than 50,000 billion m³ of water. Of these, 3,822 dams (82%) are dedicated to irrigation, holding 18 billion m³ of water (FAO, 2024). The total annual agricultural water withdrawal in South Africa is approximately 8 billion m³, accounting for 63% of total water consumption and constituting the largest water-use sector in the country's water-scarce economy (Stevens & van Koppen, 2015). As the rainy season has become shorter and is now associated with floods and extended dry spells, South Africa's extensive dam network plays a vital role in capturing runoff water used for irrigation during inter-seasonal dry periods. Irrigation in South Africa holds immense potential to boost productivity and lift rural communities out of poverty.

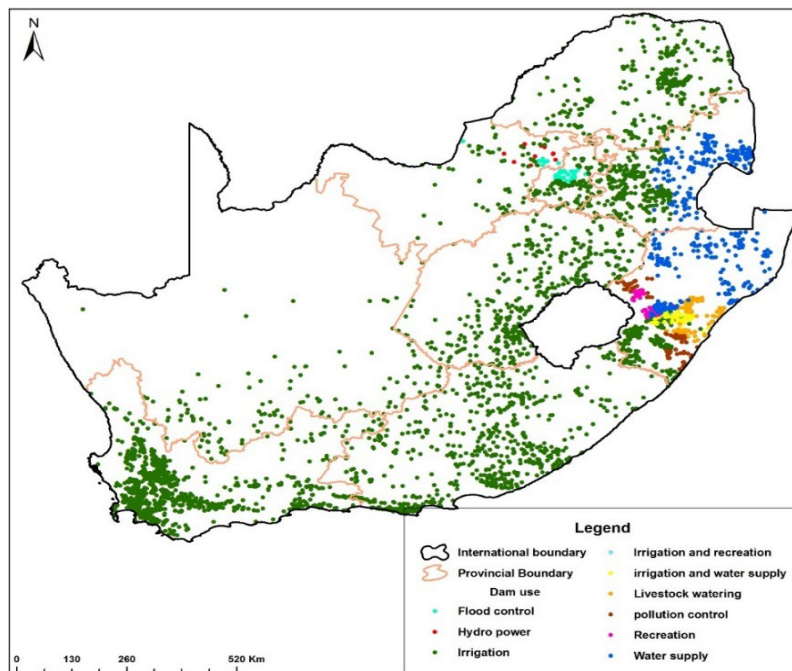


Figure 2: The dam network of South Africa by use

The status of irrigation, coupled with the low productivity of rainfed systems, uncoordinated institutional arrangements, and water scarcity, is the main factor that shapes the future of agricultural water management and irrigation development in South Africa. Taken together, these patterns highlight not only current constraints but also strategic opportunities to improve productivity, resilience, and equity in the country's water-limited context. Four core findings emerged from this assessment:

- Irrigation is extensive, but performance is highly uneven.
- Rainfed systems, mostly in smallholder areas, face the highest risk, yet receive the least support.
- The policy and institutional framework are advanced in theory yet fragmented in practice.
- There exists substantial potential for productivity and resilience gains through targeted investments rather than large-scale expansion.

Given the water constraints, unquantified ecological reserves, competing sectoral demands, and climate uncertainty, the scope of irrigation expansion is limited. However, if pursued, it needs to be holistically

considered in terms of water and energy availability. Major opportunities lie in modernising and revitalising existing irrigation schemes, scaling farmer-led irrigation, and supporting technological innovations that enhance crop-water productivity without compromising environmental integrity. These changes are driven only by a harmonised, transformative, and cross-sectoral governance framework that is currently lacking. The changes call for significant reforms from current practices supported by investment from both the public and private sectors. Rather than focusing solely on expanding irrigated area, the study proposes an inclusive strategy that holistically improves system performance, strengthens governance, and expands opportunities for smallholder farmers within existing water limits.

2 KEY CHALLENGES AND RISK DRIVERS

Despite the opportunities presented by irrigated agriculture, realising integrated AWM at scale requires confronting structural barriers (Fig. 3) identified across all four of the African Union's Irrigation Development and Water Management (AU-IDAWM) pathways (AU, 2020). These fall into four categories: technical and infrastructural constraints, governance and institutional fragmentation, socio-economic inequalities, and climate-driven uncertainty, as outlined in the Malabo declaration (AU, 2014). The common threat is a systemic failure to manage water, energy, and food as an integrated system (Mabhaudhi et al., 2018). Siloed resource-efficiency interventions have been insufficient, contributing to degraded environments, depleted water bodies, and persistent productivity shortfalls (Et-Taibi et al., 2024; Smith et al., 2023).

Technical and infrastructural constraints are prevalent in Pathways 1 and 2 of the AU-IDAWM (Pathway 1: improved water control and watershed management in rain-fed farming; Pathway 2: farmer-led irrigation development (FLID)). Smallholder farmers in rainfed and farmer-led irrigation systems generally lack access to precision technologies, real-time data, and updated extension support, leaving the pathway disproportionately exposed to climate variability (Dirwai et al., 2024; Serote et al., 2023; Touch et al., 2024) as shown in Fig. 3. Governance and institutional fragmentation cut across all pathways, i.e., water, energy, and agriculture sectors are largely planned and budgeted in silos, preventing the coherent nexus-based solutions that integrated AWM demands (Richelle et al., 2025). Policy frameworks compound this fragmentation when they fail to reflect on-the-ground realities or exclude smallholder voices from design processes (Touch et al., 2024). Socio-economic inequalities amplify vulnerability, particularly in Pathway 2 FLID contexts, where land tenure insecurity, limited access to credit, and inadequate market linkages prevent farmers from adopting available technologies (Nguyen et al., 2023). Finally, climate uncertainty poses growing planning risks across all pathways. Unpredictable rainfall, intensifying droughts, and extreme weather events make long-horizon infrastructure investment progressively harder, especially in rainfed Pathway 1 systems (Stringer et al., 2021). Fig. 3 summarises the inherent barriers across the four pathways, and overcoming them is a precondition for the investment opportunities.

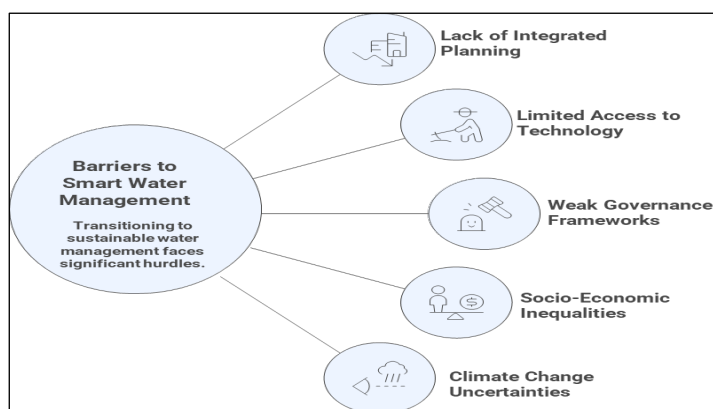


Figure 3. Key barriers to the adoption of smart AWM practices

3. CLIMATE RESILIENCE AND ENVIRONMENTAL SUSTAINABILITY

South Africa is prone to recurring droughts and other extreme weather events (heatwaves, floods, novel pests and diseases, increased evapotranspiration) due to the El Niño Southern Oscillation (ENSO) phenomenon (Baudoin et al., 2017). The extreme weather events are exacerbating water and food insecurity in the country. These extreme events continue to affect parts of the country, with the coastal provinces enduring most of these extremes, and KwaZulu-Natal and the Eastern Cape are affected by extreme flooding each year (Byaruhanga et al., 2025; Ndlovu et al., 2021).

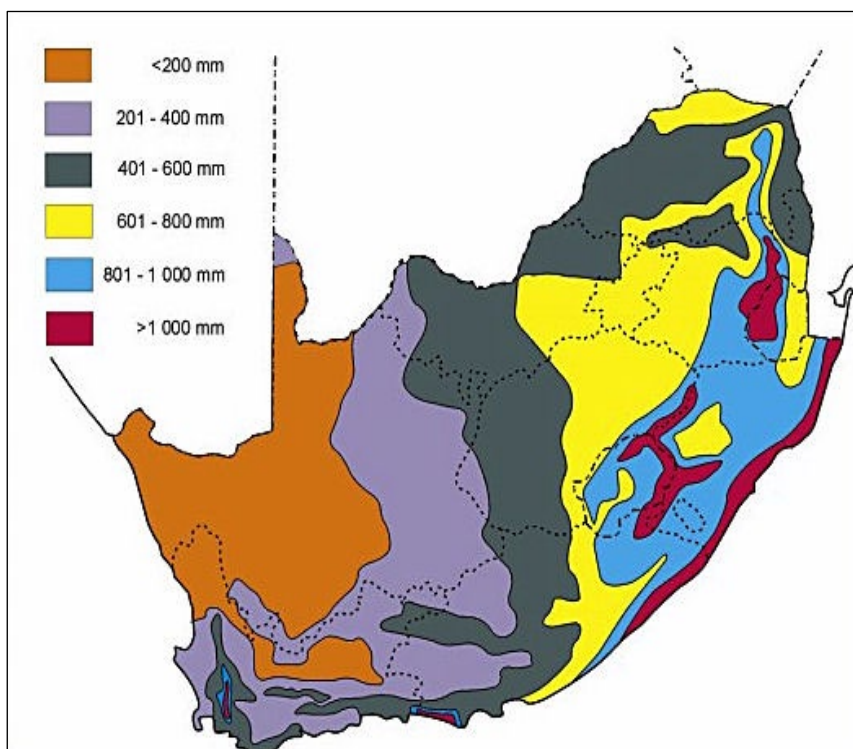


Figure 4. Annual average rainfall distribution in South Africa

Approximately 80% of the country is semi-arid to arid, and only 18% is classified as dry sub-humid or sub-humid (Fig. 4) (Bonetti et al., 2022). Climate change projections for South Africa indicate that temperatures will increase by 1°C to 2°C in coastal regions and by 3°C to 4°C in interior regions by 2050 (Mbokodo et al., 2020). Rainfall patterns are expected to shift, potentially leading to low streamflow in western regions (Xulu et al., 2023). Some regions in the southwestern provinces are projected to receive above-normal rainfall, with a risk of floods that may result in crop and infrastructure destruction and loss of human life (Mbokodo et al., 2020). These weather extremes will have implications for agriculture, as yields are expected to decline, affecting food and nutrition security (Ndlovu et al., 2025).

The overall impact of climate change and variability on water resources is uncertain, but it will certainly vary significantly from place to place (Kusangaya et al., 2014). Of late, most areas have been affected by climate change-induced floods, resulting in property destruction and loss of life (Ndlovu et al., 2021). The increasing population in South Africa and the water-use trends indicate that the country will exceed the planetary boundary of economically usable water resources by 2050 (Nhamo, 2015; Stevens & van Koppen, 2015). Thus, the adverse impact of climate change and variability is projected to exacerbate existing systemic water insecurity challenges. As already stated, South Africa's agricultural sector accounts for about 63% of the available freshwater resources, yet estimates indicate that irrigation water demand will increase by about 4% and 6% by 2030 to meet the food demands of a growing population (Ngarava, 2021). The increased demand for irrigation water should also be viewed within the context of

increased demand for energy generation and domestic use due to a growing population. The increased frequency of droughts and floods is threatening rainfed agriculture by increasing the risk of crop failure (Nhamo et al., 2019).

3.1. Adaptation strategies in irrigation systems in South Africa

Climate change impacts are projected to intensify, necessitating urgent actions and strategies to improve resilience and adaptation, and to ensure food and water security (IPCC, 2022). The intensity and frequency of weather extremes are exacerbating water scarcity in arid countries, including South Africa, the 30th driest in the world. The study proposes the following key interventions to enhance adaptation and resilience: (i) rehabilitating and revitalising existing irrigation schemes, (ii) expanding the area under irrigation, (iii) exploring opportunities to use groundwater for irrigation, (iv) implementing policies and investment programmes targeted towards smallholder farmers to stimulate productivity, (v) subsidising agricultural inputs for smallholder farmers, (vi) promoting agronomic practices and improving crop-water productivity, (vii) exploring other opportunities to improve crop-water productivity in the rainfed agriculture system, (viii) improving water harvesting technologies, (ix) mainstreaming drought-tolerant and indigenous underutilised crops that are adapted to shortened rain seasons and higher temperatures, require fewer inputs than commercially bred varieties, provide nutritional resilience when staple crops fail, and reduce agricultural water demand across both rainfed and irrigated systems (Ndlovu et al., 2024; Nhamo, Van der Walt, et al., 2022) and (x) using earth observation technologies to monitor, collect and disseminate agro-meteorological information in near real-time for farmers to make informed on-field decisions (Fanadzo & Ncube, 2018). Rather than advocating indiscriminate expansion of irrigated area, the study highlights the pathways to improve water productivity, resilience, and equity in both irrigated and rainfed systems, and how policy and institutional arrangements need to evolve to support that shift.

4. IRRIGATION MODERNIZATION PATHWAYS

As irrigation is a key climate change adaptation strategy, the AU's IDAWM Framework supports its expansion in Africa by identifying investment opportunities and strengthening strategic interventions to drive the strategic framework (AU, 2020). The AU-IDAWM Framework is anchored on four pillars that identify strategic development pathways for enhanced spatio-AWM practices across scales in Africa. The four AU-IDAWM pathways were developed in response to the varied farming scales existing in Africa. As an example, Pathway 1 targets rainfed farming, which is predominant compared to irrigated agriculture. Rainfed farming is generally practised by smallholder farmers located in marginalised rural areas due to historical imbalances. Pathway 2 addresses the farmer-led irrigation development (FLID) pathway, which has dominated research and development. Most smallholder farmers rely on common-pool resources (CPRs) such as water to irrigate their fields. FLID setting resembles a typical irrigation scheme, managed by a water user association (WUA). Pathway 3 emphasises modernisation over developing new schemes due to the high establishment costs of initiating them. In contrast, Pathway 4 focuses on using unconventional water sources for irrigation to alleviate pressure on freshwater demand (AU, 2020).

4.1. South Africa's IDAWM pathways development

South Africa has approximately 60,000 commercial farmers cultivating nearly 102 million ha of land (StatsSA, 2019). The land area under commercial farming is decreasing due to low productivity and droughts. This has subsequently created a surge in smallholder agriculture. The commercial sector operates from a more advantageous position than the smallholder sector, as it has access to credit to improve farming operations. The agricultural sector applies different AWM practices depending on scale and sub-sector (Table 1).

Table 1. Agricultural water management typologies under Pathway 3: Irrigation Scheme Development and Modernisation

Scale	AWM practice	Description
Smallholder	Ridging	Although it is primarily done to prevent soil erosion, it subsequently increases contact time between the water and the soil interface. This increases the plant's available water.
	Mulching	This technology uses crop residue retention to increase ground cover and minimise bare-soil evaporation.
	Rotation and inter-cropping	Rotation implies continuous sequencing of crops in a defined pattern. Dryland farmers practice rotation between cereals (maize) and legumes to prevent pests and diseases and to diversify their diets. This practice improves soil fertility, which enhances soil water retention. Intercropping provides soil cover and reduces soil evaporation.
Commercial	Mulching	Build up soil organic matter to reduce evaporative water loss and maximise the soil's water-holding capacity.
	Technological shift: Micro and drip irrigation	Use more efficient irrigation systems, such as drip irrigation.
	Drones	Drones for mapping soil moisture stress for targeted irrigation.
	Operation and maintenance	Maintain irrigation systems regularly.
	Water budgeting	Recording actual water use to compare against registered use.
	Drought-tolerant cultivars	Using drought-resistant varieties

South Africa is largely arid to semi-arid, making irrigation a requirement to sustain irrigated agriculture for food production and to meet the food demands of an increasing population. Table 2 presents the challenges and opportunities for each AU-IDAWM pathway.

Table 2. Opportunities and challenges in irrigation development and agricultural water management in South Africa, for each of the AU-IDAWM framework pathways

Pathway	Challenges	Opportunities
Improved Water Control and Watershed Management in Rain-fed Farming	Rudimentary irrigation methods (bucket system)	Water harvesting techniques employed
	Unreliable rainfall due to climate variability	Availability of treadle and motorised pumps for water abstraction from shallow wells
	Poor or no access to extension services that provide knowledge on spatially available run-off and locating run-off generating areas for effective rainwater harvesting	
	Low-level investment in agricultural development	
Farmer-led Irrigation Development (FLID)	Laborious	Investments for revitalisation
	No titling as land largely belongs to traditional authorities	Some degree of knowledge on the benefits of CA and intercropping is evidenced by engaging in the practices
	Limited knowledge capacity on implementing climate-smart agriculture (CSA)	Availability of treadle and motorised pumps for water abstraction from shallow wells Attract the youth to agriculture through the deployment of smart technologies
	Poor O&M programmes for canals Unwillingness by farmers to pay water fees meant for O&M programmes. Vandalism of upgraded hydraulic infrastructure	A willingness by higher learning institutions to invest in research around FLID. Participatory irrigation management (PIM) for an increased sense of ownership

Pathway	Challenges	Opportunities
Irrigation Scheme Development and Modernisation	Modernisation is happening in phases, and some farmers might be left out. High government expenditure for small to medium schemes that are performing below expectations	Improved water conveyance and water application infrastructure for improved water use efficiency
		Participatory irrigation management (PIM) for an increased sense of ownership
Unconventional Water Use for Irrigation	Absence of a guiding framework at the national level	Availability of low-cost DEWATS systems
	Over-reliance on surface water abstraction and operational procedures	Pilot DEWATS projects a data hub for identifying challenges and bright spots
	Un-utilised desalination plants	
	High establishment costs for desalination plants	
	Health and sanitation hazards for wastewater usage	

4.2. Opportunities for integrated systems adoption in water management

Building on the pathway-level gaps identified in the comparative analysis, three convergent opportunity streams offer the most tractable entry points for South Africa. Each maps directly onto specific AU-IDAWM pathway weaknesses. Precision and technology-enabled irrigation upgrades primarily focus on Pathway 3 (scheme modernisation) and Pathway 2 (FLID efficiency deficits). Mainstreaming indigenous and water-efficient crops strengthens Pathway 1 (rainfed AWM resilience). Integrating wastewater reuse and renewable energy directly advances Pathway 4 (unconventional water use), which currently remains urban and niche. Together, these streams implement an integrated and transformative nexus approach that promotes holistic management of water, energy, and food resources to enhance sustainability, equity, and climate resilience, while also providing a framework for cross-sectoral investments (Mabhaudhi et al., 2018) (Table 3). In South Africa, this is particularly important because irrigation already accounts for roughly 63% of the national available freshwater withdrawals, meaning that productivity gains must come primarily from smarter use of existing water rather than large additional abstractions. This is augmented by smart technologies, which enable more efficient water delivery to crops, minimising losses from evaporation and runoff, thereby ensuring that water is used precisely where and when it is needed (Parra-López et al., 2025).

Precision and smart irrigation technologies represent the first stream (Table 3). Sensor-driven scheduling, automated delivery, and variable-rate application minimise evaporation and runoff losses while maximising yield per unit of water, thus directly addressing the productivity gaps identified across both commercial and smallholder systems in South Africa (Abdul-Gafaar et al., 2025). The second stream is mainstreaming indigenous and underutilised crops into both irrigated and rainfed systems. Their lower input requirements and greater tolerance of erratic rainfall build resilience within Pathway 1. At the same time, their nutritional value provides a safety net when commercially bred varieties fail under drought or heat stress (Mabhaudhi et al., 2019). The third stream integrates wastewater reuse and renewable energy into irrigation systems, advancing Pathway 4 while reducing the energy and fertiliser costs that constrain scheme viability. Treated wastewater closes nutrient loops and reduces dependence on synthetic fertilisers; solar-powered pumping lowers operational costs and energy footprints (Abou Jaoude et al., 2025). Nexus frameworks provide the institutional logic for packaging these streams into coherent investment programmes (Adamos et al., 2023). South Africa can use these integrated approaches not only to increase efficiency, but also to tackle equity gaps, especially by targeting smart AWM investments to underperforming smallholder schemes and rainfed systems where the largest resilience gains are likely.

Table 3. Cross-sectional opportunities for integrated systems adoption in irrigation development and water management

Characteristic	Smart Irrigation	Wastewater Reuse	Integrated Farming Systems	WEF Nexus
Water Use Efficiency	Improved water delivery	Nutrient recovery for reuse	Optimises water resources	Promotes sustainable resource management
Crop Yields	Enables efficient water delivery	Reduces reliance on synthetic fertilisers	Increases food production	Integrates food waste into resource cycle
Sustainable Farming	Minimises losses from evaporation	Minimises water pollution	Reduces environmental impact	Formulates coherent strategies
Energy Use	Leverages renewable energy sources	Reuses nutrients from wastewater	Lowers energy footprints	Optimises energy use
Crop Selection	Water-efficient crop selection	Mainstreams underutilised crops	Improves crop productivity	Promotes sustainable food systems

5. GOVERNANCE AND INSTITUTIONAL FRAMEWORKS

Irrigation governance in South Africa is anchored in a comprehensive, post-apartheid legal framework designed to promote equity, sustainability, and efficiency, primarily through the National Water Act (NWA) of 1998 and the Water Services Act of 1997 (Nhamo, Mpandeli, et al., 2022). The system is largely decentralised, placing water resource management under the management of regional and local institutions, with the Department of Water and Sanitation (DWS) acting as the public trustee of the country's water resources. The country's water governance and institutional frameworks are aligned to regional and global frameworks, such as the AU-IDAWM Framework and the water instruments of the Southern African Development Community (SADC). The country's water and agricultural policy, guided by the National Water Act (1998), is highly advanced, focusing on equitable allocation and sustainability, aligning with the AU IDAWM's emphasis on climate-resilient, inclusive, and efficient water use. The framework supports SADC goals by emphasising Integrated Water Resources Management (IWRM) and climate-resilient agricultural practices.

The Constitution of the Republic of South Africa is the overarching document that guides all other legislative and policy instruments adopted by the government (RSA, 1996). Water access to all is enshrined in the Constitution and implemented by the work of ordinary status, as highlighted by the Constitution. The Constitution states that everybody has the right to access sufficient water, food, and energy. The Constitution informs the development and implementation of the National Water Act and the White Paper on Agriculture, among others (Table 4). South Africa's governance frameworks are influenced by regional and international agreements that inform the country's own governance frameworks. Thus, the country's governance frameworks are implemented in alignment with these international frameworks.

Table 4. Policy frameworks governing the water and agriculture sectors in South Africa.

Water sector	Agriculture (food) sector
National Water Act 36 of 1998 National Environmental Management Act 107 of 1998 National Water Resource Strategy 3 (2020-2030) White Paper on a National Water Policy for South Africa Water for Growth and Development Framework Water Services Act (Act 108 of 1997)	White paper on energy policy (1998) White paper on renewable energy (2003) 1 Integrated energy plan (IEP, 2003 and 2005) Integrated resource plan (IRP, 2011) Strategic Agriculture Sector Plan Agriculture & Agro-processing Master Plan (2022)

The policy frameworks, primarily the National Water Act and various agricultural policies, are the instruments that drive equitable access to resources, sustainable development, and economic growth. They transition from a historical and exclusionary practices to equitable allocation, environmental protection, and support food security through sustainable, efficient agriculture. These frameworks are crucial for managing the country's limited water resources for agriculture, particularly in the face of climate change and increasing competition with industrial users (Khwidzili & Worth, 2017).

6. INVESTMENT OPPORTUNITIES FOR IRRIGATION IN SOUTH AFRICA

There are promising investment opportunities for irrigation development in South Africa. A prerequisite for the success of irrigation development is ensuring that related policies and institutions are in place, aligned, and enforced. Additionally, these governance frameworks should be supported by realistic and practical long-term plans that address context-specific national needs. Thus, policy coherence and institutional harmonization are key to promoting cross-sectoral development. Irrigation development has the potential to transform the agricultural sector into a resource-use-efficient sector that supports resilience and adaptation initiatives and rural development, while creating jobs and minimising resource depletion and environmental degradation, supported by transformative approaches (Naidoo et al., 2021).

The investment case for IDAWM in South Africa is grounded in the structural conditions of the water and agriculture sectors. Irrigation already accounts for approximately 63% of the national available freshwater withdrawals, a share that cannot grow materially, given that the country's irrigation potential is effectively fully developed at around 2.28 million ha (Stevens & van Koppen, 2015). The strategic imperative is therefore to invest in productivity, efficiency, and equity within the existing footprint, rather than in area expansion. The NDP identifies smallholder farming as a priority vehicle for rural economic development (NDP, 2013), and the Department of Agriculture has set a target to revitalise approximately 330 schemes cultivating some 1.3 million ha, at an estimated cost of R200,000 per hectare (Carelsen et al., 2021). Against this backdrop, four investment categories directly aligned with the AU-IDAWM pathways offer the highest returns for South Africa's policy and institutional efforts.

First, Pathway 3 (scheme revitalisation) demands investment not just in hydraulic infrastructure but in soft components such as water-use associations, farmer training, market linkages, and irrigation scheduling. These components determine whether rehabilitated schemes remain productive beyond the initial construction phase (Dirwai et al., 2019). Second, Pathway 2 (FLID) requires making affordable, solar-powered equipment accessible to formerly disadvantaged communities, particularly women and youth in peri-urban and smallholder settings where market and food security potential is highest (Nhamo et al., 2024). Third, investment in Pathway 1 (rainfed AWM) should draw on South Africa's substantial research capacity to deliver locally adapted soil-water conservation practices through community-led programmes that restore watersheds and generate multiple downstream benefits (Okello et al., 2024). Fourth, Pathway 4 (unconventional water use), particularly the safer reuse of treated wastewater for irrigation in peri-urban areas and for non-food crops, requires both targeted infrastructure investment and concurrent information and education campaigns to address health and regulatory barriers (Ukoha-Onuoha & Horsfall, 2026). Table 10 summarises these investment priorities by pathway.

Table 5. Investment opportunities for the four IDAWM pathways in South Africa

Rainfed	Farmer-led irrigation	Irrigation scheme development	Unconventional water reuse
Draw on strong research capacity to target capacity-building for previously disadvantaged farmers in locally adapted soil-water conservation practices. Prioritise inclusive, community-led programmes to restore and sustain watersheds, achieving multiple benefits locally and downstream. Encourage sustainable land and water management practices by commercial rainfed farmers.	High potential to produce for local and international markets; high potential in peri-urban areas. Make affordable equipment available targeted to formerly disadvantaged communities, including women and youth. Promote solar-powered pumps.	Focus on revitalising smallholder schemes in partnership with farmers from previously disadvantaged communities. This requires coherent strategies that focus on promoting human capacity development, enhancing market links, and revitalising and modernising infrastructure. On schemes serving commercial farmers, encourage investments to make water more productive.	Focus on safely using wastewater for irrigation in peri-urban areas through partial treatment and information and education campaigns. Explore the use of wastewater for the irrigation of non-food crops.

7. CAPACITY DEVELOPMENT AND HUMAN CAPITAL

Capacity development and human capital in South Africa's irrigated agriculture are essential for improving productivity and ensuring sustainability, especially as the sector shifts from a supply-driven to a demand-oriented management approach (van Koppen et al., 2017). Some of the main challenges facing the irrigation sub-sector include an ageing workforce, skill shortages, and insufficient training for smallholder farmers (Cai et al., 2017). The sector must adapt to technological advancements and respond to changing environmental conditions, including extreme weather events. Efforts in capacity development should prioritise technical skills, water management training, and mentorship. Additionally, it is crucial to connect smallholder farmers with input and output markets.

Capacity development in South African irrigated agriculture should focus on smallholder farmers, who encounter significant barriers to adopting modern technologies and lack the resources to adapt to changing climate conditions. Although smallholder irrigation schemes have the potential to alleviate poverty and enhance rural livelihoods, they are currently underperforming due to a mix of technological, infrastructural, and financial constraints, making targeted intervention essential (Fanadzo & Ncube, 2018). Many irrigation schemes in the country are undergoing revitalisation to overcome decades of neglect and to move from a cycle of "refurbishment-degradation" to sustainable, profitable operations (Serote et al., 2023). Initiatives should prioritize supporting rural development and improving the livelihoods of smallholder farmers. As the country grapples with challenges of water insecurity, human capacity development in irrigation should aim to promote the adoption of technologies that enhance irrigation scheduling, infrastructure maintenance, and water-use efficiency (Nhamo et al., 2023). An important factor in farmer capacity development is retraining extension advisors and equipping them with relevant technical and leadership skills, moving away from outdated traditional methods.

Although South Africa has an advanced irrigation system, the sector faces a significant lack of trained personnel and knowledge in irrigation management (Serote et al., 2021). There is, therefore, a need to improve education and training frameworks in agricultural colleges to equip agricultural professionals and emerging farmers with relevant skills that address current challenges and enhance the adoption of technological advancements. As most irrigation schemes have faced collapse due to infighting and mismanagement, smallholder farmers need continuous mentorship to improve their managerial capacity (van Koppen et al., 2017). These initiatives are key to enhancing smallholder farmers' climate change adaptation and resilience. The strategic interventions needed to ensure the sustainability include training and mentorship, institutional support, and technical empowerment in advanced manufacturing for agricultural products and modern farming practices. Enhancing human capital is crucial for the success of irrigated agriculture, particularly for bridging the gap between existing infrastructure and actual production efficiency.

8. LESSONS LEARNT AND STRATEGIC PRIORITIES

South Africa is broadly aligned with the AU-IDAWM Framework and is already prioritising modernisation, water-use efficiency, and institutional reform rather than large new-scheme construction. Compared with other African countries, South Africa has a relatively mature and fully allocated irrigation infrastructure (Thabane et al., 2025). Still, it faces familiar constraints, including ageing systems, uneven performance, and deep inequalities between commercial and smallholder users (Serote et al., 2023). At the same time, the country's governance and knowledge base (including the National Water Resource Strategy (NWRS), the Water Research Commission, and participation in global platforms such as International Commission on Irrigation and Drainage (ICID) and International Water Association (IWA) position it closer to advanced irrigating economies such as Australia, Brazil, India, and parts of the USA than most regional peers (Seago, 2016).

The country faces several priority gaps and opportunities to benefit from the irrigation potential. First, smallholder irrigation schemes consistently underperform relative to large-scale commercial farms, reflecting a legacy of historical marginalisation, weak management, and under-maintenance, but also indicating substantial room for productivity and income gains if governance, technology, and support systems are improved (Nhamo, Mpandeli, et al., 2022). Second, irrigation already accounts for around 63% of national freshwater withdrawals, underscoring the importance of water conservation and demand management, as emphasised in the NWRS and associated research and policy investments. Third, while irrigation potential is effectively fully developed in area terms, comparing with other African and international experience shows that on-farm technologies, management practices, and scheme governance can still be upgraded to close water-productivity gaps and reduce losses (Serote et al., 2021). Realising these opportunities would allow South Africa to leverage its existing irrigation footprint to: (i) enable more reliable multi-season production and support transitions from subsistence to commercial farming, (ii) provide a buffer against droughts and water scarcity, and (iii) revitalise schemes in ways that create jobs and attract younger farmers through modern technologies. The key actionable practices required to unlock this transformation are summarised in Table 8.

Table 6. Key actionable practices to transform irrigation in South Africa.

Action	Practice
Modernising irrigation technologies	Transitioning from traditional and inefficient irrigation systems and modernising and adopting smart technologies to reduce vulnerability and enhance resilience.
Data-driven water scheduling	Using soil moisture monitoring tools allows farmers to accurately determine when to irrigate, saving time and resources while increasing crop yields and profitability.
Establishing agricultural innovation platforms (AIPs)	Establishing platforms for farmers, researchers, and extension officers to collaboratively address local challenges to foster social learning and sustainable, long-term adoption of new techniques
Revitalising smallholder irrigation schemes	Reviving 315+ smallholder schemes, particularly in former homelands, through improved infrastructure maintenance and supporting independent irrigation initiatives creates jobs and enhances local food security.
Promoting capacity building and training	Focusing on "soft components"—training farmers in high-value crop production, business skills, and maintenance—is as critical as fixing hardware to prevent the failure of many government-backed schemes.
Securing land tenure	Improving land rights for smallholders encourages long-term investment in and maintenance of irrigation systems.

Given the above, the study proposes the following key recommendations:

- Refocusing from area expansion to performance improvement and equity.
- Launching a targeted national programme for the rehabilitation, refocusing, and modernisation of strategic irrigation schemes.
- Scaling farmer-led irrigation and implementing climate-smart agricultural water management (AWM) practices in priority rural districts.

- Defining mandates and strengthening institutional capacities and coordination for improved AWM practices.
- Support technological innovations for improved irrigation scheduling, resource-use efficiency, data collection, monitoring, and early warning systems to enhance preparedness and support resilience and adaptation initiatives.
- Embedding risk, resilience, and social justice in irrigation development from a context perspective.

7. CONCLUSIONS

Irrigated agriculture is a climate change adaptation strategy due to its various benefits, particularly for smallholder farmers. Increasing smallholder irrigation in South Africa is feasible, but it needs a multidisciplinary approach to adapt to current climate change. Revitalising smallholder irrigation is important to sustainably increase food production and improve food and nutritional security and rural livelihoods. Targets to increase the area under irrigation should be matched with available water and energy resources, as informed by circular and transformative approaches. This will enable coordinated interventions and sustainable improvements in agricultural productivity. Including smallholder farmers through investments in small-scale irrigation schemes will help develop resilient food systems and strengthen their capacity to adapt to climate variability and change. There is a need for human capacity development to ensure that smallholder farmers are equipped to benefit from the investments. This will sustain gains achieved from revitalising smallholder irrigation and facilitate a shift in smallholder farming management toward climate-smart agriculture. In this regard, climate-smart agriculture practices are envisaged to (i) promote rainwater harvesting and soil water conservation, (ii) use improved crop varieties with high water productivity, and (iii) strengthen improved agronomic practices and alternative practices such as intercropping that contribute to increased water productivity.

REFERENCES

- Abdul-Gafaar, S., Boamah, P. O., Onumah, J., Sam, F., Gyaang, R., Appiah-Essuman, D., Korda, D. R., Buadi, A. M., Tabari, L., & Wulnye, F. A. (2025). Integrating Machine Learning and Drone Technology for Precision Agriculture: A Smart Solution for Automated Irrigation and Crop Management. *Environmental Challenges*, 101393.
- Abou Jaoude, L., Kamaledine, F., Said, R. B., Mohtar, R. H., Dbaiibo, R., & Yanni, S. F. (2025). Treated wastewater reuse and its impact on soil properties and potato and corn growth. *Science of the Total Environment*, 958, 178130.
- Adamos, G., Caucci, S., Charpentier, L., Chediek, J., Krol, D., & Laspidou, C. (2023). Exploring nexus policy insights for water-energy-food resilient communities. Sustainability Nexus Forum,
- AU. (2014). *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*.
- AU. (2020). *Framework for Irrigation Development and Agricultural Water Management in Africa*.
- Baudoin, M.-A., Vogel, C., Nortje, K., & Naik, M. (2017). Living with drought in South Africa: lessons learnt from the recent El Niño drought period. *International Journal of Disaster Risk Reduction*, 23, 128-137.
- Bonetti, S., Sutanudjaja, E. H., Mabhaudhi, T., Slotow, R., & Dalin, C. (2022). Climate change impacts on water sustainability of South African crop production. *Environmental Research Letters*, 17(8), 084017.
- Byaruhanga, N., Kibirige, D., & Mkhonta, G. (2025). Understanding South Africa's Flood Vulnerabilities and Resilience Pathways: A Comprehensive Overview. *Water*, 17(17), 2608.
- Cai, X., Magidi, J., Nhamo, L., & van Koppen, B. (2017). *Mapping irrigated areas in the Limpopo Province, South Africa* (9290908513).
- Carelsen, C., Ncube, B., & Fanadzo, M. (2021). Classification and characterisation of smallholder farmers in South Africa: a brief review. *South African Journal of Agricultural Extension*, 49(2), 97-106.
- Dirwai, T., Senzanje, A., & Mudhara, M. (2019). Assessing the functional and operational relationships between the water control infrastructure and water governance: A case of Tugela Ferry Irrigation Scheme and Mooi River Irrigation Scheme in KwaZulu-Natal, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 112, 12-20.

- Dirwai, T. L. L., Taguta, C., Senzanje, A., Nhamo, L., Cofie, O., Lankford, B., Harsen, N., & Mabhaudhi, T. (2024). Status of Agricultural Water Management Practices in Africa: A Review for the Prioritisation and Operationalisation of the African Union's Irrigation Development and Agricultural Water Management (AU-IDAWM) Strategy. *Environmental Research Letters*. <http://iopscience.iop.org/article/10.1088/1748-9326/ad76bf>
- Et-Taibi, B., Abid, M. R., Boufounas, E.-M., Morchid, A., Bourhnane, S., Hamed, T. A., & Benhaddou, D. (2024). Enhancing water management in smart agriculture: A cloud and IoT-based smart irrigation system. *Results in Engineering*, 22, 102283.
- Fanadzo, M., & Ncube, B. (2018). Challenges and opportunities for revitalising smallholder irrigation schemes in South Africa. *Water SA*, 44(3), 436-447.
- FAO. (2024). AQUASTAT: FAO's Global Information System on Water and Agriculture (Food and Agriculture Organisation (FAO). www.fao.org/aquastat/statistics/query/index.html;jsessionid=093F4377E504C95B99EB79DDEEB8728A
- IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability: Summary for Policymakers. A report of Working Group II of the IPCC* (9291691593). (Part of the Working Group II Contribution to the Sixth Assessment Report of the IPCC, Issue.
- Khwidzhili, R. H., & Worth, S. H. (2017). Evaluation of policies promoting sustainable agriculture in South Africa. *South African Journal of Agricultural Extension*, 45(2), 73-85. <https://doi.org/10.17159/2413-3221/2017/v45n2a443>
- Kusangaya, S., Warburton, M. L., Van Garderen, E. A., & Jewitt, G. P. (2014). Impacts of climate change on water resources in southern Africa: A review. *Physics and Chemistry of the Earth, Parts A/B/C*, 67, 47-54.
- Mabhaudhi, T., Chimonyo, V. G. P., Hlahla, S., Massawe, F., Mayes, S., Nhamo, L., & Modi, A. T. (2019). Prospects of orphan crops in climate change. *Planta*, 1-14.
- Mabhaudhi, T., Mpandeli, S., Nhamo, L., Chimonyo, V. G., Nhemachena, C., Senzanje, A., Naidoo, D., & Modi, A. T. (2018). Prospects for improving irrigated agriculture in southern Africa: Linking water, energy and food. *Water*, 10(12), 1881.
- Magidi, J., van Koppen, B., Nhamo, L., Mpandeli, S., Slotow, R., & Mabhaudhi, T. (2021). Informing Equitable Water and Food Policies through Accurate Spatial Information on Irrigated Areas in Smallholder Farming Systems. *Water*, 13(24), 3627.
- Masipa, T. (2017). The impact of climate change on food security in South Africa: Current realities and challenges ahead. *Jamba: Journal of Disaster Risk Studies*, 9(1), 1-7. <https://doi.org/10.4102/jamba.v9i1.411>
- Mbokodo, I., Bopape, M.-J., Chikoo, H., Engelbrecht, F., & Nethengwe, N. (2020). Heatwaves in the future warmer climate of South Africa. *Atmosphere*, 11(7), 712.
- Meza, I., Rezaei, E. E., Siebert, S., Ghazaryan, G., Nouri, H., Dubovyk, O., Gerdener, H., Herbert, C., Kusche, J., & Popat, E. (2021). Drought risk for agricultural systems in South Africa: Drivers, spatial patterns, and implications for drought risk management. *Science of the Total Environment*, 799, 149505.
- Naidoo, D., Nhamo, L., Mpandeli, S., Sobratee, N., Senzanje, A., Liphadzi, S., Slotow, R., Jacobson, M., Modi, A., & Mabhaudhi, T. (2021). Operationalising the water-energy-food nexus through the theory of change. *Renewable and sustainable energy reviews*, 149, 10. <https://doi.org/10.1016/j.rser.2021.111416>
- Ndlovu, M., Clulow, A. D., Savage, M. J., Nhamo, L., Magidi, J., & Mabhaudhi, T. (2021). An assessment of the impacts of climate variability and change in KwaZulu-Natal Province, South Africa. *Atmosphere*, 12(4), 427.
- Ndlovu, M., Scheelbeek, P., Ngidi, M., & Mabhaudhi, T. (2024). Underutilized crops for diverse, resilient and healthy agri-food systems: a systematic review of sub-Saharan Africa. *Frontiers in Sustainable Food Systems*, 8, 1498402.
- Ndlovu, M., Schütte, S., Nhamo, L., Scheelbeek, P., Ngidi, M., & Mabhaudhi, T. (2025). Understanding Climate Risks for Water and Agri-Food Systems: Implications for Smallholder Farmers. *Frontiers in Water*, 8, 1725767.
- NDP. (2013). *National development plan: Vision 2030*. N. Government of South Africa.
- Ngarava, S. (2021). Long-term relationship between food, energy and water inflation in South Africa. *Water-Energy Nexus*, 4, 123-133. In.
- Nguyen, T. T., Grote, U., Neubacher, F., Do, M. H., & Paudel, G. P. (2023). Security risks from climate change and environmental degradation: implications for sustainable land use transformation in the Global South. *Current Opinion in Environmental Sustainability*, 63, 101322.
- Nhamo, L. (2015). *Trends and Outlook: Agricultural Water Management in Southern Africa*. SADC AgWater profiles (Project report submitted to the United States Agency for International Development's (USAID's) Feed the Future Programme). IWMI.
- Nhamo, L., Mabhaudhi, T., & Modi, A. (2019). Preparedness or repeated short-term relief aid? Building drought resilience through early warning in southern Africa. *Water SA*, 45(1), 75-85.

- Nhamo, L., Mpandeli, S., Liphadzi, S., Dirwai, T. L., Mugiyo, H., Senzanje, A., Lankford, B. A., & Mabhaudhi, T. (2024). Why Do Farmers Not Irrigate All the Areas Equipped for Irrigation? Lessons from Southern Africa. *Agriculture*, 14(8), 1218.
- Nhamo, L., Mpandeli, S., Liphadzi, S., Hlophe-Ginindza, S., Kapari, M., Molwantwa, J., & Mabhaudhi, T. (2023). Advances in water research: Enhancing sustainable water use in irrigated agriculture in South Africa. In *Progress in Sustainable Development* (pp. 233-248). Elsevier.
- Nhamo, L., Mpandeli, S., Liphadzi, S., & Mabhaudhi, T. (2022). Securing Land and Water for Food Production through Sustainable Land Reform: A Nexus Planning Perspective. *Land*, 11(7), 974. <https://doi.org/10.3390/land11070974>
- Nhamo, L., Taguta, C., Mpandeli, S., Dirwai, T., Liphadzi, S., & Mabhaudhi, T. (2025). Transforming Agricultural Water Management Through the Water-Energy-Food Nexus: Trends, Opportunities, Barriers and Solutions. *Irrigation and Drainage*, 0:1(12). <https://doi.org/10.1002/ird.70032>
- Nhamo, L., Van der Walt, M., Moeletsi, M., Modi, A., Kunz, R., Chimonyo, V., Masupha, T., Mpandeli, S., Liphadzi, S., & Molwantwa, J. (2022). Optimal production areas of underutilized indigenous crops and their role under climate change: Focus on Bambara groundnut. *Frontiers in Sustainable Food Systems*, 6, 13. <https://doi.org/10.3389/fsufs.2022.990213>
- Nhemachena, C., Nhamo, L., Matchaya, G., Nhemaehena, C. R., Muchara, B., Karuaihe, S. T., & Mpandeli, S. (2020). Climate Change Impacts on Water and Agriculture Sectors in Southern Africa: Threats and Opportunities for Sustainable Development. *Water*, 12(10), 2673. <https://doi.org/10.3390/w12102673>
- Okello, C., Githiora, Y. W., Sithole, S., & Owuor, M. A. (2024). Nature-based solutions for water resource management in Africa's arid and semi-arid lands (ASALs): A systematic review of existing interventions. *Nature-Based Solutions*, 6, 100172.
- Parra-López, C., Abdallah, S. B., Garcia-Garcia, G., Hassoun, A., Trollman, H., Jagtap, S., Gupta, S., Ait-Kaddour, A., Makmuang, S., & Carmona-Torres, C. (2025). Digital technologies for water use and management in agriculture: Recent applications and future outlook. *Agricultural Water Management*, 309, 109347.
- Richelle, B., Mao, F., & Liebe, U. (2025). Towards equitable, integrated, and adaptive water-energy-food nexus research in Africa: A systematic literature review. *Environmental Impact Assessment Review*, 115, 108043.
- RSA. (1996). *Constitution of the Republic of South Africa (Act 108 of 1996)* (Government Gazette No. 25799, Issue. RSA.
- Seago, C. (2016). *A comparison of the South African approach to water resource management and planning with four international countries* (WRC Report, Issue. WRC.
- Serote, B., Mokgehele, S., Du Plooy, C., Mpandeli, S., Nhamo, L., & Senyolo, G. (2021). Factors Influencing the Adoption of Climate-Smart Irrigation Technologies for Sustainable Crop Productivity by Smallholder Farmers in Arid Areas of South Africa. *Agriculture*, 11(12), 1222.
- Serote, B., Mokgehele, S., Senyolo, G., du Plooy, C., Hlophe-Ginindza, S., Mpandeli, S., Nhamo, L., & Araya, H. (2023). Exploring the Barriers to the Adoption of Climate-Smart Irrigation Technologies for Sustainable Crop Productivity by Smallholder Farmers: Evidence from South Africa. *Agriculture*, 13(2), 246.
- Smith, M. D., Sikka, A., Dirwai, T. L., & Mabhaudhi, T. (2023). Research and innovation in agricultural water management for a water-secure world. *Irrigation and Drainage*, 72(5), 1245-1259.
- Smith, M. D., Sikka, A., Taguta, C., Dirwai, T. L., & Mabhaudhi, T. (2024). Embracing complexities in agricultural water management through nexus planning. *Irrigation and Drainage*, 73(5), 1695-1716.
- StatsSA. (2019). *Towards measuring food security in South Africa: An examination of hunger and food inadequacy*. StatsSA.
- Stevens, J., & van Koppen, B. (2015). *Trends and Outlook: Agricultural Water Management in Southern Africa. Country report-South Africa.[Project report submitted to the United States Agency for International Development's (USAID's) Feed the Future Program]*.
- Stringer, L. C., Mirzabaev, A., Benjaminsen, T. A., Harris, R. M., Jafari, M., Lissner, T. K., Stevens, N., & Tirado-von Der Pahlen, C. (2021). Climate change impacts on water security in global drylands. *One Earth*, 4(6), 851-864.
- Thabane, V. N., Agholor, I. A., Ludidi, N. N., Morepje, M. T., Mgwenya, L. I., Msweli, N. S., & Sithole, M. Z. (2025). Irrigation water and security in South African smallholder farming: assessing strategies for revitalization. *World*, 6(1), 32.
- Touch, V., Tan, D. K., Cook, B. R., Li Liu, D., Cross, R., Tran, T. A., Utomo, A., Yous, S., Grunbuhel, C., & Cowie, A. (2024). Smallholder farmers' challenges and opportunities: Implications for agricultural production, environment and food security. *Journal of Environmental Management*, 370, 122536.

- Ukoha-Onuoha, E., & Horsfall, I. T. (2026). The evolution of wastewater reuse for irrigation: Lessons learned and future directions. *Next Sustainability*, 7, 100253.
- van Averbek, W., Denison, J., & Mkeni, P. (2011). Smallholder irrigation schemes in South Africa: A review of knowledge generated by the Water Research Commission. *Water SA*, 37(5), 797-808.
- van Koppen, B., Nhamo, L., Cai, X., Gabriel, M. J., Sekgala, M., Shikwambana, S., Tshikolomo, K., Nevhutanda, S., Matlala, B., & Manyama, D. (2017). *Smallholder irrigation schemes in the Limpopo Province, South Africa* (Vol. IWMI Working Paper 174). International Water Management Institute (IWMI).
- Vink, N., Conradie, B., & Matthews, N. (2022). The economics of agricultural productivity in South Africa. *Annual Review of Resource Economics*, 14, 131-149.
- Xulu, N. G., Chikoore, H., Bopape, M.-J. M., Ndarana, T., Muofhe, T. P., Mbokodo, I. L., Munyai, R. B., Singo, M. V., Mohomi, T., & Mbatha, S. M. (2023). Cut-Off Lows over South Africa: A Review. *Climate*, 11(3), 59.

INTRODUCTION TO THE IRRIGATION STATUS OF THE REPUBLIC OF KOREA

Dr. Sung-Hee Lee¹

1. Natural Environment and Agricultural Status

1.1 Area of Agricultural Land

Of the 10,046 thousand ha land area in Korea, the forest area is 63% and the farmland area is 1,505 thousand ha, accounting for 15% of the nation's land. Of the farmland area, rice paddies are 761 thousand ha (51%) and upland are 743 thousand ha (49%).

The farmland area continued to decrease due to industrialization and urbanization, decreasing 35% from 2,293 thousand ha in 1970 to 1,505 thousand ha in 2024, and in particular, the upland area decreased by 28%, but the paddy area decreased by 40%.

< Farmland Area >

Area(thousand ha)	1970	2024	Decrease	Ratio(%)	Remark
Farmland	2,298	1,505	-793	-34.5	Main statistic yearbook of MAFRA(2025)
- Paddy	1,273	761	-512	-40.2	
- Upland	1,025	743	-282	-27.5	

*MAFRA(Ministry of Agriculture, Food and Rural Affairs)

1.2 Climate

Korea has a monsoon climate with four distinct seasons of spring, summer, autumn, and winter. The annual average temperature is 12.5°C (during 1991-2020), but it drops to a maximum of 40°C in summer and a minimum of minus 20°C in winter. Due to climate change, the temperature in summer rises, and the summer period is getting longer from June to August to May to September. In terms of annual average temperature, 2023-2025 ranked first and third in history.

In addition, the annual average precipitation is 1331.7mm (normal), but the summer precipitation from June to August is 727.3mm, and 55% is concentrated in the summer. In particular, the occurrence of torrential rain in summer has gradually increased in recent years, and the precipitation in winter and spring has been gradually decreasing. In addition, extreme rainfall and extreme drought are occurring in specific areas, and regional deviations are also intensifying. (Source KMA; Meteorological Administration)

1.3 Agricultural Population

Korea's population is 51.7 million (2024). Although it increased 1.6 times compared to 32.2 million in 1970, the population is expected to decrease due to a decrease in the fertility rate. In particular, the population of farmhouses was 2.0 million (3.9% of the total population), which is rapidly decreasing compared to 14.4 million (45% of the total population) in 1970.(Source: MAFRA)

In addition, the proportion of the elderly aged 65 or older is 22% of the total population in Korea as of 2024, but 56% (1,114,000 out of 2,004,000) is based on the farm population, and the aging population

¹ Executive Director, Korea Committee on Irrigation and Drainage (KCID), Rural Research Institute, Korea Rural Community Corporation (KRC), #870, Hae-an-ro, Sangnok-gu Ansan-si, Gyeonggi-do 15634, South Korea. E-mail: kcidkr@gmail.com

is serious along with the hollowing out of rural areas (population decline). This means not only the disappearance and collapse of rural communities, but also a decrease in agricultural production manpower. (Source : MAFRA). According to the risk index for population extinction in 2026, 61% of local governments in Korea are at risk of extinction, and most of them are rural areas.

1.4 Agricultural Status

Korea has traditionally been a rice-farming country. Rice Paddy account for 51% of all Farmland, and among farmers, the number of rice farmers is 365 thousand (37% of all farmers).

The share of agriculture, forestry, and fisheries in the total national production of 2,594 trillion KRW in 2024 is 37 trillion KRW and 1.4%. It gradually decreased from 26% in the 1970s. In agriculture, forestry, and fisheries, 69% are cultivation, 12% livestock, and 12% are fishing. (Ref ; 1,000 KRW is 1.5 USD in 2025)

In the 1970s, the cultivation industry was the highest at 78%, but as people's income gradually increased and their diet became westernized, rice consumption decreased and meat and seafood consumption gradually increased. Rice consumption was 136 kg per person a year in the 1970s, but it gradually declined to 56 kg in 2024, almost 41 percent. (Source: MAFRA)

2. Irrigation status and management

2.1 Irrigation status

Among the water resource usage in Korea, agricultural water is 154 billion m³ (63%) of which 13.1 billion m³ (85%) of paddy farming, 2 billion m³ (13%) of upland farming, and the rest of livestock water. The water source is 86% of surface water and 14% of ground water. Therefore, agricultural water in Korea means paddy farming water, and surface water (reservoir, rivers) is used.

Of the 761 thousand ha of rice paddies, the number of irrigation facilities installed is 651 thousand ha, which is 86%. There are a total of 78 thousand irrigation facilities, 17 thousand reservoirs (420 thousand ha of beneficial area), 8,000 pumping stations (149 thousand ha of beneficial area), and 18 thousand reservoirs (41 thousand ha of beneficial area). Based on the beneficiary area, 65% of the reservoir, 23% of the pumping station, and 6% of the weir.

The irrigation channel is 119 thousand km, the drainage canal is 71 thousand km, the structured (concrete) irrigation canal is 59 %, and the drainage canal is 40 %. The rest is the earth canal, and most of the irrigation canal is the open canal (gravitational type) rather than the pipe line.

< Irrigation facility and Area >

Year		In 1980		In 2024		Remark
		places	Area(ha)	Place	Area(ha)	
Paddy Area		-	1,306,789	-	761,011	2025 Statistical yearbook of land and water development for agriculture (MAFRA,KRC)
Facility/Area		65,837	893,994	78,148	651,320	
Facility	Reservoir	18,581	456,143	16,973	420,212	
	Pumping station	4,188	140,141	8,327	148,566	
	Weir	20,338	122,080	18,534	40,712	
	etc	22,730	175,630	34,314	41,830	

2.2 Irrigation management

In Korea, the MAFRA (Ministry of Agriculture, Food, and Rural Affairs) is in charge of managing irrigation water (agricultural water), and the MCEE (Ministry of Climate, Energy, and Environment) is in charge of domestic and industrial water. Therefore, policies, legal systems, and budgets for irrigation development and management are overseen by the MAFRA. Among Irrigated area, It is divided into the management area of the KRC (Korea Rural Community Corporation), a public institution under the MAFRA, and the management area of local governments.

The KRC's management area is 461 thousand ha (71%) and the local government management area is 191 thousand ha (29%). In terms of management facilities, there are 3.4 thousand reservoirs, 320 thousand ha (76% of the KRC's management area), 3.9 thousand pumping stations, 119 thousand ha (26%), 4.2 thousand reservoirs, and 3,000ha (1%).

Among the management areas of local governments, there are 13 thousand reservoirs, 101 thousand ha (53% of the management area of local governments), 4 thousand pumping stations, 29 thousand ha (15%), 14 thousand weirs, and 38 thousand ha (20%). Irrigation facilities have many local government management facilities, but large facilities are managed by KRC.

< KRC and Local government's Irrigation Management >

In 2024		KRC		Local Government		Remark
		Place	Area(ha)	Place	Area(ha)	
Irrigation Facility and Area		14,479	460,536	63,669	190,784	2025 Statistical yearbook of land and water development for agriculture (MAFRA,KRC)
Facility	Reservoir	3,428	319,649	13,545	100,563	
	Pumping station (Intake)	3,920	119,473	4,407	29,093	
	Drainage Pumping Station	982	-	363	-	
	Weir	4,168	3,033	14,366	37,679	
	Etc	1,981	18,381	30,988	23,449	

2.3 Drainage management

In Irrigated area, Drainage canal are installed alongside the irrigation canal. Irrigation water supplied from irrigation canals is used in the rice paddies and subsequently discharged through drainage channels. Additionally, during rainfall, water stored in the paddies naturally drains into the river through drainage canal, driven by the difference in water levels.

However, if the water level of the river is high during rainfall and cannot be excluded by the natural discharge, the drainage pumping station must be operated forcibly to perform mechanical drainage. Based on 982 construction management drainage pumping station, the beneficiary area (drain area) of the drainage site is 125 thousand ha. Drainage in rice fields is different from the underground drainage method, which is discharged by burying pipes underground in fields. There are not many underground drainage facilities in Korea, but it is expected that the number of underground drainage facilities will increase recently in order to expand multi-purpose farmland that is used both as rice paddy field and upland.

2.4 Changes in irrigation management (2000)

The beginning of modern irrigation management in Korea was established in 1908 by the Ok-gu Western Irrigation Association. Since then, the Irrigation Association has undergone many changes, and in 1999, there were 103 Irrigation Association nationwide. In 1999, there was the RDC(Rural Development Corporation) and the FLIA(FarmLand Improvement Association same as Irrigation Association), which were carrying out the design and construction of irrigation facilities. The government merged three organizations (103 FLIAs, RDC, and the Federation FLIA) in 2000 to become the current KRC.

The FLIA, which implemented irrigation management centered on farmers, was transformed into the KRC as national management system. This was a very rare case at a time when PIM(participatory irrigation management) was recommended worldwide. It was a change from PIM in the era of Irrigation associations to PubIM(Public Irrigation Management).

The reason for the change in irrigation management entities is that in order to respond to drought and floods in the era of climate change, one unified national organization is more efficient than 103 distributed Irrigation Associations, can resolve regional water conflicts and disputes, integrate disproportionate finances between Irrigation Associations, and manage integrated from irrigation development (planning, design, and construction) to maintenance. Since 2000, farmers have been exempted from Irrigation Association fees(as water tariff) due to the integration of three institutions.

3. Achievements of irrigation projects

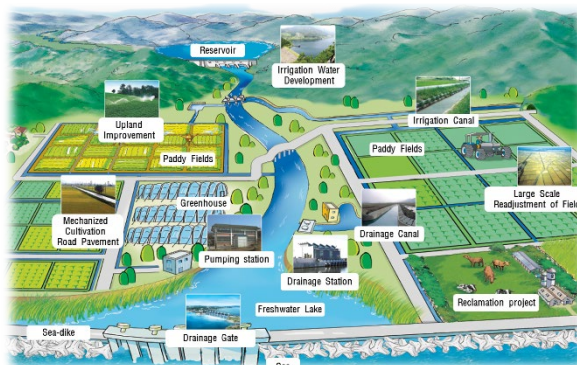
3.1 Scope of irrigation projects

In Korea, irrigation projects have been promoted based on the Rural Development Act. In the Rural Development Act, the types of agricultural water development projects, drainage improvement projects, farmland consolidation projects, and reclamation projects were specified in the framework of the "agricultural production infrastructure project". Facilities installed through these projects are referred to as "agricultural production infrastructure", and these include reservoirs, pumping stations(intake), drainage pumping station, weir, seawalls, Irrigation and drainage canals.

3.2 Progress of irrigation projects

After the Korean War in 1950, irrigation projects began in earnest to self-sufficiency of food from the 1960s. It was urgent to secure excellent farmland to increase the production of rice as the main crop, and to develop irrigation facilities to supply stable agricultural water.

From the 1970s to the 1980s, the agricultural water development project was intensively implemented, and in the 1990s, the farmland consolidation project to secure superior agricultural land was intensively implemented. After 2000, as the existing irrigation facilities deteriorated and the occurrence of disasters due to climate change increased, the "Irrigation facility renovation (enhancement) project" to cope with this expanded. In addition, the "water quality improvement project" was began by enhancing interest in the environment. And the "TM/TC(Tele-monitoring, Tele-Control) project" as water management automation project was started in the era of science and information technology.



In particular, entering the 2010s, the era of "development" in which new facilities are newly constructed has changed to the era of "modernization" in which existing facilities are strengthened. Examples of

modernization projects include the agricultural reservoir bank enhancement project, the flood prevention capacity increase project, and the agricultural water use system reform project.

3.3 Outstanding achievements of irrigation projects

The irrigation project, which has been implemented in earnest since 1960, not only achieved the food self-sufficiency rate, which is the main grain, but also laid the foundation for industrialization in Korea. The ability to respond to disasters such as drought and flood has improved.

The quantitative performance of irrigation projects is the Irrigated area rate, production per area, farm household income, labor productivity, land productivity, and working hours. There are many factors in the increase of rice production and farm household income, but irrigation projects also contributed importantly.

3.3.1 *Irrigated area rate and rice self-sufficiency rate*

The irrigated area rate increased from 34% in 1955, 59% in 1970, and 86% in 2024, through which the rice production per unit area increased from 3.3 ton/ha in 1970 to 5.1 ton/ha in 2024. The rice self-sufficiency rate achieved rice self-sufficiency from 94% in the 1970s to 96% in the 1980s and 98% in the 1990s.

3.3.2 *Farm Income*

Rice is the main source of income for farm households. Therefore, the increase in rice production had a great impact on farm household income. Net agricultural income (excluding non-farm and transfer income) increased from 194 thousand KRW in 1970 to 10,469 thousand KRW in 1995 and 12,961 thousand KRW in 2021. For reference, farm household income in 2021 is 48 million KRW, of which 13 million KRW (27%), non-farm income 18 million KRW (39%), and transfer income 15 million KRW (31%).(Ref ; 1,000 KRW is 1.5 USD in 2025)

3.3.3 *Labor productivity and working hours*

As irrigation facilities were installed through irrigation development, working hours spent for irrigation by farmers were reduced, which led to improved labor productivity. Labor productivity increased from 4.9 thousand KRW/hour in 1990 to 21.44 thousand KRW/hour in 2016 (15.5 thousand KRW/hour in 2024). Labor intensity decreased from 126 hours/10a in 1990 to 70 hours/10a in 2016 (107 hours/10a in 2024).

3.3.4 *Land Productivity*

The productivity of farmland increased with the installation of irrigation facilities. In the same area, income increases. Land productivity increased from 625 thousand KRW/10a in 1990 to 1,766 thousand KRW/10a in 2023. (1,653 thousand KRW/10a in 2024)

3.3.5 *Mechanization of agriculture*

In Korea, the farmland clearing project was implemented as part of the agricultural production base project including the irrigation project. In the farmland consolidation project, small and irregular farmland is standardized with a parcel of 1ha or more, and the Irrigation and drainage canal are newly constructed. Agricultural mechanization has increased based on farmland and farming road by irrigation projects and farmland consolidation projects.

In paddy farming, the rate of agricultural mechanization increased from 62% in the 1990s to 99% in 2020. This rate of agricultural mechanization has contributed to the reduction of the labor force and the improvement of labor productivity and land productivity mentioned above.

4. Challenges and hazards associated with irrigation systems

4.1 Extreme and localized droughts and floods

Since 2000, droughts and floods due to climate change have become frequent. Timely and regional deviations in precipitation are intensifying. Local droughts may occur because it does not rain when it is necessary or in the necessary area. Sok-cho city, for nearly 25 years, was abundant enough to hold a water festival, but extreme drought occurred at the O-bong Dam in Gang-neung city where is nearly city. In the case of torrential rains in summer, guerrilla rainfall is becoming more frequent, which pours extreme rainfall in specific areas. As rainfall exceeds 100 mm per hour in Seoul and Gunsan, flood damage is occurring. The pattern of rainfall that has been steadily maintained for a long time in the past has changed.

4.2 Deterioration of facilities, past design standards

Korea's Irrigated Area rate is 86%, which is a very high rate worldwide. However, it has been a long time since irrigation facilities have been installed, and aging is accelerating. The number of facilities installed before World War II (1945), that is, the number of facilities that have passed 80 years, is 13 thousand out of 78 thousand facilities, accounting for 17 thousand facilities. In particular, there are 8.6 thousand reservoirs out of 17 thousand (420 thousand ha of beneficial area), 51% based on facilities and 23% based on area. As the number of years elapsed, it became impossible to fulfil the functions of irrigation facilities.

In addition, since it was constructed according to the design standards at the time of installation, there are many facilities that have not applied newly strengthened design standards due to climate change since 2000. Therefore, it is not possible to respond to drought and floods that are intensifying due to recent climate change.

As irrigation facilities were installed with a limited budget, the ratio of irrigation canal to be structured was low. Based on irrigation canal, the structured canal (concrete) is 59% and the earth irrigation canal is 41%. Therefore, the water loss due to the earth water canal is large, the flow of water is hindered due to the water plant of the irrigation canal and the sedimentation of soil, etc., and damage such as overflow and collapse of the irrigation canal can easily occur in case of flooding.

4.3 Response to Integrated Management

In Korea, water-related functions are divided into various central ministries (institutions), so the need for integration has been steadily raised. Until 2018, dams for domestic and industrial water (MOLIT ; Ministry of Land, Infrastructure and Transport), reservoir(dam) for agricultural water(MAFRA, KRC), and hydroelectric dams(MOTIR ; Ministry of Trade, Industry and Resources, KHNP ; Korea Hydro and Nuclear power) were managed by different ministries (affiliated agencies), and in particular, water quantity (MOLIT, Basin Flood Control Office) and water quality management (ME ; Ministry of Environment, Basin Environment Office) were divided.

In 2000, the first integrated management of agricultural water was realized. This is because the irrigation management, which was distributed by region with 103 FLIAs, was integrated into a single institution of the KRC, and the institution in charge of designing and constructing irrigation facilities was combined into one.

With the enactment of the Principal Act on Water Management (new establishment of the National Water Management Committee) in 2018, the water quantity management work (drought, flood) managed by the MOLIT and the water management work for common use were transferred to the ME(Ministry of Environment). As the ME expanded to the MCEE (Ministry of Climate and Energy and Environment) in 2025, the MOTIR's hydroelectric dam management work was integrated. However, the quantity and water quality management work of agricultural water are managed by the MAFRA and the KRC as before.

As the era of national integrated product management arrives, many demands for agricultural water are occurring at the national level. The most important issues are as follows.

- (1) As the area of Farmland is reduced, the amount of agricultural water used will decrease, so it should be made available in domestic and industrial water, which is increasing in demand.
- (2) (Management aspect) Agricultural water is high water loss rate. It should be managed to reduce the amount of water loss and ensure that farmers do not waste it. Information measured on agricultural water is insufficient or inaccurate, and what there is not well disclosed.
- (3) Water level management (water measurement side) of reservoirs during flood season should contribute to the reduction of flood volume in the watershed.
- (4) The water quality of reservoirs (environmental aspect) should be improved. It plays a role in deteriorating water quality due to the use of fertilizers and pesticides in paddy farming. In addition, paddy farming, which cultivates freshwater, intensifies carbon emissions.

4.4 Changes in agricultural form

It is a rice paddy farming country in Korea. It have invested in many agricultural technologies and production infrastructure for self-sufficiency in rice. As a result of these efforts, rice self-sufficiency was achieved and high-level irrigation facilities were established.

However, the traditional agricultural form is changing. Rice consumption decreased due to changes in dietary habits according to changes in income levels, and production of high-value-added vegetables and fruits increased to improve farm household income.

This has led to an increase in the cultivation of field crops, not rice farming, even though it is a rice paddy. It is easy to see the increasing number of greenhouses and glass greenhouses in the rice fields.

Several issues arise in terms of agricultural water management.

- (1) (Four-season water) Rice fields require water supply only from April to September, but four-season water supply is required for upland crops for example fruit and vegetable. Out of the rice growing season, farmers hope to supply water for four seasons, including winter and spring.
- (2) (Drainage expansion) Upland crops are very vulnerable to flooding during the flood season. Therefore, drainage during the flood season is very important. However, drainage canal and drainage pumping station installed in paddy fields are designed to allow flooding for a certain period of time in accordance with the characteristics of rice growth. Therefore, when upland crops are grown in paddy fields, the damage will inevitably increase due to flooding, and accordingly, farmers are requesting the expansion of the drainage pumping station.
- (3) (Clean water) Upland crops, especially agricultural water supplied to vegetables and fruits grown in houses, require clean water quality. Therefore, it requires a high-quality water suitable for upland crops, not agricultural water quality (grade 4, BOD 8 ppm) that meets the paddy farming standards.

5. How to Modernize: How are we working it out?

5.1 (Powered capacity enhancement project) Strengthen flood response

Although droughts and floods occur frequently due to climate change, there is a high interest in floods that are directly related to people's lives and property damage. Therefore, many projects have been conducted to respond to floods in the field of irrigation.

A representative one is the "Project to Expand the flooding prevention Capacity of Agricultural Infrastructure (2013~)". It is a project to improve the flood discharging ability by reinforcing facilities such as spillway and embankments of reservoirs in preparation for torrential rains caused by climate change. In Korea, Reservoir (dam) are mainly installed to supply agricultural water, so there are not many reservoir (dam) with gates to discharge. Even if there is a gate for water level control (8% of KRC's reservoirs), it is installed based on the amount of flood at the time of installation, so it does not reflect the increase in the amount of flood caused by recent climate change.

The most representative project is the "Ye-dang flooding prevention Capacity Enhancement Project" (2013-2019, 1101 billion KRW). The existing flood control capacity was increased 3.4 times through the expansion of the flood discharge capacity.

5.2 (Rural Water Utilization System Reform Project) Strengthening Drought Response

There is a method of developing a new reservoir to minimize drought damage, but it is difficult to develop a new reservoir due to the spread of negative awareness on the environment and strong opposition from resident and NGOs. Therefore, it is necessary to promote a project to increase the usability of existing irrigation facilities.

"The Irrigation Water Use System Reform Project (2008~) is a project to efficiently allocate and utilize spare water resources from existing irrigation facilities to resolve the imbalance in water supply between regions and water systems.

For example, a project to connect reservoirs (basins) and reservoirs (basins) to supply water from reservoirs (basins) that are sufficient for water supply to reservoirs (basins) that are insufficient for water supply, and a project to reuse water dumped into the sea from downstream rivers.

Representative projects include rivers and reservoirs, freshwater lakes and freshwater lakes, Gongju-Yedang water system connection project that connects freshwater lakes and reservoirs, A-geum-ma water system connection project, and A-sap-dae water system connection project.

<The Irrigation Water Use System Reform Project(outstanding) >

Project	Period	Water supply capacity	Budget	Remark
Gongju-Yedang	In 2015~2018	130 thousand m ³ /day	102 billion KRW	1,000 KRW = 1.5 USD in 2025
Asan-sapgyo-daeho	In 2017~2021	330 thousand m ³ /day	90 billion KRW	
A-geum-M	In 2018~2021	40 thousand m ³ /day	47 billion KRW	

5.3 (Water Management Automation Project) Physical Smart

Since 2000, the "TM/TC (Tele-monitoring, Tele-Control) project" as Water Management Automation Project (2002-2025)" has been promoted, which can remotely measure (monitor) and control distributed irrigation facilities using ICT technology. This is a project to efficiently and scientifically manage water and facilities by systematically managing irrigation facilities such as reservoirs, pumping station, Sluice gate, Canal by remote control facilities at the central management center.

Central management offices (water management control rooms) are installed in all 93 branch offices of the KRC, and measurement facilities (water level, supply water, CCTV, etc.) are installed in irrigation facilities distributed in the site to monitor the situation in real time. When the measured (monitoring) data is collected at the central management office, the managers of the branch offices grasp the situation

and remotely control the irrigation facilities in real time (opening/closing the gate of reservoir, turn on/off pumping station, and operating sluice gate).

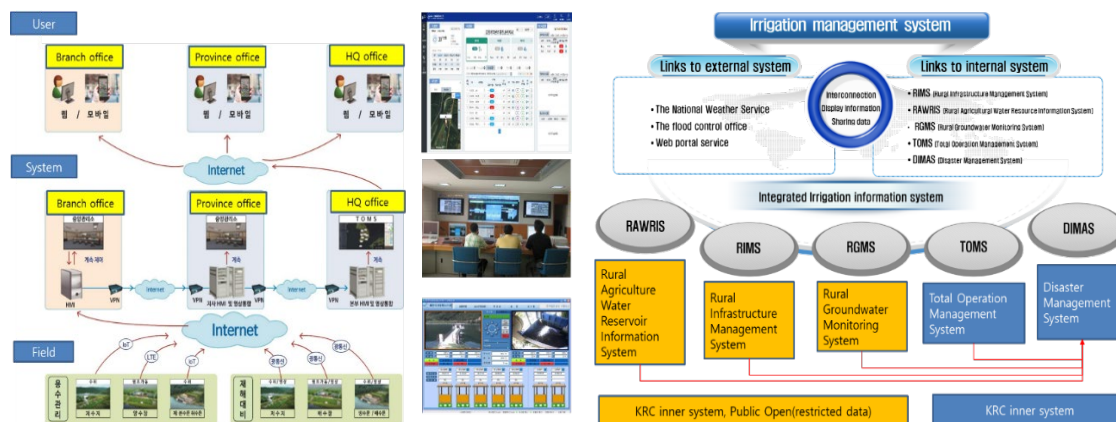
After the completion of the first phase (2001-2025) project, the KRC plans to promote a water management automation project incorporating AI technology as a second phase project.

5.4 (Smart water management system) soft smart

The first important thing for smart water management is to secure data. The first start of smart water management was the establishment of the Rural Water Management Information System (RAWRIS) in early 2000 by installing a water level meter in the reservoir to measure the amount of water stored in real time and provide services on the website.

Since then, the establishment of an Rural infrastructure management system (RIMS) (2003-2008) for specification information on KRC's irrigation facility, water management, and rehabilitation history has been started, and since then, it has been operated until now through the advancement of systems (2013-2016) such as GIS-based facility management, mobile management, and disaster management (drought and flood). In addition, individual systems such as water quality management system (reservoir water management) and rural groundwater management system (ground water measurement network) have been established and are being serviced by mobile.

However, since there are many and wide targets to be measured for agricultural water in Korea, more investment is required in the generation of measured data. In addition, quality control of existing measured data (data to be measured in the future) is important. This is because there is a limit to the application of advanced technologies such as decision-making in line with the AI era when the reliability is low no matter how much data is measured.



5.5 Strengthen measures for field crops and irrigation measures

5.5.1 Strengthening Project for Drainage Improvement of upland Crops

Areas where farmers switch from rice paddy to upland for vegetable and fruit cultivation, or grow vegetables and fruit while maintaining rice paddy fields, have increased. However, the drainage system of rice fields (drainage canal, drainage pumping station) is designed to allow flooding for 24 hours according to the growth characteristics of rice, and the design rainfall is also a frequency of 20 years. However, as the area of cultivation of vegetables and fruit in the rice paddy fields increased, and extreme rainfall increased due to climate change, countermeasures were needed.

In addition to expanding the drainage improvement project every year, the design standards for drainage pumping station have been strengthened from 20 years to more than 20 years in paddy fields in 2023 and from 30 years to more than 30 years in upland. In addition, an un-manned control system for drainage pumping station was established in 2020, so that the drainage pump was automatically operated when the dangerous level was reached for 619 drainage pumping station of KRC.

5.5.2 Four-season water supply project for upland farming

Greenhouses farming increased 1.4 times from 50,000 ha in 2000 to 70,000 ha in 2025, and the area of upland crops in rice paddies increased to 19.7% in 2024. In order to cope with these changes, it is planned to start the groundwater recharging project in 2024 and implement it for 21 agricultural complexes by 2038. In addition, the water supply project for multi-purpose paddy field, which supplies clean water to the horticultural complex by purifying river water, started in 2024. It is preparing to implement a groundwater dam project in 39 places, which can be used by storing groundwater by installing a dam underground of a river.

6. Governance and institutions

6.1 Governance of Irrigation

The KRC form a central operation council to explain the irrigation project and maintenance plan of the KRC, and seek advice and cooperation. By region, the representative council for irrigation management is formed for each of 93 branches, and annual irrigation projects and maintenance plans are explained. In addition, a briefing session of water management is held for farmers who are local water users.

However, in the FLIA as irrigation association before the integration in 2000, the representative committee and farmer's promoting group (Heung-nong-gye) were activated. The representative committee had the right to elect the president of FLIAs and approve the FLIA's project (irrigation plan, etc.) and the preliminary settlement. Farmer's promoting group (Heung-nong-gye) was an organization that participated in maintenance labor such as water plant removal and water canal dredging. In the past, when it was changed to a public organization, governance such as farmer participation and responsibility in irrigation management was better established.

Therefore, it is a task of how to build governance on the role participation of current farmers.

6.2 Irrigation Laws and Systems

6.2.1 Rural Development Act

The Rearrangement of agricultural and fishing villages Act was enacted in 1994 and has been maintained for more than 30 years. Currently, all irrigation projects are being promoted based on its Act. However, since 2000, it has not been able to meet changes in the agricultural environment and trends in the irrigation sector. Since several projects are mixed in one Act, it is not a suitable legal system for the irrigation sector. Compared to the others water sector, which has been newly revised since 2000, the legal system has been weak.

6.2.2 Rationalization Plan for Rural Water Use, Plan of Agricultural Production infrastructure

Since the 1960s, mid- to long-term plans for irrigation projects have been established. The first, second, third, and fourth mid- to long-term irrigation development plans were established every 10 years, and the project was carried out according to the plan.

Then, in 2000, a plan to rationalize the use of rural water and a mid- to long-term plan for agricultural production infrastructure projects were established. In particular, in the 2023 Agricultural production infrastructure project plan (2023-2032), a mid- to long-term plan for water use, water safety, and water

environmental fields suitable for climate change and agricultural environment change was recently established. For the plan to rationalize the use of rural water, the third plan was established in 2025.

6.2.3 *Establishing a stable legal system*

Since the 1960s, laws for irrigation projects have undergone many changes. The Improvement of Land Act (1961-1970), the Modernization of Agriculture and Rural Development Act (1971-1996), the Acceleration of Farmland Expansion Act (1975-1995), and the Rearrangement of agricultural and fishing villages Act (1995-present). Currently, the Rearrangement of agricultural and fishing villages Act is the only parent law for irrigation development and management.

However, the Rearrangement of agricultural and fishing villages Act includes not only irrigation projects but also various projects such as rural environment improvement and agricultural industry. In addition, although it was partially revised as necessary, the need to enact a comprehensive revision, that is, a new law, has emerged in the era of integrated water management, the 4th industrial era, and global cooperation.

Therefore, it is necessary to prepare for a new paradigm for irrigation projects by creating new laws such as the Agricultural Water Management Act and adding content appropriate to the situation of the times.

6.3 Participation of farmers

6.3.1 *Issues with the Beneficiary's Responsibility Principle (Cost)*

Since 2000, 103 FLIAs have been integrated into the KRC, a government-affiliated organization, and the government has abolished the Irrigation Association fee (Water tariff) borne by FLIA's members (farmers) as a result of integration. It meant that the three organizations (103 FLIAs, RDC, and Federation FLIA) would reduce the burden on farmers by improving management efficiency through integration.

However, the international community, such as the OECD, was critical of Korea's exemption from Irrigation fees (water tariff). It was criticized as a violation of the beneficiary burden principle and as a form of direct assistance for farmers.

In this regard, there was a review on the re-imposition of Irrigation fees, but it was not conducted for various reasons, such as farmers' willingness to bear (capacity) and economic effectiveness (administrative costs due to imposition). Therefore, it is practically difficult to discuss re-imposition of irrigation fees (water tariff) now, 26 years after the exemption from irrigation fees.

6.3.2 *Participation of farmers (labor force)*

The participation of farmers does not simply mean the cost burden (water tariff). There may be various types of farmer participation, such as labor burden (reduction in maintenance costs) and decision-making participation. However, in the form of the irrigation association before the integration in 2000, through the Representatives Committee and the Farmer's Promoting Group (Heung-nong-gye), etc., they were able to participate in the decision-making on the Irrigation association's operation, and through the Farmer's Promoting Group (Heung-nong-gye), they paid the labor force burden. However, since the integration in 2000, the participation of farmers in decision-making has been very limited, and the burden of labor has gradually disappeared. In the past, the consciousness of farmers who took the maintenance of irrigation canal for granted has changed, and the KRC, that is, the Government, has changed to solve everything (something that must be solved).

This is not just because the management organization has changed from an irrigation association to a governmental organization, the KRC. Since 2000, the aging and hollowing of farmers in Korea has

progressed rapidly. Therefore, there is a shortage of farmers who can participate in water management. It is a structure in which water management is difficult to maintain without the support of the government.

6.3.3 Saving farmers' water (demand management)

Due to the characteristic of agricultural water in Korea, there is no competition with other water. If agricultural water is saved, it is converted to other water, but there is a limit to the irrigation supply system.

From the perspective of farmers, it is not motivating why water should be saved. It has been customarily irrigation of freshwater and has been used without shortage. This is because saving reduces the cost (water tariff) burden, or it is not a system that receives profits (compensation) as much as saving. Therefore, what used to be taken for granted by farmers to save water, such as trading water rights, saving agricultural water, or compensation for interruption, has now changed to a situation where incentives must be given.

7. Finance

7.1 Financial resources for irrigation projects

The insufficient budget for the irrigation project, which began in the 1960s, was covered by overseas loans. The "large-scale comprehensive development project" which requires large-scale project expenses was implemented through overseas loans such as WB (IBRD) and ADB (Yeong-san-gang, Sae-man-geum, Geum-gang Project, etc.). This continued until the 1990s.

With the advent of the WTO era in 1995, a "Special Agricultural Tax" for agricultural rural development was newly established to minimize damage to the agricultural sector. The financial resources provided by the special agricultural tax were used for project expenses necessary for irrigation projects.

In addition, the "Farmland Management Fund" was established in 1990. Those who wish to change their farmland for other purposes must pay the "farmland exclusive charge", which created the Farmland Management Fund. The Farmland Management Fund was invested in the "reclamation project(ex, Sae-man-geum project)" to secure new farmland that was reduced as farmland was converted, and the "farmland consolidation project" to increase the productivity of farmland, and the project cost for the farmland Size-up project (ex, expansion of farmland, farmland lease).

The MAFRA's 2022 budget is 17 trillion KRW. The general budget is 8.8 trillion KRW (5.1 trillion KRW for special agricultural taxes) and the fund is 8.1 trillion KRW (1.8 trillion KRW for farmland management funds). Special agricultural taxes and farmland management funds account for 40 percent of the MAFRA's total budget. . (Ref; 1,000 KRW is 1.5 USD in 2025)

7.2 Ratio of financial resources

Currently, the MAFRA (central government) is 100% responsible for most irrigation development projects (water development, drainage improvement, reclamation projects, etc.). However, in 1980, 70% of the MAFRA and 30% of the local government were responsible, but in the 1990s, it was changed to 100% of the MAFRA. In the case of the farmland consolidation project, it was changed from 50% in the MAFRA, 30% in the local government, and 20% of the farmers in 1971 to 80% in the MAFRA and 20% in the local government. The ratio of the MAFRA's financial burden is increasing.

7.3 Irrigation Maintenance costs

Prior to the integration of 103 FLIAs nationwide into the KRC in 2000, irrigation associations collected irrigation association fee (IAF) for irrigation facility management. The cost of maintaining irrigation facilities was covered by the IAF and the FLIA's own profitable business (water sales, facility rental, etc.).

The standard for imposing IAF was 30kg (0.1ha) of rice in 1981, 25kg in 1987, 10kg in 1988, and 5kg in 1989, and 6,000 KRW in cash in 1996, which was abolished in 2000.

The government began providing governmental subsidies in 1987 instead of lowering the IAF. Accordingly, the maintenance share increased from 77% of the IAF and 23% of its own profits in 1981 to 66%, 27% of its own profits and 7% of the governmental subsidy in 1987. Since then, it has increased to 13%, 26% of its own profits, and 61% of the governmental subsidy in 1989.

After the consolidation in 2000, IAF (as water tariff) have disappeared, with 60% of KRC's self-income and 40% of the governmental subsidy. Despite inflation such as labor and electricity bills every year, governmental subsidies are fixed at around 160 billion KRW, making it difficult to secure sufficient budgets.

< Irrigation management cost and source >

Classification/year		FLIA					KRC		
		In 1981	1987	1988	1989	1996	2000	2010	2025
IAF(per 0.1ha)		Rice 30kg	Rice 25kg	Rice 10kg	Rice 5kg	6,000 KRW	-	-	-
Ration of Irrigation management cost	Farmer(IAF)	77%	66%	23%	13%	9%	-	-	-
	Governmental subsidy	-	7%	45%	61%	32%	30%	48%	40%
	FLIA/KRC	23%	27%	32%	26%	59%	70%	52%	60%

7.4 Difficulties in investment in irrigation projects

In Korea, food self-sufficiency has been one of the top priority government policies since 1960. Therefore, investment in irrigation projects was made, and insufficient financial resources were provided through loans. Since 1990, a special agricultural tax and farmland management fund have been established to provide stable financial resources for irrigation projects.

However, as agricultural GDP has decreased since 2000 and rice production has been excessive, fiscal authorities such as the Ministry of Economy and Finance have raised objections to the budget investment in irrigation projects. We need to answer the question of why we should invest in irrigation projects when there is rice left.

Irrigation projects are not only for the purpose of agricultural production, but also to protect the lives and property of farmers through drought and flood response. Furthermore, it is promoting that it provides various public interest (multilateral) values to the general public, but questions are still being raised why investment in agriculture is needed. Agriculture and irrigation projects are increasingly recognized as declining industries.

8. Lessons and recommendations

8.1 It is the first start of national development of irrigation projects

Since 1960, Korea has prioritized food self-sufficiency and invested in irrigation projects through mid- to long-term plans and financial securing (loans, agricultural special taxes, funds). Considering the difficulties in promoting new SOC projects due to recent environmental issues, etc., the full investment in the early stages of industrialization was timely.

8.2 Response to climate change is urgent

Since 2000, irrigation has been modernized to respond to climate change. In addition to the renovation project of old facilities, the flooding prevention capacity increase project and the irrigation system connection project have been promoted since 2010. Irrigation projects and policy changes were promoted in a timely manner in accordance with external changes.

8.3 The basis of smart water management is quality data

In line with the era of the 4th industrial revolution, the foundation for establishing an information system for smart irrigation management was laid. However, securing more measurement data and quality control of data are the problems. This is because the quality of data is life for decision-making suitable for the AI era.

8.4 Water management suitable for changes in the agricultural environment is necessary

Since 2000, it has changed from participatory management to government-led management. Criticism has been raised against the exemption of irrigation fee (water tariff) and low participation of farmers (decision-making, labor force), but since 2010, it has been an additional avoidance choice (the way to go) considering the aging and hollowing out of rural areas. In addition, ICT-based irrigation management is needed for automation suitable for changes in the agricultural environment.

8.5 It is necessary to discover the logic of investment in irrigation projects

The justification for investment in irrigation projects by the national finance is decreasing due to the decline in GDP of national agriculture and the increase in rice inventories. It is necessary to persuade fiscal authorities and the public to understand in order to secure the budget continuously.

8.6 Agricultural water, eventually to go together

In Korea, governance with farmers who are users has weakened as agricultural water changed to government-led irrigation management in 2000. As the MAFRA and the KRC have long exclusively managed it, cooperation with related ministries (the MCEE and the MOLIT) and governance with the general public and civic groups have been weak. Therefore, governance not only with the agricultural sector but also with other sector is important to recognize the pluralistic value of irrigation projects and to gain consensus on government budget investment.

Reference

2025 Main Statistic of Agriculture, forest and Livestock (MAFRA)
2025 Statistical yearbook of land and water development for agriculture (MAFRA, KRC)
2025 Main Handbook (KRC)
Weather Information system (KMA)
National Water Management Principal Plan (Nation water management committee)
National law information system (www.law.go.kr)

IRRIGATION IN UKRAINE : BACKGROUND, REALITY, AND PERSPECTIVES – UKRAINE¹

In Ukraine, the largest share (43 million hectares, of which 32.5 million hectares are arable land) is agricultural land. In the structure of the land fund, agricultural land occupies 69.2%, including arable land - 53.8%, perennial plantings - 1.5%, hayfields - 4%, pastures - 9.2%, fallow land – 0.7%. At the same time, Ukraine has a unique soil cover - more than 60% of its area is occupied by black soils, which are characterized by a high level of fertility. But the high fertility potential of soils cannot be fully utilized due to the insufficient level of their natural moisture supply throughout the entire vegetation period in the Steppe and Forest-Steppe zones, as well as due to the excess of moisture in the spring and its deficiency starting in July in the Polissya zone. Therefore, in Ukraine, a significant role in ensuring sustainable crops production was assigned to hydrotechnical land melioration - irrigation and drainage. Upon gaining independence in 1991, Ukraine inherited 2.65 million hectares of irrigation systems from the former USSR. During the years of independence, due to climate change, which for Ukraine is characterized by the presence of the so-called "hot phase" (Figure 1), the highest rates in Europe (0.7°C/10 years) of increase in average annual air temperature (Figure 2) and practically unchanged average annual precipitation (Figure 3), which caused the emergence and progressive development of the process of dehydration of the territory of Ukraine as a whole and the further deterioration of the level of natural moisture supply of soils in particular, the need for irrigation has significantly increased.

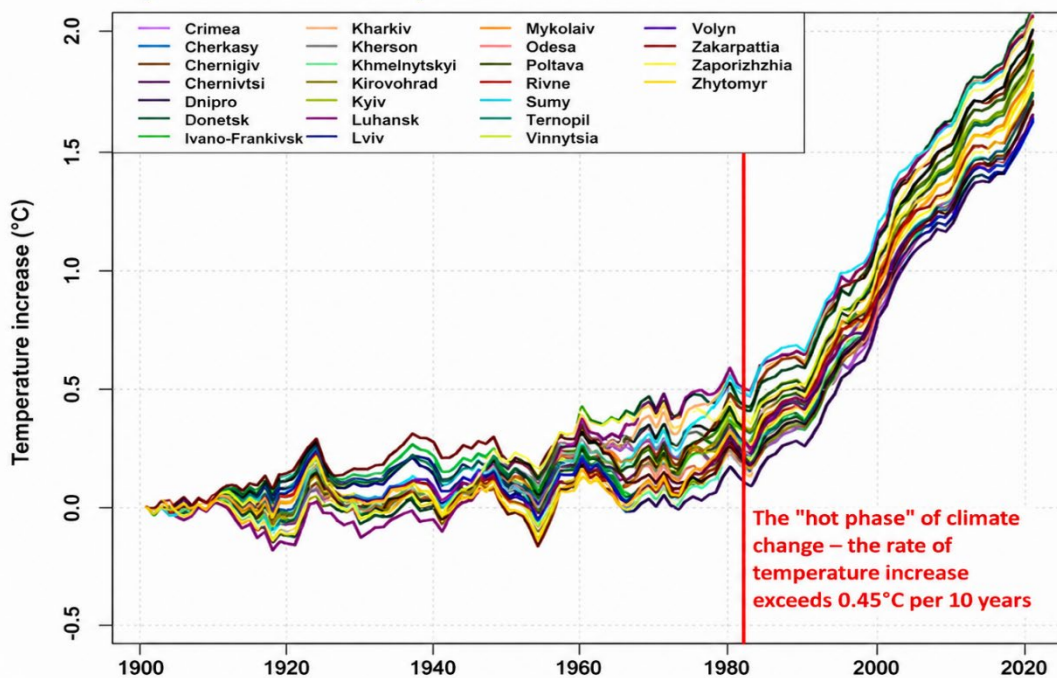


Figure 1. Dynamics of air temperature growth in Ukraine since 1901

¹ Ukraine National Committee of ICID (UACID)

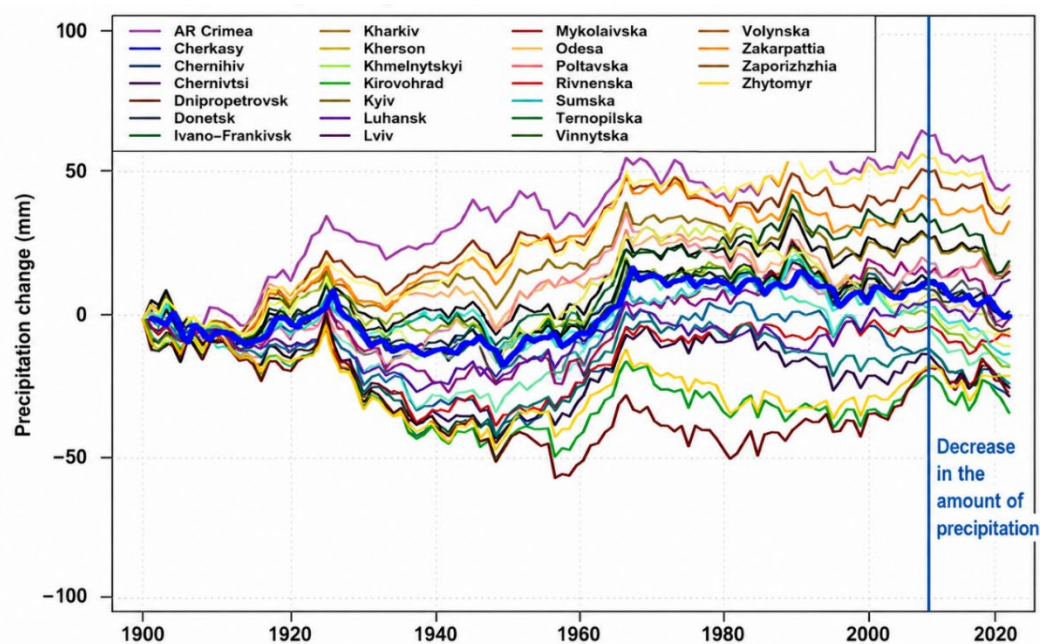


Figure 2. Growth rate of average annual air temperature for 1991 - 2020, °C/per 10 years

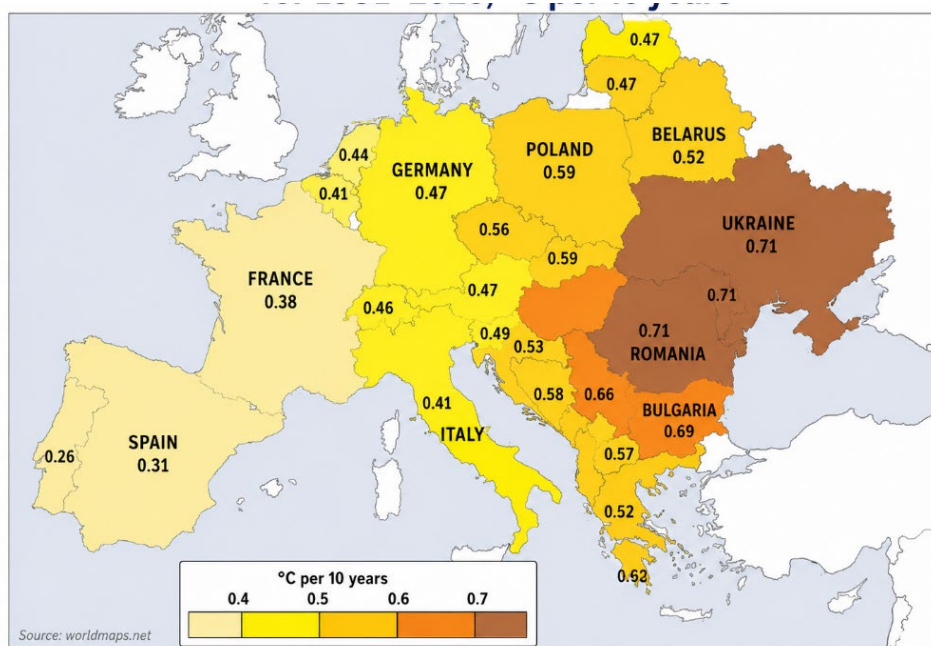


Figure 3. Annual precipitation in Ukraine since 1901

Unfortunately, in practice, there was a sharp reduction in the area of actual irrigation, from 2.29 million hectares in 1990 to 613 thousand hectares in 2013, to 482 - 487 thousand hectares in 2014 -2017 (Figure 4).

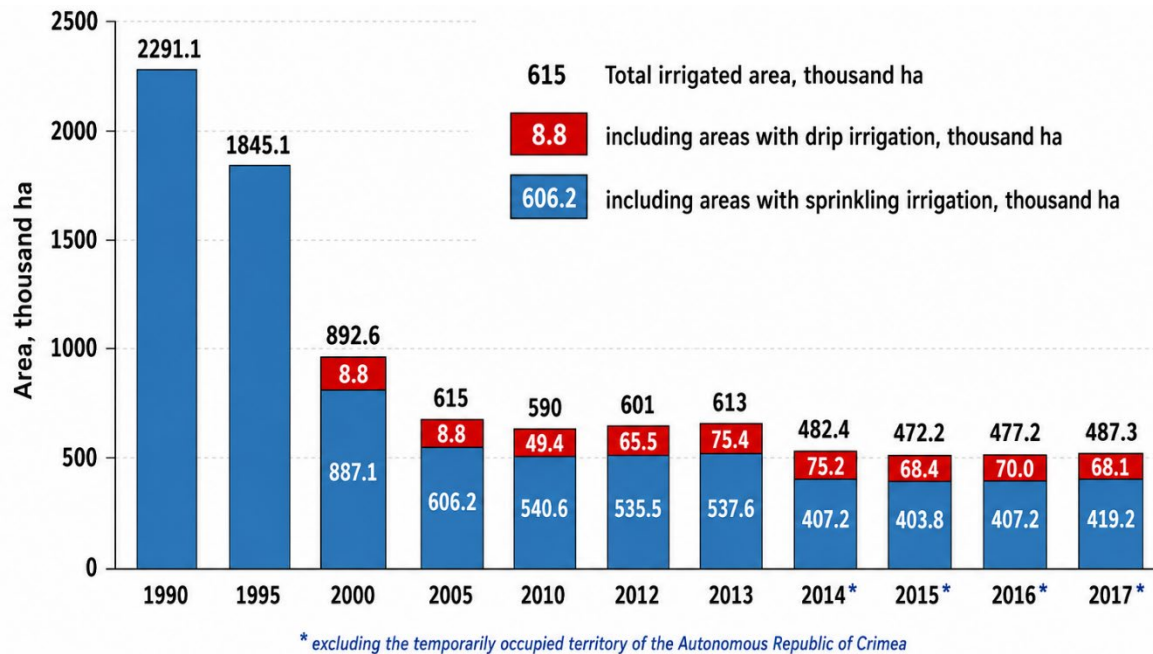


Figure 4. Actual irrigated areas (1990 – 2017)

The unsatisfactory state of use of the existing irrigation potential was formed as a result of a number of factors of an objective and subjective nature, the main of which are the reform of economic relations, privatization of land and material and technical resources, loss of markets for agricultural products, insufficient level of budget financing, incomplete land reform, lack of mechanisms for state support of the industry, imperfection and inconsistency of the existing management system with the new economic conditions of the water management and organization system, etc.

Start of reforming process

During 2015-2018, a working group specially formed by the Cabinet of Ministers of Ukraine, consisting of representatives of the authorities, local governments, water users, and scientists, with the participation of experts from the World Bank and FAO, developed and in August 2019 approved by the Cabinet of Ministers of Ukraine the "Irrigation and Drainage Strategy in Ukraine for the period until 2030" (Order No. 688-r dated August 14, 2019).

Subsequently, in order to develop the main provisions of the "Strategy...", the Cabinet of Ministers of Ukraine approved the "Plan of Actions for the Implementation of the Irrigation and Drainage Strategy in Ukraine for the Period Until 2030" (Order No. 1567-p dated October 21, 2020) and a number of regulatory acts on the reform of the water resources management system and land reclamation, and in 2022 the Parliament of Ukraine adopted the Law of Ukraine "On Water Users Organizations and Stimulation of Hydrotechnical Land Reclamation". The adoption of this law launched the process of forming water user organizations (WUOs), into whose ownership, in order to ensure exploitation, the so-called (according to the current Law of Ukraine "On Land Reclamation") intra-farm reclamation systems (networks) with pumping stations were transferred, that is, water and land users were actually involved in the management of irrigation systems, which, according to the authors of the Law, was supposed to launch the process of accelerated expansion of irrigation areas and highly efficient, resource-saving and environmentally friendly use of irrigated lands.

In order to ensure the implementation of the tasks of the "Strategy..." in terms of separating the functions of forming and implementing the state policy on water resources management from the policy on the development of land reclamation and management of water and reclamation infrastructure, the Cabinet of Ministers of Ukraine in 2021 established the State Agency of Ukraine for the Development of

Reclamation, Fisheries and Food Programs, entrusting it with the functions of implementing the policy on the development of reclamation and the operation of reclamation infrastructure owned by the state, and transferred the functions of forming this policy to the Ministry of Agrarian Policy of Ukraine, leaving the functions of forming and implementing the state water policy to the Ministry of Ecology and the State Water Agency of Ukraine, respectively. The Cabinet of Ministers of Ukraine also obliged the State Water Agency to transfer the reclamation infrastructure to the State Fisheries and Land Reclamation Agency, which should ensure not only its operation, but also its reconstruction and modernization.

In recent years, irrigation systems have suffered significant losses due to Russian military actions and the destruction of infrastructure, in particular the destruction of the Kakhovka reservoir, which led to the loss of 70% of the available irrigation potential and a reduction in the area actually irrigated by approximately 75%. At the same time, losses from the loss of irrigation infrastructure exceeded 7 billion USD, and losses from crop failure on previously irrigated lands amounted to 1 billion USD annually. After the destruction of the Kakhovka reservoir by the Russian Federation, the irrigation area in Ukraine decreased to 133 thousand hectares - this is almost 2.5 times less than it was in 2022 and 4.5 times less than it was in 2021 (before the start of the Russian Federation's full-scale military aggression). Currently, the area of irrigated land in Ukraine is about 0.6% of the total area of agricultural land in the territories controlled by Ukraine, so irrigated land has lost the ability to play the role of an insurance fund in the resource and food supply of the state in years with adverse weather conditions. Therefore, the task of restoring the effective, ecologically balanced use of the potential of irrigated lands is one of the priority areas of Ukraine's state policy and the development of the agricultural sector of its economy. It is the development of the irrigation sector that is considered an objective prerequisite for ensuring an annual level of grain production in the amount of 80-100 million tons, which will allow Ukraine to remain one of the world's food donors.

The state of the irrigation sector in Ukraine is currently critical due to outdated, poorly maintained, and damaged melioration infrastructure, which leads to significant water losses (over 30%) and threatens the sustainable development of agriculture. In many regions, there is a significant problem of aging, and wear and tear of irrigation systems, which reduces their efficiency. Infrastructure modernization, the introduction of innovative and resource-saving technologies are necessary to increase irrigation productivity and save water resources.

To overcome these problems, in 2025, in addition to the existing "Irrigation and Drainage Strategy..." and the "Plan of Actions for its Implementation...", the "Long-term Development Plan for the Irrigation Complex of Ukraine for the period until 2050" was approved by the government, aimed at the modernization, restoration and expansion of irrigation systems and reservoirs, which is integrated into the national water resources management strategy and has received support from international partners. The "Long-term Development Plan..." was developed to implement the European Union initiative "Ukraine Facility", introduced by EU Regulation of the European Parliament and of the Council dated 29 February 2024 No. 2024/792.

The « Long-term plan... » is aimed at restoring and developing of irrigation systems, which is a priority area of Ukrainian state policy in the development of the agricultural sector, as well as to solve key problems in agriculture, ecology, and climate adaptation.

The main principles of the « Long-Term Plan... » are:

1. Ensuring food security – a stable water supply allows farmers to grow crops even during dry periods, reducing the risks of food crises.
2. Adaptation to climate changes – due to global warming, the number of droughts and abnormal weather events is increasing. Irrigation systems help farmers adapt to these changes.
3. Rational use of water resources - water is a limited resource, so Ukraine seeks to stimulate the use of modern irrigation methods to reduce water losses.

4. Environmental protection – it is important to prevent soil depletion and water pollution due to inefficient irrigation. The use of treated wastewater and rainwater is also a priority.
5. Economic stability of agriculture – financing of irrigation infrastructure ensures increased competitiveness of the agricultural sector and promotes investment attraction.
6. Reducing dependence on food imports – the development of irrigation contributes to increased yields and makes it possible to grow crops that cannot be grown without irrigation, such as vegetables, which enhances food security.

In addition, the Parliament of Ukraine developed and in 2026 adopted a law introducing the institution of operators of state-owned land reclamation systems, which should become the main economic entities for the management and operation of these systems; a two-rate tariff was introduced for fair and transparent payment for water use at the water users associations level.

The Cabinet of Ministers of Ukraine, after the adoption of the law "On Water users Organizations..." annually renew a program of state support for irrigation, according to which the state compensates 50% of the cost for the reconstruction of systems at the farm level and 50% of the restoration of pumping stations. WUOs also receive grants and long-term support from international donors, one of which is USAID.

In general, the investment needs for the restoration and modernization of Ukraine's irrigation infrastructure are estimated at billions of US dollars. Therefore, for the implementation of projects for the reconstruction and modernization of existing and the construction of new irrigation systems, in addition to state and local budget funds, it is planned to attract private, including foreign, investments on the basis of public-private partnerships, credit resources from mainly international (World Bank, EBRD, EIB, etc.) financial institutions, as well as reparations funds that will be collected from the Russian Federation for the damage caused by it to the irrigation infrastructure.

Projects, as defined by the "Strategy...", should primarily involve the restoration of irrigation through the reconstruction and modernization of on-farm networks and pumping stations that are not used for irrigation but have not lost their potential. Therefore, the first priority should be to establish WUOs within these networks, which would allow for an accelerated expansion of irrigation areas. Accordingly, the substantive part of the projects should include: replacing outdated pumps with energy-efficient ones with adjustable drives; using low-pressure, low-intensity sprinkling and drip irrigation; mainly closed, less often open, but with anti-filtration geomembrane coatings, water supply networks; pools - accumulators of daily regulation, autonomous renewable sources (solar, wind) of energy supply; adaptive compensation-type irrigation modes; digital technologies - internet weather stations, moisture sensors, remote control, smart meters for accurate water metering, information and advisory irrigation management systems, etc. In general, it can be stated that the technical and technological development of irrigation in Ukraine corresponds to world trends and in many cases to the world level. Thus, despite the military aggression of the Russian Federation, Ukraine has established and continues to operate its own production (LLC « Variant Agro Bud », LLC « Fregat ») of new generation sprinklers and modern drip irrigation equipment (LLC « Irrigator Ukraine »), Internet weather stations, etc. Domestic irrigation equipment not only successfully competes with leading world manufacturers on the Ukrainian market, but is also exported in increasing volumes.

However, despite the high level of legislative and regulatory support, the presence of its own production and technological base, and scientific support of practically world-class level, the current state of the irrigation industry in Ukraine is characterized by the presence of a number of challenges and problems. The first and most negative of these is the military aggression of the Russian Federation, as a result of which Ukraine lost its largest source of water for irrigation - the Kakhovka reservoir, the largest area of actual irrigation (about 500 thousand hectares) and the largest potential of irrigation infrastructure (almost 1 million hectares), which, in terms of its technical condition, was most suitable for a quick and relatively inexpensive (up to 2 thousand USD/hectare) restoration of irrigation. It is in view of this that the World Bank was ready to start financing works on the restoration (expansion) of irrigation in the

Kakhovka and other irrigation systems of the Kherson, Zaporizhia and Mykolaiv regions starting in 2022. Therefore, the military aggression of the Russian Federation, in addition to the huge (over 7 billion USD) damage caused to the irrigation infrastructure, also made it impossible to implement the largest (in terms of the amount of financing attracted from the most reputable international financial institution) irrigation restoration project during the independence period in accordance with the tasks of the "Strategy".

Another challenge in increasing irrigation potential is the limited volume of both surface and groundwater resources suitable for irrigation purposes, especially in regions that are most in need of irrigation due to progressive climate warming, namely Odessa, Mykolaiv, Vinnytsia, Kirovohrad, and Ukrainian-controlled territories of Kherson, Zaporizhia, and Dnipro regions. That is why the "Strategy..." and the "Action Plan..." included among the priorities (from 2020) the implementation of work on the development of feasibility studies and design projects to involve water resources of the Danube river to improve water supply to the southern regions and restore the water-regulating and water-accumulating capacity of Polissya.

Unfortunately, the failure to carry out these works, as well as the inventory of existing irrigation and drainage systems, has practically jeopardized, despite the adoption of another, updated regulatory act on the development of irrigation, namely the already mentioned "Long-term plan for the restoration of the irrigation complex of Ukraine ..." the very possibility of expanding irrigation areas even in the volumes declared by these program documents, not to mention the volumes required to ensure the sustainability of agriculture in the conditions of climate changes and compensate for losses in agricultural production volumes and the reduction in the export potential of the agricultural sector of the Ukrainian economy due to the temporary loss of 20% of farmland and 70% of irrigation infrastructure and areas of actual irrigation.

The process of increasing the area of irrigation has also been slowed down, in our opinion, by the unjustified fetishization of the role of WUOs, especially given that their creation occurs almost exclusively on lands where irrigation was carried out even without the presence of WUOs, and where there are practically no significant reserves for expanding the area of irrigation due to the lack of water, as well as due to the need to build a new irrigation infrastructure for this, and not by restoring the functionality of the existing one, which requires larger amounts of funds.

The fact that, contrary to world experience, the recommendations of eternal science and the provisions of the "Strategy...", the law "On Water User Organizations..." provides for the transfer of irrigation infrastructure to the WUOs not for free lifelong use, but for ownership, which in turn necessitated the development of a number of by-laws to regulate the procedure for UACs to acquire ownership rights to the acquired infrastructure and to legislatively regulate the issue of paying VAT for irrigation infrastructure transferred to the WUOs (the relevant decision was made only in August 2025), therefore the fact of the creation of WUOs did not yet mean (before acquiring ownership rights) that they had the opportunity to implement projects to expand irrigation areas, even if funds were available.

Among the challenges and problems, it is also necessary to highlight the almost complete absence of examples of creating WUOs based on irrigation infrastructure, which is currently not used for irrigation, but whose technical condition allows for the restoration of irrigation by developing and implementing projects for its reconstruction and modernization.

This process is also hampered by the incompleteness of the process of transferring infrastructure from the State Water Agency to the State Agency for the Development of Reclamation and Fisheries, and the failure to carry out work on the inventory of irrigation infrastructure and, as a result, the inability to identify those infrastructure facilities that can be offered to landowners and land users for the creation of WUOs and, on this basis, the implementation of irrigation restoration projects.

It is clear that the creation of aWUOs on a non-functioning irrigation infrastructure will require, in addition to conducting an inventory, also a mandatory resolution of the issue of financing irrigation restoration projects by providing WUOs with access to medium- and long-term soft loans. Summing up the consideration of current challenges and problems regarding the implementation of the tasks of the

irrigation sector reform as the basis for increasing the area of irrigated land, we consider it necessary to emphasize that Ukraine has created almost the entire legislative and regulatory framework for the successful completion of the reform - it is only necessary to clearly and timely fulfill all the tasks provided for by the relevant program documents.

First of all, this concerns the inventory of existing irrigation infrastructure in the territories controlled by Ukraine, the results of which should form a list of objects (systems) with irrigation infrastructure that is not currently used for irrigation, but whose technical condition allows for the restoration of irrigation by developing and implementing projects for its reconstruction and modernization, and these objects should be offered to landowners and land users for the creation of WUOs. At the same time, the results of the inventory should become the basis for developing feasibility studies and design projects that will be implemented by the newly created WUOs to restore irrigation in the territories they serve.

In our opinion, the inventory work should be carried out by the State Fisheries Agency at the expense of the state budget. Only in this way can a reserve of areas suitable for the earliest and least costly restoration of irrigation based on the use of the existing irrigation infrastructure be formed. The next type of work, the implementation of which should also be organized by the State Fisheries Agency and financed from the state budget, is the development of feasibility studies and design projects for attracting water resources from the Danube river and restoring the water-regulating and water-accumulating capacity of Polissya.

The territory of Ukraine should also be zoned according to the volumes of surface and underground water resources available for irrigation purposes. There is the methodology recently developed by the Ukrainians researcher for that specific purpose and conditions.

Without setting out to provide an exhaustive list of works that must be carried out to ensure the implementation of the main task of the irrigation sector reform, namely the rapid increase in irrigation areas, we would like to emphasize once again that this list includes the "Plan of Actions for the Implementation of the Strategy..." and the "Long-term Plan for the Restoration of the Irrigation Complex..." - it is simply necessary to ensure their implementation. It is clear that the process of creating new WUOs must be continued, as well as the ongoing training of members of already created WUOs in all components of effective management of WUOs activities must be established.

Of course, the expansion of irrigation areas requires significant financial resources, so the issue of creating conditions for access of WUOs, especially those formed on the basis of irrigation networks that have not previously been used for irrigation, to medium- and long-term preferential loans requires a mandatory and as soon as possible solution. Possible options for its solution may be the introduction of a targeted nationwide program of preferential lending for irrigation and drainage works, as well as the provision of state guarantees when using loans from international financial institutions. A mechanism for full or partial exemption of WUOs from taxation for the period of implementation of projects to expand irrigation areas is also not excluded.

In general, in the context of climate changes and the loss of significant areas of agricultural land due to the temporary occupation of the Russian Federation and military damage and pollution, irrigation reform is key to ensuring food security and preserving, and in the long term, increasing the export potential of the agricultural sector of the Ukrainian economy. Its implementation will also be a significant step towards the modernization of the agricultural sector and sustainable use of water resources.



ICID•CIID

Invitation to Join ICID *As* Direct Member

Invitation to Join!

The International Commission on Irrigation and Drainage (ICID) is a leading scientific, technical, and professional not-for-profit international organization established in 1950 with headquarters in New Delhi, India; working in the field of irrigation, drainage, and flood management to promote and achieve 'sustainable agriculture water management' through its vision "A water secure world free of poverty and hunger through sustainable rural development".

ICID's Membership is open to Private Companies, Institutions, and Individuals involved in agriculture water management to join as a 'Direct Member'. By joining ICID as a "**DIRECT MEMBER**", companies, institutions, and individuals working or dealing with irrigation, drainage, flood-related issues, and other allied fields would be part of an international network that offers opportunities to exchange knowledge and experience, establish partnerships; stay informed on recent irrigation, drainage and flood management news and events through Commission's publications; make their voice heard and contribute to improved understanding among stakeholders, enabling new ideas on water policy; benefit from worldwide exposure of their organization's activities by using the Commission's communication tools and by participating in

the Commission's activities; and influence policymakers to develop sound irrigation-related policies and give it higher priority in the political agenda.

ICID organizes triennial International Congress on Irrigation and Drainage – addressing specific questions; World Irrigation Forum, Regional Conferences, International Drainage Workshops, International Micro Irrigation Conferences, etc. regularly. The Commission brings together experts from different parts of the world to share their experiences and knowledge on specific issues through the ICID technical workbodies. The workbodies bring out manuals, guidelines, and special publications from time-to-time.

For more information related to Direct Membership, please visit: https://icid-ciid.org/member/direct_member

Apply Online for Direct Membership: https://icid-ciid.org/member/dm_membership_form

Contact:

*The Secretary General, ICID, 48 Nyaya Marg,
Chanakyapuri, New Delhi 110 021, India,
Tel: +91-11-41510420, E-mail: icid@icid.org
Website: <http://www.icid.org>*





ICID•CIID

26^E CONGRÈS INTERNATIONAL DES IRRIGATIONS ET DU DRAINAGE DE LA CIID

12-17 October 2026, Marseille, France

Hosted by:

Eau, Agriculture et Territoires

Association française pour l'eau agricole, une irrigation et
un drainage durables, 500 rue Jean-François Breton, 34093
Montpellier Cedex 5, France, E-mail: afeid@inrae.fr
Website: <https://www.eau-agriculture-et-territoires.com/>



ICID Central Office:

48 Nyaya Marg, Chanakyapuri, New Delhi 110021, India.
Tel: +91-11-41510420, E-mail: icid@icid.org,
Website: www.icid.org

Follow ICID on :

