A Retrospective of Lending for Irrigation

Reflections on 70 Years of Bank Experience

DISCUSSION PAPER

MARCH 2024

Hervé Plusquellec
with the assistance of Sanjiva Cooke

WORLD BANK GROUP

Cover design: Bill Pragluski, Critical Stages, LLC.

Photo credits: © Hervé Plusquellec/World Bank unless otherwise noted. Additional cover photos are courtesy of the following: ORMVA Doukkala, Morocco (top right), CARPI (lower left), and BORIS international (lower right).

W23016.indb 2 26/03/24 8:01 PM

Contents

BOXES

FIGURES

PHOTOS

TABLES

Foreword

Since the first loans for irrigation projects in Iraq and Thailand in 1950, the World Bank Group has contributed to the financing of over 800 projects related to irrigation, with cumulative lending of about $60 billion in 2010 US dollars. Irrigation was the top focus of World Bank lending in the 1970–80s, before declining according to the same pattern as that of official development financing. Over the past three decades, commitments to the water sector have focused more on water supply and sanitation than agricultural water. In recent years, in light of the climate crisis, food security and rural job security, new engagements and new objectives are being formulated. As this new generation takes flight, this retrospective discussion paper by our eminent former colleague Herve Plusquellec on 70 years of bank engagement is very valuable and timely.

As this document illustrates, the World Bank engagement in the irrigation and drainage sector reflects the global dialogue and trends, as well as internal reforms. From the early years to the Green Revolution in the 1970s but also beyond there has been a steady increase in irrigated area globally (over 100% in the last 70 years), to hover around 20% of cultivated area currently, and irrigated production represents majority of the value of agricultural output. From an initial focus on large scale infrastructure and canal-based systems, infrastructure has become broad-based including through innovations in groundwater pumping in the 1990s, individual and small scale irrigation, as well as dams/reservoirs and drainage solutions. This broader range of climate-smart agricultural water management solutions, and in particular the on-farm solutions provide flexibility of service to users and have taken a huge flight. Farm owners and the private sector invested more in techniques to extract groundwater and also to save water, as opposed to surface water projects. Irrigation canal systems were left to stagnate in some countries (such as in Asia). The author of this report argues that not enough attention has been given to the complex engineering problems of reducing losses from irrigation canals and increasing the flexibility of their services to users.

Institutional governance, farmer participation and later service delivery have become mainstays of the irrigation sector since the 1980s/1990s, with water users' associations, participatory irrigation management, and management transfer, as well as issues of pricing and financial sustainability. As a reaction to the earlier infrastructure focus, the prevailing view in the 1980s became that the issues in irrigation management were essentially institutional and financial. There has been a progressive realization that engineering and institutional innovations should come together in an integrated and mutually reinforcing manner. Yet, the author argues that the belief that these irrigation challenges can be solved separately through improved management and physical repairs, is still entrenched in some country programs.

Since the 2000s there has been increasing awareness on environmental sustainability, the climate crisis and global food security and water crises, which led to renewed engagement and investment in the sector and the desire to reformulate policy to address both the harmful externalities in terms of water quality, salt intrusion, riverine ecosystem loss, non-point pollution, and resource depletion in some regions, as well as a renewed awareness of the positive adaptation and mitigation role of agricultural water management in climate resilience, food security, rural jobs, stability, and managing floods and droughts. More holistic integration of water stewardship, integrated water resources management and innovations in technology, conjunctive use, circular economy, and recently emissions reduction in rice cultivation have been started to recalibrate the sector for future challenges and opportunities.

Today, the Bank supports clients in a broad understanding of all forms of water in agriculture, including irrigation. This last category includes not only irrigation canal systems but also, and importantly, farmer-led irrigation development, better water accountability through accounting, water allocation and water stewardship, and a performance-based institutional reform agenda that considers wider basins and food systems and their interrelations with institutions, information, and indeed infrastructure.

An increasing focus on the circular economy, virtual water, rural water security, water-smart diets, climate-smart land management, and agronomy is delivering tangible insights into solutions and trade-offs in the water-agriculture nexus. Innovation and disruptive technology are helping overcome legacy problems, and more inclusive service delivery is creating new dynamism in many of the Bank's counterpart agencies. Within this broader understanding, the nature of the Bank's analytical work and its irrigation interventions will continue to change, but the centrality of irrigated agriculture to the big challenges of tomorrow is beyond question, including the very complex technical challenges of making these irrigation systems, both large and small, deliver the outcomes that the people and the planet need.

In major parts of the world, irrigation development has reached its limits in terms of land and water resources, as evident in the alarming overexploitation of groundwater resources and the deterioration of their quality. In other parts, intensification with sustainable and smart irrigation solutions is the most viable way to build climate resilience and combat food insecurity. This report advocates for:

1. Improving the quality of irrigation services through a combination of better design, adoption of modern technologies, and attuned operation and maintenance.
2. A bold risk-taking approach to irrigation modernization and sustainable expansion based on lessons learned by restoring legitimacy through strong technical, institutional, and economic engagement in reforming the subsector.

The irrigation sector is complex and to realistically live up to the many opportunities that it provides to lift people out of poverty will require concerted effort, reformulation of goals, and greater accountability for performance to users and society at large. The subsector is not the only one facing these challenges, but a retrospective will help unearth specific impediments and unresolved issues within the sector as much as the sector looks across to other infrastructure service sectors and ahead to tomorrow's challenges.

This publication provides a personal perspective on this retrospective and does not aim to discuss these past trends comprehensively, much less opine on future scenarios. It is intended to be of interest to Bank staff involved in the formulation of country assistance strategies at all levels, and in the formulation and implementation of irrigation projects to irrigation agencies and research and training institutions. It is hoped that the retrospective will stimulate debate among current practitioners on how to best support the irrigation subsector, moving forward and especially in light of the increasing climate change impacts, water scarcity, and food security challenges seen across the globe.

This publication is divided into two parts: the first part analyzes trends in the Bank's lending and ratings of completed projects. It also summarizes several key policies that shaped the irrigation and drainage subsector. A second part is devoted to analyzing the performance of large- and medium-scale irrigation projects. Information on the volume of Bank lending and the ratings of completed projects presented in this document are extracted from Bank data. Statistics on the Bank's performance in project preparation and implementation reflect the findings of the former Operations Evaluation Department, now the Independent Evaluation Group (IEG), which reports directly to the Bank's Board of Directors. It complements recent reviews from IEG (2009–19) and the Bank's qualitative portfolio review, *Water in Agriculture* (2022), by giving a long-term view.

As discussed at the end of this publication, it should be of concern to the Bank's management that the shape and size of the current portfolio does not seem to reflect the level of ambition by client countries. This may be an indication of a decline in the Bank's perceived value addition, the technical rigor and innovative nature of the solutions it brings. The sector is rapidly evolving, innovating, and yet struggling with unresolved performance issues, and we see this report as a call for introspection: Is the World Bank set up to support these new approaches and shake off past misconceptions? Is the Bank's value proposition attractive to today's clients and challenges, and are internal arrangements (incentives, staffing, budgets) adequate to follow through on recommended action?

We are very grateful to Herve Plusquellec for having volunteered his time to prepare this document on 70 years of Bank lending to this critical subsector and for hinting at potential answers presented by history.

Pieter Waalewijn
Lead Water Resources Management Specialist
World Bank, Washington, DC

Amal Talbi
Global Lead, Water in Agriculture
World Bank, Washington, DC

Preface

The document is divided into two parts. Part I is a historical review of Bank lending for the irrigation subsector. It draws heavily from Bank-published documents.

Chapter 1 broadly presents the importance of irrigation in food production and the diversity of irrigation related to historical development.

Chapter 2 outlines the quantitative evolution of Bank lending for irrigation over a 70-year period and the geographic distribution by region and country.

Chapter 3 presents the Bank's directives and their application to the irrigation subsector, as well as the policy and strategy for development of water resources.

Chapter 4 presents the performance of Bank-financed irrigation projects evaluated across three periods using different performance criteria.

Part II focuses on large- and medium-scale irrigation projects and considers the reasons why they have performed below potential, such as overoptimistic economic evaluation of projects, use of outdated or inadequate design standards, and the mixed results of implementing participatory irrigation management.

Appendix A reviews several key studies of irrigation projects' performance put forward by the Operations Evaluation Department and, later, the Independent Evaluation Group.

Appendix B outlines key reorganizations of the Bank's structure since 1972 and considers their impact on irrigation lending.

Appendix C lists several Bank directives from the years 1971 to 1982 applicable to the irrigation subsector.

Appendix D is devoted to irrigation lending to the two largest irrigating countries, China and India, where the development of irrigation exceeds 65 million ha in total.

Appendix E considers the interaction between the World Bank and other international organizations involved in the irrigation subsector.

In conclusion, appendix F features several tables and figures not included in the main report.

Key Points

The Importance of Irrigation

- The irrigation subsector contributes to about 40 percent of food production while covering only about 20 percent of the world's cultivated areas.
- Irrigation supports the livelihoods of rural populations all over the world, and the global reduction of poverty and hunger.
- About 70 percent of water diverted from surface and groundwater resources is for irrigation.

Findings

- World Bank supported irrigation projects, especially large- and medium-scale systems, performed below expectations in the 1970s and 1980s. Thereafter, they have performed as expected.
- Overoptimistic assumptions and inattention to technical issues were among the main causes of poor performance in the early years of lending for irrigation, which was limited to canal irrigation with no consideration of groundwater use.
- The Bank has not been a strong advocate of the adoption of advanced technologies in its operations at the canal system level. Most advanced techniques in canal lining and water control are applied without financing by the Bank or other international finance institutions.
- Apart from the earlier poor performance, and shifting economic priorities, internal Bank factors also contributed to the slowdown of lending in the 1980–90s and to the stagnation of lending in comparison with other infrastructure sectors.
- Greater attention to technical and management issues in unison, and especially the promotion of advanced irrigation technologies in operations, would expand the limits of agricultural productivity.
- Amid greater water scarcity and a growing population, the coordinated management of surface and groundwater is a must.

Acknowledgments

The author wishes to express his appreciation to current and former World Bank Staff in the 1818 Society and the Water in Agriculture Solutions Group in the World Bank. In particular, the author thanks Pieter Waalewijn's support during the final stages of document preparation, and in particular his highlighting of valuable lessons from the past and support in drafting research on new paradigms in chapter 5. The author is grateful to Sanjiva Cooke for invaluable assistance in the collection and processing of data on Bank lending for irrigation. He also wishes to acknowledge constructive comments from the following reviewers: Greg Browder, April Connelly, Gabriella Izzi, IJsbrand de Jong, Francois Onimus, Ahmed Shawky, Joop Stoutjesdijk, Amal Talbi, and Svetlana Valieva as well as Kevin Cleaver, Patrick Labaste, Nadim Khoury, Rory O'Sullivan, and Volker Branscheid (retired). Much appreciation goes to Fayre Makeig for editing the document.

About the Author

This document was prepared by Herve Plusquellec, former Irrigation Adviser in the Central Department of Agriculture and Rural Development of the World Bank. The author joined the Bank in 1976 and has almost half a century's experience in World Bank operations, within a 62-year professional life, with a focus on irrigation, first as a staff member and then after his retirement in 1997 as a consultant with the World Bank and outside. He has extensively published on a variety of topics, from the modernization of irrigation to land consolidation and performance diagnostics. The author, a hydraulics engineer, brings the engineering perspective of the irrigation task of delivering reliable and steady flow with minimum losses to a multitude of users from a large flow of water diverted at headworks and conveyed through a network of canals mostly under unsteady flow conditions. The purpose of the report is to document the long-term engagement of the World Bank in the sector from the operational perspective. This approach does not aim at completeness in the sector, but to provide a well-researched retrospective on key events, decisions, volumes of lending, based on experience, a portfolio review and published World Bank documents, and to add the personal reflection by the author.

This book was written as a voluntary contribution to document the Bank's lending history in irrigation with the 1818 Society and the Water in Agriculture Global Solutions Group. It provides a unique practitioner's perspective based on historical documentation and the author's professional experience. The first part of the report includes a data-based history analyzing trends in the Bank's lending and ratings of completed projects based on bank documents. This is based on World Bank statistics and was accomplished with support from staff of the World Bank. The second part provides the author's analysis of the historical performance of large-and-medium scale irrigation portfolio.

Executive Summary

The irrigation subsector encompasses a diverse variety of physical activities. These span the construction and rehabilitation of large reservoirs and networks of canals or pipes, pumps, water regulation structures, on-farm development within those schemes, drainage, and flood control, as well as the strengthening of social organizations, institutional reforms, the various processes of agro-industries, and the provision of extension services.

Today, irrigation underlies 40 percent of agricultural production. Irrigation is an integral component of two sectors—agriculture and water—and has some links with other areas such as private sector development, social protection, energy, and the environment. With such a multitude of linkages, the history of World Bank lending for irrigation reveals many lessons in the development of both water- and land-based resources in the Bank's client countries.

This document consists of two parts:

- Part I is a data-based history of the irrigation subsector, as supported by the Bank over a 70-year period, based on findings and conclusions of Bank documents.
- Part II considers the performance of large- and medium-scale irrigation projects in the 1980s and 1990s, based on the author's own experience in and outside the Bank, and the experience of other experts in the irrigation subsector. Part II concludes with some recommendations based on cost and official development assistance considerations.

Volume of Lending for Irrigation and Drainage

The Bank had supported 818 irrigation investment operations as of the end of fiscal year 2018. After a slow start in the 1950–70 period, annual Bank lending for irrigation grew quickly in the 1970s to reach a peak of $1.2 billion in nominal dollars in 1980 before a sharp decline in only five years. This decline continued, ending in a record low of $200 million in the early 2000s, followed by a modest increase in the years since.

The initial rapid growth of lending for irrigation was the Bank's response to the food crisis of the 1960s, which was primarily addressed through the extension of irrigated areas and the development of high-yielding varieties, known as the Green Revolution. South Asia and East Asia together account for about 62 percent of the total historical financial commitments for irrigation and drainage. India, with 86 operations accounting for one-fourth of the Bank's total commitment, has been by far the largest borrower for irrigation. The main causes for the sharp decline in lending for irrigation are multiple and discussed in Chapter 2.

Bank Policies and Irrigation

Changes in Bank policies have also influenced its lending for irrigation. In its early years of operation, the Bank rejected lending for the rehabilitation of any civil works. The rationale was that lending for rehabilitation would encourage poor maintenance of existing infrastructure. Later, it was deemed arbitrary to separate rehabilitation from the upgrading of existing facilities. This change in Bank policy in the late 1960s boosted lending for irrigation during the 1970s.

In the 1970s, the Bank's central departments issued policies for most sectors. It was up to regional operational units to adapt these general policies to the needs of project locations. Although a policy specific to irrigation was not developed, several sector-wide directives applicable to the irrigation subsector were issued in the 1970s, especially concerning cost recovery, dam safety, international waters, involuntary resettlement, and tribal people. These directives were later incorporated in Bank-wide safeguards policies and in the Environmental and Social Framework.

It was only in the 1990s that a Bank policy paper specific to water resources management was issued. Many organizations in the United Nations and other development agencies were concerned about the increasing scarcity of water worldwide and the need to protect natural resources and the environment. The Dublin and Rio conferences, held in 1992, called for greater innovation in the development and management of freshwater resources. The Bank issued a policy paper on water resources management in 1993 that defined water policies for each water subsector. A Water Resource Sector Strategy was issued about a decade later in 2004.

Performance of Bank Projects in the Irrigation Subsector

The Operations Evaluation Department and then the Independent Evaluation Group have carried out time-slice reviews of the performance of Bank-supported irrigation projects. According to these reviews, such projects' overall success rate improved from 67 percent before 1994 (OED 1996) to 76 percent between 1994 and 2014 (Keith 2006) and then to 78 percent of projects completed in the past 15 years.[1]

An analysis of all Bank-supported irrigation projects covering the 50-year period between 1970 and 2020 was carried out for this document. The analysis encompasses both dedicated projects and those that have less than 30 percent commitment to irrigation and drainage.[2] The average Bank-wide optimism gap[3] has decreased from 10 percent of projects completed during the 1990s to an insignificant 3 and 1 percent—but with a peak of 7 percent in some regions (e.g., Latin America and the Caribbean) during 1980–89.

The size of this gap in the 1990s is largely due to the underperformance of large irrigation projects in India, where unrealistic assumptions (e.g., regarding crop yields and construction periods) were adopted at appraisal. More difficult to detect is an overly optimistic assumption of overall irrigation efficiency, which determines the volume of water available for crop needs and thus determines the cropping intensity and ultimately the agro-economic benefits and the viability of an irrigation project.[4]

Projects in the South Asia and Africa regions were consistently the worst performers until the mid-2000s, while the best performers were observed in East Asia in terms of outcome, sustainability, and institutional development. **The remarkable improvement of the average success rate in the South Asia region,** which rose to 92 percent in the past 15 years, would deserve in-depth research beyond the scope of this report.

Performance of Large- and Medium-Scale Projects

The second part of this review is an attempt to provide insights into the causes of the below-expected performance of a cohort of medium- and large-scale irrigation projects appraised in the 1970–90 period, which together account for a major part of the Bank's total irrigation lending.

The most important criterion for irrigators is the quality of service provided by an irrigation system in terms of reliability and flexibility. Given the poor service rendered by canal systems in many countries, farmers turned to capturing groundwater when the prices of pumping equipment and drilling wells became affordable. The flexibility of this resource has contributed to the explosive growth of groundwater use, resulting in its declining quality and over-abstraction in many areas. The Bank addresses this critical issue by supporting projects focused on the coordinated management of surface and groundwater.

Starting in the 1980s, many researchers criticized engineers for their lack of sensitivity to the social and environmental aspects of irrigation. A consensus was developing within international organizations that the causes of poor performance were related to deficiencies in institutions and policy rather than technology. Very few scholars challenged this consensus.

Such thinking led to a new generation of projects that involved water users in the management of irrigation systems, through support of participatory irrigation management. This approach was undertaken with the expectation that users themselves would be more effective in operating irrigation systems according to their specific requirements, and that they would be willing to pay for their operation. For decades, the establishment of user associations was systematically associated with the rehabilitation of irrigation projects. Thirty years later, it became clear that this new generation of projects had yielded mixed results—with the exception of "star" countries, such as Mexico and Peru.

Impacts of World Bank Reorganizations on Irrigation Lending

The Bank's internal structure has gone through five major reorganizations and follow-up adjustments over the past 50 years. The first, in 1972, was imposed by the growth in lending and the need for a regional decentralization through the creation of regional vice presidencies. The four subsequent reorganizations were attempts to strengthen the Bank's ability to achieve two operational objectives: responsiveness to clients and technical excellence.[5] Under the reorganizations of 1987 and 1997, the irrigation subsector lost its visibility. The highly specialized regional irrigation divisions that were created under the 1972 reorganization were absorbed into agricultural units accountable to country units under the 1987 organization and again in 1997 when a matrix management system was established.

With the full transfer of responsibility for dialogue with client countries and the formulation of the Bank's lending program to country departments, irrigation projects which were costly and time-consuming to prepare and trigger most new Safeguards were not at the top of the list of sectors for lending by these departments. Country departments were deterred from accepting irrigation projects proposed by client country governments (Keith 2006).

The 2014 reorganization of divisions into Global Practices (GPs) marked a new chapter for the irrigation subsector, which, combined with other water-consuming subsectors, became the responsibility of the Water GP. The choice, after long debate at the Bank management level, was to combine irrigation with other water-using sectors and not with other agriculture-related activities contributing to the objective of food production.

The Technical Dimension: Slow Modernization

A more balanced view of how to improve performance has recently gained acceptance: physical improvements alongside institutional and policy reforms. To focus on one without the other will not ensure projects' success, as shown by past experience. Yet upgrading irrigation infrastructure is a slow process. Many irrigation agencies stick to old design and operational practices, and strongly resist changes to design concepts and standards. Consulting firms are also hesitant to present their clients with new ideas and, if their experience is limited to specific regions, they may not have experience in implementing up-to-date technologies.

Projects that focus on modernizing irrigation have been rather limited to date. The conversion of gravity canal systems to pressurized pipe irrigation systems in middle-income countries (such as Morocco and Turkey) has been successfully supported by the Bank. However, related programs largely replace existing infrastructure with completely new construction. There are limited examples of the successful upgrading of existing infrastructure. One of the best is a project in Vietnam in which the construction of control structures reduced the frequency of required gate adjustments by a factor of 10. Here, a remote monitoring system has been operational for nearly 10 years. Advanced modernization techniques of canal systems are implemented in some countries without financial and technical support from any international finance institutions, instead using government or local funds, a possible indication of a perceived decline in the technical superiority of these organizations or their ability to orchestrate transformational change.

Geosynthetic materials, widely used in waste landfill, transportation, and mining projects for the past 50 years, are yet to be used widely for canal lining. Though millions of dollars have been invested in canal lining, the use of inefficient technologies aggravated by the poor quality of construction has resulted in continuing losses due to seepage.

The author proposes several reasons for the slow modernization of Bank-supported irrigation projects. First, when formulating irrigation projects, the Bank has no other way than to adopt a short-term approach, such as rehabilitation, leaving little space for experimentation or a stepwise approach flexible enough to be adopted over successive projects. Limited supervision budgets also make it difficult to adopt modern techniques that require intensive assistance either from Bank staff or highly specialized consultants. Numerous failures of modernization components could have been avoided with the short-time intervention of experts. These and similar technical improvements could be supported by integrating engineers into the project design process.

Looking Forward

Looking forward, an increase in lending for irrigation may be expected for a number of reasons, chief among them to meet the needs of a growing world population (which is projected to increase to 8.2 billion by 2030 and climate change; World Bank 2006a) with changing dietary habits. A background paper for the Second Irrigation Forum, held in Thailand in 2016, projected that 2006 food production levels would need to increase by 60 percent by 2050 (Kadiresan and Khanal 2018). Farmers will require higher levels of flexibility and reliability than are currently available, while climate change and environmental considerations will necessitate more efficient use of water resources at the basin level in areas with absolute or growing water scarcity; and will necessitate shifts from rainfed agriculture to irrigated agriculture elsewhere due to extended agricultural droughts and shocks in areas where water resources are still untapped. The canal irrigation schemes built during and after the Green Revolution, when the world's irrigated area was increased by 100 million hectares (to the current area of approximately 340 million hectares), have reached the end of their service lifespan (ICID 2019). The cost of rehabilitating dilapidated schemes, combined with modernization, could reach about 50–70 percent of the cost of new schemes.

While there are serious flaws in the design concepts and construction techniques of many large-scale irrigation systems, the solutions are well known and proven. Why is it that despite the abundant technical literature on system modernization, and the numerous workshops and conferences organized on this subject, only a few countries have shifted from outdated techniques to modern technologies and modern management that support twenty-first century agriculture and basin needs?

Looking ahead, the World Bank, along with other multilateral development banks, has an immense role to fulfill in supporting the improved performance of irrigation worldwide to meet the growing demand for food while preserving the natural resource base of surface and groundwater.

Notes

1. The methodology used to evaluate the performance of projects funded by the Bank changed with reforms introduced in the late 1990s. Attention shifted from an economic evaluation of related investments to the meeting of project development objectives defined at appraisal. Some caution is therefore required when comparing statistical analyses of clusters of projects from the years before and after this change.

2. Dedicated projects are defined as those projects in which at least 30 percent of the commitment of finance is earmarked with the irrigation and drainage sector code. In nondedicated projects, between 1 and 30 percent of the commitment is to irrigation and drainage.
3. The optimism gap is the difference between the value of economic rate of return (ERR) at appraisal and at completion/evaluation.
4. Values of overall efficiencies were estimated at or over 50 percent for all projects evaluated during a decade in India, a value not even reached in the irrigation districts of the western United States at that time.
5. These are not to be confused with the Bank's twin objectives of eradicating poverty and supporting shared prosperity.

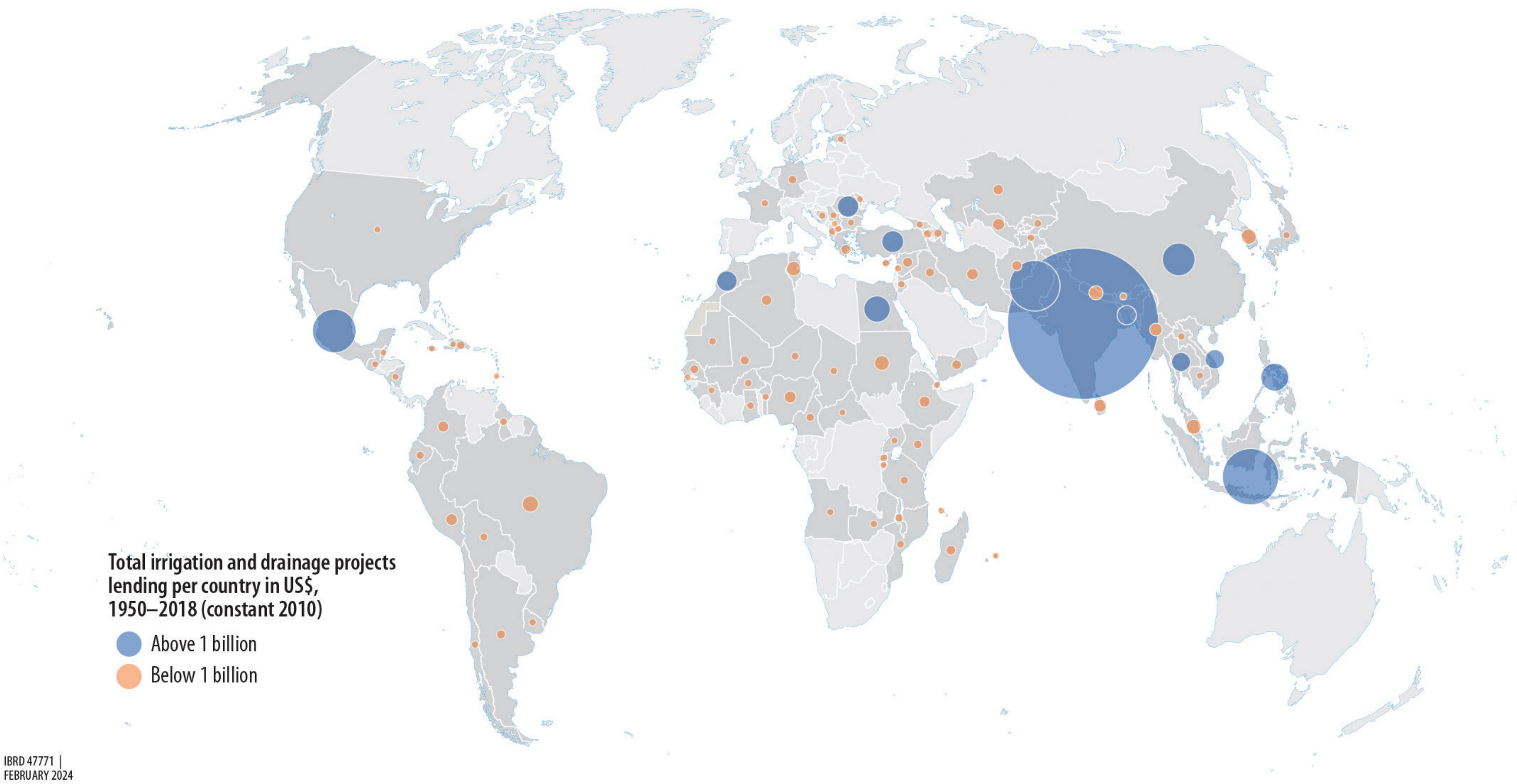
Abbreviations

AGF	agriculture and food
AGR	agriculture and rural development
ERR	economic rate of return
FAO	Food and Agriculture Organization
FY	fiscal year
GP	Global Practice
IBRD	International Bank for Reconstruction and Development
ICID	International Commission on Irrigation and Drainage
ICOLD	International Commission on Large Dams
ICR	Implementation Completion and Results Report
IDA	International Development Association
IEG	Independent Evaluation Group
IPTRID	International Program for Technological Research on Irrigation and Drainage
IWMI	International Water Management Institute
MCC	Millennium Challenge Corporation
O&M	operation and maintenance
ODA	official development assistance
ODF	official development finance
OED	World Bank Operations Evaluation Department
PPP	public-private partnership
RID	Royal Irrigation Department (Thailand)
SCADA	Supervisory Control and Data Acquisition
WUA	water user association

Bank Documents

CPM	Central Projects Memorandum
OMS	Operational Manual Statement
OPM	Operation Projects Memorandum
PPAR	Performance Project Assessment Report
SAR	Staff Appraisal Report
ESF	Environmental and Social Framework
DPF	Development Policy Financing

PART I:
HISTORICAL REVIEW



1. The Importance of Irrigation

The World Bank has been the largest source of external assistance to the irrigation subsector worldwide. Its history of lending for irrigation is characterized by a sharp increase during the period from 1960 to 1980, followed by two decades of continuous slowdown until the early 2000s, and then a slow recovery during the past two decades to about one-third of the peak period. At the peak of lending for irrigation in the early 1980s, the irrigation subsector accounted for about one-tenth of total Bank lending and one-third of lending for the agricultural sector. As of the mid-1990s, irrigation accounted for less than 2 percent of total Bank lending (Jones 1995). The importance of irrigation in meeting global food requirements is clearly illustrated by the fact that about 40 percent of food production in the world comes from irrigated lands representing about 20 percent of cultivated areas. Irrigation makes a significant contribution to food security in Asia. Irrigated lands account for as much as 80 percent of food production in Pakistan, some 70 percent in China, and over 70 percent in India and Indonesia. The growth of irrigated areas along with the technologies of the Green Revolution averted the threat of famine in the Asia region.

Increased world food security through the Green Revolution[1] is one of the greatest achievements of the past 70 years, especially considering the tripling of the global population from 2.5 billion in 1950 to 7.6 billion people in 2017. This achievement was driven by a sharp increase in irrigated area from 110 million hectares (ha) in 1950 to 325 million ha in 2015 (of which about 275 million ha are effectively irrigated) and by the increase of crop yields. In the two decades following an acute food shortage in Asia, mainly in India in the mid-1960s, irrigation was the major focus of lending from donor agencies, on par only with the energy sector. The greatest benefits of irrigation investment in that period were increased food production and food prices affordable for the poor.

Irrigation has been vital in meeting quickly rising food demand. In the past 40 years, demand for food in developing countries tripled, increasing much faster than population growth rates. The production of fruits and vegetables increased multiple times during that period (World Bank 2006b). Irrigation development is not limited to food and fiber production. Irrigation contributes to the livelihoods of the rural population through the generation of jobs and reduction of poverty. Irrigation enables smallholders to adopt more diversified cropping patterns, and to switch from low-value subsidence production to high-value marked-oriented production. It avoids costly migration to urban areas. Drainage has positive impacts on public health and reduces damages to buildings. Even in those countries where a protective irrigation strategy has dominated irrigation development, such as in India, “Notwithstanding the problems of inequalities, one cannot be but impressed by the eco-dynamism of the region. Irrigation is more productive and more profitable than rain-fed farming” (Mollinga 2003).

Agricultural water management has also mitigated the impact of floods and droughts and contributed to shaping the countryside.

However, by the mid-1980s, it had become evident that irrigation projects were performing below expectations, as will be discussed in this document, resulting in declining interest among donors in irrigation development. That performance of irrigation projects contrasted, however, with the overall positive contribution of the irrigation subsector to food security during the period following the Green Revolution. Poor performance of public large-scale irrigation has been offset by the use of groundwater by individual farmers.

On the negative side, as of 2015, about 0.25 to 1.5 million ha of irrigated lands were estimated to be lost annually from salinization due to bad irrigation practices. The 34 million ha affected by salinity worldwide represent 11 percent of the total area equipped for irrigation.

There are critical needs to invest in governance, policy, institutions, practices, and technologies that support the improvement of agricultural water management, particularly in developing countries.

This document seeks to draw lessons from the past, in preparation for the coming decades, when modernized irrigation will be critical for food security amid climate change.

1.1 The Diversity of Irrigation Systems at Large

The considerable diversity of large- and medium-scale irrigation[2] is important to discuss as a preamble to the Bank's history of lending for irrigation. The classification of projects by size varies from country to country. A small size project in South Asia would be a large-scale project in some Sahel Countries.

Irrigation systems can vary in size from traditional systems of a few hectares to gigantic projects serving from 500,000 to over 2 million ha. Examples include the Narmada project in India, the Karakum system in Turkmenistan with a 1,300-kilometer-long main canal, and the ancient Dujiangyan scheme in China, built in 252 B.C. and now serving 668,700 ha. Small, traditional irrigation systems are developed and operated by end users using rustic infrastructure and governed by evolved rules of water allocation, while large systems are generally government managed.

The infrastructure can consist of a hierarchical network of main, primary, secondary, and tertiary canals or a combination of canals and pipe systems delivering pressurized water to users. Water application can be through surface irrigation (e.g., furrows or basins) or via pressurized techniques. Canals can be unlined or lined with rigid brick, concrete, or with advanced, flexible materials. The cropping pattern may include field crops, monocrops (such as rice), industrial crops (such as sugarcane or cotton), or a combination (e.g., fruits and vegetables).

Approaches to the design of irrigation systems built by colonial powers in developing countries during the 19th and 20th centuries were strongly influenced not only by local physical parameters such as water resources and geography, but also by the social conditions prevailing in the

Photo 1.1. Diversity of Water Applications: Surface, Sprinkler, and Drip

a. Surface **b. Drip** **c. Sprinkler**

Sources: a: Florence Deram Malerbe/World Bank; b: diyanadimitrova/Adobe Stock; c: David A Litman/Adobe Stock. Further permission required for reuse.

Photo 1.2. Three Types of Water Control and Allocation Systems

a. Rigid Flow Division

b. Hydro-Mechanical, Manual Operation of Level Control

c. Electronic, Manual Operation of Level Control

respective countries. For example, the design of irrigation systems on the Indian subcontinent was dictated by the objective of avoiding famine by spreading water as widely as possible and minimizing the number of control structures, while the design of canals in Sudan nearly 100 years later was influenced by farmers' strong opposition to irrigating at night.

The distribution of canal water to the largest area possible, known as protective irrigation, has had a considerable impact on the performance of irrigation projects and the evolution of water resources in the Indo-Gangetic Plain. Canal capacities were often designed to irrigate about half of the area during the wet season and about one-quarter of the area during the dry season. Avoiding famine, and not high productivity, was the intention of the colonial power in India through the 1873 Irrigation Act. The capacity of canals was not designed for full irrigation, leading to shortages and inequitable water distribution between head and tail users, and ultimately to the explosive development of the use of groundwater for irrigation over the past 30 years. However, that situation is unique to the Indian subcontinent and not found elsewhere.

Standard practices of technical assistance and the use of international consulting firms have also played a key role in the design of irrigation projects. For example, the automation of canal control developed by French industrialists in Algiers during World War II was widely adopted in the Mediterranean Basin as early as the 1950s. The Dutch developed large-scale irrigation in Indonesia, which was based on a dual system of (colonial) export-oriented estates (largely sugar) and village irrigation (largely rice), with built-in differential rules (e.g., night irrigation for rice). The standards of the US Bureau of Reclamation were exported to several US partner countries, such as the Philippines, Thailand, and Mexico after World War II. Later, consulting firms introduced water allocation models and control equipment across countries. While cumbersome technologies worked well under research conditions and in pilot projects, they were doomed to failure without appropriate technical assistance. Moreover, some of these systems and water regimes worked under the location-specific setups of colonial administration. They were thus ill-suited to more diverse, more equitable agricultural and governance systems.

The success of an irrigation system can be estimated in different ways by various stakeholders involved: users, financing agencies, and government. Whatever the type of irrigation system, the most important indicator of performance for the end user is the quality of the water service provided by the system. Ideally the delivery of water should be timely, reliable, equitable, and flexible, which is no small feat given the highly temporal nature of irrigation, the vast command areas, and the enormous volumes of water that need to be transported through the network and then divided into small individual allocations.

An important criterion for a financing agency is the economic viability of the project at evaluation, at completion, and at audit a few years after completion. In recent years, financing agencies attached greater importance to the environmental impacts of irrigation projects. Irrigation agencies or management companies should be concerned with the financial and environmental sustainability of their projects, whatever the source of funds—either through service charges to the end users or any form of government subsidy. Ideally, users should pay water charges to cover at least the operation and maintenance costs and preferably a certain portion of the investment costs, to ensure financial sustainability, appreciation of the value of water (incentivizing rational use), and accountability for service delivery.

Irrigation projects in advanced countries (such as Australia, Western European countries, Japan, the Republic of Korea, and the United States) generally meet the above criteria. Projects in such countries have kept technology up to date through successive modernization programs, such as the modernization of control infrastructure, conversion from canals to pressurized systems, adoption of water-saving techniques either at the individual farm level or among groups of farmers, and replacement of manually operated systems by modern automated systems.

However, worldwide, many irrigation systems do not meet key performance criteria. Water delivery is either unreliable or delivered in a very rigid mode that does not adequately meet crop water requirements and farmers' needs. In many developing countries, water charges paid by farmers cover only a small fraction of the operation and maintenance costs. As a result, the irrigation infrastructure is not maintained adequately, thereby leading to a vicious cycle of rehabilitation-deterioration-rehabilitation. The reasons for this situation are several. The number of consultants with up-to-date technological experience is rather limited, and furthermore, most consultants have no experience in the operation of the systems they have designed (Burt 1999).

Table 1.1 shows the areas irrigated by surface and groundwater as of 2015 in six of the countries with the largest irrigated areas. When combined, they represent about half of the area irrigated worldwide. These countries with the exception of Iran represent the major borrowers from the Bank for the irrigation subsector. Groundwater accounts for about 38 percent of the total irrigated area worldwide. There is a strong contrast between the groundwater-use areas in India, about two-thirds of the irrigated area in that country, and such areas in China, which compose nearly one-third of the total irrigated area.

Table 1.1. Countries with Major Irrigation Development (in thousands of hectares) as of 2015

Country	Surface Water		Groundwater		Mixed Surface and Groundwater	Total
	thousands of hectares	%	thousands of hectares	%		
India (2002)	22,482	36.3	39,426	63.7	—	61,908
China	43,569	69.2	19,369	30.8	—	62,938
Pakistan (2012)	7,630	38.2	4,130	20.7	8,230	19,990
Iran, Islamic Rep. (2007)	3,078	37.1	5,054	60,9	—	8,132
Mexico	3,876	60.1	2,196	33.9	437	6,509
Indonesia	6,655	99.0	67	1.0	—	6,722
World			124,700	38.4		325,100
For reference:						
United States (2007)	9,373	35.2	17,256	64.9		26,629

Source: FAO AQUASTAT (2015 data).
Note: Data on areas irrigated by the conjunctive use of surface and groundwater are not available in AQUASTAT for most countries. Millions of hectares in canal areas are now benefiting from groundwater use through individual wells. Considerable duplication of irrigated area by groundwater and canal agencies is suspected.

Box 1.1. Worldwide Development of Drip and Sprinkler Systems

The total worldwide area irrigated under drip irrigation is 10.3 million hectares (ha). India, China, Spain, the United States, Italy, the Republic of Korea, Brazil, South Africa, the Islamic Republic of Iran, and Mexico are the ten countries with the largest areas under drip irrigation. Only three countries exceed 1 million ha under drip irrigation (India, China, and Spain with 1.89, 1.66, and 1.64 million ha respectively). As of 2004, Israel had 168,800 ha under drip irrigation. There are no statistical data available on the sources of water or on whether pressurized irrigation systems are collective or individual. However, it is known that drip irrigation has been mostly used in groundwater-based systems, especially in China and India.

The total worldwide area irrigated under sprinkler is about 42.7 million ha. Twelve countries have an area under sprinkler irrigation exceeding 500,000 ha: the United States (12.3 million), India (3.0 million), China (2.9 million), Russia (2.5 million), Brazil (2.4 million), France (1.38 million), Italy, South Africa, Spain, Saudi Arabia, Canada, and Germany. Israel had 60,000 ha under sprinkler irrigation as of 2000.

When drip and sprinkler irrigated areas are expressed in percentages of total national irrigated areas, Israel and Jordan (78% as of 2005) are at the top of the list of countries, followed by Brazil (62%), the United States (56.5%), South Africa (77%), Russia (56.6 %), Spain (70%), Italy, and France.

Source: 2012 ICID Survey.

1.2 Partnerships

The World Bank has had a long and fruitful collaboration with a number of international organizations, mainly the Food and Agriculture Organization, International Commission on Irrigation and Drainage, and International Water Management Institute, all involved in irrigation development through the exchange of state-of-the-art technologies, participation in congresses, conferences, and irrigation/water weeks over several decades. The World Bank, together with the International Commission on Irrigation and Drainage, has been instrumental in the creation of the International Program for Technical Research on Irrigation and Drainage. The Bank hosted the program at its headquarters before it was transferred to the Food and Agriculture Organization. Following the success of irrigation management transfer in Mexico in the early 1990s, the Economic Development Institute (later the World Bank Institute) created the International Program for Irrigation Management, but this small organization did not survive due to lack of financial support.

The interaction between the World Bank and other international organizations is further discussed in appendix E.

Notes

1. The Green Revolution was triggered by a series of research studies beginning mostly in the late 1960s that increased agricultural production around the world. Cereal production more than doubled in developing countries between 1961 and 1985.

2. A variety of activities are covered by the term "irrigation subsector," such as the construction of large infrastructure, dam safety, rehabilitation and modernization of existing canal and pressurized systems and drainage works, groundwater use, on-farm development, institutional reforms, agro-industries, and specific agricultural inputs.

2. Evolution of Bank Lending for Irrigation

2.1 Lending for Irrigation (1950–2018)

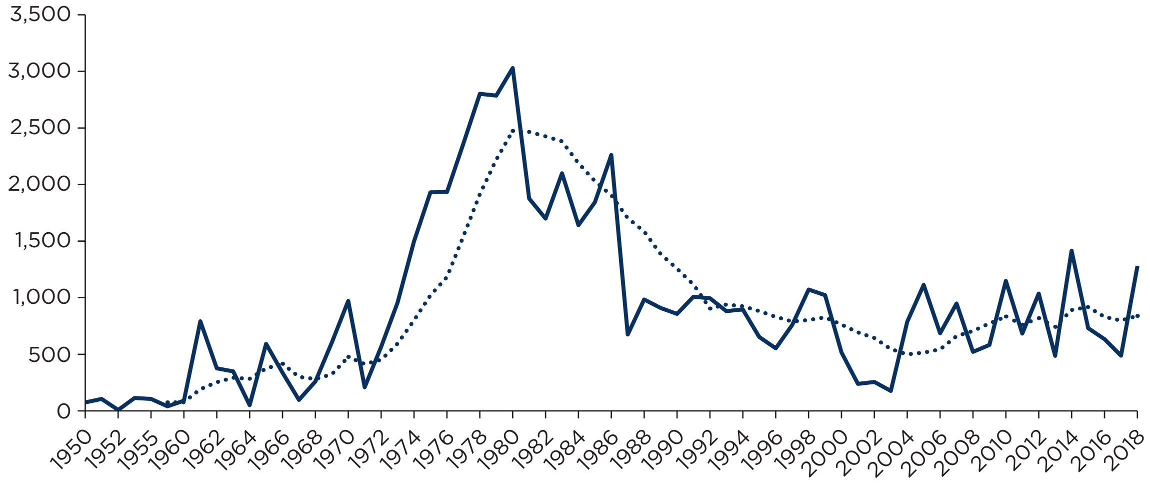
During the 70-year period from 1950 to 2018, the World Bank lent approximately $59.5 billion (in 2010 constant dollars) to 92 countries through 818 projects with irrigation components. With the contribution of borrowing governments, farmers, and various co-financiers, irrigation-supported operations represented a cumulated investment of about $100 billion.

The irrigation subsector encompasses a wide variety of projects, including the construction of single- or multi-purpose storage dams, development of new irrigation and drainage systems, flood control, groundwater, rehabilitation of dilapidated infrastructure, irrigated agricultural research, and extension services. All the tables and figures below on lending for irrigation refer to the commitments for irrigation only, and not the total commitments of the projects involved.

As shown in figure 2.1, lending for irrigation by the World Bank made a slow start in the 1950s, and then rose sharply during the 1970s to reach a peak around 1980. After falling to a low level in 2002, it slowly recovered to about one-third of its previous peak. [1] The first Bank loan for irrigation was a flood control project in Iraq in 1950 followed by six lending operations in Thailand, Chile, India, Peru, Japan, and Sudan in that decade. The number of approved irrigation projects per year increased sharply to nine in 1961, of which four were in India and one in Pakistan.

Figure 2.1. Annual World Bank Commitments to Irrigation Projects, 1950–2018

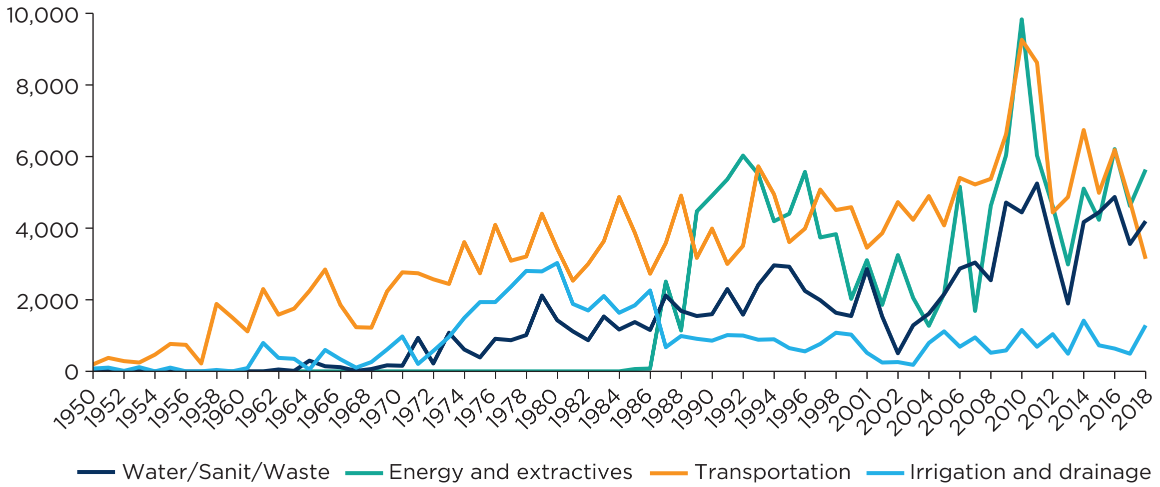
In constant 2010 US$ millions



W23016.indb 9 26/03/24 8:02 PM

Figure 2.2. Lending for the Irrigation and Drainage Subsector versus Other Infrastructure Sectors, 1950–2018

In constant 2010 US$ millions



Note: Sanit = sanitation; IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

As for many other infrastructure sectors, such as hydropower and transportation, the share of lending for irrigation sharply declined in the past two decades (figure 2.2) in favor of human development sectors, such as education and health (Keith 2006). Lending for irrigation, which reached 10 percent of the overall Bank portfolio in the late 1970s, now accounts for less than 1 percent**.**

2.2 Regional Distribution (1950–2018)

During the period from 1950 to 2018, the South Asia region dominated lending for irrigation ($22.2 billion) followed by East Asia ($14.8 billion), which together represented about two-thirds of the total commitments for irrigation ($59.5 billion). Lending for the Africa region, with less than 5 percent of the area irrigated worldwide, was far behind with $4.23 billion (figure 2.3).

South Asia had the largest number of projects (214) during this 70-year period. East Asia and Africa are next with a total number of loans of about 160 each.[2]

2.3 Distribution of Global Lending for Irrigation by Decade

In constant dollars, annual lending peaked at $17 billion during the 1980s. The decade with the lowest lending ($5.8 billion) was the 2000s, which was followed by an increase of about 40 percent for the first nine years of the 2010s (figure 2.4). The number of loans with irrigation components increased from 38 in the 1960s to 180 in the 2010s.

Figure 2.3. Regional Distribution of Bank Commitments for Irrigation ($,millions)

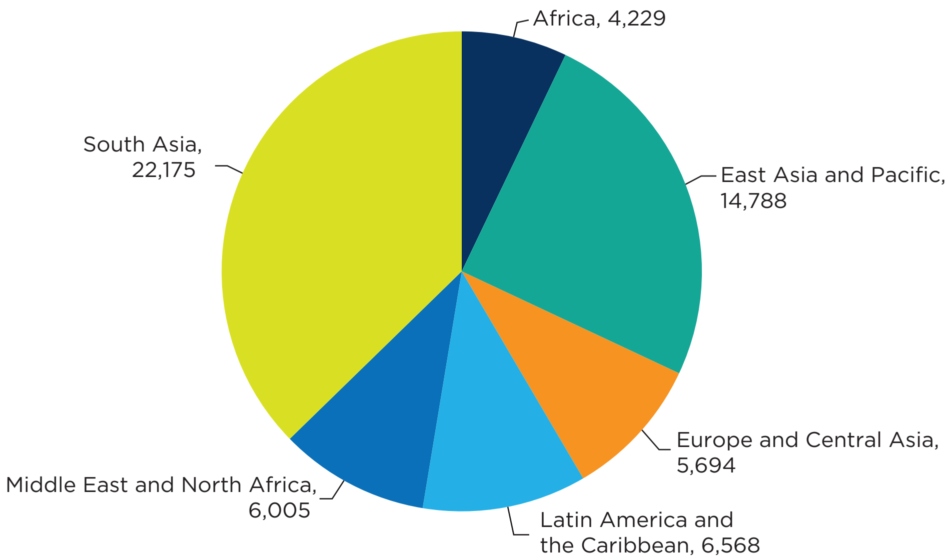
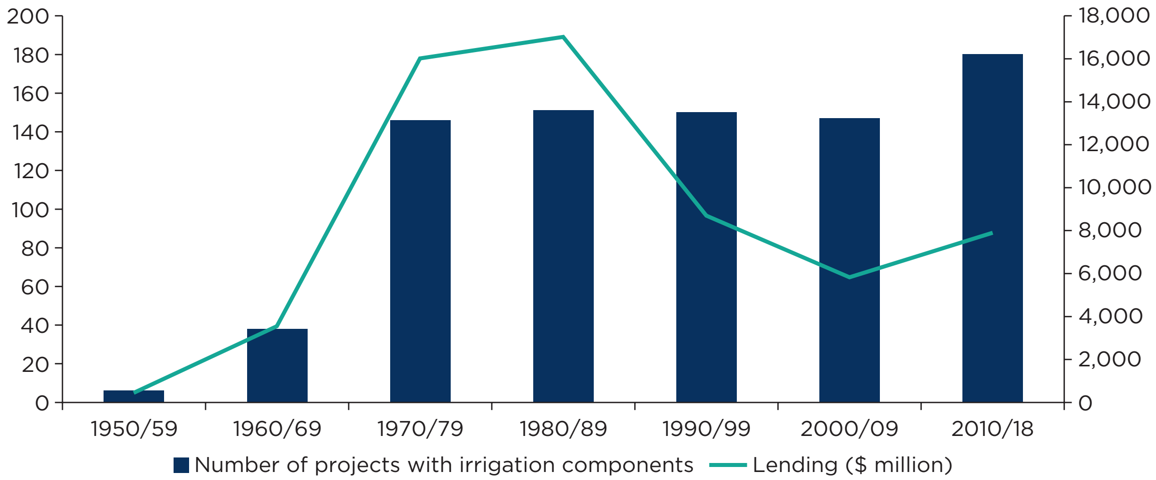


Figure 2.4. World Bank Lending for Irrigation by Decade, 1950–2018

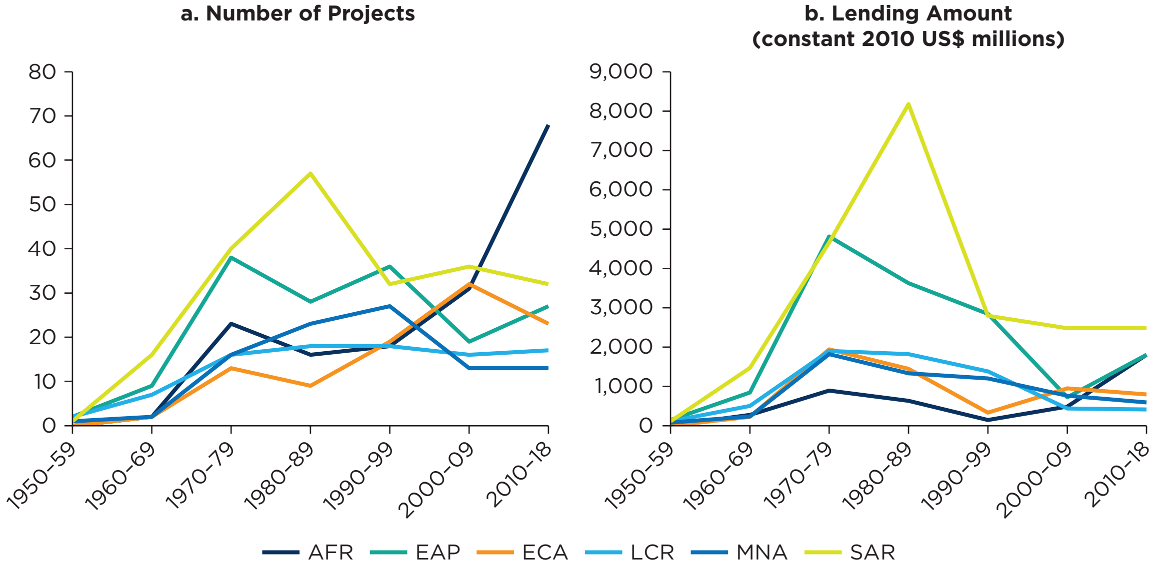


This number of projects increased steadily, alongside the number of agriculture and rural development projects with small irrigation components. The rapid growth of irrigation in the 1960s was in response to a food crisis that was overcome through the Green Revolution, which combined the development of high-yielding varieties with an increase in total irrigated area.

Furthermore, over a 70-year period, the Bank's irrigation portfolio has evolved from dedicated projects with 100 percent of the commitments devoted to irrigation toward multisectoral projects with ratios of commitments to irrigation ranging from less than 10 percent to over 80 percent.

Figure 2.5 shows lending by decade and by region. The threefold increase in lending and the doubling of the number of projects in the Sub-Saharan Africa region are remarkable. Lending for

Figure 2.5. Number of Projects and Amount of Lending by Region and Decade, 1950–2018



Note: AFR = Africa; EAP = East Asia and Pacific; ECA= Europe and Central Asia; LCR = Latin America and the Caribbean region; MNA = Middle East and North Africa; SAR = South Asia.

the Middle East and North Africa region and the Latin America and the Caribbean region during the past two decades is far below the lending in the 1980s and 1990s, while lending for the South Asia region dropped sharply in the 1990s (the tabulated data are presented in appendix F).

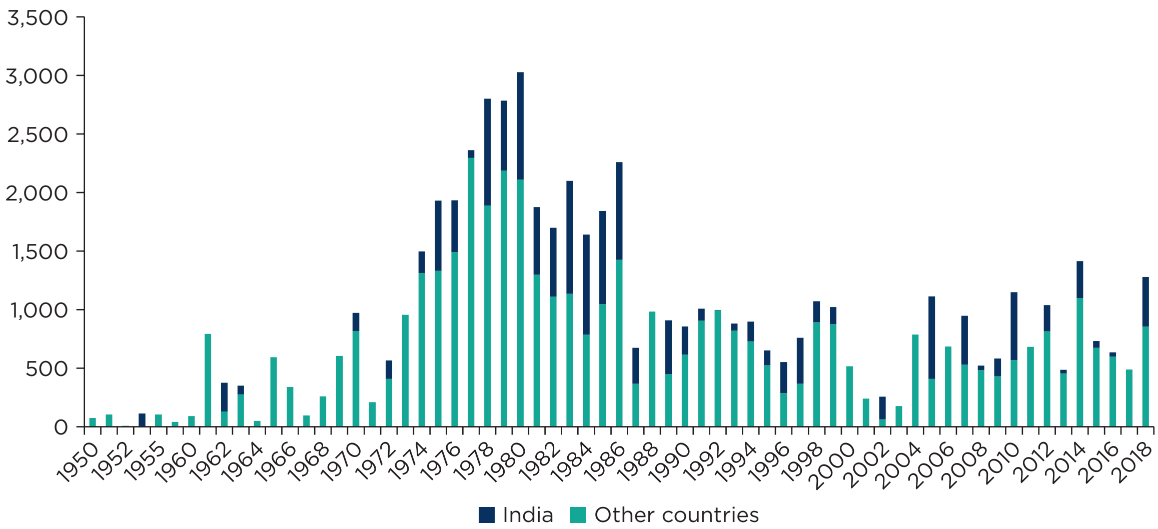
2.4 Country Distribution (1950–2018)

The distribution of lending for irrigation by country over the past 70 years generally reflects the irrigable areas created in the developing countries supported by the Bank. India, with a total commitment of over $14.7 billion in current dollars for 86 operations, or nearly 25 percent of the total lending for irrigation, has been the largest recipient country (figure 2.6). India is followed by Indonesia in terms of lending volume, and by Pakistan in terms of number of projects. China, with $2.6 billion for 32 projects, is the fifth-largest recipient country. China became a member of the Bank in 1982 (about 20 years after India) and consequently had lower lending levels with respect to the development of irrigated areas.

Exceptions are countries from Central Asia with large irrigable areas totaling over 15 million ha, which joined the Bank in the early 1990s. As the private sector came to play a bigger role in Brazil over the past two decades, Brazil's irrigation sector came to rely less on World Bank support, as the private sector came to play a larger role. Some borrowers became inactive for political reasons (such as the Islamic Republic of Iran and Iraq) or due to other considerations.

The switchback curve of lending, starting in 2002 (see figure 2.6), is due to some large commitments for projects in India that were made at two- or three-year intervals, in contrast

Figure 2.6. IBRD/IDA Commitments to Irrigation and Drainage: India versus Other Countries (nominal $, millions), 1950–2018



Note: IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

with the continuity of lending for India during the period from 1978 to 1986. As can be seen in Table 2.1, total lending for 13 countries exceeded $1 billion and, for another 10 countries, totaled between $0.5 and 1 billion.

2.5 Lending for Irrigation after a Record Low in the Year 2000

Average lending for irrigation partly recovered in the years following the 2002 record low and averaged about $900 million per year during the past 15 years, with variations in lending between $450 and $1,400 million from year to year. Each peak is due to a major loan, many of which were made to India, but also to Vietnam and Nigeria. About 73 percent of the volume of lending was for 15 countries.[3]

After the low record of lending in the early years of this millennium, some changes in the ranking of the main borrowing countries for the irrigation subsector are noticeable, with India accounting for about 23 percent (still in first place), followed by Pakistan. Vietnam, benefiting from a major loan of $390 million for a dam safety project, became the third-largest borrower; China has stayed in fifth place.

Three countries that were among the most active borrowers in the past have had no activity with the Bank since the year 2000—Korea, Thailand, and Sudan. These three countries as well as four active countries—Bangladesh, Brazil, Romania, and the Philippines—have had far less activity than in earlier decades (table 2.2). Thailand, with 12 irrigation projects financed by the Bank in the 1970–80 period, was the largest rice exporter. Mexico, a major borrower before the year 2000, fell from fifth to ninth position during this time period.

Table 2.1. Major Borrowing Countries for Irrigation and Drainage, 1950–2018

Countries with Total Lending Exceeding $1 Billion	Total Lending ($, millions)	Number of Projects
India	14,713	86
Indonesia	5,062	39
Pakistan	4,473	49
Mexico	3,709	20
China	2,626	32
Philippines	2,166	24
Egypt, Arab Rep.	1,994	17
Turkey	1,540	10
Romania	1,480	9
Morocco	1,361	17
Vietnam	1,279	15
Bangladesh	1,271	25
Thailand	1,241	12
Countries with Total Lending between 0.5 and $1 Billion		
Brazil	954	23
Korea, Rep.	859	5
Malaysia	829	9
Sudan	821	7
Tunisia	770	17
Nepal	737	20
Myanmar	590	8
Yugoslavia, former	544	4
Uzbekistan	535	9
Nigeria	521	4

Table 2.2. Irrigation Lending during the Period 2000-18 ($, millions)

Country	Total Lending (FY00–FY18) ($, millions)	Ranking of Countries	
		Full Period 1950–2018	2000 up to 2018
India	3,170	1	1
Pakistan	1,202	3	2
Vietnam	892	9	3
Indonesia	705	2	4
China	671	5	5
Uzbekistan	535	22	6

2.6 Official Development Financing to the Water Sector and Irrigation Subsector

A decline of commitments to the irrigation subsector is observed not only in the World Bank but also among other international agencies. For example, the Asian Development Bank's lending for irrigation has declined sharply since 2000. In 2016, it was 14 percent (from 40 percent in 1990) of overall lending in water. Data on lending from other key organizations can be found in the database of global financing assistance of the Organization for Economic Co-operation and Development's Development Assistance Committee (OECD/DAC) (Winpenny et al. 2016).

Official development financing (ODF) to the water sector comprises concessional development assistance or official development assistance (ODA) and non-concessional financing. Development banks make concessional loans through a "soft lending" window such as the International Development Association and non-concessional loans through a "hard-lending" window such as the International Bank for Reconstruction and Development.

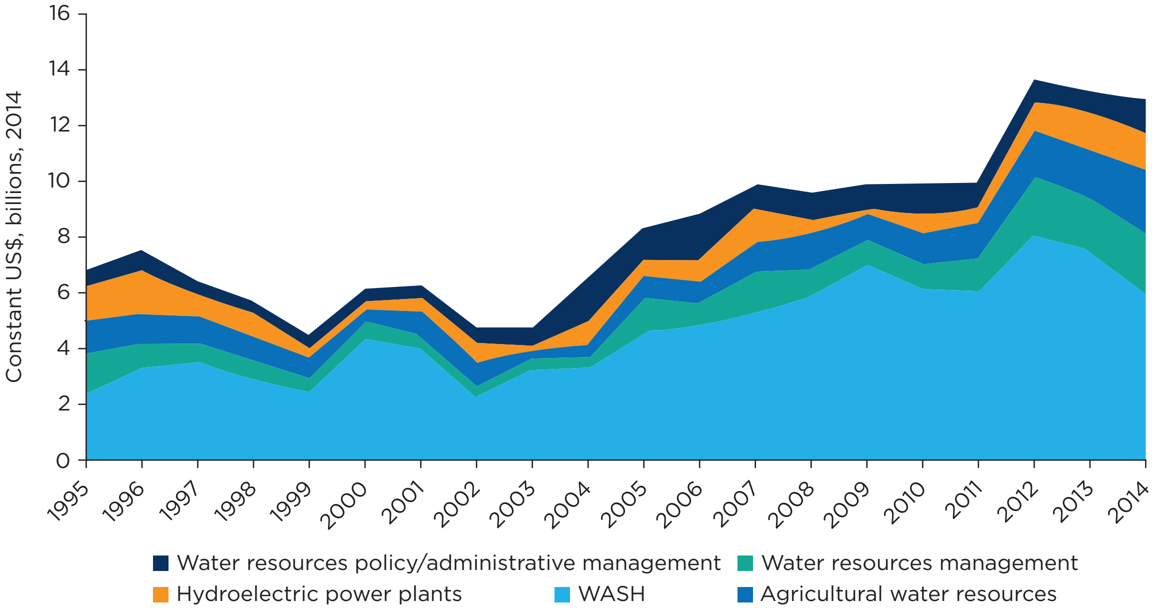
A review of World Bank Group lending since the mid-1990s indicates that ODF to water nearly tripled between 2003 and 2014, rising from an annual allocation of $6 billion in 2003 to close to $18 billion in 2014. This was in response to the appeal to international financiers made by Camdessus's report of 2003 (World Water Council 2003) to double the annual flows of financing to water. However, ODF for water was primarily targeted to water supply and sanitation activities as opposed to irrigation and water resources management. Commitments to water supply, sanitation, and hygiene (WASH) comprised 57 percent of total ODA flows over the 1995–2014 period, and 52 percent of non-concessional financing from multilateral development banks, followed by water resources management (16 percent) and hydroelectricity (14 percent). Agricultural water resources received only 10 percent of the total ODF commitments (figure 2.7).

ODA commitments for irrigation reached a maximum of around $2.3 billion in 2014 and were around $300 million in 2002. Annual non-concessional loans did not reach $1 billion during the period 1995–2014 (figure 2.8; OECD/DAC database 2016).

A background paper prepared for a roundtable on financing agricultural water convened by the Food and Agriculture Organization in 2021 provides further information on financing irrigation during a five-year period. According to OECD data, about $1 billion was spent per annum on water-related agricultural investments in recent years (2014–18) and an average of $385 million of other official assistance was made available by multilateral agencies (non-concessional) (OECD 2021).

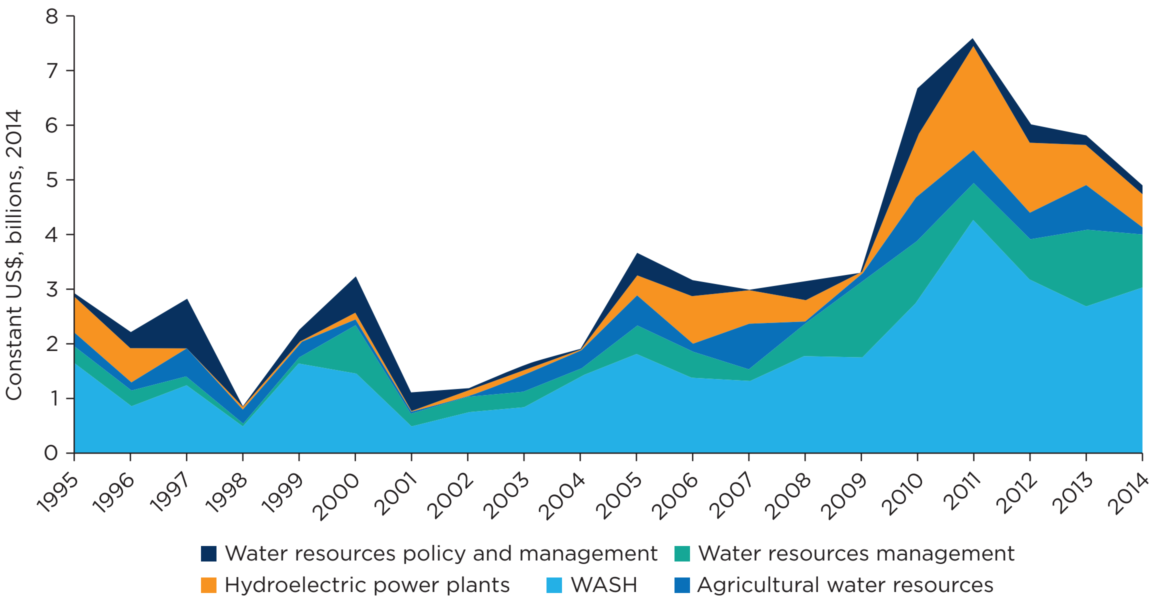
Investments required to achieve projected irrigation expansion in East Asia and Pacific and South Asia are estimated to cost, on average, a total of $3.1 billion per year between 2015 and 2030 (Asian Development Bank) (of which 41.7 percent is to improve water use efficiency). Combining the acceleration of irrigation expansion and improvement of both irrigation efficiency and soil and water management would require an estimated $6.8 billion per year in East Asia and Pacific and $5.1 billion in South Asia.

Figure 2.7. Official Development Assistance to the Water Sector by Subsector, 1995–2014



Source: OECD DAC database, accessed October 25, 2016.
Note: ODA = Official development assistance, WASH = water, sanitation, and hygiene.

Figure 2.8. Nonconcessional Loans to the Water Sector by Subsector, 1995–2014



Source: OECD DAC database, accessed October 25, 2016.
Note: OOF = other official flows; WASH = water, sanitation, and hygiene.

Notes

1. Lending for irrigation in current dollars is shown in appendix F, figure F.1.

2. A change in the regional distribution has taken place during the past decade. South and East Asia, which had been the top regions for irrigation lending (accounting for about two-thirds of the total) together accounted for only 10.5 percent of FY22 lending. With 11 out of 18 projects, the Africa region took the lead, with 65 percent of the total in FY22. Also, irrigation composed only 20 percent of the commitments to these 18 projects, which focused on other elements of agriculture and water supply.

3. Lending for irrigation during the two years following the period under study ($727 and $646 million in FY19 and FY20, respectively) was close to the average annual lending, excluding India.

3. Evolution of Policies Applicable to the Irrigation Subsector

Several periods can be distinguished in Bank lending for irrigation, based on Bank policies applicable for the subsector. These policies are highlighted in the first review of Bank lending for irrigation by the Operations Evaluation Department, an independent unit responsible for the evaluation of the World Bank Group's activities and reporting directly to the Bank's Board of Directors through the Director-General, Evaluation. Irrigation lending was first marked by an emphasis on infrastructure (1950–71), then on agricultural expansion (1972–81), and, since 1982, there has been a consolidation phase consisting of completing, rehabilitating, and modernizing existing schemes. This last phase is still ongoing, but participatory irrigation management became an important objective of these projects. It is only in the 1990s that water resources management policies, applicable to irrigation, were issued. Current trends related to service delivery, including innovation, the energy-water-agriculture nexus, issues of resilience and water scarcity management, farmer-led irrigation, and water accounting, are not discussed in detail in this historical overview.

3.1 The Infrastructure Period (1950–71)

From the time the Bank initiated lending for irrigation in 1950 to the Bank reorganization of 1972, consistency in irrigation lending policy was not an issue. All agricultural projects, including irrigation, were processed by a single division, which later became a single department. There was no need for policy papers or operational directives, as consistency was assured by discussions among staff.

Through the 1950s, irrigation lending had been primarily for construction of dams and distributary canals (such as the Bhumipol storage dam in Thailand), but there was a growing realization that dams and canals were not enough. Thus, in the 1960s, irrigation lending expanded to include complementary investments needed to make the investments in dams and canals more efficient through on-farm works, input supplies, extension, farm roads and food processing, marketing, and credit. Lending for irrigation was expanding rapidly, but not as rapidly as for agriculture as a whole. As a result, the share of lending for irrigation in agriculture fell from 77 percent in the earlier years to 34 percent in the early 1970s (OED 1996).

In its early years of operation, the Bank refused to lend for rehabilitation of any civil works. Rehabilitation was considered something that the borrowers should do with their own resources.

To lend for rehabilitation would simply encourage poor maintenance, it was believed. This limited lending policy was removed in the late 1960s. This change proved important for Bank irrigation lending as rehabilitation became the most important physical component of irrigation projects. The water charge policy embedded in the loan agreements usually provided for recovery of operation and maintenance (O&M) costs and at least a partial recovery of investment costs.

3.2 The Agricultural Expansion Period (1971–82)

An urge to formalize Bank policies blossomed in 1971. Coordination became necessary because operations were decentralized into geographic departments. A sectoral operational policy memorandum was issued in March 1971. Works on the sectoral policy papers started in 1972. Producing an irrigation policy paper was part of the work program of the Agriculture and Rural Development (AGR) Division of the Central Project Department, which was newly created to assure policy leadership and coordination to the Bank's newly decentralized operational units. Twelve rural subsectors were covered by policy papers during those years. However, irrigation, although being the largest subsector, was not covered.

The irrigation adviser at that time, Fred Hotes, used an AGR review of all draft appraisal reports to stress his two favored themes: (1) the importance of drainage, and (2) greater cost recovery. The same themes were stressed in seminars and AGR working papers. Cost recovery was clearly salient in Bank lending. Operation Projects Memorandum (OPM) 2.61, dated March 1971, stated that "the recovery of all project costs from beneficiaries is a norm aimed for all projects financed by the Bank."

The Bank's great expansion of the 1970s and its efforts to meet lending targets led to the writing of the Operational Manual Statement (OMS) 2.28 in 1978. Among others, OMS 2.28 stated that detailed design for works to be conducted during the first year of implementation should be completed prior to appraisal. During that period, the Bank promulgated directives governing its lending. These directives did not play a large role in day-to-day irrigation policy making and lending but contributed in defining the context.

3.3 The Consolidation Period

Many practitioners, mainly engineers, resisted the creation of an overarching irrigation policy. They pointed out that irrigation is the most variable and site-specific aspect of agriculture. Therefore, they argued that by nature, few generalizations apply to irrigation as a whole. Irrigation requires maximum ingenuity to solve the specific problems of specific sites (OED 1995).

From the early 1970s, several Bank instruments applicable to all projects were issued. They can be divided into directives including operational policy memoranda and operational directives as well as those that provide staff guidance—Central Projects' Memorandum, Central Projects Notes, and Operational Policy Notes. The most relevant for irrigation projects are described in appendix C.

Policy directives issued during the 1970s were later introduced in the safeguard policies developed by the Environment Department, created in 1987. The introduction and interpretation of these safeguard policies slowed down the preparation of irrigation projects (Keith 2006). Another consequence has been Bank teams' greater accommodation of environmental experts, and an increase in the cost of project preparation and supervision.

Before the 1980s, compliance with the OMS 2.28 was not an issue for very active borrowing countries such as the Philippines, Thailand, and Mexico. Financing for detailed preparation of further projects was included in each project, a process known as piggybacking. With the slowdown of lending in these countries, and the long interval between Bank operations, piggybacking is not always possible for financing the detailed design of new projects. But the Bank now has a facility—Project Preparation Facility —through which up to $6 million may be made available to the International Development Association borrowing countries as an advance. This facility is most often used in African countries, but does not address the preparation time constraints.

An Irrigation Strategy Review (Jones 1995) marks the beginning of a fourth period in Bank lending for irrigation. Its "new style" of projects combine a mix of physical upgrading and management reforms, such as rehabilitation and system improvements, user participation, improved financial performance, and attention to O&M. The progressive shift from developing new lands to completing and improving existing schemes was observed since the late 1970s. The key characteristics of the "new style" of projects seem to be: (1) a move toward sector projects and program loans of national or regional scope, and (2) a focus on irrigation management transfer to user associations patterned on the business-type model of most Latin American countries.

During the period 1980-1990 an abundant literature on the main issues affecting the irrigation subsector in many countries was published. These highlighted a vicious cycle caused by a lack of maintenance, poor irrigation services, farmer dissatisfaction, low rates of fee collection, and, consequently, weak irrigation budgets. The result was a cycle of construction-deterioration-rehabilitation with the financial support of donor agencies. Some countries have adopted such a strategy in order to avoid budgeting for maintenance of irrigation and drainage structures.

To break this vicious cycle, a new style of program was introduced that combined a mix of physical rehabilitation and management reforms, improved financial performance and attention to O&M, stronger linkages to support services, as well as overall water resources and user participation. But in efforts to implement this model, the importance of physical rehabilitation and modernization has too often been ignored.

It is unlikely that lending for the irrigation subsector would regain the volume it reached at its record peak in 1980–82. At that time, lending was to a large extent for the construction of new schemes and large infrastructure. However, some increase in lending may be expected as the cost of full rehabilitation of dilapidated schemes needs to be combined successfully with modernization and could reach about 50 and even up to 70 percent of the total cost of new schemes. Irrigation development in the Africa region is expected to at least double in the coming decades.

3.4 Water Resources Management Policy and Strategy

A World Bank Policy Paper: Water Resources Management (1993)

Management of water resources has been one of the most important areas of World Bank lending since its creation. Through its support to investments in irrigation, water supply and sanitation, flood control, and hydropower, the Bank has contributed to the development of many countries. However, investments supported by the Bank in these areas often encountered implementation, operational, and social problems. Underlying these problems was a vicious cycle of poor quality and unreliable services that resulted in consumers' unwillingness to pay, which in turn generated inadequate operating funds, lack of maintenance, and further deterioration in services.

In 1993, the Board of the World Bank endorsed a water resources management policy paper, developed under the leadership of Guy Le Moigne (Senior Water Resources Adviser), that reflected the broad global consensus that was forged during the Rio Earth Summit of 1992. Modern water resources management should be based on three fundamental principles, known as the Dublin principles. The first one was that independent management of water by different water use sectors was not appropriate, the river basin should be the unit of analysis, land and water should be managed together, and much greater attention should be paid to the environment. The second principle argued that water resources management is best done when all stakeholders participate, including the state, private sector, and civil society. The third principle argued that water is a scarce resource and that greater use must be made of incentives and economic principles to improve allocation and enhance the quality of water provided.

The Bank policy paper provided a comprehensive framework for analyzing policies and options that would help guide decisions about managing water resources in countries where significant problems exist concerning the scarcity of water, efficiency of service, allocation of water, or environmental damage. For irrigation, the objectives were to achieve the following improvements over time: (1) modernized irrigation practice and greater attention to cost recovery, drainage, and salinity control; (2) measures to reduce pollution from agricultural activities; (3) improvement in O&M of existing systems; and (4) investments in small-scale irrigation and various water-harvesting methods. These call for the development of institutions and technologies that respond to farmers' need for higher-quality service provision, including greater participation of community groups and water user associations.

The Water Resources Sector Strategy (2004)

A decade later, a review of the Bank's experience in water projects concluded that while the 1993 policy paper remained relevant and appropriate, the major challenge was developing context-specific, prioritized, and realistic approaches to implementation. Following intensive consultations with major borrowing countries and with Bank staff, a Water Resource Strategy was prepared under the leadership of John Briscoe. That strategy identified areas where the Bank was doing well and other fundamental areas where there was no global consensus, or where the Bank had not performed well, and where Bank practices needed to improve.

This new strategy was discussed extensively with the Board of Executive Directors of the World Bank. The discussions were long, lively, and substantive. The Board played a critical role in ensuring that all views were heard and that a strategy was produced, which, in their views and the views of World Bank management, repositions the World Bank toward becoming a more effective partner to developing countries in a sector that is central to sustainable growth and poverty reduction.

A new instrument introduced in the strategy was the Country Water Resources Assistance Strategy (CWRAS). During the past 15 years, the Bank's regional departments have prepared several CWRASs in countries with major water resources development, such as India and Brazil. Items of the irrigation reform agenda with major implications for water resources management were identified as follows:

- *Greater attention to basin-wide efficiency.* In some cases, one farmer's water loss is another farmer's recharge; improved canal system and on-farm efficiencies do not result in real water savings. In other cases, water losses end up in saline body waters.
- *Increased attention to drainage*. An estimated 25 million ha are becoming unproductive as a result of the twin menaces of irrigation-induced waterlogging and salinity. Large amounts of water were lost through nonbeneficial evaporation, such as in the Tarim River Basin in Western China before the two Tarim Bank-financed projects.
- *Reducing perverse subsidies for groundwater pumping*. Energy subsidies have resulted in heavy overexploitation of groundwater. It is estimated that 10 percent of the world's food supply is based on unsustainable pumping of groundwater. Phasing out such subsidies is simultaneously an economic and environmental necessity and a daunting political challenge.
- *Recognizing and managing water rights*.

Many of the conflicts between water development and environmental sustainability represent conflicts between irrigation needs and environmental conservation. Large-scale diversion of rivers and pumping of aquifers have adversely affected wetlands, fisheries, and the populations that depend on them. Inadequate drainage has led to large-scale waterlogging and salinity.

The strategy outlined the challenges facing the irrigation subsector in some detail since overall water resources management is so fraught with daunting institutional and political obstacles. For example, in just one state in India, over 100,000 public sector civil servants are employed in the irrigation department. Therefore, a reform program must deal as much with issues of fiscal and civil service reform as it does directly with irrigation issues.

The challenges facing the irrigation subsector as outlined in the strategy consisted of the following:

- Increasing the productivity of water and infrastructure,
- Developing a realistic, sequenced approach to cost recovery,
- Scaling up user associations and ensuring that they are representative of all farmers,
- Modernizing formal irrigation institutions and the framework in which they operate,
- Explicitly addressing the political economy of reform, and
- Supporting partnerships that focus on the production of new crop technologies.

Box 3.1. The Main Messages of the Water Resources Sector Strategy (2004)

- Water resources management and development are central to sustainable growth and poverty reduction, and therefore of central importance to the mission of the Bank.
- Most developing countries tend to be active in both management and development of water resources. The Bank must approach water resources challenges without preconceptions. The Bank must not fall into the trap of thinking that all problems can be solved with reforms—or the equally dangerous trap of assuming that all problems can be solved with infrastructure.
- The World Bank needs to assist countries in developing appropriate stocks of well-performing infrastructure, and in mobilizing public and private financing, while meeting environmental and social standards.
- To be a more effective partner, the World Bank should re-engage with high-reward/high-risk hydraulic infrastructure, using a more active business model.
- The Bank's water assistance must be tailored to country circumstances and be consistent with the overarching Countries Assistance Strategy and Poverty Reduction Strategy.
- Together, the 1993 policy paper and the 2004 Water Strategy provided broad principles for World Bank engagement and not inflexible prescriptions. What is appropriate in a particular country (or region) at a particular time will involve adaptation of these general principles to the specific, economic, political, social, cultural, and historical circumstances of a particular country.

However, this Water Resources Strategy did not recognize and identify weaknesses in the design of large-scale canal irrigation systems and propose corrective solutions. Thus, the strategy did not provide specific guidance on the importance of institutional and policy reforms alongside the upgrading of water infrastructure. Seeking remedies to the poor performance of canal irrigation systems only in institutional reforms has led to a continued lack of attention to the design and operational problems that plague many large canal systems. It is of concern that none of the policy and strategy documents made mention of the importance of addressing the issues of outdated and, in some cases, inappropriate designs of canal irrigation systems. The discussions in the strategy are thus limited to lack of attention to policy reforms and the obstacles to their application.

3.5 A Global Change in the Culture of the World Bank

A fundamental change in the formulation and evaluation of Bank projects took place between 1995 and 2000. Before around 1995, projects were evaluated with a focus on returns on investments. For the irrigation subsector, the main project objective was increasing agricultural production and recovery of investments or at least of O&M costs. The project cycle is centered on the contribution of a project to its development objective. Moreover, projects should be in line with the Country Assistance Strategy prepared by the Country Departments and recently renamed Country Partnership Strategy.

Over time, the definition of Project Development Objectives and Development Indicators were improved. A new category of staff, monitoring and evaluation (M&E) specialists, was created to assist in the development of these indicators during project preparation and follow-up during implementation. A new component for M&E was to be added to the project activities and a consulting firm specialized in M&E was often recruited to collect and analyze the data.

3.6 Other Bank Initiatives Aimed at Revitalizing the Irrigation Subsector

Several initiatives were undertaken by the managers responsible for the irrigation subsector and by individuals to attempt to revitalize that sector during the sharp decline of lending. It progressively became clear that institutional and policy changes alone would not solve the issues facing the irrigation subsector.

Shaping the Future of Water for Agriculture: A Source Book for Investment in Agricultural Water Management (World Bank 2005)

Three World Bank corporate sectoral strategies—for the rural development, environment, and the water resources sector (as presented above)—all called for using water more productively as well as for managing water and land resources in a more sustainable manner. To respond to this challenge, and to the challenge of the Millennium Development Goals, of halving poverty and hunger by 2015, the World Bank compiled a selection of good practices that were expected to guide practitioners in the design of high-quality investments in agriculture. the agriculture management source book centered on a number of key challenges to agricultural water management. More than 50 investment notes under nine thematic groups were prepared, of which the most relevant to irrigation were:

- Building policies and incentives,
- Designing institutional reforms,
- Investing in irrigation systems' improvement and modernization,
- Investing in groundwater irrigation, and
- Investing in drainage and water quality management.

The focus of this source book was operational emphasis on:

- The policies and institutional reform needed to make improved water productivity more profitable for the farmers through governance, management, markets, and trade policy; and
- The investments, technology, and management required for increasing water productivity.

Box 3.2. The Trigger of Participatory Irrigation Management: A Study Tour of Mexico

During the 15-year period from 1982 to 1997, irrigation advisers in the Agriculture and Rural Development Division (AGR) of the Central Project Department organized study tours for Bank staff in a number of countries of special interest: Morocco (advanced water control), Spain (traditional user associations and river basin organizations), Argentina and Chile (water markets), China, the United States, and Mexico twice. All these study tours were appreciated by the staff participating and contributed to the strengthening of the Bank irrigation community. While these tours covered a large variety of topics including policy, civil engineering, and research, they had limited impact on the formulation of projects because of the diversity of the visited sites—from storage dams to agro-industries—and the specificity of the visited countries' contexts. Learning from these earlier experiences, the second tour in Mexico, held in 1997, was designed as a workshop focusing only on the Mexican experience in the transfer of management to water user associations in two of the most advanced districts in that process. Another tour in Spain focused on river basin organizations and user-managed systems.

The originality of the Mexican transfer program was in the size of the associations covering thousands of hectares each and the full managerial and financial responsibilities attributed to these associations. This contrasted with the experience in Southeast Asian countries, which was limited to small associations assisting irrigation agencies in maintenance and in collecting water fees. The experience of Mexico was so convincing that the Economic Development Institute accepted the AGR proposal to create a special unit named the International Network for Participatory Irrigation Management.

The International Network for Participatory Irrigation Management organized training workshops in several countries and international events. However, the message was too narrowly oriented and neglected the importance of a functional infrastructure system. The management transfer program in Mexico was supported by two large rehabilitation projects in 1991 and one modernization project in 2003 totaling $700 million. Turkey was the first country to adopt the Mexican approach, thanks to a Bank staff member (J. Mohamedi) who travelled from Mexico to Turkey to report his observations. Soon after, Mexico organized a series of training workshops for Turkish experts, and the Mexico Irrigation Management Transfer Program turned out to be a successful model for Turkey for the next two decades. Participatory irrigation management had mixed results in countries where it was considered as a means to reduce the annual government budget for irrigation, and also in countries where the size of associations was too small in scale for them to efficiently manage their systems, and where the training of board members and system managers was overlooked. In some of these countries, there was no real transfer of management responsibilities.

The source book documented a range of solutions and good practices from the Bank and worldwide experience that could be mainstreamed in the World Bank portfolio such as policy and institutional reforms, investments in hardware and software, and recent innovations.

A note on the source book stated that one of the biggest challenges to implementation is the scarcity of specialists who understand the service concept and the hydraulic principles involved in managing canal systems.[1] The note also stated that lack of attention to technical details is a major cause of poor performance.

Years after the preparation of the source book, the pace of technological change in irrigation is still slow (see chapter 10 in Part II).

Reengaging in Agricultural Water Management (2006)

Concerned by the very sharp slowdown of the irrigation portfolio in the 1990s, the Bank called for a reengagement in agriculture water management, which resulted in the preparation of a book by a team of Bank staff and consultants under the leadership of the Water Adviser Salah Darghouth, entitled *Reengaging in Agriculture Water Management: Challenges and Options,* published in 2006 (World Bank 2006b). The book acknowledged that returns to public investments in irrigation systems and drainage were disappointing, especially for large-scale irrigation, and that water productivity was low. New solutions were needed based on new management options and widely available technologies.

The overall goal of that report was to give strategic focus to the integration of agriculture water management components in corporate strategies. The specific objectives were to set out the changing context of demand and supply for agricultural water, and to identify the policy, institutional, and incentive reform options that would accelerate productivity improvements and pro-poor growth.

The book expresses clear objectives for large-scale irrigation:

> *the objective should be to improve farming profitability sustainably through improved service at the least cost. Improvements in profitability have to be made through integrated system modernization. Physical improvements will include a broad range of hardware investments and related management practices to ensure an efficient least cost water service delivery that meets farmer needs. Large-scale modernization thus requires an integrated package of physical improvements and institutional change in addition to agronomic improvements (p. 8).*

Contributions of the Agriculture and Rural Development Department

In view of the old concepts and design standards found in many appraisal reports, an irrigation adviser in the 1980s–90s (the author of this present report) initiated the preparation of books and audio-visual materials on the principles of modern canal control: (1) modern water control in irrigation, and (2) improving the operation of canal systems.

The Bank, with the support of the International Program for Technical Research on Irrigation and Drainage (IPTRID), initiated a review of the performance of 16 irrigation schemes with an element of modernization, either physical or institutional, through a diagnosis method (later known as the Rapid Appraisal Process).

The study was conducted by the California Polytechnic Institute in 1995–96 and a resulting report was published by the FAO's Bangkok Office. The main findings of that study were:

- Hardware modernization can drastically improve the ease of system operation and the degree of water delivery service provided.
- The level of service provided to farms in the majority of schemes would be insufficient to allow for modern irrigation scheduling.[2]
- Anarchy in water distribution (and resulting inequality and inefficiency) was largely absent in projects with modernization aspects, in contrast with conventionally designed irrigation projects.
- There was limited modernization in the 16 projects under study. However, motivated personnel in combination with partially modernized projects had succeeded in delivering irrigation water in a relatively orderly manner.

In summary, the report concludes:

- There is an urgent need for considerable and practical training in the concepts and details of modernization and a longer-term commitment to training.
- Most policy and institutional reforms cannot be fully implemented without the right physical environment. The application of volumetric water charges and quotas, the implementation of water rights and active water markets, and demand management are reform tools that require users' confidence in water delivery services—and proper water controls to provide those services.

That study also provided the basis for the preparation of a performance tool for irrigation by the FAO's Land and Water Development Department (known as MASCOTTE). Workshops for the application of RAP and MASCOTTE were organized by the FAO in several client countries of the World Bank.

Safeguard Policies and Their Impact on Lending for Irrigation

Environmental concerns became an explicit part of World Bank activities as early as 1970, when the position of an environmental adviser was created. Over the years, the Bank's concern for the environment increased, partly under the pressure of nongovernmental organizations. A significant milestone was the establishment of a Central Environment Department during the 1987 reorganization with the responsibility to develop a series of policies to ensure that people and the environment were protected from potential adverse impacts. These policies required the borrowing governments to address certain environmental and social risks in order to receive World Bank support for investment projects.

The environmental and social policies, known as "safeguard policies," provided the mechanism for addressing environmental and social issues in project design, implementation, and operation. These requirements included conducting environmental and social impact assessments. Because of the multifaceted nature of the irrigation subsector, with possible impacts of projects on people, land, water, and soils, as well as the magnitude of the investment in infrastructure required, a large number of these safeguard policies were triggered during the preparation of irrigation projects, in particular for those applicable to: (1) natural habitats, (2) involuntary resettlement, (3) safety of dams, (4) projects in international waterways, (5) indigenous people, and (6) pest management. The preparation of environment and social assessments, addressing a part or all these safeguards, is given considerable attention by the Bank's task team leaders during project preparation.

Replacing the safeguard policies, the Environmental and Social Framework (ESF) was issued in 2016 to shift the focus of environmental and social safeguards "from a predominantly risk-management perspective to a more proactive engagement with stakeholders" (World Bank 2018). Historically, environmental mitigation measures applicable to a project have been included in Environmental and Social Management Plans, Project Appraisal Documents, and Operational Manuals. These have now been augmented through an Environmental and Social Commitment Plan (ESCP) under the ESF. It is important to note that the ESF is only applicable to investment project financing operations. It is as yet unclear whether the intended shift from upfront risk management to a co-learning approach in implementation has been successful.

Notes

1. That note was prepared by Charles Burt from the California Polytechnic Institute.
2. Note from the author: The only schemes where modern scheduling would have been feasible were the ones in Morocco. However, because of a three-year drought at the time of the study, management took over the allocation of water and delivery service.

4. Performance of Bank-Financed Irrigation Projects

"All large organizations and all administrators, managers, and professionals, if they are honest, will admit that they have successes and failures."

– Robert McNamara

The irrigation subsector has unique characteristics that make it difficult to compare to other infrastructure sectors, such as hydropower, transport, water supply, or to other industries. The performance of irrigation is not based on manufactured products, such as the number of cars or tons of fertilizer, the energy generated, or the volume of potable water charged to the users. The success of an irrigation project is measured in terms of the increased productivity of agriculture. Results depend on a complex set of factors such as the use of other inputs by water users and the international price of commodities. Also, and importantly, results depend on the method of analysis, which varies across countries. Australia, for example, evaluates the performance of irrigation water supplier companies through a benchmarking process at the farm gate.

By contrast with other infrastructure sectors, where benefits occur soon after construction, such as in hydro-power projects, the benefits of irrigation mature over a long period after completion—especially for new projects. At completion (the time of the typical World Bank Operations Evaluation Department [OED] or Independent Evaluation Group [IEG] review), the benefits are still speculative. The economic rate of return (ERR) calculations are based on updated costs and the duration of works. However, agricultural production is still based on projections.

Irrigation also has multiplier effects and externalities because benefit calculations miss other direct benefits such as better health, better access to domestic water, and increased employment in on-farm and agro-industries (OED 1995). This is not to state that the quality of irrigation investments should not be subject to the same scrutiny as for other sectors, on the contrary – the sector has in the past and should continue to improve in formulating realistic sectoral performance targets at completion as well as do ex-post evaluations to evaluate realism of projections.

4.1 Reviews of Irrigation and Drainage Projects Conducted by the OED and Independent Evaluation Group

Studies on the performance and strategy of the Bank's irrigation subsector at the country, regional, or sector level have been carried out by the OED and later by the Independent Evaluation Group (IEG). The OED of the World Bank was created in 1972 under Robert

McNamara and was retitled the IEG in 2004. The findings of these studies are summarized in the following paragraphs.

The evaluation methodology used by the OED and IEG are discussed below, and the results and findings of each evaluation are presented in appendix A.

The Operations Evaluation Department, 1972–2004

Since 1972, the Bank's operations staff have been required to prepare a project completion report on each closed loan. The next stage in the evaluation was an independent audit conducted by the OED, a level reached by about 40 percent of Bank projects. An audit typically consisted of a one-week field visit that included interviews of irrigators and agency staff and desk work. Audits do not recalculate rates of return. The last stage in the evaluation was an impact evaluation of projects with a long gestation period, of which irrigation has a large number.

The OED evaluated 208 projects using two types of assessment apiece. One outlined satisfactory or unsatisfactory ratings (in other words, whether the project was a good thing for the borrower and whether, overall, the project met its objective); the other estimated the economic returns to project investments. The economic rate of return (ERR) of a project, for it to be approved by the Board, was 12 percent, later reduced to 10 percent. The same threshold was used for rating a project at completion.

The Independent Evaluation Group, 2005–present

The IEG is responsible for assessing the relevance, efficacy, and efficiency of World Bank Group operational policies, programs, and activities, and their contribution to development effectiveness. The IEG conducts independent evaluations of specific projects and programs, country programs, and a range of sectoral, thematic, and corporate issues. In addition, it reviews and validates individual project and country program completion reports from the World Bank, International Finance Corporation, and Multilateral Investment Guarantee Agency.

The IEG seeks to prepare project performance assessment reports (PPARs) for about 20–25 percent of the World Bank's lending operations each year. The selection of projects to be covered by PPARs is based on several criteria: (1) alignment with IEG program priorities, (2) the potential for learning from innovative projects, and (3) the presence of disputed ratings or external requests from the Board or World Bank management. The efforts required to prepare a PPAR are similar to those of audit reports prepared under the OED: (1) a visit to the borrowing country to discuss the operation with the government, and (2) interviews with World Bank staff and donor agency staff at headquarters and in local offices.

An impact evaluation is a very specific type of evaluation set to detect whether changes in outcomes are attributable to a specific intervention. The PPAR ratings go into the Bank's data system and supersede the Implementation Completion and Results Report (ICR) review ratings. However, the results of impact evaluations do not go into the system.

Most Bank lending operations have been re-coded by the Bank back to fiscal year 1990. The new coding system allows for up to five themes and five sectors per activity. Guidelines were developed by a working group in 2005 to harmonize evaluation criteria for ICRs and working group evaluations.

The three aspects now assessed in IEG evaluations are as follows (Keith 2006):

Outcome: The extent to which the project's major relevant objectives were achieved—or expected to be achieved efficiently.

Sustainability: The resilience to the risk of net benefit flows over time.

Institutional development impact: The extent to which a project improves the ability of a country or region to make more efficient, equitable, and sustainable use of its financial and natural resources.

Evaluation Studies by OED and IEG, 1972–2019

The first evaluation study of the irrigation subsector was carried out by the OED in 1994, covering all projects approved and completed to date; a second study was carried out by the IEG covering the period 1994–2004. Two regional studies covered the humid tropics of South Asia and three projects, the state of Andhra Pradesh, India. Ratings by the IEG of the 130 projects completed during the period 2005–18 are available in IEG data files. Results and findings of these studies are presented in appendix A.

The success rate of the irrigation projects completed during the 50-year period is 72 percent (table 4.1), with a lower rate (70 percent) for the dedicated projects than for the nondedicated projects (77 percent). This unexpected finding is caused by the low percentages of dedicated projects (63 and 67 percent) during the two decades 1980–99.

The irrigation subsector has been one of the best in terms of projects receiving an ERR estimate at appraisal and evaluation. ERR was calculated at appraisal for about 68 percent of 600 irrigation projects completed so far with a high of 80–90 percent during the three decades 1970–99, dropping to about 30 percent in 1999–2019 (table 4.2). The percentage for the 407 dedicated projects and the 192 nondedicated projects is, respectively, 85 and 33 percent.

Table 4.1. Outcome Ratings of Overall Lending for Irrigation, by Exit Fiscal Year

	1970–79		1980–89		1990–99		2000–09		2010–19		1970–2019	
Project Type	No. Rated*	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf
> 50% irrigation and drainage components	37	76	156	63	104	67	61	80	46	78	**404**	**70**
< 50%	0		2	100	33	79	82	76	74	78	**192**	**77**
Total	37	76	158	64	137	70	143	78	120	78	**596**	**72**

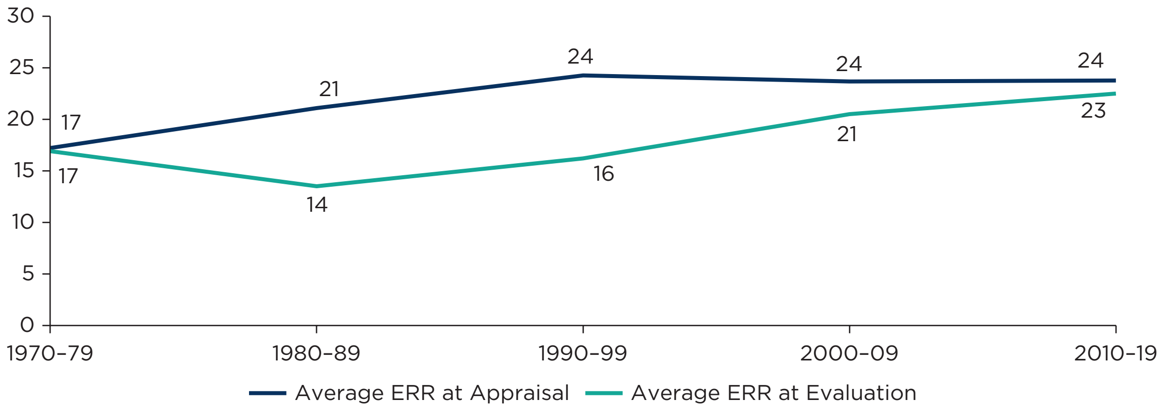
Note: Table includes International Bank for Reconstruction and Development and International Development Association projects with irrigation and drainage components.

Table 4.2. Percentage of Irrigation Projects Receiving ERR Estimate at Appraisal

	1970–79	1980–89	1990–99	2000–09	2010–19	Total 1970–2019
Dedicated	86	96	91	74	47	85
Nondedicated		100	70	31	18	33
Irrigation subsector total	86	96	86	49	29	68

Note: ERR = economic rate of return.

Figure 4.1. IBRD/IDA Projects with an Irrigation and Drainage Commitment Greater than 50 Percent: ERR at Appraisal and Evaluation, by Exit Fiscal Year



Note: ERR = economic rate of return; IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

For the decade 1970-79, average ERRs were higher at evaluation than at appraisal for two regions, but were lower at evaluation for two others (South Asia and Sub-Saharan Africa). For the following decades, 1980–99, all regions show an optimism gap between 3 and 10 percent (figure 4.1). The average ERR value reported at evaluation for dedicated projects increased from 17 percent in the first decade to a steady average of 22–24 percent. The optimism gap for dedicated projects reached 8 percent before declining to 1–2 percent in 1999–2019.

A possible source of bias in ERRs is overestimation of long-term benefits. The typical ERR includes benefit flows that last 25–30 years, yet the sustainability of such flows is rarely verified after the first 7–10 years. ERR calculations assume that benefit flows in later years remain at a constant high level or continue growing. With an average rating for sustainability of 56 percent for irrigation projects, the overall ratings based on results at completion is a valid question.

The success rate of the irrigation projects completed during the 50-year period is 72 percent, with a lower rate (70 percent) for the dedicated projects than for the nondedicated projects (77 percent). This unexpected finding is caused by the low percentages of dedicated projects (63 and 67 percent) during the two decades 1980–99.

5. Causes of the Slowdown of Irrigation Lending since the Mid-1980s

Official development assistance to irrigation, based on FAO data, declined steadily after the 1980s, and irrigation expansion slowed dramatically from 2.5 percent in the 1970–80s to about 1.2 percent per year in the next two decades. Lending by the Bank for irrigation declined in monetary terms and in numbers of operations to about one-third the peak level of the early 1980s.

Over the past decade, the worldwide trend has been indicating an emphasis on the rehabilitation and management improvements of existing schemes. The slowdown is most likely linked to factors such as (1) a trend toward economywide reforms that result in reduced fiscal resources for irrigation, a subsector that has traditionally relied heavily on public funding; and (2) growing adverse publicity related to negative environmental impacts of large irrigation schemes.

The causes of the decline in investments in irrigation in the world are multiple. The retrenchment of the Bank and more generally the world from investments in irrigation was attributed, in a 1995 OED review, to historically low prices for food staples, combined with the high investment cost of new irrigation projects making it difficult to justify investments in the development of new irrigated areas. As a result, public sector investment has fallen.

Moreover, several factors internal to the World Bank have also contributed to the decline of lending for the irrigation subsector. To support the objectives of poverty alleviation and promoting environmental sustainability, the Bank has been giving greater attention to social sectors, such as population, gender, governance, education, and health care, as strongly suggested by the 1990 *World Development Report.*

In addition, to respond quickly to the demands of its clients, the Bank has shortened project preparation processes, a trend that is not in favor of the funding of complex multifaceted irrigation projects. The Bank budgets for lending preparation declined from $150 million in 1993 to $122 million in 2000.[1]

The Bank strategy in terms of staffing reflects its drive toward policy-base lending and a new focus on poverty and human resources and institutions. The numbers of technical irrigation engineering staff steadily declined from a total of 49 in 1989, of which 12 were agricultural engineers and 37 irrigation engineers, to 35 engineers in 1996. The number of staff working regularly in the irrigation subsector under the Water Global Practice (Water GP) at the time of this report is about 30, of which about 22 are graduated engineers. These agri-water specialists represent 10 percent of the professional staff at the Water GP (290 staff in total). The Agriculture and Food (AGF GP) has only a handful of irrigation specialists and relies largely on Water GP cross-support. This comparatively low staffing in relation to the size of the portfolio (in dollars and number of projects), and the inherent complexities of irrigation investment lending, create a large workload per person. About 13 out of 22 engineers are now based at the Bank headquarters while the others are in country offices, a major change from 1989 when all 49 engineers were based in Washington, DC.

Some of this staffing change can be explained by a desire for a more multidisciplinary approach to irrigation (including economics, governance, agronomy, sociology) and by a more generalist support across the water and agriculture portfolio (see below). However, with the number of irrigation staff reduced, the Bank has lost part of its bandwidth and actual expertise in technical assistance for irrigation and agricultural water management.

5.1 Staffing Qualifications and Bank Process Review

The Bank staff focused on irrigation have considerably evolved over the past 50 years, reflecting the new objectives, policies, and operational processes of Bank projects. The typical preparation/appraisal team from the 1970s to early 1990s was composed of an irrigation engineer, an agronomist or agricultural engineer, and an agricultural economist, occasionally with the support of a procurement officer an expert such as a dam engineer, and an expert in crop markets, greenhouses, farm mechanization, or land consolidation. During the past two decades, the project team has expanded to include environmental and social experts. In that respect, the Bank has gained unique expertise in dealing with water resources projects, including irrigation. As a result, the total staff involved at large in irrigation projects almost tripled over 30 years from about 60 in the mid-1990s to a total of about 200 in the late 2010s.

However, the same inherent complexity of the irrigation process, which has long affected the preparation of lending for irrigation projects, has not vanished. Designing large-scale irrigation schemes providing modern irrigation delivery service (and reliability and flexibility) is a uniquely complex engineering problem (Charles M. Burt, professor emeritus of irrigation at the California Polytechnic State University, often states that designing a canal system is more difficult than designing a large dam). The challenge is to convey and then distribute a large flow into small streams to a large number of users through a reticulated network of canals without major losses, taking into account travel times, conjunctive use, and shifting demands because of weather conditions, while maintaining strict water levels in canals without overtopping, and adequate supply and delivery to canals of the next level. All these objectives should be achieved despite the dispersion of control structures and the possibility that their resetting can amplify or dampen waves and irregularities in the system. Designing an irrigation canal to convey water at design flow only—as often is the case—without carefully planning for flow variability is a simplistic approach that is proven to fail. However, a formal review process to investigate the appropriate aspects of each specific project would be one way to avoid repeating the inadequate designs of the past.

As a general rule, any Bank project cannot be presented to the Board without the formal agreement of the environmental and social adviser. To pass this step, the appraisal team's work inevitably focuses on meeting the requirements of the safeguards. Similar requirements could be made for technical issues, or at minimum, project appraisal documents could be required to include a technical annex (covering similar topics as the former technical engineering annex of Staff Appraisal Reports). In case detailed designs are not ready at appraisal, the technical annex could include a plan for when this information becomes available and commit to an internal technical review during implementation and prior to commissioning works.

Note

1. In real terms, the Bank's budget for lending preparation declined by 44 percent between 1993 and 2001. However, the total number of Bank loans fell by only 13 percent in the same period as a result of efficiency improvements and a preference for smaller, less risky, and less costly projects in sectors other than infrastructure and rural development.

6. The Recent Search for New Irrigation Paradigms

Given the multiple food security crises in the world, governments and donors should anticipate the risks of a food crisis that would be far more difficult to overcome than the earlier ones. There is much less potential for expansion of irrigation (outside Africa) that once supported the use of new high-yielding crop varieties and other agricultural inputs. Experience has shown that improving the performance of existing irrigation systems or building new schemes is a long process that involves technological, institutional, and behavioral changes.

Focusing the attention of donors and governments on irrigation development and, by default, on food security issues is not a simple matter in the present context of food sufficiency and low-price commodities. Other challenges include ensuring livelihoods, safeguarding the environment, and improving the economic performance of irrigated agriculture.

The public irrigation subsector has not changed its basic development paradigm for over 70 years. The model relies on public funding for capital investment combined with public management and supply of water resources to farmers at subsidized rates. In the mid-2010s, some experts believed that this archetype was beginning to change amid the exigencies of climate change, constraints on water resources, and the need for increased agricultural yields to resolve food security.

6.1 Public-Private Partnerships

One solution that gained acceptance a few years ago was to combine public and private expertise, using a model that had succeeded in improving water supply and power distribution in some large cities of borrowing countries. The objective is to improve delivery of irrigation services and management of irrigation systems. To that end, a World Bank handbook published in 2016 (Mandri-Perrot and Bisbey 2016) was intended as a practical guide to design and tender sustainable public-private partnership (PPP) arrangements in the irrigation subsector.

However, bringing private participation into the irrigation subsector is complicated. The system needs to be designed in a sustainable way, not only from an engineering and environmental perspective, but also in terms of operation and maintenance. Appropriate institutional arrangements and contractual frameworks need to be put in place. Fundamentally, a PPP in irrigation has the following important requirements:

- One private sector firm is willing and able to take on the responsibilities defined in a PPP contract. A private investor must express some interest if it can recover any costs incurred in providing the services and at the same time obtain a reasonable return.
- A government or institution is willing to sign off on the PPP contract with a private firm. Governments will only enter the arrangement if it is confident that the private firm can meet the requirements set out in the contract.
- Farmers and water user associations are able to contribute necessary service fees and, more generally, to accept the private sector taking over responsibility for the provision of irrigation services. Farmers would only be willing or able to pay service fees if the irrigation services help them increase their income to a level that enables them to afford the fees.

The above three conditions for a concession PPP are not typically met in most irrigation projects. The key requirement for an irrigation scheme to be financially self-sustaining is that the project needs to be able to pay water fees at a level that enables the private firm to recover capital and O&M costs. The income of most farmers producing staple foods or other low-value crops is too low to cover the full cost of O&M, not to mention to repay the investment cost to be made by the PPP firm.

Several key lessons may be gleaned from past experience with PPPs:

- PPPs are more appropriate for new and modern schemes serving commercial farmers than for irrigation schemes under operation.
- There are very few private companies in the irrigation subsector worldwide. The development of any joint public-private initiative must include an efficient marketing campaign.
- PPP concession models are not the only mechanisms for involving the private sector in irrigation. Other models of private sector involvement, such as management contracts, could be considered.
- It is advisable for the public promoter of PPP projects to hire advisory services with legal and technical skills as well as international experience to optimize design and to avoid unbalanced allocation of risks in PPP design.

The number of initiatives centered on PPPs in irrigation worldwide increased in the 2000s. However, the World Bank and/or International Finance Corporation (IFC) were involved in only a few of these PPPs, and not all successfully. The most known PPP experience is the El Guerdane project in the Souss valley in Morocco. In 2008, an 80 km pipe from a large Aoulouz reservoir to commercial citrus farmers was financed in an area where groundwater had been nearly exhausted. In this case, IFC played the role of an independent adviser to the Government of Morocco.

Peru has had a long experience with financing irrigation projects through borrowing from the private sector. The first phase of the Majes project in Arequipa Province was financed through a loan to the Peruvian government from a consortium of private banking groups of European countries in the 1970s. Similarly, Phase I of the Chavimochic project in Central Peru was implemented through the same method. The first PPP concession contract for the construction of the Olmos project (43,000 hectares [ha]) was signed in 2010 and a second one for Majes II (38,000 ha) in 2011.

Both projects were financed through sales of land to investors by lots of 400 ha for commercial farming for export to the North American market (mainly asparagus and mangoes) as well as through volumetric sales of water. These first contracts were very favorable to the private sector since all financial risks were supported by the government. Further PPP contracts for irrigation in Peru balanced the risks between the private sector and the government, for example, for the next phase of Chavimochic (17,000 ha).

In the Arab Republic of Egypt, the Bank, together with the IFC, was deeply involved in the preparation of a PPP project in the west area of the Nile Delta to replace a deep aquifer under depletion with water pumped from the old delta El-Nasr canal. Five consortia were prequalified, but no response was received at the first bidding and only one at the second bidding. The PPP initiative was aborted because of the local political situation in the mid-2000s.

In conclusion, the irrigation community is advised not to consider the PPP mechanism as the new panacea for solving problems associated with the poor management of existing irrigation schemes or a lack of resources for new development. PPPs should instead be considered only when specific conditions are met. In most cases, other institutional arrangements should be considered such as irrigation management transfer and outsourcing of private services (Trier 2014).

Lately, the discussion is moving more broadly to the enabling of private finance, which opens a broad spectrum for private sector participation—from financing in public entities through management and operating contracts, lease agreements to concessions, and divestiture (e.g., a Water Scarcity in Agriculture roundtable, or the World Irrigation Forum of the International Commission on Irrigation and Drainage [ICID]). Also, this opens up a pathway to different ways of thinking about the role of the private sector and links with performance contracting, enabling credit for farmer finance, guarantees, smarter subsidies, payment for environmental services, and carbon trading. The financing discussion brings us back to the fundamentals of value creation and value capture, credible financial management, returns on investment, and the performance of service delivery that de-risk private investment and build trust to attract funding. The question going forward is not how to structure the private financing of irrigation development, but how to reform the basic development model in irrigation so that it becomes an interesting proposition for private investment.

6.2 Irrigation Services Delivery Revisited: INSPIRE and the Irrigation Operator of the Future

The Independent Evaluation Group carried out an intermediate evaluation of irrigation service delivery in 2019 (IEG 2019) and highlighted emergent areas in the sector such as service delivery, multipurpose water resources management, environmental externalities, markets, governance, and climate change. Under radically changing circumstances, the evaluation observes a proclivity for repeat projects with marginally expanding sets of objectives generally centered on rehabilitation. It argues for a broader results framework and a focus on irrigation as a service to gain a more holistic approach to the sector. To tackle combined financial, technical, and management challenges under changing circumstances and enable the professional responses of service providers, the last few years have seen a convergence around improved management accountability that translates into specific operational improvements. This has been enabled by the rise of digital technology, remote sensing, and water accounting tools that provide a wealth of data hitherto not available to scheme managers and the general public. They create contestability and allow adaptive management. Besides the technological information revolution, there is also the growing consideration that the "management only" or "infrastructure only" paradigms have not delivered in designing solutions in the wider system. The provision of services to consumers, consisting of commercial and technical irrigation services—and supported by the organization strategy, human resources management, and financial management that "produce" the service—are discussed as a service pyramid. Example publications include *Governance in Irrigation and Drainage—A Practitioner's Resource* (Waalewijn et al. 2020) and *The Irrigation Operator of the Future: A Toolkit* (Waalewijn et al. 2022), which look to public sector reform, efforts to assess water service delivery performance, and design improvement programs with service providers. The International Network of Service Providers for Irrigation Excellence (INSPIRE), under formation as an ICID working group with many international partners, including the World Bank, aims to respond to the demand for a dialogue among irrigation service providers on finding service delivery solutions that work. In the coming years it will become clear whether the sector has been able to provide higher-quality services to farmers, show itself as credible to financiers, and in general turn around the public sector delivery model for performance and expansion.

6.3 A Joint Initiative: Farmer-Led Irrigation Development

It is widely accepted that farmers should ideally have autonomy over decision-making related to local irrigation development and implementation. This concept is not new, but it has gained considerable attention under a new initiative, FLID farmer-led irrigation development based on this principle. For example, in some irrigation schemes where user associations are well organized (e.g., Portugal), feasibility studies, detailed design, and, finally, works for upgrading infrastructure obtain approval from the farmers. To consider another example, the Bank-financed Sierra Natural Resources and Poverty Alleviation Project in Peru (approved in January 1997) is based on farmer demand and the specifically the qualification criteria of associations or at least 20 farmer family units. Under FLID, current generation of projects are facilitating farmers to make their design and management decisions, going beyond consultative processes in government-led interventions.

In the Sub-Saharan Africa region, the Bank has had a historical preference for large state-led irrigation schemes, including a centrally managed irrigation canal system. The failure of many of these schemes to meet expectations suggests a need to pursue other options. In African countries (and increasingly beyond), farmer-led irrigation is mostly related to creating an enabling environment for individual farmers or small groups to develop their own irrigation solutions. The aim is to empower a wider set of farmers in, for instance, drilling wells; supplying pumping and filtration equipment, solar panels, and pressurized systems; and enabling access to finance and private sector supply and service arrangements. The World Bank with the IFC and the Daugherty Water for Food Global Institute, Nebraska (the United States), are actively involved in the promotion of the farmer-led model. It requires a fundamentally different approach for government and financiers in the sector, focusing not on the delivery of irrigation, but in creating the conditions (finance, technology, quality assurance, incentive and challenge funding) ideally suited for the widespread situation in Africa, where water is available in shallow groundwater, nearby streams, and urban return flows and where climate resilience can be enhanced through rainfall risk management. FLID is growing faster than any public investment program on the continent, thanks to its focus on inclusion and sustainability while getting to scale.

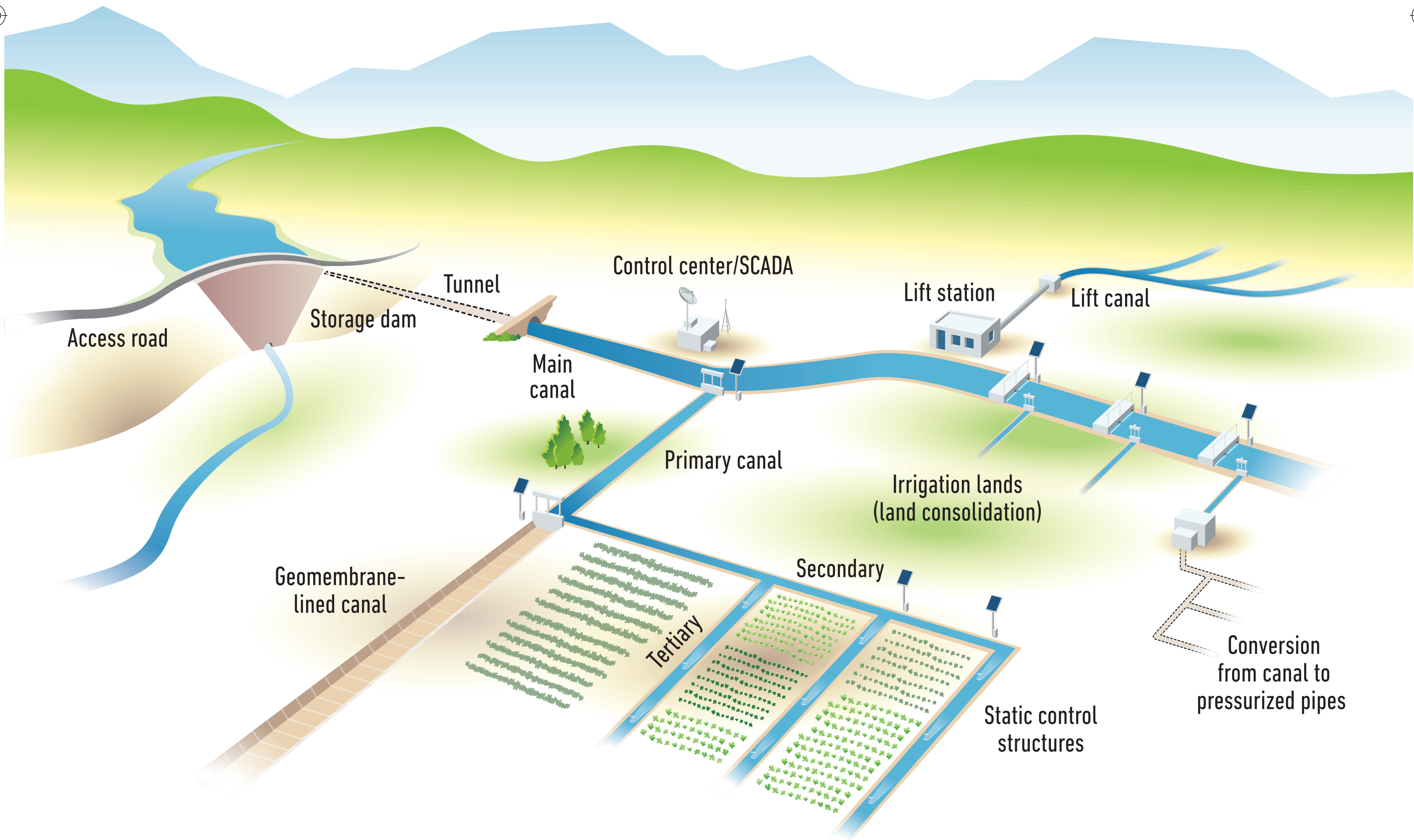
6.4 Policy Lending

The irrigation subsector has so far made limited use of Bank financing instruments such as Development Policy Financing (DPF) and Program-for-Results. The highest levels of government are involved in DPF, which triggers reforms that create an enabling institutional environment for the sector. Pakistan has seen a series of irrigation-related DPF instruments. DPF's effectiveness resides in its ability to revise sector laws and regulations. Accounting for roughly one-quarter of total Bank lending, this policy-based financing instrument can be used to facilitate the adoption of high-level institutional and policy reforms for an improved irrigation subsector. Such policy development processes or reforms may include a national water sector policy revision, legislative and regulatory changes, and organizational improvements. They will be increasingly important in ensuring that the negative externalities of irrigation are considered in decision-making, and, importantly, that institutional models are designed for improved results.

Bank-financed Program-For-Results operations in the irrigation and drainage subsector provide a platform to collaborate in larger country programs. They allow for strengthening relevant institutions and building capacity through partnerships with client governments, development partners, and other stakeholders. These programs help shift from inputs to outcomes (e.g., reduced methane emissions from paddy rice in China through better irrigation services; improved financial sustainability and ringfencing; real water savings). Even more than DPF, because they allow gradual improvement and technical assistance, these will be key to future sector performance improvements.

PART II: LARGE- AND MEDIUM-SCALE IRRIGATION PROJECTS IN REVIEW

LARGE-SCALE IRRIGATION SYSTEM



7. A Closer Look at Two Decades

Part II is an attempt to explore the causes of the irrigation Bank subsector's performance, which fell below expectations for two decades (1980s and 1990s), besides the reasons given in policy and strategy papers produced by the Bank and other research organizations. Part II is limited to large- and medium-scale irrigation, which is approximated by focusing on dedicated projects with an irrigation component exceeding 50 percent of project commitments[1].

Worldwide, the irrigated areas under large-scale schemes are estimated at 130 million hectares (ha), or about 40 percent of the 320 million ha irrigated (table 7.1).

As discussed in chapter 4 of part I, on average, nearly three out of four projects with irrigation components have been rated moderately satisfactory or above by the Operations Evaluation Department (OED)/ Independent Evaluation Group (IEG) with significant improvements noted in the past two decades. However, there are important variations between regions and over time. The South Asia region, which had the lowest performance in the 1994–2004 IEG review, is now at the top of global regions, just behind the East Asia region for the projects closed after 2005. Explanations for this remarkable progress are tentatively proposed in appendix D. The reasons for good or poor performance of large- and medium scale irrigation projects are multiple and cannot be narrowed down to one specific aspect of design, construction, management, financing, and use.

Table 7.1. Global Irrigation and Large-Scale Irrigation Systems

Region	Total Irrigated Area (ha)	Irrigated Areas under Large-Scale Irrigation Systems (ha)	%
South and East Asia	205,669,000	90,355,700	44
Central Asia	11,465,400	10,365,400	90
Latin America	18,952,000	6,783,650	36
Sub-Saharan Africa	4,216,000	731,200	17
Middle East and North Africa	14,652,000	6,805,820	46
Remaining Regions (Europe and North America)	65,000,000	15,000,000	22.5
Total	320,000,000	130,000,000	40

Source: Lankford et al. 2016.

7.1 An Engineering Solution to the Dual Use of Surface Water and Groundwater for Irrigation

Addressing the challenge of the overexploitation of groundwater in areas where both surface and groundwater are used for irrigation would require a modernization of canal systems. This would enable a much better-quality irrigation service, and thus encourage farmers to adopt crop diversification and cultivate high-value crops, slowing down the pumping of groundwater. Experience has provided evidence that rehabilitating canal systems using outdated technology combined with policy and organizational reforms is not enough to provide a level of service needed to slow the fall of groundwater levels. High-cost conversion from canals to pressurized systems has an economic feasibility limit. A limited number of countries have the expertise in modern automation and communications control techniques or the right policy to explore a public-private mechanism for financing such modernization projects. In countries where canals are undersized by design, such as South Asia, increasing the capacity of canals would be a critical issue.

7.2 Viewpoints of Irrigation Stakeholders and Experts in the 1990s

The most severe criticism of irrigation projects has been in the sphere of social and political sciences. In 1996, Sandra Postel stated that: "*policy makers have yet to realize that water problems can no longer be fixed by engineers alone*." A social scientist stated that:

> *Irrigation engineers know little about the actual principles of distribution of water on schemes in developing countries. They often assume that there is no better way of distributing water than according to the rules they had in mind when they designed and built the irrigation systems. Empirical data on the diversity in dynamics of the farms, the group of irrigators, the organizational patterns and local political structures are rarely available* (Diemer and Huibers 1996).

The 1996 Food and Agriculture Organization (FAO) guidelines on the preparation of irrigation projects supported these views:

> *Building ownership and commitment through participation has often been difficult to achieve in the past. On implementation, government engineers for their part, have usually seen irrigation only from an engineering, rather than a farming or social perspective. They have been reluctant to adopt participatory approaches with farmers, mainly because of a misplaced belief that farmers are unable to understand or make any contribution to technical matters, or because of concerns that participation might delay implementation or result in design changes that compromise the quality of the final product.*

Managers from government agencies have been targets of the critics: [….] *most national engineers have little incentive to engage with farmers, colleagues, and politicians to improve water delivery. Operation usually deviates from the assumptions in design. Political patronage is endemic in many schemes because they form part of the national political landscape. Maintaining the status quo is also the interest of national engineers* (Diemer and Huibers 1996).

Donor agencies were also blamed for the poor performance of the irrigation subsector. It is right that the procedures imposed by most multilateral and bilateral donor agencies create severe constraints to the modernization of large-scale systems. Most donor agencies limit the duration of development loans to five to seven years and provide a budget for project preparation only about one or two years before the expected date of loan approval. This time frame is suitable for some sectors, such as hydropower projects where site investigations and detailed design studies have been conducted many years in advance, and bidding documents are often ready before approval. However, this time frame is far too short for irrigation projects in countries that are not familiar with the innovations and technologies to be considered and projects for which only a concept paper is available at the start of the appraisal process, as the actual design is and has to be an iterative participatory process with future users. The Bank must prioritize whether to focus budgets on project preparation, supervision, or quality. Because of the persisting pressure to lend, the decision to proceed with negotiations and Board approval is often made with a focus on policy, environmental, and other considerations, but not technical ones. (The issue of insufficient budgets for supervision is further discussed in chapter 10 on the need to modernize Bank-financed irrigation projects.)

The preparation of the Vietnam Water Resources Application Project offers an important example of what can be accomplished by dedicating adequate resources to preparation and supervision. Nearly two years were spent to train the staff of government agencies and local consulting firms through workshops on the rapid appraisal process, modernization concepts and techniques, and user participation, before proceeding with the detailed design preparation and procurement.

The causes of poor performance of the irrigation subsector have also been attributed to neglect of some aspects in the development cycle of projects: inadequate policies, lack of user participation, and inadequate maintenance. According to the widespread consensus within the irrigation community in the 1980s, poor irrigation performance was rooted in poor management. The incumbent president of the International Commission on Irrigation and Drainage (ICID) stated at the ICID Congress held in Cairo in 1996: "*There is now a wide recognition that deficiencies in management and related institutional problems, rather than the technology of irrigation, were the chief constraints of poor performance of irrigation systems.*" This thinking persisted in the irrigation community for several decades.

As Elinor Ostrom wrote in a book on infrastructure policy, "*Where maintenance is inadequate, public investments deteriorate long before their expected useful lives are completed. This premature deterioration in capital assets results in a further drain of the already scarce resources of low-income countries*" (Ostrom 1993). The 1994 World Development Report (World Bank 1994)—*Infrastructure for Developme*nt—endorsed Ostrom's diagnosis by stating: "*Inadequate maintenance has been an almost universal (and costly) failure of infrastructure provided in developing countries. Poor maintenance can also reduce service quality and increase the costs for users, some of whom installed back-up generators or water storage tanks and private wells.*"

A number of irrigation specialists in the 1980–2010 period thought that involving users in the management of irrigation systems out of the direct government sphere would inevitably

lead to improvements in the sustainability of irrigation and drainage systems and agricultural production. The rationale was that users were more likely to operate systems effectively and according to their requirements and would be willing to pay for the operation. The dominant perception was that public irrigation management organizations lack the incentives and responsiveness to enhance performance, whereas water users have a direct interest in cost efficiency, profitability, and the physical conditions of irrigation facilities.

User participation in irrigation management was part of a package of recommendations on how to move away from the vicious cycle of irrigation projects' sequential rehabilitation, poor collection of service fees, insufficient budget for operation and maintenance, system deterioration, and poor service to users, to a virtuous cycle. For two decades, the establishment or strengthening of user organizations was systematically associated with the rehabilitation/modernization components of irrigation projects. In several countries, the government sped up the establishment of user organizations and the delegation of the management and operation of irrigation infrastructure to user organizations—even before systems was rehabilitated to provide a reasonable level of service.

Thirty years later, it became clear that projects consisting mainly of rehabilitation of the infrastructure combined with the transfer of management to user associations had yielded mixed results. Good examples can be found in Latin American countries and Turkey, where the policy has been to organize user associations large enough to be sustainable and supported by specific rules on user participation. But it became clear that improved management alone was not able to boost the performance of poorly designed and/or poorly built irrigation projects.

One high-performing scheme is that of the well-documented Chancay-Lambayeque district in the coastal region of Peru, equipped with well-designed and built simple water control infrastructure. Farmers place their water orders and pay the fees a few days in advance to the office of the user association. Water is delivered volumetrically through simple devices by skilled canal operators. Social cohesion and user oversight are two important factors behind the performance of this scheme.

Photo 7.1. Chancay-Lambayeque Scheme in Peru

Another example is the Dantiwada project in India, in which the operators of cross-regulators communicate with the operators of the upstream regulator, ensuring timely operation of the main canals.

The emphasis on inclusive participatory development and institutions was an important course-correction of an engineering-only paradigm, but created new binaries and blind spots. In most cases of poor performance, many of the problems can be traced to the initial design, layouts with confused hierarchies and institutional setups, poor operational strategies, poor quality of water delivery to farms, lack of flexibility at all levels, and, on top of these, poor-quality construction. The causes of the vicious cycle may also be rooted in overoptimistic assumptions adopted during project preparation, and the use of outdated standards. These two topics are discussed in the following chapters.

7.3 Rent Seeking in the Irrigation Subsector: A Neglected Dimension

Rent-seeking behavior among stakeholders involved in the irrigation subsector attracted little attention in water debates until the publication of two papers in the early and mid-1980s by Robert Wade and Robert Repetto. These papers came as a shock to the international professional community. They drew attention to the fact that irrigation is particularly prone to rent seeking and corruption. They denounced the hidden interests of stakeholders in agricultural water management that open doors to opportunistic behavior—thus perpetuating technical and economical inefficiencies (Huppert 2013). The conclusions of Wade and Repetto, political economists well known for their work on Indian irrigation management in the 1980s, were unambiguous: rent seeking and corruption are the two determinants of failures in the operation and maintenance of public irrigation systems.

Wade drew attention to the fact that operators kept water allocation to irrigation farmers intentionally unpredictable and thus invited side payments for timely and preferential water provision. Repetto concluded with a pessimistic note that: "*Those concerned with irrigation are trying to work against the improvement of public irrigation systems through physical rehabilitation and efforts to strengthen management as exploitation can best be done in a chaotic system. These efforts, although critical, are unlikely to succeed*." The work of Wade was limited to his observations on the South Asia region, but Repetto added that rent seeking is not restricted to that region and to developing countries.

Part of the preparation of feasibility studies and appraisal reports based on these studies is to decide on important assumptions. In case a given assumption appears to be central to the success of a project but is not likely to occur during implementation, the assumption became a "killer factor." This implies that the project needs to be redesigned or has to be rejected (Huppert 2013). This statement is highly relevant to the overestimation of two key parameters in the formulation of large-scale irrigation projects, the overall efficiency of water use and, consequently, the cropping intensity and projected benefits, as discussed in chapter 8.

Box 7.1. Irrigation Efficiencies, River Basin Water Balances: Metrics Matter!

The classical definition of irrigation efficiency for canal or pipe systems (conveyance/distribution efficiency) is the same as the input/output used in energy engineering: volumes delivered to the next level/volumes diverted at the heads. The definition of on-farm irrigation efficiency (or application efficiency), the volume used by the crops compared to the volumes delivered at the farm gate, is of a different nature from evapotranspiration as it can be adjusted through deficit irrigation or other means. The global efficiency (combining conveyance and application efficiency) of a surface water system ranges from 25 percent to 50 percent and above for systems designed and operated for efficient water delivery, including with pressurized and drip application.

In the last decade another understanding of efficiency and water savings has come to the forefront of policy dialogue, driven by groundwater depletion and ecological deprivation. To look at real water savings at the basin level is to consider the beneficial and nonbeneficial uses of water for irrigation (among other uses). This incorporates return flows and storage changes into an overall water balance. Such a detailed water balance is now also required for all projects under the Bank's Environmental and Social Framework (ESF).

For investment planning and policy guidance in irrigation, water savings at the basin level is an important metric. However, this does not explain optimal water productivity at a planetary scale, where planetary rather than basin boundaries, trade, and relative water (and carbon) footprints in agricultural water productivity have to be assessed, including for rainfed and irrigated agriculture.

These different metrics are not opposed to one another and should coexist. Basin-level water use and environmental impacts need to be accounted for, and all water fluxes including return flows and nonbeneficial uses. The irrigation subsector can then determine where system improvements lead to higher or lower overall and beneficial consumption within a basin. Having an understanding of the water footprint in food production helps tailor investments in water savings, in increasing the productivity of water use, or increasing access to irrigation where resources allow. The classical definition of irrigation efficiency remains a critical factor for the dimensioning/costing of storage reservoirs, intakes, pump and canal capacities, and for managing water distribution within the canal network; and without having a good understanding of it, no credible solutions for basin water savings can be designed.

Reviewing the last decade of irrigation documentation and portfolios clarifies the need to better explain the different metrics for measuring performance, and to increase the ambitions to measure progress toward context-specific targets. Misunderstandings, false juxtapositions, and a lack of clarity in the use of language and metrics can be seen across the efficiency/water balance discussions. In many documents, efficiency

box continued on next page

Box 7.1. Continued

is neither defined nor calculated and merely stated as a higher-level objective. Often the intuitive error is made that high water consumption means low efficiency and that there is ample scope for "improvement" without having clear indicators. This in turn has led to the justification of investments that resulted in little of their intended impact.

A debate is ongoing on whether "to line or not to line" irrigation canals. In most cases, seepage water stored in aquifers is not lost and groundwater has an added accessibility value in terms of reliability and flexibility. However, lining comes with pumping requirements and associated costs, and a potential risk of waterlogging and salinization reducing agricultural production and creating an unhealthy environment for the local population. From a resource efficiency perspective, no single position can be maintained, as the best choice depends on the specific operational and construction costs, water flows, and specific technical local conditions.

Note

1. This part deals with irrigation projects with an irrigation component exceeding 50 percent. They are not necessarily ALL large scale using the definition specific to each country, as some projects with over 50 percent commitment may not be of the large-scale category, but it is considered an acceptable approximation.

8. The Need for a Realistic Economic Evaluation of Projects at Appraisal

Overoptimistic assumptions have been adopted at the planning stage and during the preparation of feasibility studies submitted by governments. The most important one is the value of the overall irrigation efficiency, or scheme efficiency, used in water balance studies. This "automatically" determines the volume of water available to meet crop needs and consequently the area that can be irrigated given a set cropping intensity and pattern with limited water resources. Overoptimistic values of scheme efficiency were not challenged during the appraisal of irrigation projects by Bank staff in the early decades of lending for irrigation. Scheme irrigation efficiency is the product of field efficiency and conveyance/distribution efficiency.

A study of irrigation projects cowritten by the author of the present report, alongside two senior staff from the Operations Evaluation Department (Plusquellec, McPhail, and Polti 1990), was the first to draw attention to overoptimism in the irrigation subsector. That study indicated that overall system efficiencies[1] and, consequently, cropping intensities at impact evaluation (about five years after project completion) were substantially below the values expected at appraisal, as a result of inefficiencies at all system levels. Out of four evaluated projects, only one, in Morocco, was still rated satisfactory with an economic rate of return nearly unchanged at audit (table 8.1).

The worst cases of the 1970–90 period include the irrigation projects set up in India, none of which achieved efficiency rates of 50 percent or higher. At that time, the average efficiency of irrigation districts in California was estimated at 39 percent, a value that increased to 42 percent after several years of modernization. Assuming a farm efficiency of 60 percent

Table 8.1. Indicators of Performance of Four Selected Irrigation Projects at Appraisal (A) and Review by OED/IEG (B)

Project	Efficiency (%)		Cropping Intensity (%)		ERR (%)	
	A	B	A	B	A	B
Philippines	58	36	194	155	13	8.9
Thailand	55	28	150	115	26	9
Mexico	52	37	n.a.	n.a.	12	9
Morocco	50	42	n.a.	n.a.	11.4	11.7

Note: n.a. = data are not available in the completion reports; ERR = economic rate of return.

for India's gravity irrigation, a conveyance/distribution efficiency of over 80 percent would be needed to reach an overall value of 50 percent. Given that seepage losses from lower-level canals can reach up to 40 percent, appraisals of irrigation projects in India were obviously unrealistic (appendix D).

During the post-evaluation process of Bank projects, the evaluators, who were mostly economists, focused on the agro-economy inputs to the economic evaluation. They generally disregarded a scheme's irrigation efficiency, although this is what determines the cropping intensity that can be achieved with limited water resources. The link between water resources management and a project's economic evaluation, that is, between engineering and the project economy, has been missing. Consequently, economic rates of return on projects have been overestimated at appraisal, and this has not been detected at completion. A much higher level of modernization is needed to attain a high value of efficiency, as in the most advanced districts in Australia.

Most staff appraisal reports, now called project appraisal documents (PADs), for irrigation have historically included detailed technical annexes on water balances comparing irrigation water demand and water resources by unit of time. These annexes provided agroclimatic data such as effective rainfall, crop coefficient, evapotranspiration, and values of on-farm and canal system efficiencies for each crop season, differentiated by paddy and non-paddy crops. A cursory review of projects appraised after 2000 indicate that these data are now rarely provided in Project Appraisal Documents.

Not only are the expected benefits of canal irrigation projects overestimated at appraisal, but it has also been commonly assumed that they would remain constant once they had matured. This assumption is contradicted by the reality in the field. To reduce seepage losses, a substantial portion of irrigation canals is lined. In many countries, rigid lining, either cast-in-situ or precast concrete panels, is still the preference of irrigation agencies and consultants despite the well-known deterioration of concrete over time. However, concrete or brick rigid lining, even with small imperfections, has limited effect on the control of seepage losses. Even lining that appears to be in good condition may not be an effective seepage barrier; small cracks or inadequately sealed seams enable water flow paths that considerably reduce the efficacy of the lining.

The inefficient control of water seepage in lined canals was denounced by several speakers at an international workshop on canal lining and seepage organized in Lahore, Pakistan, in October 1993 (Skutsch 1993). Seepage losses from the unlined and lined sections of the Chashma Canal in Pakistan were practically in the same range after a few years. Field tests in Punjab, India, in the 1990s indicated that seepage losses from lined canals may increase several times after a few years of service (Habib and Garces-Restrepo 1993). Assuming constant benefits across the entire life of a canal irrigation project may contribute to an overestimation of the rate of return.

The service life of conventional linings could be much shorter than assumed, sometimes in the order of a few years only. Failed joints and cracking can develop within a very short period, to the point that the lining becomes ineffective.

Photo 8.1. Cracks in Lining of Canals Financed by the Bank in the 1970s

a. Peru: San Lorenzo Project **b. Kosovo: Iber Canal**

The rate of deterioration of rigid canal lining is strongly related to the quality of construction, particularly the compaction of the embankment of canals and the placing of concrete, and to the inadequate operation of canals that are drained too quickly. Under certain climatic and soil conditions, the process of deterioration of concrete lining canals can be accelerated. In areas with long periods of below-freezing temperatures, the concrete panels on the side slopes are displaced by the formation of ice (Plusquellec 2019a).

Rigid lining also quickly deteriorates in canals running in poor soils, such as gypsum soils found in the Middle East and Spain, loess soils found in some parts of Central Asia, which collapse in the presence of water, and swelling clay soils widely found in peninsular India.

The subject of irrigation efficiency is indeed very complex. The simple approach used in the earlier years of Bank lending for irrigation was correct as it considered that the surface resources available for a scheme were limited to surface water. The frustration of farmers facing insufficient water supply to meet the needs of an oversized system has contributed to the explosive use of groundwater where aquifer potential was adequate. Today the Bank addresses global water resources at the basin level, considering the water balance and earning threshold accounting, a process initiated under the Second Tarim II project in China appraised in 2008.

The Bank has financed irrigation projects dealing with surface and groundwater resources and their conjunctive management in the past two decades. Efficiency of a scheme is still an essential consideration when estimating the area that can be irrigated through a canal system, and the volumes of water that would contribute to the recharge of the aquifers or may escape to a saline water body.

For project cost considerations, it is essential to design a canal system with the highest but realistic efficiency levels. Canals with low efficiency levels are oversized and water is lost while being transported or at the field level.

Note

1. Efficiency is a ratio used in the energy sector to compare input and output. In irrigation, efficiency can be applied to: (1) any level of canals in the hierarchy of main, primary, secondary, or tertiary canals, comparing the volume of water distributed to canals of the next level to the volume supplied at the heads of a particular canal (canal efficiency); and (2) at the farm level, in comparing the crop irrigation requirements to the total water delivered (on-farm efficiency). The combination of all efficiencies is called "overall efficiency." The overall efficiency of water use at the basin level is complex. For example, the overall efficiency of the Nile in Egypt is estimated at 73 percent, although efficiency of each scheme is low because of night losses in the valley, which are recaptured at the next barrage. Seepage from the reclaimed areas on the fringes of the Nile Valley caused waterlogging in the lowlands of ancient Egypt.

9. Both Institutional and Engineering Changes Are Needed to Improve Irrigation Subsector Performance

The upgrading of the performance of irrigation systems to its potential requires the modernization of infrastructure. The multiple benefits of modernization include:

- Improved services to users
- Reduction of water losses
- Reduction of operation and maintenance costs
- Reduction of negative environmental impacts

The word *modernization* is found in the title or subtitle of one of the components of many projects approved in the past decades. Few authors have challenged the widespread view that managerial and institutional deficiencies—not the technology of irrigation—are the main causes of underperformance of irrigation schemes. Horst (1998) ended up writing a book on the dilemmas of designing irrigation systems, stating:

> *Is management really the crux of irrigation problems? Do we need to apply cosmetic surgery by only trying to improve the management environment without considering the technology? Is it now time to examine the root of the problem: the design of irrigation systems?*

An International Commission on Irrigation and Drainage publication on the automation of irrigation canals states that: *"One of the main factors contributing to poor performance is lack of effective water control"* (Goussard 1993).

The voices of these well-known experts were not echoed among the irrigation community.

An automation manual issued by the US Bureau of Reclamation (Buyalski et al. 1991) started with the remarkable statement that the systems designed in the past could not be operated efficiently. The authors of this manual had a realistic view of many systems worldwide. Indeed, few staff of design firms have ever operated the systems they designed. The complexity of the hydraulics of

Photo 9.1. Inadequate Design: A Lack of Water Control Structures at Construction, Later Built by Farmers Using Local Materials

irrigation canals operated under unsteady flow is not well understood to this day in common designs. For example, the absence of water level regulators when canals are operated under design flows is a frequent error, typically quickly identified and corrected by the water users.

A 1996 Operations Evaluation Department study of irrigation operation and maintenance and system performance in Southeast Asia is remarkable for its candor. Sophisticated computerized water scheduling was introduced in Southeast Asia in the late 1980s under a program whose successful application was tied to the presence of consultants. The laborious requirements for the collection of field data were too demanding for the irrigation service provider. Other devices, such as the constant head orifice or baffle modules, have been promoted and installed at canal and farm intakes in a large number of countries, with success in many and rejection in others, where these devices were seen as too cumbersome for flow measurement in field conditions or requiring high levels of design and no tampering. Such devices are well suited to specific settings within an established and well-designed irrigation regime, and should not be implemented without an understanding of local management conditions. Too often, irrigation design still does not take heed of the socio-technical circumstances for proposed water management practices; the resulting complexities show many textbook modernization attempts to be ill-advised.

9.1 Quality of Service Provided to Users

Irrigation service delivery in schemes with a fixed rotational delivery system is rigid by concept. Ideally a flexible canal irrigation system is one where the farmers receive water on-demand in terms of timing, duration, and flow. In that ideal case, the farmers can adjust irrigation depending on the type of crops, the rainfall and temperature, and the type of irrigation application (surface, drip, and sprinkler). The farmer can even stop irrigation at any time. A canal system can be partially flexible (for example the flow is set by the irrigation district). In some districts in California, the farmers cannot stop once they start irrigation on an agreed schedule.

In many schemes water delivery is unreliable and inefficient because of the inherent complexity of operation of a hierarchical network of canals equipped with manually operated gates that have to be checked and reset at frequent intervals and thus cannot be operated efficiently.

In some schemes, water delivery is rigid, since the time, duration, and flow are preset. In some South Asian countries, branch canals and below are operated under a rotational on/off system and the duration of each irrigation is set by the minutes between user within a block of 100–150 hectares in proportion to the size of cultivated area of each farm.

These rigid distribution systems do not enable shifting from low-value cereal or pasture crops to high-value crops, to crop diversification, or to the adoption of water-saving techniques at the farm level. In sum, the agricultural benefits are constrained by design. In areas where groundwater is abundant and easily accessible, such as in the Indo-Gangetic plain, farmers have largely turned to the exploitation of groundwater, enabling changes in crop and farming practices. However, the depletion of groundwater and the decline of its quality are consequences of overexploitation in the absence of any regulations.

The quality of water services is as much or even more important to the users than the volume allocated. In a comparative study of the performance of irrigation projects in four countries with different institutional arrangements, an important finding is that *farmers would not invest in on-farm inputs if water delivery were not reliable and flexible* (Bottrall 1985).

The concept of irrigation scheduling is to apply water to the crop in the correct amount and at the proper time to maximize crop production and/or profit, while maintaining a reasonably high level of irrigation efficiency. Ideally, irrigators should have direct access to water so that they can react adequately to changes in the soil moisture status, optimize their irrigation schedules, and synchronize them with other on- and off-farm activities.

Farmers need reliability first and then prefer delivery with greater flexibility. In most irrigation schemes, this flexibility in canal systems is difficult to provide, and the amount of water available or the timing of supply is often constrained by deficiencies in flow control infrastructure, in addition to the scarcity of water resources. Modernization of delivery services by upgrading the existing infrastructure and reforming institutions is a challenging process requiring considerable experience.

The right water allocation strategy and the type of water control structures in large- and medium-scale canal schemes are essential for the reliability and flexibility of irrigation water services. Relying on manually operated structures that require daily checking and resetting is not operationally realistic.[1]

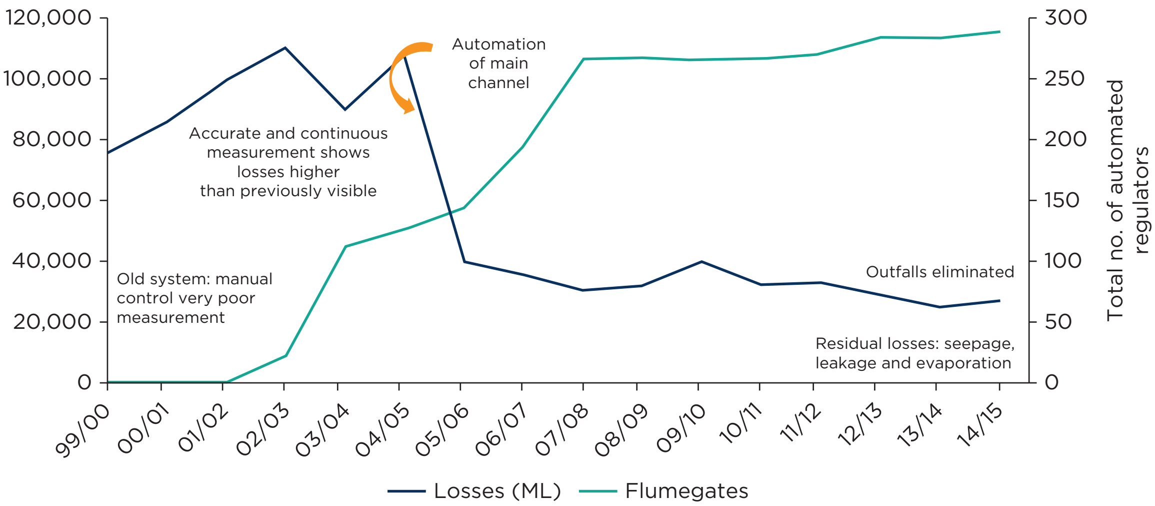
9.2 Reduction of Losses in Irrigation Canal Systems

Water losses from a canal system reduce the area that can be irrigated within that system, unless these losses contribute to the recharge of the groundwater and are reused by pumping. In tropical and semi-tropical areas where double cropping is possible, inefficient water use during the wet season reduces the volume available in storage reservoirs for the command area during the next dry season. The potential cropping intensity of irrigation by the canal system (for example, the Chao Phya Plain in Thailand) is negatively affected by excessive losses during the wet season. However, the global cropping intensity is not, if surface water use is complemented by groundwater use. (In the 100,000 ha Phitsanulok project in Thailand, there is one groundwater well for every five or so hectares.)

The losses in an irrigation system include losses at the farm level and upstream of farms in the conveyance and distribution systems. Saving water at the farm level is aggressively promoted by the private irrigation industry and encouraged by donors and irrigation agencies. Much less attention has been given to saving water resources upstream of farms. Water losses through the hierarchical irrigation systems, from the main canal to the primary, secondary, and tertiary canals down to the farm gate, are of two different natures: (1) operational losses when the operation is deficient, and (2) seepage losses.

Operational losses are the losses of water caused by an irrigation system's lack of flexibility and its inability to adjust supply to precisely match demand. Any surplus water released from the water source of a particular scheme ultimately ends up in a drainage channel, where it can be recaptured further downstream within the basin—unless it ends up in a salty water body—but the water is lost for this system, which has an impact on the financial balance of irrigation districts where water charges are volumetric, and on the water allocated to each irrigator. If the operator needs to reduce operational losses, advanced techniques in hardware and software have to be adopted and installed, such as Supervisory Control and Data Acquisition (known as SCADA), automatic gates, and compensation reservoirs along or within the main canal. The example in figure 9.1, illustrating a system-based distributed control system known as total channel control, shows the reduction in system spills as more automated technology is commissioned.

Figure 9.1. Coleambally Irrigation District, Australia: Residual Losses after Installation of Automated Regulators (with the authorization of RUBICON), Fiscal Years 1999–2014



Source: Hawke 2016.

Very few data on operational losses in canal systems are available worldwide. Australia is an exception. Using the above technologies, operational losses have been eliminated as demonstrated by the precise water accounting in the modernized Coleambally irrigation district in Australia.

The second and most important source of losses are the seepage losses through infiltration from unlined and lined canals. Studies on seepage losses from canals in India in the 1980s found that typically losses ranged from 10 to 40 percent of the diverted flow into a canal system. The complex issue "to line or not to line" irrigation canals is the subject of a heated debate, with several objectives in opposition to one another. One the one hand is the recharge of aquifers and improved quality of services to irrigators, and on the other is the cost of recapturing leaked water, and risk of waterlogging and salinization—in addition to geotechnical factors. The consequence of inefficient use of irrigation water worldwide is that about 35 million hectares of prime agricultural lands have become unproductive due to irrigation-induced waterlogging and salinization. On the other hand, advanced[2] techniques with the use of geosynthetic materials—mainly geomembranes—and geotextiles provide sustainable solutions for long-term effective canal lining.

Looking back, conjunctive management has remained elusive in many parts, due to both the large cost differential between surface and groundwater irrigation (distorted by subsidies), the institutional mis-match and the unresolved debate on how to manage conjunctive use. In fact, groundwater accounts for two-thirds of irrigation water in India and contributes to many of the objectives of food security and efficiency, yet it is not adequately captured in a management vision for irrigation.

9.3 The Thus-Far Unachievable Vision of Volumetric Pricing

Adoption of volumetric pricing in irrigation has been strongly advocated for decades by economists because it would provide incentives for users to save water, in contrast to the method of charging for water on a per-land-unit basis or even the better method of a crop-land basis.

The emphasis should be first on the importance of volumetric monitoring. However, the challenge is the measurement of the volume of water delivered to each user or group of farmers. Pricing of water is to recover costs and create accountability and volumetric monitoring to improve efficiency and reliability of service to users. In conventional canal systems equipped with manually operated systems and staff's visual observations of gauges, it is an unrealistic goal because the fluctuations of water levels and flows in canals require frequent measurements. Unused measuring devices, mainly old-type staff gauges, installed under Bank-financed projects can be found in many canal schemes worldwide. In contrast, volumetric pricing and water markets are widespread in areas that rely on groundwater pumping and charge for electricity (e.g. West Bengal).

The problem was solved in most countries in the Mediterranean basin, where modular baffle distributors, providing a set flow within certain variations of the upstream water level, were installed. Only the duration of water delivery is required to determine the volume to be charged. Without volumetric measurement of water from one canal to another of a lower level or to a group of users, the two other priorities of economic theory, water rights and the water market, cannot be implemented. Installation of modern automatic monitoring devices, mostly of an acoustic type, can solve the problem of volumetric measurement under unstable flow conditions.

Notes

1. The FAO MASSCOTE document (Renault, Facon, and Wahaj 2007) provides a detailed discussion of the sensitivity of control structures that should be installed. Electronic automated systems have become available during the past three decades; however, their adoption and their level of sophistication should be consistent with the capacity of available human resources.
2. About 56 percent of the command area of the Indira Gandhi Canal in Rajasthan suffers some degree of waterlogging. The loss to agricultural productivity and the economy—amid increased crop production expenses and reduced crop yields—is huge. There are also extensive social costs, as a result of submerged villages and the road network, and the migration of farmers from affected areas to new areas (Sharma and Rao 2009).

10. The Need for Modernization of Irrigation Infrastructure

Modernization is a process of change from supply- to service-oriented irrigation. The process involves institutional, organizational, and technological changes. Modernization in this sense is a response to current social and economic trends, and is characterized by a shift from protective to productive irrigation. It implies changes at all levels of irrigation schemes from water supply and conveyance to the farm level. The ultimate objective is to improve irrigation services to farmers.

The modernization of existing systems is a complex process involving a compromise between the objectives of making use of existing facilities at a minimum cost, on the one side, and of improving the performance and quality of services, on the other. The solution adopted will depend on the potential productivity of the project and the government policy on the development of water resources. Developing a modernization plan requires assessing the services currently provided by the system, the impact of the current services on farmer irrigation management, and the potential benefit that would result from improved services. Successful modernization requires adoption of a service attitude, as well as comprehensive strategies for the design and operation of water distribution facilities at all levels of a project.

The reasons for the slow adoption of modern innovative techniques for hydraulic management and the lining of canals are both administrative and behavioral (Plusquellec, Burt, and Wolter 1994):

- Resistance to change among irrigation service providers, risk aversion, and respect for obsolete conceptions
- Lack of motivation among planners
- Lack of contractual motivation among consultants to introduce new technologies
- Lack of sufficient information on new technologies tested by consultants
- Lack of training at all levels, from the field to the university
- And in some cases, failures of pilot projects, leading to a long delay before the adoption of innovative techniques

The main constraints to modernization have been the denial of the importance of technology in irrigation performance, a strong resistance to change in the irrigation community, and the limited expertise available to promote and apply modern concepts in the design of irrigation systems. These obstacles will not be overcome without a recognition of the importance of technology in the performance of irrigation projects by all international and national organizations involved in the development of water resources and the adoption of modern design concepts in the water resources development/irrigation policies of donor agencies.

Modernization of irrigation was not a dominant consideration in the formulation of Bank-supported projects during the first 50 years of Bank operations. In the earlier years of Bank lending for development of new irrigation, the model was design-build-management. Each country had developed or inherited design criteria from colonial times, which became entrenched in the culture of the local engineering community. A policy of water allocation had also developed in these countries which became immutable. The relation between design and operation was overlooked. It was unusual for Bank appraisal teams to challenge the use of the national design standards.

As water lost through seepage or spills into the drainage system can be recovered through pumping of groundwater or from drains, some water resources generalists therefore argue against modernization since it does not save water. While there is theoretical merit to this argument, it ignores some very important considerations:

- The quality of the water is usually degraded as it acquires pollutants (pesticides, insecticides, fertilizers) in moving through drainage or groundwater systems, resulting in contamination and eutrophication.
- Excessive water accessions can create water logging and land salinization, reducing agricultural productivity especially in adjacent areas located at lower elevation.
- Out of irrigation season, flows in surface drains foster weed growth and additional maintenance requirements.
- The capacity of the canals should be increased and the sections should be oversized to be able to carry out the lost water.

10.1 Case Studies

Malaysia was a rather unique case of a country open to innovations. Three main granary projects financed by the World Bank (MUDA 1965; MUDA II June 1979; Kemubu June 1967) were designed by different consulting firms. Each one imported its own international experience in water control: hydraulic automation and long crested weirs (Kemubu project), overshot locally control gates (MUDA), and the constant head orifice (Krian-Kerian).

The Office du Niger, Mali, was a rare example of the modernization of a large-scale scheme in the mid-1980s. The manually operated undershot gates were replaced with automatic equipment and static-level control structures (long-crested weirs). This case became a model for the design of medium and large schemes in West Africa.

Another remarkable example is in Vietnam. Static-water-level structures were built in five schemes of the Vietnam Water Resources Assistance Project, (2004–13) and a SCADA system was installed along the multipurpose 45-kilometer-long east main canal of the Dau Tieng project. This had a capacity of 64 cubic meters per second delivering irrigation water to 47,500 hectares (ha) and domestic raw water to Ho-Chi-Minh.

Photo 10.1. Three Approaches to Water Control in Malaysia

The year 2013 saw the publication of a new manual prepared by the staff of the Vietnam Water Resources Academy, which is now used for the design of projects financed by a regional agency.

The dominant model of projects in the 1980s—whereby the rehabilitation of infrastructure was associated with institutional reforms, most of them centering on the creation and strengthening of user associations—yielded mixed results.

Simple solutions—consisting of the development of the groundwater resources underlying canal irrigation systems to improve the quality of services—have nearly reached their limits in many arid and semi-arid areas. Furthermore, these solutions are not sustainable when they lead to overexploitation of groundwater.

On-farm water-saving techniques have been adopted in many countries. However, to a large extent, these techniques have been used in areas using groundwater resources, which provide high-quality, reliable, and flexible irrigation services. Drip and sprinkler irrigation are used in places where water is delivered from pressurized irrigation systems such as Chavimochic in north Peru; in areas under conversion from gravity or sprinkler to drip irrigation, such as the Jordan Valley and Karnataka State, India; and in large systems as in Morocco. However, the cost of conversion from canals to pressurized systems, in the order of $5,000 to $8,000/ha, can only be justified for high-value crops.

To meet the conditions of the future, water service should be more flexible and reliable. Operational rules should be transparent and understood by the users. The volumetric measurement of water is a prerequisite to the establishment of water rights, water trading, and volumetric water charges. Potential benefits should be adequate to recover at least the sustainable costs of irrigation, which include operation, maintenance, and replacement costs.

These objectives cannot be met without modern management of irrigation schemes, including some form of automation. Automation has the potential to yield agricultural benefits as well as environmental benefits: increased delivery flexibility and dependability will benefit farmers and facilitate routine work for canal operators, while better management reduces water losses and the deterioration of the quality of water flowing to the drains and aquifers.

Photo 10.2. Vietnam: Phu Ninh Irrigation Scheme; Construction of Long Crested Weirs on the Main and Secondary Canals

Photo 10.3. Vietnam: Dau Tieng East Main Canal; SCADA under Operation

As a result of the abundant literature on irrigation modernization produced by Bank and other organizations (the Land and Water Department of the Food and Agriculture Organization of the United Nations; the American Society of Civil Engineers) and numerous workshops and trainings, the importance of modernization has emerged in some projects since the 2000s. However, the insufficient experience of local irrigation staff in some countries has hindered the realization of the modernization objectives expressed in appraisal documents or in the preparation of detailed design bidding documents. Ultimately, some projects ended up carrying out canal lining and the repairs of crumbling structures as they were originally designed.

Even if efforts toward modernization survive pass the preparation stage, there is still a risk of failure during implementation because of inadequate supervision of civil works contractors and suppliers of equipment. Two pilot modernization components consisting in the transfer of a simple control technology failed because the contractors ignored the importance of the precise installation of long-crested weirs and the associated baffle outlets (Indonesia and Mexico).

In Egypt, the night storage issue addressed since 1984 has not yet been solved because of the defects in locally manufactured float-operated gates.

Policy reforms cannot be implemented without an appropriate physical environment. Public investment may be required to improve irrigation systems to provide better control and measurement of water deliveries before volumetric pricing, the establishment of water rights, and their trades can be implemented. On the other hand, public policies may have to be implemented while modernizing large-scale irrigation systems to encourage improvement in farm-level water management and to enhance agricultural productivity.

The roles of user associations in the modernization process of irrigation projects should be recognized. Any strategy for improving the performance of the irrigation subsector should consider the relationship that exists between the design and functions of user associations and the plans for a better level of service. Physical and organizational improvements are not isolated actions; they are part of a well-planned process.

The need to improve the performance of large-scale irrigation is compelling. There is a large choice of technology, whether for new development or rehabilitation of existing schemes, from the simple adoption of static-level control structures to float-operated automatic gates and baffle modular gates to electronic gates either locally or remotely controlled under supervisory control combined with acoustic meters.

The development of water-level and flow sensors and SCADA systems by the telecommunications and electronics industry has led to improvements in the performance of irrigation schemes; automatic monitoring certainly helps the accounting and allocation of water at the project and basin level. However, to be fully operational, a monitoring system should be combined with an automated control system.

10.2 The Problem of Insufficient Financial Resources for Supervision

The insufficiency of Bank budget for supervision has been critiqued in a number of reviews. An OED (1995) report justified the budget ceiling imposed on operation departments by stating that supervision would tend to expand over time because operational staff develop a strong interest in the implementation of the project they appraise. That argument is valid for standard or repeated projects. However, a much larger budget allocation is needed for innovative irrigation projects such as projects with pilot modernization components or that need institutional reforms to succeed. Pilot modernization components of projects have at times failed when no one on the Bank supervision teams and/or on teams of consultant firms responsible for supervision had the specific expertise, in most cases very basic, to avoid errors during construction.

The same OED (1995) report provided interesting data on staff input in the supervision of irrigation projects. The average staff input was 15.6 weeks, 12 percent above the average for all Bank projects. Staff input was below the average for projects in European countries and 40 percent above the average for the South Asia region. The present supervision budget allocation for variable costs ranges depending on factors such as the complexity of the project and travel costs. While it can cover international trips of the team leader and local staff, it is insufficient to recruit international experts, when needed.

10.3 Modernization without Bank Support

A number of irrigation projects worldwide with major modernization components are being implemented without Bank support. For example, SCADA systems including automated controllers were installed in all the main canals in the Fergana Valley through Swiss assistance in the early 2000s.

The modernization of water control in four provinces of China (Shanxi, Gansu, Inner Mongolia, and Ningxia) included the installation of a total of 800 automated gates.

In Karnataka State, India, installation of about 4,000 gates and a total channel control system in the Narayanpur Left Bank Canal area started in 2020, and will be completed in 2022.

Some sections of the Pench Canal in Maharashtra State, India, which suffered 43 breaches between 2006 and 2014, were lined with bituminous geomembranes in June 2019. Innovations were introduced in the design of the high-level Pehur Canal in the northwest of Pakistan. They consisted of an adoption of downstream control and parabolic canal sections under a project financed by the Asian Development Bank.

A large worldwide application of geomembranes in canal lining dated from 1975. Some sections of the canals serving 260,000 ha in the Zayandeh Rud Basin around Esfahan, Iran, were lined with

Photo 10.4. Central Asia: SCADA Operations of the Syr Darya Water Works, Showing the Hydraulic Conditions

a. Overall Fergana Valley **b. Details of One Large Diversion Structure**

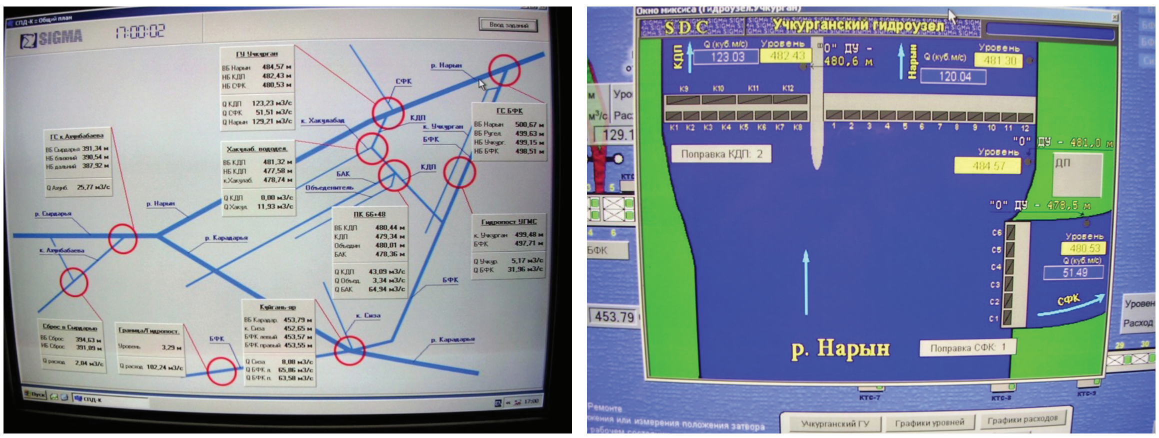


Photo 10.5. China: Shanxxi Province: Automatic Overshot Gates

Source: RUBICON Australia. Used with permission. Further permission required for reuse.

butyl rubber geomembranes because of the high content of gypsum in the soils, and protected with concrete.

In Brazil, the last dedicated irrigation project (Jaiba Irrigation), completed in 1997, was similar in concept to the modern sprinkler projects equipped with automatic canal equipment in the Mediterranean countries. Recently, a private group completed the preparation of a 31,000-ha drip irrigation system for the production of sugarcane in rotation with tomatoes, adopting the most advanced techniques in canal control and canal lining.

Brazil is among the most advanced countries in Latin America, if not globally, in adopting modern irrigation technology. Nearly all existing technologies, including the most modern ones, are being implemented in some form or the other. These include surface flooding, sprinklers, center pivots, and localized irrigation (Asad 1999).

The Bank is not involved in some projects with high level of modernization. For example, about 240 km of canals were lined with geomembranes protected with fiber concrete in the New Valley project in Egypt. The on-going Anatolia project in Turkey using Euphrates water includes advanced techniques for canal lining and water control. And the Transposition project in Brazil, which diverts water from the San Francisco River to the arid northeast provinces, uses geomembranes to line parts of the 455-km-long main canal.

Photo 10.6. Installation of Automated and Acoustic Flow Meter Gates at the Narayanpur Left Bank Canal in Karnataka State, India

a. Automated Canal Gates | **b. Acoustic Flow Meter Gates**

Source: RUBICON Australia. Used with permission. Further permission required for reuse.

Photo 10.7. Lining of Large Canals with Geomembranes

a. Egypt: Toshka Canal HDPE Geomembrane Protected with Fiber Concrete | **b. Maharashtra State, India: Lining of a Section of the Pench Main Canal with Bituminous Geomembrane**

Sources: a. A. M. Yasdani; b. Coletanche. Used with permission. Further permission required for reuse.

10.4 Capacity Building in Storage Infrastructure and Large/Medium Irrigation Systems

A comparison between capacity building in storage infrastructure and large/medium irrigation systems may contribute to understanding the slow modernization of the systems themselves. The planning, design, and construction of large infrastructure at the head of large and medium irrigation systems—mainly storage and diversion dams—raises highly technical multidisciplinary issues in the selection of dam sites, reservoir and dam site geology, soil and rock mechanics, concrete, flood routing, and others. Environment and resettlement issues associated with the creation of large reservoirs could have a considerable impact on the feasibility of a dam project. All the mitigation measures needed to meet the triggered Bank safeguards are essentially a preconstruction or a prefilling of reservoir activity.

Experts in dam engineering, either individual consultants or consulting firms, are highly specialized. They are well trained in and knowledgeable of the advanced techniques through continuous attendance of the events organized by the International Commission of Large Dams (ICOLD) and the availability of numerous technical bulletins covering all aspects of dam building.

The questions asked at the ICOLD Congress in 2018 were very practical and specific: the considered geology and dams (geology of foundations, foundation treatment), safety and risks (seismic risks, instrumentation), reservoir sedimentation. Dam experts are well aware of the dramatic consequences of the failures of the large works they design and operate. A high level of expertise and responsibility is expected from them.

The development of the large or medium irrigation systems downstream of the storage and diversion infrastructure is of a widely different nature. The hierarchical network of canals from a main canal to a branching system of canals to farm outlets and then on-farm development works involves two-dimensional territorial development, requiring the construction of thousands of kilometers of canals as well as land shaping on thousands of hectares.

The operation of such complex systems is not an afterthought, postconstruction. The delivery of water to innumerable water users should be considered at the planning and detailed design stage. The diversity of the design of large systems and therefore the variations in the flexibility of water distribution have been considered earlier in this report. The reasons for the slow modernization of irrigation systems have been developed in a number of publications by several authors (e.g., Plusquellec, Burt, and Wolter 1994).

> *Managers of irrigation agencies are not aware of the constraints imposed by their outdated designs and not knowledgeable of the advances in techniques to improving the performance of the irrigation systems. Deficiencies in design and construction of canal systems are of limited visibility compared to dam engineering and do not affect the carriers of the managers of these systems. Changing approaches to design standards and water allocation could require considerable efforts in countries with democratic governance (Plusquellec, Burt, and Wolter 1994).*

The updating of technical documentation on the specifics of design and construction of large or medium irrigation systems by international organizations sharply contrasts with the dynamics of the working groups in dam engineering:

- The last FAO irrigation and drainage paper on canal lining dates back from 1977. The last International Commission on Irrigation and Drainage (ICID) Congress to address canal lining took place in San Francisco in 1957.
- The last ICID congresses addressing the question of canal rehabilitation and modernization of irrigation systems were in Grenada in 1999, following the 1987 congress in Casablanca, Morocco, and the 1981 congress in Grenoble, France, on the same topics.

Geosynthetics are widely used in all civil engineering applications such as transportation, waste landfill, dam engineering, and mining. However, the use of these materials in irrigation canal engineering to control seepage losses is still limited to a few applications.

Automatic canal control and operation is an area of engineering where progress is remarkably slow. Some irrigation agencies stick to old control infrastructure introduced during the colonial period or later by local consulting firms that did not have practical experience in canal operation. Control equipment well adapted to flow measurements in laboratory conditions, but not adapted to field conditions and requiring frequent adjustments daily, have been introduced in some national design standards.

Up-to-date publications are available, but they are prepared at the initiative of individual experts and not given enough visibility. ICID publications on the automation of irrigation systems (Goussard 1993) and on the use of geosynthetics in canal applications are on sale from the ICID Secretariat. The American Society of Civil Engineers published a scientific document prepared by a group of top 12 experts in the field of canal automation (Zimbelman 1987).

In conclusion, the ICID congresses address fundamental long-term issues, but do not provide many practical answers to the day-to-day questions faced by irrigation agencies and their consultants to improve irrigation services to users.

10.5 Conclusions

"Irrigation has served the nation in the past in supporting an increase in food production, but it must evolve to adjust to the new economic environment" (Gardner et al. 1996 in reference to the United States of America).

Modernization of large- and medium-scale irrigation systems requires an integrated package of physical improvements and institutional changes in addition to on-farm improvements and water-saving techniques. Physical improvements include a broad range of hardware improvements and related management practices to ensure efficient, least-cost water service delivery that meets farmers' needs. The parallel institutional changes to create a demand-responsive water service delivery typically include a reduction in the role of governments in the management, financing, and promotion of decentralization, agency accountability, and scheme financial autonomy (World Bank 2006b).

The history of the World Bank's support of irrigation provides ample evidence that the causes of ineffectiveness are not limited to poor institutions and policies alone. There have been serious flaws in design concepts and construction techniques of large-scale irrigation systems. The solutions are well known and proven. However, a valid question remains: Why, despite the abundant technical literature on modernization of these systems and the numerous workshops and conferences organized on these subjects, have only a few countries really shifted from outdated techniques to modern technologies? The case of the Office du Niger in Mali in the mid-1980s and of Vietnam in the early 2000s, as discussed in this chapter, are successful examples of the effective modernization of existing systems, yet represent isolated cases among developing countries. The World Bank has an important role to play in encouraging other countries to reap the benefits of modernization. Why has the Bank not been more effective in convincing its clients of the likely substandard performance of proposed projects and the need to adopt up-to-date techniques? The sector has been traditionally conservative, risk averse and slow to adopt and disseminate new technologies. The author hopes lessons from 70 years of engagement support a reflection as the Bank formulates its forward looking engagements in the sector.

11. Lessons Learned

11.1 Financing the Irrigation Subsector

World Bank lending for irrigation remained at a low level for about three decades after a sharp fall during the 1980s, while lending for other infrastructure sectors increased multifold. Several ongoing forces of change should lead to a more dynamic sector to respond to the increased demand in food caused by a burgeoning population, increased competition for water, and climate change, mainly in North and Sub-Saharan Africa.

The consensus of the 1990s that the main challenges facing the irrigation subsector were a lack of institutional and policy reforms rather than technical inadequacies was misleading. Transfer of management to user associations is not a guarantee of success, even when associated with massive rehabilitation works, if not combined with some form of modernization to improve water delivery service to users. The best operation and maintenance alone cannot restore the potential of poorly designed or constructed projects (Keith 2006).

Realistic assumptions regarding the impact of projects should be adopted at appraisal, consistent with the physical works being supported. A high degree of scheme efficiency can be achieved only if flexible delivery paths to users, efficient on-farm application, and durable canal lining techniques are adopted.

The present low level of Bank lending for irrigated agriculture is not at the scale required to meet the food demand and competition for water anticipated by international organizations and think tanks.

The 2004 Water Resources Sector Strategy (World Bank 2004) already warned of paralysis if Bank financing could not assume affirmative engagement with risk, which irrigation infrastructure investments inevitably pose. It concludes, among others, that early and active engagement in the early design stage is critical for impact beyond mere "processing" and "compliance." It went further in describing disincentives for moving the needle on complex programs that are high-risk and high-reward, and efforts toward preparation and supervision that are typically greater than the norm. Making risk assessments explicit and more transparent has helped highlight the role of such programs within a portfolio, but with notable exceptions, risk aversion continues to limit transformational engagement in the sector. Future engagement needs to explain how it is not only a repetition of the productivity objective of the past and how the sector adapts to changing circumstances, climate, jobs and food security crises.

Irrigation is as relevant as ever and its value proposition needs to be better explained to Bank management and decision-makers in client countries. Ongoing projects need to demonstrate that they are living up to the promise. Only that will reestablish confidence.

11.2 Technical Options

The financial needs of modernization are colossal. A background document submitted to the World Panel on Financing Water Infrastructure (called the Campdessus panel after its chair) estimated that future financing needs over the next 20 years would be up to twice present levels, that is an expected annual financing level of about $4 billion. This estimate is based on preliminary assumptions for the period 2005–25 that about 80 million hectares (ha) would be modernized and 60 million ha would be rehabilitated in addition to irrigation and drainage projects in new areas (World Bank 2006b).[1] The present level of lending by the World Bank is hardly enough to convert about 70,000 to 100,000 ha from canal to pipe systems, and indeed the Bank is much more looking at leveraging private funding.

Broadly speaking, there are two approaches to the modernization of large-scale canal irrigation systems: (1) improving the delivery of water through the modernization of water control structures, and (2) converting canals through pressurized pipe systems, enabling the application of drip or sprinkler irrigation at the farm level. It is evident that the main canals in a large irrigation system are not part of the conversion process.

There is no fit-for-all-method of canal control for the different layers of a canal network. A canal could be partly under upstream control and the other part under downstream control. The main and branch canals could be under supervisory control or under centralized control. The lower layers of the system could be designed for pressurized pipe systems. However, adoption of advanced technologies requires that certain conditions of management be met, such as the commitment of the irrigation agency to maintaining the canal infrastructure, adequacy of the maintenance budget, and qualifications of the staff (ASCE 2014).

The cost of any degree of modernization of a canal network is a very important consideration for any public or private irrigation organization, whether financially independent or supported through loans or grants. There are large differences in costs and expected benefits between technical options. Impacts on manpower requirements constitute another essential consideration for countries with high labor costs.

There are scant data on the costs of modernizing canal systems because of the very limited number of projects with real modernization supported by donor agencies. In most cases, project components involve both rehabilitation and modernization.

Typically, the total cost of the structures playing a role in the operation of a canal system (headworks, regulators, turnouts, and escapes at each layer of the system) is about 10–15 percent of a new irrigation system depending on the percentage of the canal control system for which lining is provided. The cost of conversion to a pipe system could be up to ten times more than the modernization of a canal system. The average cost of conversion to pipes, excluding on-farm drip or sprinkler equipment, is about $5,000 to 6,000 per ha while the cost of modernization of the canal system is about $500 per ha (boxes 11.1 and 11.2).

The performance of large-scale irrigation projects will not improve without some form of modernization. An evaluation of Bank projects with regard to or lack of modernization is much needed. The background paper for the 2016 World Irrigation Forum, prepared by a group of 10 high-level experts, concluded:

> *Modernization of existing infrastructure can lead to making better use of existing infrastructures should be given priority. It should be based on current and future market prospects and water service needs rather than those needs for which the system was initially designed. Modernization requires serious funding, excellent training, a design that envisioned how the project will operate on a minute by minute and great attention to details. There are no quick, magical solutions* (ICID 2016).

Next steps include reestablishing the confidence of Bank country management units in irrigated agriculture projects meeting the benefits expected at appraisal. Also, lending instruments should be developed—or used if existing—for the preparation of projects (or pilot projects) long in advance of the appraisal process.

It is also important to increase the number of specialized staff focused on the irrigation subsector, and achieve a better balance between generalists and irrigation experts, including experts in hydraulics. The budget for project supervision needs to be sufficient to recruit expert consultants with practical experience, and to increase the time devoted to project preparation and planning.

Box 11.1. Modernization of Canal Control

A recent modernization project in the state of Karnataka, India, provides an upper limit for the modernization of canal control though the installation of equipment produced by an Australian firm (RUBICON) from the headworks and through the primary, secondary, and tertiary canals down to the farm turnouts serving on average about 100 hectares at an average cost of $500 per hectare.

The cost estimate put forward by the same Australian firm for the modernization of the upper and lower main canals of the Regional Office in Doukkala, Morocco, ranges from about $120 to $145 per hectare depending on the selection of the type of gates compatible with the available heads at each location. The most expensive item when calculated per area unit is the farm meter gate.

The total cost of installing a SCADA system along the 60-kilometer-long long Dau Tieng East Main canal under the Vietnam Water Resources Assistance project was about $1.4 million, or less than $50 per hectare. The SCADA cost for the South Fergana canal in Uzbekistan financed by the Swiss Development Corporation was about the same.

The construction cost of long crested weirs along main canals and distribution systems is even less than the cost of a SCADA. It is the least expensive and least risky solution when the institutional environment is not suitable for more advanced types of modernization.

Box 11.2. Cost of Conversion from Canal to Pressurized Pipe System

A cost comparison analysis is based on a review of the conversion to pipe systems in European countries (France, Spain) and North Africa (Morocco, Tunisia).

The PROMER Project in Morocco was financed by the World Bank ($115 million), converting 21,167 hectares (ha) from canals to pressurized pipes in three large-scale areas: Tadla, Haouz, and Doukkala. At an average cost of about $5,400 per hectare, about 15,000 ha were previously irrigated by gravity before the project and 6,190 ha through sprinkler irrigation.

The San Joaquin Irrigation District in Central California has provided pressurized water to 3,800 acres at a total cost of $14 million (about $9,200/ha) excluding on-farm equipment. Works include one pumping station, a reservoir, and a pressurized pipe system.

Table B11.2.1 provides a summary of the cost of conversion to pressurized systems in three countries: Spain, France, and India. The unit cost per hectare ranges between $5,000 and $9,000 with some extreme values ranging from $4,500–6,000 to a maximum of $17,000 in Spain.

Table B11.2.1. Cost of Conversion to Pressurized Pipe Systems in Four Countries (excluding on-farm equipment)

Country and project names	Irrigated area (ha)	Year of construction	Total cost (millions)	Unit cost of off-farm (per ha)
Spain				
Valle Uxio	2,913	2010		€8,854
Bambezar	12,231	2007	€43.7	€4,365
France				
CCAG	300	2004		€5,600
BRL Sommeirois	465	2016	€3.5	€7,526
BRL Beziers	1,520	2015	€7.24	€4,764
			US $	**US $**
United States				
San Joaquin	1,520		$14	$9,210
India				
Ramthol/Marol Karnataka (1)	24,000	2015–17		$4,950
Morocco				
Doukkala, S6	1,192	2015-2020	6.75	5,664
Haouz, Oulad Gail	2,200	2015-2020	9,30	6,642
Tadla, Annour	3,331	2015-2020	17.96	5,393

To address the overextraction of groundwater in areas where both surface and groundwater are used for irrigation requires the modernization of canal systems. In turn, better-quality irrigation services will encourage farmers to diversify crops, cultivate high-value crops and slow down the increasing pumping of groundwater. Experience has repeatedly shown that rehabilitating canal systems using outdated technology combined with policy and organizational reforms is not enough to provide a level of service needed to slow down sustainably the falling of groundwater levels. Also, the high-cost conversion of canals to pressurized systems has an economic feasibility limit. A limited number of countries have the expertise in modern automation and communications control techniques or the right policy to explore public/private mechanism for financing such modernization projects. In countries where canals are undersized by design, such as in South Asia, increasing the capacity of canals is a critical issue, difficult to solve.

Note

1. This is equivalent to about $600 per hectare, which is probably just enough to cover the cost of urgent repairs in deteriorated systems.

Appendix A. Review of Performance Studies of Irrigation Projects by OED and IEG

The World Bank and Irrigation (1995)

In 1993, a major study by the Operations Evaluation Department (OED) examined the Bank's 614 irrigation-related projects approved from 1950 through 1993, and 100 ongoing projects. The study focused on the 208 projects that were evaluated through 1991. Evaluation tools consisted of project completion reports and audit and impact evaluations by the OED with preference given to impact and audit evaluations over completion reports in case of differences in ratings. This review examined the project results, traced shifts in policy, and explored trends in lending. The focus was on the ex-post viability of projects and their socioeconomic impact. This section also assessed whether the recommendations of the OED review were incorporated in the projects appraised during that period.

The evaluations have rated 67 percent of the number of irrigation projects as satisfactory. This was slightly better than the average rating of 65 percent for all Bank-supported agriculture projects, but less than the 76 percent figure for all Bank projects during the same period. The OED report stated that lower rating of small projects dragged down the overall performance of the irrigation subsector.

At appraisal, an average economic rate of return (ERR) of 22 percent was estimated for the cohort of projects evaluated by the OED. At post-evaluation, the average rate of return was reduced to 15 percent. The OED report commented: *A return of 15 percent on investment after allowing for inflation is quite impressive especially given that most irrigation projects require large investments and have a long gestation period before net benefits materialize.*

A significant "optimism gap" between appraisal and evaluations started emerging for all Bank projects in the early 1970s. There was a dramatic drop in evaluating ratings in 1998. In 1990, this change was reinforced by fall in the ratings on irrigation projects in the largest borrower for irrigation, India.[1] This study stated that the optimism gap between appraisal and post-evaluations of irrigation projects was not significantly different than for all projects. The study assessed the gap in irrigation projects in terms of the most important inputs to the calculation of rates of return:

irrigated area, crop yields, cropping intensity, crop prices, investment cost, and implementation delay.

The ERR of irrigation projects in most cases declines from the evaluation at completion, then the review by the OED, and ultimately at the impact level. An exception to that trend is a project in Brazil, for which the rating was changed from unsatisfactory to satisfactory after construction of a highway between the project area and the market of urban centers.

At appraisal, all these inputs represent projections by nature. At completion, the rates of return are recalculated using actual investment costs and crop prices. However, in most cases, when construction of infrastructure is just completed, it is too early to assess the actual crop yields and the cropping intensities. The values of these two inputs are still speculative. It is only about five years after completion of the projects that actual values can be used for final calculations of ERRs.

The study pointed out that the average evaluation estimate of cropping intensity was almost identical to the appraisal estimate. The evaluator at completion or at audit has no reason to change the value of cropping intensity unless there is strong evidence that the performance of the project in terms of water management has been overestimated. The authors of the OED report—who were mostly project economists—only identified the direct inputs to the economic evaluation but missed to recognize that the areas which could benefit irrigation were grossly overestimated because of unrealistic overall efficiency used for the water balance simulation studies.

Water Management in Agriculture: Ten Years of World Bank Assistance, 1994–2004 (IEG)

From FY94 to FY04, the Bank approved 161 agricultural water management (AWM) projects with irrigation and drainage identified as a target of interventions. The 2004 IEG study had a double objective: (1) to assess the design and performance of the agriculture water portfolio for the period 1994–2004 and (2) to update lending trends. To facilitate the analysis of projects under this review, the projects were divided into two groups, dedicated and nondedicated. The former group identifies all those projects where the amount committed to irrigation and drainage is greater than 50 percent of the total International Development Association/International Bank for Reconstruction and Development amount committed to the whole project. Of the total number of 161 projects, only 60 were classified as dedicated irrigation projects and 101 as nondedicated projects.

Overall, 74 percent of the projects have satisfactory outcomes. With regard to sustainability, the overall average for that period was 56 percent rated likely or better, which was lower than the rating of 60 percent sectorwide. Furthermore, the overall average rating for institutional development was only 40 percent. The average ERR declined over time from 25 percent in 2002 to 17 percent in 2006, which provided few incentives for the Bank to invest more in AWM.

Of the 71 so-called AWM projects completed during the period 1994–2004, only 32 had estimated ERRs at both appraisal and completion. The overall average estimate at exit was

22 percent. The economic efficiency was less than in most other infrastructure sectors such as energy and mining (43 percent), transport (37 percent), environment (24 percent), and water supply and sanitation (22percent).

The Europe and Central Asia and Latin America and the Caribbean regions performed best with respect to the three ratings and the South Asia and Africa regions performed the worst (Keith 2006). That IEG study made two important observations: (1) the majority of projects that performed poorly primarily do so because of institutional problems, and (2) simultaneous attention to community operation and management (O&M) and physical modernization of water distribution networks has not been very common, reducing the efficacy of both interventions.

OED Study of Irrigation Projects in the Humid Tropics of Southeast Asia (OED 1997)

In 1996, the OED published an impact study of irrigation systems and operation and maintenance restricted to Bank-supported projects in three countries of the humid tropics of Southeast Asia: Thailand, Myanmar, and Vietnam.[2] The impact evaluations concluded that paddy-based irrigation in the tropics yielded returns of 7 percent or less, well below the appraisal estimates, which supported the conclusions of OED studies of the overall portfolio. Results were between 32 percent and 72 percent of appraisal estimates.

The study challenged the widespread precept that mismanagement of irrigation arose from mismanagement by official agencies. The report stated that:

> *O&M performance by both agencies and irrigators in the large government-operated, gravity-fed irrigation systems in South East Asia is, with few exceptions said to be dismal. This conclusion is consistent with the alarming reports of degrading public infrastructure of all categories in developing countries, and of irrigation structures in particular.*

The most important conclusion of this 1996 study was that the gap between appraisal expectations and actual results cannot be attributed to decaying infrastructure. It is rather due to the combined results of the adverse price for paddy, excessive optimistic assumptions of crop irrigated areas, design faults, and construction deficiencies.

> *Inappropriate technology and faulty construction are two factors that explain poor O&M performance. On the one hand, critics alleged that the reticulated gated structures under manual control that Bank-financed schemes in the humid tropics have normally installed to control water levels and water flows are ill-suited to the demands of small-farm paddy irrigation in either the wet or dry season. On the other hand, the canal structures have been badly constructed, usually because contractors have short cut the design specifications. In either case, the systems perform poorly, and* ***no amount of O&M can fully restore the scheme potential.***

The section on irrigation in Thailand commented that water allocation programs and water control gates introduced by international consulting firms were abandoned by the Royal Irrigation

Department because of their complexity of application. This OED report referred to the conclusion of a Bank document issued in 1985 discussing the lessons of experience of irrigation projects in Thailand up to the earlier 1980s (World Bank 1985). This report, challenging two decades of conventional engineering in the Asia region, started a long debate among irrigation engineers in the Bank and outside about irrigation design and management (OED 1996).

IEG Review of Irrigation Projects in Andhra Pradesh, India (World Bank 2008)

An impact evaluation of two irrigation projects limited to Andhra Pradesh State, India (World Bank 2008) found that the beneficial impacts of these projects were less than expected. Yield increases on average about half of appraisal estimates. The expected crop diversification has not occurred. The overall return on the investment was just below 2 percent. The returns were further undermined by long construction delays and large cost overruns. The evaluation report concludes that the standard for sensitivity analysis were too simplistic. Appraisal studies consider risks one at a time, and not the possibility that more of the assumption in the analysis is not realized. Excessive faith was placed in water user associations as the means of solving problems of sustainability and equity in water distribution (World Bank 2008).

The same study mentioned that the IEG rated 8 out of 10 irrigation projects in India over the years 1991–95 unsatisfactory at outcome. All 10 suffered from implementation delays and had economic returns far below the appraisal estimates. The problems included overoptimism with time frame, poor project design, and poor management.

A review of staff appraisal reports by the author indicates that the overall water use efficiency of the entire cohort of irrigation projects financed by the Bank in India during the 1975–85 period was estimated to be 50 percent and above which was obviously overoptimistic given that the average efficiency in the US irrigation districts at that time was 39 percent (see part II of the report).

Project Performance Assessment Reports (PPARs) of Irrigation Projects (for projects closed during the period 2005–18)

The IEG has published a report analyzing the key performance indicators of projects closed during the period 2009–2018. The report found that the proportion of projects moderately rated or above was 76 percent, which compares favorably with those of projects across all sectors of 78 percent.

To avoid a five-year gap (2005 to 2009) in the analysis of closed projects, this document covers the period 2005–18. One hundred and thirty projects with at least a 20 percent irrigation component were closed since FY 2005. The IEG has assessed the performance of only 18 projects during that period. The selection of assessed projects does not reflect the importance of the Bank portfolio in irrigation. Only one project in India, the largest borrower in irrigation and one in China were selected, whereas three projects were selected in Sri Lanka, all of them rated unsatisfactory.

The percentage of projects rated moderately satisfactory or above on outcome has slightly increased from 76 to 78 percent. Most remarkable is the improved average rating of projects in the South Asia region (82 percent), which has moved to the second position just behind East Asia (96 percent). This change reflects the strong contrast between the outcome ratings of irrigation projects in India closed before 2005 and those closed during the last 15 years. For that period, only one irrigation project in India, focused on hydrology, approved in FY2005 have been rated moderately unsatisfactory or below, resulting in a percentage of 92 percent satisfactory as can be seen in table A.1.

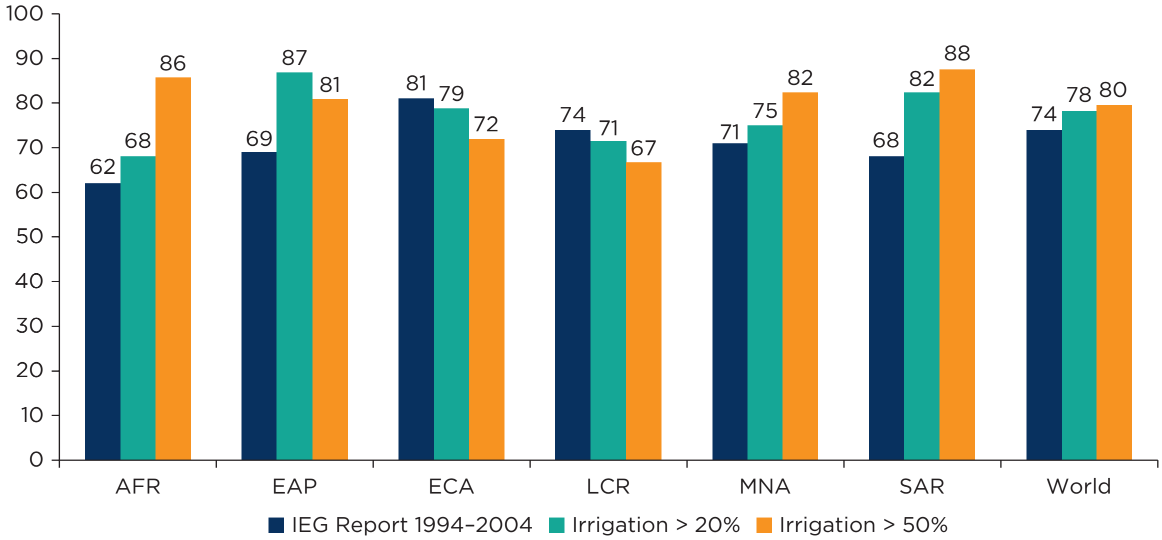
A similar picture is obtained when limiting the cohort of projects to the dedicated ones, those with an irrigation component exceeding 50 percent. East and South Asia are still the best-performing regions with a percentage of 93 and 90 percent, respectively (figure A.1).

Table A.1. Outcome Ratings of Irrigation Projects by Region (FY05–FY18)

Regions or Country	Rated Projects (No)	Satisfactory Ratings (No)	Unsatisfactory Ratings (No)	Percentage Satisfactory (%)	Ranking
AFR	20	14	6	70	4
EAP	25	24	1	96	1
ECA	27	20	7	74	3
LCR	12	8	4	67	5
MNA	18	12	6	67	5
SAR	28	23	5	82	2
Total	130	101	29	78	
India	13	12	1	92	

Note: AFR = Africa; EAP = East Asia and Pacific; ECA = Europe and Central Asia; FY = fiscal year; LCR = Latin America and the Caribbean region; MNA = Middle East and North Africa; SAR = South Asia.

Figure A.1. Irrigation Projects Assessed as Satisfactory by IEG, 1994–2004, in Total and by Percentage of Commitments to Irrigation and Drainage



Note: AFR = Africa; EAP = East Asia and Pacific; ECA = Europe and Central Asia; IEG = Independent Evaluation Group; LCR = Latin America and the Caribbean region; MNA = Middle East and North Africa; SAR = South Asia.

The spectacular improvement in performance of irrigation projects in India after the year 2005 would call for in-depth investigations. That question is beyond the scope of this document. Some plausible explanations based on the ICR of two large projects in the states of Madhya Pradesh and Tamil Nadu are proposed in appendix D, which presents lending for irrigation in China and India.

Cost-Benefit Analysis in World Bank Projects (IEG 2019)

This IEG study examines the compliance with the Bank policy, as defined in the Articles of Agreement, stating that cost-benefit analysis should be done for all projects at appraisal—the single exception is for projects for which cost-benefit analysis cannot be measured in monetary terms, in which case a cost-effectiveness analysis should be performed. Cost analysis is the technique that the Bank has used since the early 1970s.

The percentage of Bank-wide investment operations that contain an estimate of ERR in the initial project document has declined from a high of more than 70 percent in the early 1970s to approximately 30 percent in the early 2000s. Five sectors (agriculture and rural development, energy and mining, transport, urban development, and water supply) tend to produce the vast majority of ERR estimates but the remaining six sectors produce virtually none. The decline in the percentage of projects reporting ERRs is a result of two broad trends: a shift away from the high cost-benefit analysis sectors and a decline in cost-benefit analysis even within such sectors. The shift from high cost-benefit analysis sectors started after 1988.

Bank-wide, reported ERRs have doubled in 20 years from a medium of 12 percent in the late 1980s to 24 percent in 2008. This IEG report adds the comment: "Some discount this rise, believing that it indicates nothing more than an increase since 1987 in the upward bias in the measurement of economic returns. The available evidence does not confirm this belief, but it cannot be dismissed because the evidence is thin."

Performance of the Irrigation Subsector over a 50-Year Period (1970–2019)

The above OED/IEG studies present the findings of a time slice of the Bank history and irrigation and therefore do not present an overall trend of the performance of the entire irrigation portfolio. Two IEG studies are limited geographically to a cohort of projects. The IEG study on cost-benefit analysis does not dissociate the results for the irrigation subsector from agriculture and rural development. A review of the overall lending was therefore developed for this document.

Statistical analysis of the two key indicators of performance found in Bank files has therefore been carried out: (1) ratings (satisfactory or unsatisfactory) and (2) ERR at appraisal and evaluation (or at entry and exit using the language of OED). The analysis was conducted for two types of projects: dedicated and nondedicated.

The irrigation subsector has been one of the best sectors in terms of projects containing an estimate of ERR at appraisal and evaluation. ERR was calculated at appraisal for about 68 percent of 600 irrigation projects completed so far with a high of 80–90 percent during the three decades 1970–99 (table A.2), dropping to about 30 percent for 1999–2019. The percentage for the 407 dedicated projects and the 192 nondedicated projects is respectively 85 and 33 percent.

The average ERR at entry and exit was calculated by decade and by region for the 32O out of 407 dedicated projects for which both ERRs have been calculated (table A.3).

For the decade 1970-79, average ERRs were higher at evaluation than at appraisal for two regions, but were lower at evaluation for the South Asia and Africa region. For the following decades 1980–99, all regions show an optimism gap between 3 and 10 percent.

Average ERR value reported at evaluation for the dedicated projects increased from 17 percent in the first decade to a steady average of 22–24 percent.

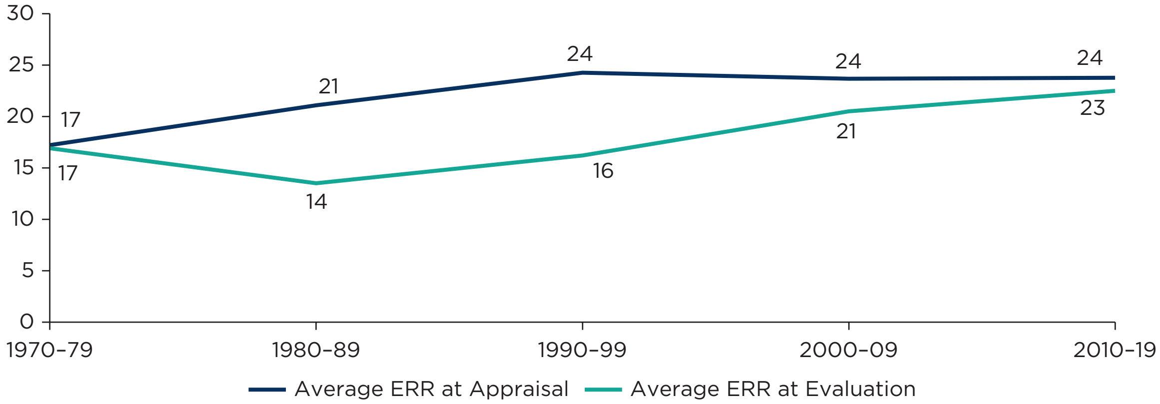
The optimism gap for the dedicated projects has reached 8 percent for the projects completed and then decreased to a range of 1–2 percent during the last two decades (see figure A.2).

Table A.2. Percentage of Irrigation Projects Containing ERR Estimate at Appraisal

	1970–79	1980–89	1990–99	2000–09	2010–19	Total 1970–2019
Dedicated	86	96	91	74	47	85
Nondedicated		100	70	31	18	33
Irrigation subsector	86	96	86	49	29	68

Note: ERR = economic rate of return.

Figure A.2. IBRD/IDA Projects with More than 50% Committed to Irrigation and Drainage: ERR at Appraisal and Evaluation, by Exit FY



Note: ERR = economic rate of return; FY = fiscal year; IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

Table A.3. IBRD/IDA Projects with More than 50% Dedicated to Irrigation and Drainage: ERR at Appraisal and Evaluation, by Exit FY

	1970-79				1980-89				1990-99				2000-2009				2010-2019				Total 1970-2019			
	No. Exiting	No. with ERR at Eval.	Average ERR at Appraisal	Average ERR at Evaluation	No. Exiting	No. with ERR at Eval.	Average ERR at Appraisal	Average ERR at Evaluation	No. Exiting	No. with ERR at Eval.	Average ERR at Appraisal	Average ERR at Evaluation	No. Exiting	No. with ERR at Eval.	Average ERR at Appraisal	Average ERR at Evaluation	No. Exiting	No. with ERR at Eval.	Average ERR at Appraisal	Average ERR at Evaluation	No. Exiting	No. with ERR at Eval.	Average ERR at Appraisal	Average ERR at Evaluation
AFR	7	5	13	9	15	14	18	3	9	8	24	12	5	2	18	22	2	1		17	**39**	**30**	**19**	**8**
EAP	11	11	23	25	42	41	21	11	20	16	23	18	15	9	21	19	6	3	27	25	**95**	**80**	**22**	**16**
ECA	3	3	15	22	16	15	16	11	4	4	17	13	12	9	30	25	12	7	23	25	**48**	**38**	**21**	**18**
LCR	4	4	13	13	20	16	21	11	8	3	20	11	9	6	24	17	1	1	25	19	**42**	**30**	**20**	**13**
MNA	2	2	11	2	18	16	22	19	16	11	22	18	10	6	22	18	6	3	18	23	**54**	**38**	**21**	**18**
SAR	10	7	17	15	46	41	24	19	48	42	26	17	10	6	22	21	13	8	26	20	**129**	**104**	**24**	**18**
Total	**37**	**32**	**17**	**17**	**157**	**143**	**21**	**14**	**105**	**84**	**24**	**16**	**61**	**38**	**24**	**21**	**40**	**23**	**24**	**23**	**407**	**320**	**22**	**16**
India	**2**	**2**	**14**	**13**	**23**	**22**	**24**	**17**	**18**	**17**	**26**	**13**	**2**	**2**	**19**	**17**	**8**	**3**	**24**	**19**	**53**	**46**	**24**	**16**

Note: AFR = Africa; EAP = East Asia and Pacific; ECA = Europe and Central Asia; ERR = economic rate of return; FY = fiscal year; IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency; LCR = Latin America and the Caribbean region; MNA = Middle East and North Africa; SAR = South Asia.

A possible source of bias in ERRs is overestimation of long-term benefits. The typical ERR includes benefits flows that last 25–30 years, yet the sustainability of such flows is rarely verified after the first 7–10 years. ERR calculations assume that benefit flows in later years remain at a constant high level or continue growing. With an average rating for sustainability of 56 percent for irrigation projects, the overall ratings based on results at completion is a valid question.

The success rate of the irrigation projects completed during the 50-year period is 72 percent, with a lower rate (70 percent) for the dedicated projects than for the nondedicated projects (77 percent). This unexpected finding is caused by the low percentages of dedicated projects (63 and 67 percent) during the two decades 1980–99 (table A.4).

Out of the 320 projects with calculations of ERR at appraisal and evaluation, 242 or about three out of four had an ERR at evaluation lower than at appraisal (table A.5).

Table A.4. Outcome Ratings of the Overall Lending for Irrigation (IBRD/IDA Projects with Irrigation and Drainage Components): Percent Rated Satisfactory, by Exit FY

	1970–79		1980–89		1990–99		2000–09		2010–19		1970–2019	
	No. Rated*	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf	No. Rated	% Satisf
>=50% I&D	37	76	156	63	104	67	61	80	46	78	**404**	**70**
<50%	0		2	100	33	79	82	76	74	78	**192**	**77**
Total	37	76	158	64	137	70	143	78	120	78	596	72

Note: *some projects that exited have not been rated by the IEG. FY = fiscal year; I&D = irrigation and drainage; IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

Table A.5. Number of Projects with ERR at Evaluation Below or Above ERR at Appraisal

Outcome Rating	ERR at Eval < Appr	ERR at Eval > Appr	Grand Total
Unsatisfactory	90	3	93
Satisfactory	152	75	227
Grand Total	242	78	320

Note: ERR = economic rate of return.

Notes

1. "Before that date, 17 out of 18 Indian projects had been rated satisfactory; in 1990, only six out of 13 were. Critics have proposed that OED evaluation standards before 1988 were unduly lax, particularly that they failed to take to task unrealistic assumptions about efficiency of irrigation water use at both appraisal and at evaluation."

2. That study was qualified by the OED as an impact evaluation. However, the report stated that the study differs from the standard design in one important respect. Whereas the standard model covers the whole range of welfare impacts, including discussion of social, institutional, and environmental change, this study is confined to economic aspects. No control cases were included and many of the important statements about impact are made by comparison with appraisal expectations, not with the farmers' original conditions.

Appendix B. The Reorganizations of the Bank and Their Impact on Lending for the Irrigation Subsector

The World Bank has been reorganized several times since its creation in response to various challenges. Each major reorganization has influenced the lending for the irrigation subsector, as discussed in this appendix. Table B.1 offers a glimpse of successive Bank reorganizations, showing the position of the irrigation subsector in the new organization. The irrigation subsector, which was the responsibility of the regional divisions after regionalization in 1972, was later assimilated first by the agriculture division and rural development units in 1987 and 1997, respectively, before joining water supply and sanitation in the Water Global Practice (Water GP) during the 2014 reorganization. These changes illustrate the duality of the irrigation subsector.

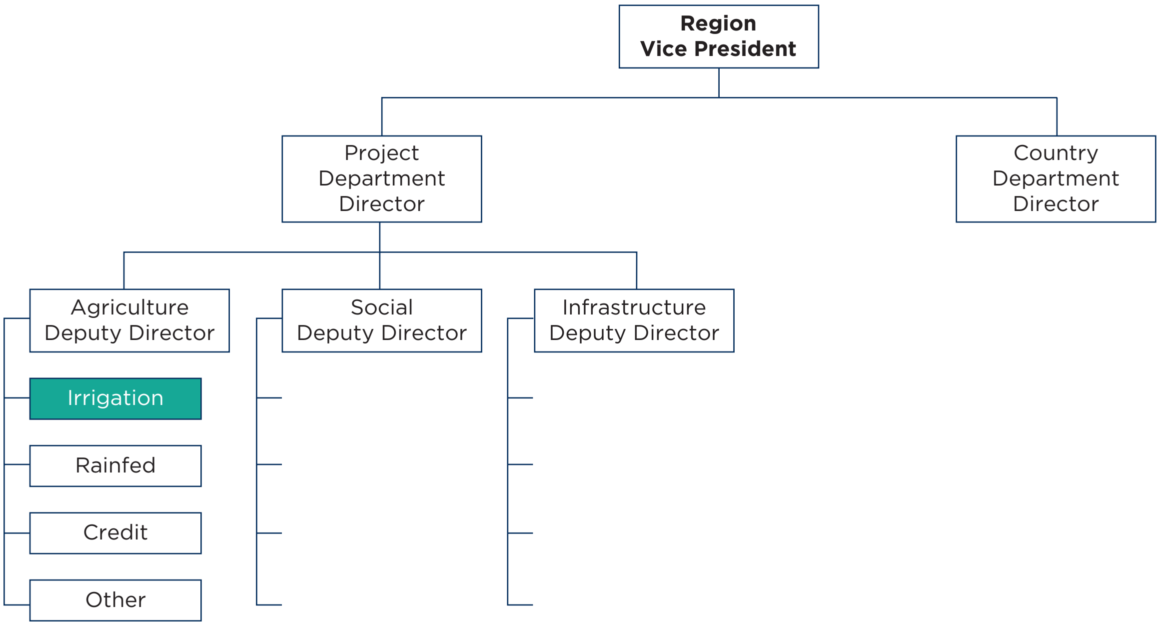
Table B.1. Evolution of the Bank's Overall Structure, Placement of the Irrigation Subsector, and Type of Investments over Time

Year of Reorganization and Name of President	Period	Main Organizational Features	Place of the Irrigation Sector
	1950–1972	**Global**	**Global Project Division**
1972, Robert McNamara	1972–1987	**Regionalization**	**Regional Irrigation Divisions**
1987, Barber Conable	1987–97	**Empowering Country Departments**	**Regional Agriculture Divisions**
1997, James Wolfensohn	1997–2014	**Matrix Management**	**Rural Development Departments**
2014, Jim Yong Kim	2014–20	**Global Practices**	**Water Global Practice and Agriculture Global Practice**

The Reorganization of 1972

The 1972 reorganization, the first after 1952, was in response to the rapid growth and expansion of the institution's activities under the presidency of Robert McNamara (April 1968–June 1981). Due to such changes, a new operational structure was required. Five regional vice presidencies were established and most of the project staff were relocated into new regional units (figure B.1). Each region was organized under the same model with a Program Department

Figure B.1. Organizational Structure of the World Bank's Region-Focused Departments, New as of 1972



and a Project Department. The Project Department included several technical divisions grouped under three themes—agriculture, infrastructure, and social—each one under the responsibility of a deputy director who reported to the department's director.

The Agriculture Group was divided into four divisions: irrigation, rain-fed agriculture, credit, and other subsectors. The irrigation division was typically staffed with irrigation engineers, agronomists, and agricultural economists. These technical divisions were responsible for the formulation, preparation, and supervision of the implementation of irrigation projects in all the countries of the regional vice presidency.

The irrigation division chiefs (Lemoigne et al.) were well acquainted with the managers of irrigation agencies in client countries, and were known within the Bank for their powers of persuasion during the projects' appraisal process. Lending for irrigation steadily increased during the first years of the McNamara presidency, from 1972 to 1980, before dropping quickly. The division chiefs were the main contacts with the borrowers in their subsector. There was a dynamic competition between divisions within a vice presidency during the annual allocation of the lending budget and the preparation of the budgets.

High-level experts were housed in a Central Project Staff Department as advisers who were responsible for reviewing projects before approval by the Board as well as for responding to questions from Bank management and for dissemination of the Bank's experience and for staff training (through organization of retreats and study tours). They also served as the Bank's representatives vis-à-vis international organizations.[1]

This organization of the Bank lasted 15 years until the reorganization of 1987. This period, marked by a strong growth of lending activities in irrigation, peaking in 1980, was the "golden age" for irrigation subsector lending within the Bank.

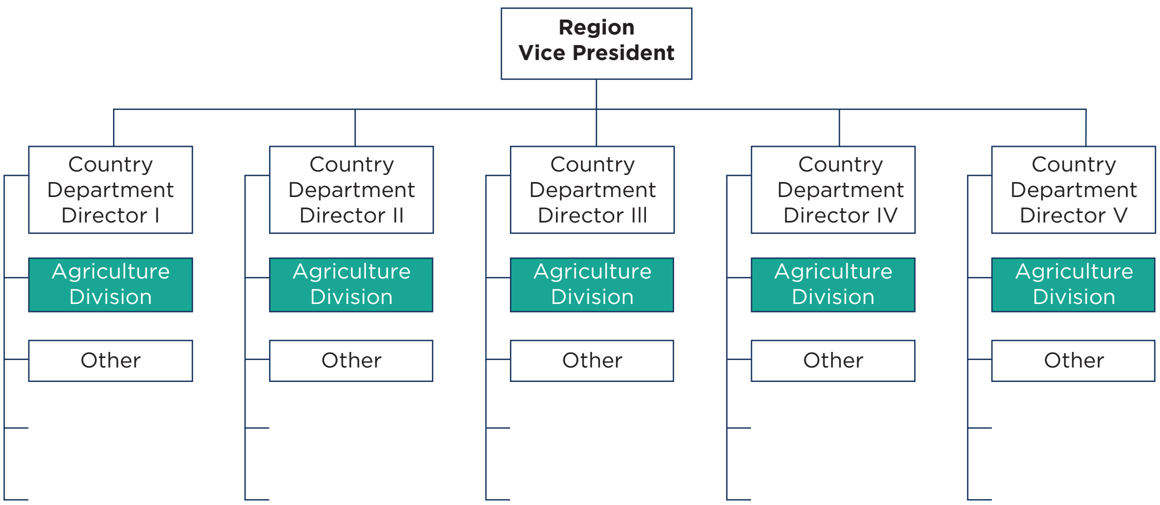
The Reorganization of 1987

The following reorganizations of the Bank, most notably in 1987 and then in 1997, consisted of attempts to strengthen the organization's ability to achieve its objectives of responsiveness to the client and technical excellence.

The 1987 reorganization under the presidency of Barber Conable (June 1986–August 1991) was primarily motivated by external criticisms of the Bank, which essentially consisted of complaints that the organization was addressing environmental and resettlement issues poorly and needed to better meet the needs of the borrowing countries. The 1987 reorganization was dictated by the objective to strengthen the country focus of the Bank's work, which was hitherto dominated by sector experts of the Technical Departments. There was a need to reinforce the Bank integration at the country level.

To that end, a novel mechanism was introduced to regulate the relationship between country and sector units in response to an assessment determining that client orientation was weak and that sector units operated in a supply-driven manner. Thereafter, country and sector units operated together under a single director, with technical staff split into sector divisions under a Country Director (figure B.2). For the Bank's client countries, the new structure provided a single senior counterpart or interlocutor, who could speak authoritatively for the Bank with client governments. This interlocutor was seen as the key decision-maker as far as the client country was concerned.

Figure B.2. Organizational Structure of the World Bank's Country-Focused Departments, New as of 1987



The operational complex of the Bank was reorganized through consolidation of the previous six regions into four, and the creation of a total of 19 country departments within these regions combining functions that were previously divided between the Programs and Projects departments, and the establishment of regional technical divisions. The country departments had full responsibility for strategy formulation, country dialogue, economic and sector work lending, technical assistance, and all other Bank services to borrowing member countries. These country departments provided effective integration of macroeconomic and sectoral perspectives in both planning and implementation of country assistance.

The management structure within the technical and country departments was composed of divisions for each of the major sectors: agriculture, industry and energy, infrastructure, and human resources. This organization reflected the attempt to balance country focus and technical excellence.

The irrigation subsector was included within the larger agriculture divisions and therefore lost its specific identity and visibility within the new organizational structure. By 1982, lending for irrigation had declined by about 25 percent after the peak of 1980, partly in response to low project performance. However, the 1987 reorganization may have also contributed to a second drop of 50 percent in lending for irrigation and then down to approximately $200 million in early 2000.

An important change for Bank operations and particularly for the irrigation subsector that started with the 1987 reorganization was the establishment of a central Environment Department. It was initially situated in the Senior Vice Presidency for Policy Planning and Research, and subsequently in a new Vice Presidency for Environmentally Sustainable Development, created in January 1993 as part of another Bank reorganization under then-president Lewis Preston. As a result, each of the Bank's then-four regional technical departments were provided with an Environmental Division.[2]

This change entailed a significant expansion in the number of the Bank's environmental and social development specialists with a primary objective of better monitoring, executing, and supporting the Bank's environment-related activities and addressing the environmental and social impacts of its lending operations. The introduction and interpretation of these rules had a side effect—the preparation of irrigation projects became more complicated, thus contributing further to the slowdown of lending to the sector.

While the reform in 1987 strengthened the country focus, technical staff worked primarily in country department silos, and the technical quality of the Bank's project work deteriorated (IEG 2012). The relationship between country units and sectors under these units remained hierarchical and perpetuated silos across Country Departments, thereby affecting knowledge flows and operational quality.

In mid-1985, studies by the Operations Evaluation Department and others indicated that the majority of irrigation projects were performing below expectations. Irrigation projects were costly to prepare and required a long period of preparation, as compared to projects in other sectors.

In addition, irrigation projects triggered most of the safeguards developed by the Environmental Central Department, which were also time-consuming to comply with.

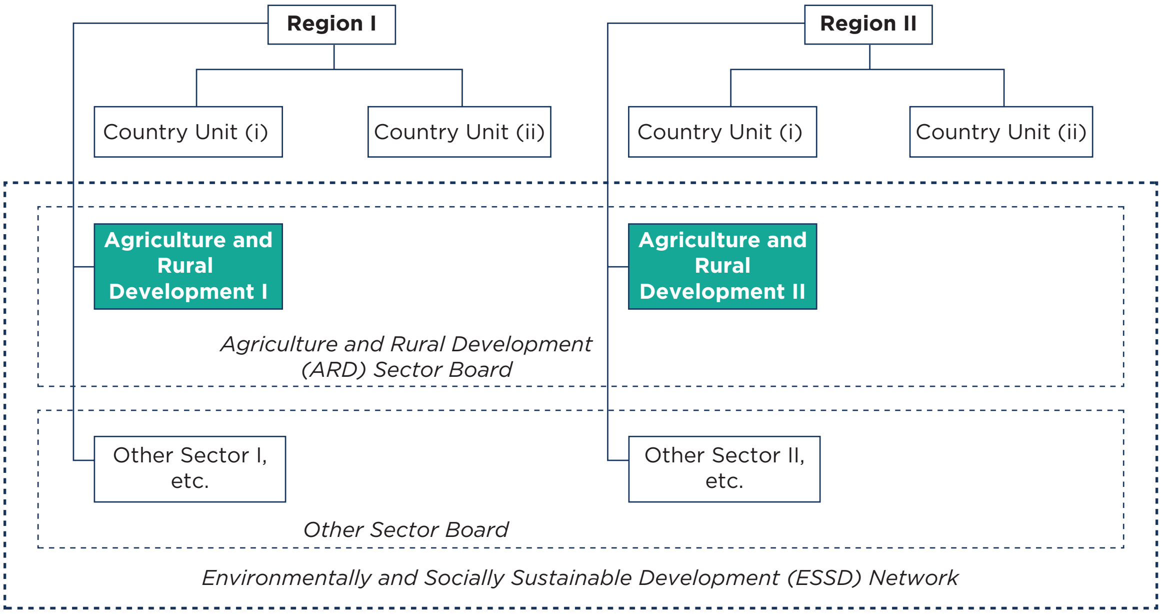
In sum, irrigation projects meant extra work and budget. Country Directors were deterred from proposing or accepting the inclusion of irrigation projects proposed by the governments of the countries under their responsibility (Keith 2006). Thus, irrigation lending declined to close to its record low in the early 2000s.

The Reorganization of 1997

Following the above, another reorganization took place in 1997 that introduced a matrix management system that is still applied more than 20 years later. This dual matrix system was set in place, first within each region between country units and sector management units, and second between newly created networks and the regions. Individual staff in sector units had a dual reporting line and were accountable to their functional and operational managers, that is, their own sector manager who controlled their performance evaluation, and their country director who controlled the final sign-off on all operational works and allocated budgets across sectors. The staff of the agriculture divisions were regrouped into large Agriculture and Rural Development units at the regional level.

Four technical networks each headed by a senior vice president were created: Environmentally and Socially Sustainable Development, Private Sector and Infrastructure, Human Development, and Financial Operations. This reorganization included a reshuffling of the subsectors between the technical divisions of the operational complex. The organization charts of the regional vice presidencies reflected the organizational networks with some variations (figure B.3).

Figure B.3. Organization Structure of the World Bank's Boards and Networks, New as of 1997



Reforms Revitalizing the World Bank under President Wolfensohn

Under the leadership of James Wolfensohn (June 1995–May 2005), the World Bank implemented several significant reforms in addition to the 1997 reorganization outlined above. The objective, which was termed the Strategy Compact, was to fundamentally transform and revitalize the Bank, making it less bureaucratic and more responsive to the changing demands of clients and global development opportunities. The ultimate objective of this reform in the Bank's processing of projects was to move from an investment lending culture that paid insufficient attention to clients' needs to one with a development perspective.

Under these reforms, greater attention was given to human development, the environment, and institutions under an overarching objective of reducing poverty and hunger. To achieve these objectives, the organization was revamped. This entailed speeding up the processes, cutting back management layers, and decentralizing functions and responsibilities to the field. To respond to the expansion of responsibilities of field offices into areas such as project supervision and procurement, the number of local staff was increased by 39 percent and international staff by 9 percent. Since that time, the staff of field offices have been playing a noticeably more prominent role in the implementation of projects.

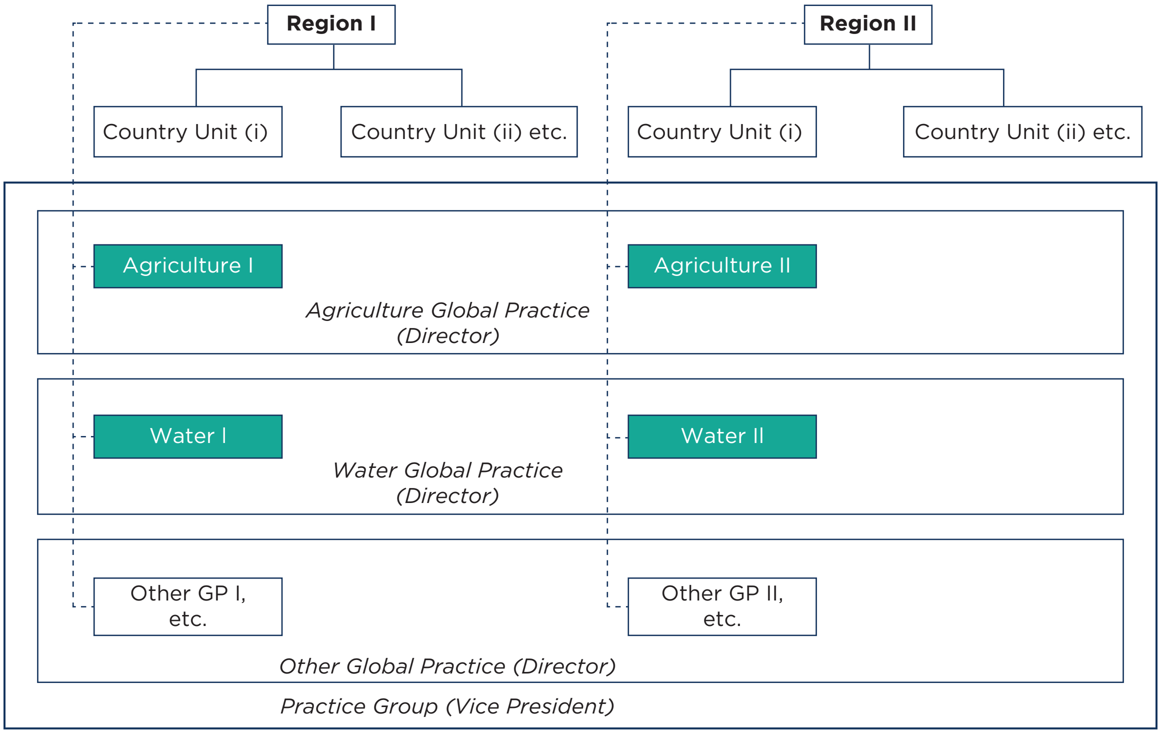
The 2014 Reorganization into Global Practices

Another reorganization took place under the presidency of Jim Yong Kim in October 2014. The idea was to create a structure that stimulated sharing of knowledge and best practices among the different divisions and regions of the Bank. The operational complex was reorganized into 14 GPs, which were envisioned to be the vertical pillars of technical expertise on their respective subjects. Experts were no longer assigned to one geographical region but to the vertical pillar of knowledge.

A GP was headed by a senior director supported by one or more practice directors. One level below the directors were a number of practice managers with geographical or technical responsibilities. The irrigation subsector was dissociated from agriculture to join water supply and sanitation in a newly created Water GP, ignited by the increasing water crisis in many countries, and the need for a broad approach to sustaining water resources, improving water service delivery, and building hydro-climatic resilience. In sum, this GP has full responsibility for water resources management and all activities related to water (excluding hydro-energy generation). Since a number of irrigation operations remained linked to the agriculture portfolio, this led to fragmentation of the irrigation portfolio between the Water and Agriculture and Food (AGF) GPs (figure B.4).

The 2014 reorganization of divisions into global practices marked a new chapter for the irrigation subsector, which, combined with other water-consuming sectors, became the responsibility of the Water GP. The choice, after long debate at the Bank management level, was to combine irrigation with other water-using sectors and not with other agriculture-related activities contributing to the objective of food production. In practice, lending for irrigation has

Figure B.4. Organizational Structure of World Bank Global Practices, New as of 2014



Note: GP = Global Practice.

ended up being equally shared between the two GPs, accounting for about 13 percent of the portfolio of each.

Analysis of Irrigation Commitments after the Creation of Global Practices (FY14–FY18)

This section analyzes the irrigation portfolio for the five-year period from fiscal year (FY)14 to FY18 using a list of projects with an irrigation/drainage code. The commitments provided in table B.2 are limited to components for irrigation and, therefore, exclude rural components such as rural roads and water supply, forestry, and other agriculture components.

The purpose of this analysis is to determine the contribution of the different GPs, mainly of the AGF and Water GPs, to the irrigation portfolio. These two practices have been working within the irrigation subsector with largely parallel programs but with different emphases, which can be characterized as climate-smart agriculture in the case of the AGF GP and irrigation service delivery for the Water GP.

During this five-year period, the Water and AGF GPs contributed 55.3 and 38.4 percent of total irrigation lending respectively. The remaining 6.4 percent is the contribution of

Table B.2. Distribution of Lending for Irrigation between Global Practices, FY14–FY18

IBRD/IDA Commitments to Irrigation and Drainage ($, millions)						
	FY14	FY15	FY16	FY17	FY18	Grand Total
Agriculture and Food GP	391	544	123	176	688	1,922
Environment and Natural Resources GP	53		9	3	50	115
Finance, Competitiveness, and Innovation GP					12	12
Macroeconomics, Trade, and Investment GP	28		11	8		47
Social, Urban, Rural, and Resilience GP		16	27	75	22	140
Water GP	1,056	236	528	286	666	2,771
Grand total	1,527	797	699	547	1,437	5,007
Irrigation as % of total Water GP	24	6	11	8	15	13
Irrigation as % of total Agriculture and Food GP	21	15	9	7	14	14

Note: FY = fiscal year; GP = Global Practice; IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

Table B.3. Total Lending for Irrigation through the Water and the Agriculture and Food Global Practices ($, millions)

	FY14	FY15	FY16	FY17	FY18	Grand Total
Total Water GP	4,405	3,646	4,958	3,486	4,571	21,066
Total Agriculture and Food GP	1,857	3,551	1,311	2,523	4,749	13,991

Note: FY = fiscal year; GP = Global Practice.

four other GPs. However, it appears that the trend is toward a balanced share between the AGF and Water GPs as the difference in the lending of these two GPs is reduced to 5 percent if we consider only the four-year period FY15 to FY18. High commitments in some years or regions are related to high costs of projects (such as, for example, for dam safety in Vietnam and development of new irrigated area in Nigeria).

It is worthwhile pointing out that while $5.01 billion is a substantial commitment over this period, if it had all been in one GP, it would be about 22 percent for the Water GP or 30 percent for the AGF GP. But because it is split, the irrigation subsector accounted for only 13 percent of the total commitment of the Water GP ($21.06 billion) and 14 percent of the AGF GP ($13.99 billion), as can be seen in table B.3.

Distribution by Region and Global Practices

Up to FY18, the East Asia region dominated lending for the Water GP ($831 million) because of two major projects in Vietnam, including a dam safety project ($390 million) (table B.4). The Sub-Saharan Africa region came in second because of a $346 million project in Nigeria (the Transforming Irrigation Management Project, which involved the rehabilitation of 11,200 ha and extension of 22,400 ha).

Table B.4. Distribution of Lending for Irrigation by the Water Global Practice between Regions by Fiscal Year ($, millions)

Region	No. of Projects	FY14	FY15	FY16	FY17	FY18	Total
SSA	3	346				234	581
MENA	2			138		116	254
ECA	6	250	11		132	28	422
South Asia	4	281	225			39	546
East Asia	5	174		390	19	247	831
LAC	1				135		135
Total	22	1,051	236	528	286	664	2,771

Note: ECA = Europe and Central Asia; FY = fiscal year; GP = Global Practice; LAC = Latin America and the Caribbean; MENA = Middle East and North Africa; SSA = Sub-Saharan Africa.

Table B.5. Distribution of Lending for Irrigation by the Agriculture and Food Global Practice between Regions and Fiscal Year ($, millions)

	No of Projects	FY14	FY15	FY16	FY17	FY18	Total
Africa	27	144	210	14	61	98	527
MENA	1					10	10
ECA	1			7			7
South Asia	11	90	231	45		549	915
East Asia	4	156	102		18	6	282
LAC	5			64	90	24	178
Total	49	390	543	130	169	687	1,921

Note: ECA = Europe and Central Asia; FY = fiscal year; GP = Global Practice; LAC = Latin America and the Caribbean; MENA = Middle East and North Africa.

The Africa region accounts for more than half of the projects under the AGF GP, which are on average substantially smaller than the Water GP projects.[3] However, in financial terms, the South Asia region dominates due to major projects in Pakistan and India (table B.5).

Dedicated Versus Nondedicated Projects under the Global Practices

Prior to the 1990s, most irrigation projects were considered to be dedicated projects.[4] In the 1990s, a new type of project—nondedicated—was supported by the Bank; examples include community development and agricultural development projects with an irrigation component. A new coding system of agricultural projects was introduced for statistical analysis at that time. Precise data on financial support by the Bank to irrigation within agricultural or other types of projects became more easily available.

While many Water GP projects continue to be dedicated, most of the projects supported by the AGF GP during FY14–FY18 were nondedicated projects. However, six projects under the AGF GP, reaching an irrigation percentage between 70 and 86 percent, were clearly dedicated irrigation projects and would have been expected to be under the responsibility of the Water GP. Table B.6 shows the average percentage of commitment for irrigation by region and by period. The average global value decreased from 47 percent to 40 percent over a 30-year period, while it slightly increased for the Africa region.

Table B.6. Average Regional Percentage of Commitment to Irrigation and Drainage

	1990–99 (%)	2000–09 (%)	2010–18 (%)
AFR	27	26	30
EAP	50	40	38
ECA	47	54	72
LCR	57	26	29
MNA	43	66	45
SAR	45	59	46
Global	**47**	**48**	**40**

Note: AFR = Africa; EAP = East Asia and Pacific; ECA= Europe and Central Asia; LCR = Latin America and the Caribbean region; MNA = Middle East and North Africa; SAR = South Asia.

In terms of amounts, Water GP projects devote larger amounts to irrigation than do AGF GP projects, as might be expected. Out of the 22 projects under the Water GP approved during FY14–FY18, 14 (63 percent) have an irrigation component exceeding $50 million. Out of the 49 projects under the AGF GP with an irrigation subsector code, 14 (28 percent) also had an irrigation allotment exceeding $50 million. Irrigation components of five projects exceeded $100 million with the percentage devoted to irrigation ranging between 44 and 82 percent under the responsibility of the AGF GP: two in India and one each in China, Pakistan, and Ethiopia (appendix F, table F.3). Two projects, in Tamil Nadu and Maharashtra states, India, have irrigation components accounting respectively for 82 and 51 percent of the commitments ($260 million and $214 million, respectively).

In conclusion, there are no clear conceptual boundaries between irrigation projects initiated by the two GPs being considered. Large civil works are typically under the responsibility of the Water GP. However, the AGF GP also plays a major role in supporting the Bank's irrigation portfolio through large, dedicated irrigation projects with infrastructure components, such as rehabilitation of small systems, upgraded lining of water courses, and modernization of conveyance systems. An AGF GP project in Tamil Nadu, with an 82 percent commitment for irrigation ($260 million), is another example of the apparent overlapping areas of responsibility between the two GPs.

A valid question is whether there is enough exchange of Bank technical staff with specialized expertise between GPs—for example, between the Water and AGF GPs—to adequately support the implementation of projects' irrigation components. Given irrigation's hybrid nature of being both a water service and an agricultural input, the institutional divides and overlaps are a long-standing problem that cannot adequately been resolved with reorganizations. At the regional and country level, exchange depends on bilateral interests and gets hampered by budget competition, and sectoral silos either among clients or perpetuated inside the institution. To solve that issue, a Global Solutions Group, Water in Agriculture, acting as a community of practice, was created between the two practices when they were created. It is co-chaired by both global practices and supports learning, quality assurance, partnerships, global policy dialogue and fosters a cross-GP partnership (and beyond these two GPs also including governance, environment, and the IFC).

Notes

1. The first irrigation adviser was Fred Hotes.
2. At that time, there were four regional Vice Presidencies: Sub-Saharan Africa, East and South Asia, Europe and Central Asia and Middle East and North Africa, and Latin America and the Caribbean. The Vice Presidencies for East Asia and the Pacific, South Asia, Europe and Central Asia, and the Middle East and North Africa were later separated.
3. The trends observed for the five-year period FY14–FY18 persisted during the three years FY19–FY21, confirming the dominant role of the Agriculture and Food Global Practice. Lending for projects under the responsibility of the Agriculture and Food and the Water global practices account for 56 percent and 32 percent, respectively, of the total lending of $1,880 million for that three-year period.
4. Projects are considered dedicated to irrigation when the irrigation component accounts for more than 50 percent of the financing by the International Development Association/International Bank for Reconstruction and Development.

Appendix C. Former Bank Directives Applicable to the Irrigation Subsector

Cost recovery. OPM 2.61, issued in 1971, stating that beneficiaries should pay public costs. In agriculture, as a minimum, operation and maintenance costs should be completely recovered. A Central Projects Memorandum (CPM 8.4) issued in 1976 provided guidance on the application of OPM 2.61 for irrigation stating that volumetric water charges were desirable and also emphasized efficiency.

Dam safety. OMS 3.80 issued in 1977 requiring independent design review and periodic inspections.

International waters. OMS 2.32 issued in 1977 stating that the Bank will not finance projects on international waters that would cause appreciable harm to other riparian countries.

Participation. OMS 2.12 issued in 1978 stating that beneficiaries and government agencies should be involved in identification and design.

Project preparation. OMS 2.28 issued in 1978 stating that detailed design for the first year of implementation should be completed before Board approval.

Involuntary resettlement. OMS 2.33 issued in 1980 which is applicable mainly to irrigation and hydropower projects stating that project-affected people must get a reasonable chance to regain or better their earlier standard of living.

Tribal people. OMS 2.34 issued in February 1982 stating that when a project encroaches on lands of tribal people their interest must be safeguarded, and if possible, their well-being enhanced.

Appendix D. Bank Lending to the Top Two Countries for Irrigation Development: China and India

China and India, with respectively 66 and 68 million hectares (ha) under irrigation, are the two countries with the largest irrigation-developed areas. Together, they account for 40 percent of the area irrigated worldwide. Both countries rely heavily on irrigation development to feed their population, which accounts for about 36 percent of the world population.

These two countries have important differences in the development of their water resources. Today, about 63 percent of the irrigated area in India is served by groundwater, whereas groundwater accounts for only 30 percent of the total irrigated area in China. In India, the surface-water-irrigated area has stagnated during the last 25 years despite huge investments in large schemes, while groundwater-irrigated areas now account for nearly two-thirds of the total irrigated areas (figure D.1).

India and China have very different profiles of lending. The Bank started operations in India in 1961 and in China in 1985. Lending to China nearly reached the level of India in the 1990s.

Figure D.1. Surface Water and Groundwater Irrigated Areas in India, 1950–2005

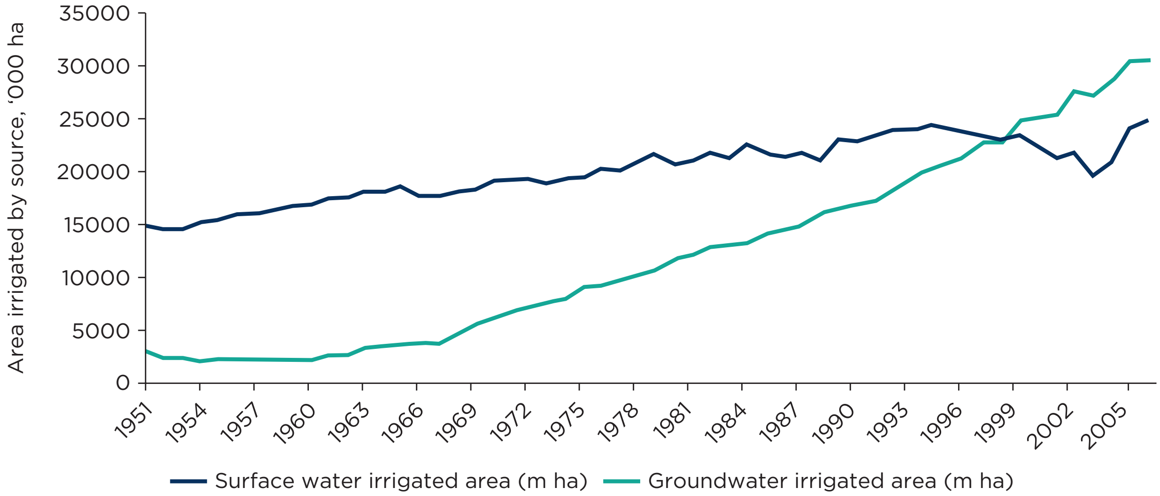
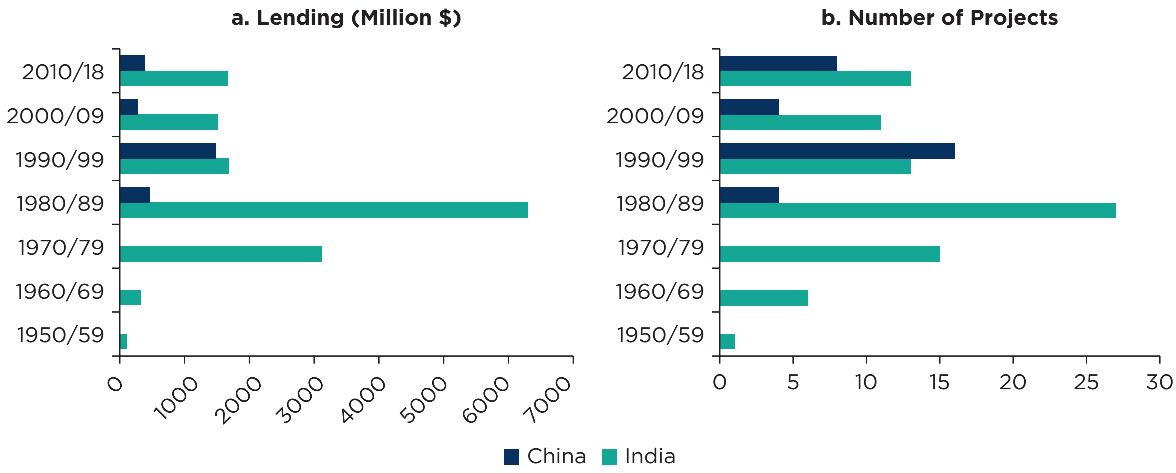


Figure D.2. Lending to China and India and Number of Projects by Decade, 1950–2018



However, lending for China has declined over the last two decades to a fraction of the lending to India (figure D.2 and appendix F, table F.4).

These two countries have also strong differences in the performance of Bank-financed irrigation projects. The share of marginally- and above-satisfactory irrigation and drainage projects supported by the Bank in India was 70 percent, far below the 95 percent rate of irrigation projects in China. There is wide recognition that the reliability and equitability of water supply is not assured in most of the schemes in India. Conflicts are common in most systems, leading to disruption of physical facilities and degradation of the systems.

These two countries also differ in the progress of institutional reforms and adoption of new technologies:

- The first water user associations (WUAs) in China were established under the Yangtze Basin Water Resources project financed by the World Bank on a pilot scale in 1995. About 83,000 WUAs were registered in China in 2016 covering about 20 million ha or 30 percent of the irrigated area. WUAs were further improved under another World Bank project using a strict set of standards requiring them to: (1) be registered and independent and have their own bank account; (2) be based on hydraulic rather than administrative or village boundaries; (3) have water measurement facilities to measure the water received from the supplier; (4) have the right to collect the water charge from farmer members and pay directly to the water supplier for the volume of water received; and (5) have adequate and reliable water facilities. They should also have the right to hire and release staff.

  The number of WUAs in India in 2016 (84,780) was about the same as that in China, covering a similar irrigated area of 17.8 million ha. In some states of India, WUAs were created in a hurry without a legal base or the capacity to engage in a reform of the scope and scale required, and inadequate support to implement the process. In addition, the lack of managerial skills within the WUAs resulted in a lack of progress in water delivery (2011). WUAs reduce the chances of rent-seeking and thus may not be fully supported in all states.

- China and India used to differ by the capacity of the administrative agencies at the federal and state levels to adopt new advanced techniques, as evidenced by the adoption of advanced canal lining technologies in China in the 1990s and the installation of advanced canal control technologies. However, recent developments in India indicate that this country is now adopting up-to-date technologies such as lining of critical sections of the Pench Canal in Maharashtra with bituminous geomembranes and large-scale modernization of the Narayana canal in Karnataka.

  Until the late 1990s, in China, as in many other countries such as those of the former Soviet Union, the standard technique to line irrigation canals was to use concrete linings or thin plastic film made of polyethylene. These geomembranes were so thin that it was impossible to seam the panels together to avoid local leakages. Since the panels overlapped one another and were not welded, the water losses were only reduced by about half.

  Representatives of the Department of Water Resources in Xinjiang Province were encouraged by the author to visit a canal construction site in Pakistan where thicker geomembranes were installed and welded. The efficient lining of these canals also contributed to a rapid decline in nonbeneficial waterlogging and to the improvement of sanitary and health conditions in the villages next to the canals The Chinese delegation was so convinced of the superiority of that technique that they decided right away to adopt it. About 455 kilometers of the main and branch canals in the Tarim River basin totaling about 5.5 million square meters were lined with that technique. It is estimated that over 500 million cubic meters of water were saved annually. The advanced lining component contributed to renewal of the flow in the Tarim River to its downstream course, which was environmentally important.

  The common technique used in most Indian states still is to line canals with brick or concrete. A large part of the canal systems in Southern India run on black cotton soils, which in the presence of water swell cause damages to the rigid concrete and brick lining.

Lending for Irrigation in India

Lending for irrigation in India has dominated the dialogue on the strategy of the Bank for irrigation and the perceptions of the performance of the subsector.

The percentage of irrigation projects in India with a calculated economic rate of return (ERR) at appraisal (79 percent) is above the average sector wide (68 percent) (table D.1).

The optimism gap for dedicated irrigation projects in India shows a similar pattern as that for the Bank-wide irrigation subsector—but with a greater optimism gap of 13 percent for the 1990s followed by a still significant value of 5 percent in 2009–2019. However, the gap has reached up to 25–30 percent for some projects such as the National Water Management project (figure D.3).

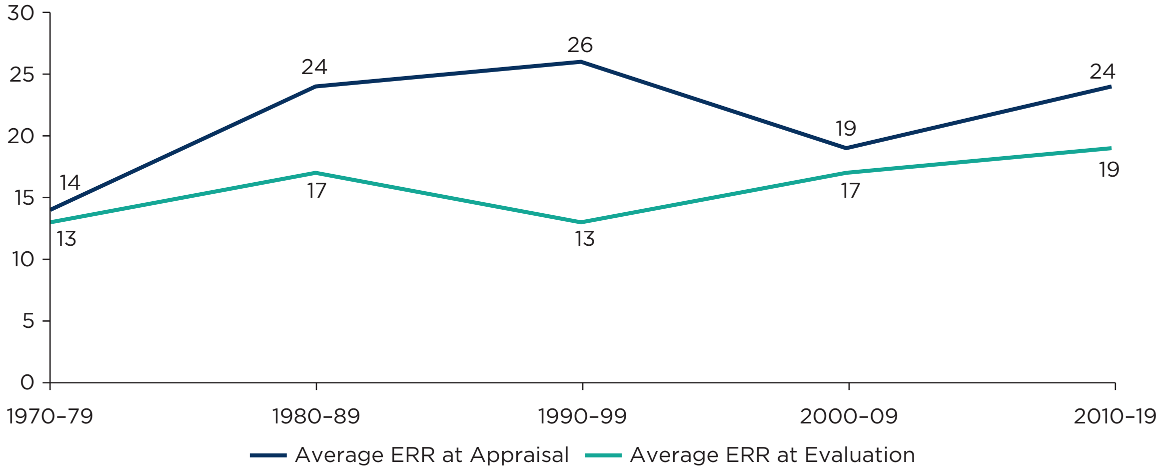
The success rate of projects approved during the fiscal year 1980 was only 55 percent, with 15 out of the 27 projects being rated unsatisfactory. Critics have proposed that the evaluation standards of the Operations Evaluation Department before 1988 were unduly lax. They particularly failed to make realistic assumptions about the efficiency of irrigation water use both at appraisal and evaluation (Keith 2006).

Table D.1. India: Projects with ERR at Appraisal

	1970–79		1980–89		1990–99		2000–09		2010–19		1970–2019	
	No. of Exits	% with ERR	No. of Exits	% with ERR	No. of Exits	% with ERR	No. of Exits	% with ERR	No. of Exits	% with ERR	No. of Exits	% with ERR
>=50% irrigation and drainage	2	100	23	100	18	94	2	100	8	38	53	89
<50%	0		0		2	50	7	57	4	0	13	38
Total	2	100	23	100	20	90	9	67	12	25	66	79

Note: ERR = economic rate of return.

Figure D.3. India: Average ERRs of Dedicated Projects



Note: ERR = economic rate of return; FY = fiscal year; IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

Appraisal of Indian irrigation projects during the peak period of lending between 1970 and 1990 has been based on overoptimistic assumptions, especially the water efficiency of the schemes, which inflated the economic benefits. About 10 projects approved in the 1980s with their conveyance, on-farm, and overall scheme efficiencies have been identified (table D.2). The overall efficiency of these projects ranges from 40 to 60 percent, which is unrealistic given the level of water control technology and the type of canal lining adopted in India during that period.[1] All these projects were rated unsatisfactory.

The projects evaluated before 1980 have an acceptable ERR, while the projects evaluated after 1980 have an estimated ERR below the estimate at appraisal and below the threshold of 12 percent strictly required at that time.

The Independent Evaluation Group's evaluation of the second and third irrigation project in the state of Andhra Pradesh concludes that the two projects achieved ERRs that were substantially less than the ERRs at appraisal. The revised ERR analysis of Andhra Pradesh is 2 percent compared to the 19 percent at appraisal.

Box D.1. Two Highly Rated Irrigation Projects in India

- The Madhya Pradesh Water Sector Restructuring (loan $394 million), closed in June 2015, was rated Moderately Satisfactory in the Implementation Completion and Results Report and by the Independent Evaluation Group (IEG).
- The Tamil Nadu Irrigated Agriculture Modernization and Water-bodies Restoration and Management (IAM WARM) project (loan of $485 million), closed in June 2015, was rated Satisfactory in the Implementation Completion and Results Report and by the IEG.

In both projects, the economic rates of return at completion are above the estimates at appraisal, which is rare for most irrigation projects (Madhya Pradesh: up from 21.6 percent to 28.9 percent; Tamil Nadu: up from 20.4 percent to 21 percent).

In Madhya Pradesh, 597,000 hectares (ha) were under irrigation at project closing compared to 242,000 ha at appraisal, that is, a 92 percent increase. The crop production per unit of water has increased from 0.4 kilograms per cubic meter (kg/m^3) to 0.78 kg/m^3 (compared to an appraisal target of 0.48 kg/m^3).

In Tamil Nadu, the area under system rice intensification (SRI) reached 272,000 ha compared to a target of 66,500 ha, whereas the area under micro-irrigation increased by 53,900 ha. In the project subbasins, the fully irrigated areas increased from about 365,000 ha to about 508,000 ha, an increase of 39 percent.

The spectacular improvement in the performance of irrigation projects in India after the year 2005 would call for in-depth investigations. That question is beyond the scope of this document. However, some paths could be investigated. The Implementation Completion and Results Reports (ICRs) of two large projects in India totaling nearly $900 million in the states of Madhya Pradesh and Tamil Nadu provide some indications of the changes in ratings of irrigation projects in that country.

The contribution of the increasing use of groundwater might be a plausible explanation for these results; however, groundwater in these two states is not as well developed as in the Ganga Basin. The excellent results in these states could also be attributed to several reforms such as the reduction of political interference, investment in last-mile distribution channel networks, and increased enforcement of the canal management protocol. This topic is, however, beyond the scope of this document.

The description of the components does not provide details on the modernization of the projects. However, the Madhya Pradesh ICR mentions interventions including canal lining, canal cleaning, and repair of hydraulic structures. These interventions are typical of the type of rehabilitation projects (canal lining and repairs) combined with the creation/strengthening of water user associations which in general have mixed results and mediocre performance ratings.

Table D.2. India's Large-Scale Irrigation Projects' System Efficiency at Appraisal and ERR at Appraisal and Evaluation, 1980–89

Name of Project	Year of Approval	Loan Amount ($ million)	Scheme Efficiency (%)	ERR (%)		Rating
				Entry	Exit	
Maharashtra	1979	210	60	15	0.6	U
Gujarat II	1981			18	3.2	U
Madhya Pradesh	1981	220		15	5	U
Subarnarekha	1982	127	55	17	7	U
Gujarat Medium	1984	172	55–60	20	30	S
Maharashtra III	1985	160	49	29	0	U
Andhra Pradesh	1986	271	50	22	11	U
Upper Krishna	1989	325	47	11	5	U
Andhra Pradesh III	1987	325	24	24	15 (2 after IEG)	U

Note: ERR = economic rate of return; IEG = Independent Evaluation Group.

ICRs for both projects mentioned that the conveyance efficiency of one of their main canals has improved from 69 to 92 percent, a very high efficiency value for an irrigation canal. Such a high conveyance efficiency could be achieved during the first years following construction of concrete-lined canals. However, concrete-lined canals may deteriorate over a few years to a point that seepage losses become substantial.

An extract from the Staff Appraisal Report of the AP III project notes: "*The AP II Staff Appraisal Report SAR) based its assessment on a canal irrigation efficiency of 50 percent but noted that if irrigation efficiency was realistically only 37 percent, a scheme expansion was not possible. ……. The overall scheme efficiency of GOAP studies was 70 percent. After review by IEG, the ERR at completion was revised at 2 percent* (World Bank 2008).

Note

1. The author has not been able to extract the efficiency values adopted for formulating the irrigation projects from the new project appraisal documents. The detailed technical annexes of the former staff appraisal reports have been moved to the implementation documents which are not available online.

Appendix E. Bank Interactions with Other International Organizations Involved in Irrigation

Food and Agriculture Organization (FAO)

The Land and Water Department of the FAO has published several technical publications in a series of irrigation and drainage papers addressing most aspects of on-farm and canal systems: small hydraulic structures; deficit irrigation practices; automated irrigation; irrigation canal lining; management, operation, and maintenance of irrigation schemes; transfer of management, operation, and maintenance services; guidelines.

The FAO has worked closely with the Bank since 1964 through the FAO Investment Center Cooperation Program (FAO/CP). About one-third of the Bank's projects in agriculture and rural development were prepared by this program. The FAO/CP provides technical assistance to borrowers for the preparation of agricultural projects including irrigation.

In 1984, the FAO/CP issued guidelines for the identification and preparation of irrigation projects. The objective was to provide guidance for the preparation of engineering studies of the preferred option before appraisal of the projects, and technical information to produce preliminary design upon which estimates of quantities and costs and economic evaluation could be based. These guidelines provide specific guidance on the estimates of irrigation crop requirements.

These guidelines were updated in 1996 to reflect the new thinking and approaches in the planning of the irrigation process, as presented in the World Bank Water Resources Management Policy. The updated guidelines considered that irrigation is a justified option only within the context of an overall national water strategy. The focus of the 1996 guidelines was therefore on: (1) the participation of all stakeholders in the planning and implementation process, (2) the creation of water user associations, (3) the role of nongovernmental organizations in participatory development, and (4) the issue of financial sustainability. The alternative technical options to improve design and operations were not discussed in these Guidelines because they were available in a number of FAO, World Bank, and other papers and proceedings of conferences. However, a brief presentation of the options with some comments on the pros and cons of the variety of techniques of canal control and canal lining would have been very useful for the irrigation agencies and their consultants.

International Irrigation Management Institute/International Water Management Institute (IWMI)

Following the broad consensus in the late 1980s that the poor performance of existing irrigation schemes was mostly related to management issues rather than to technical issues, an International Irrigation Management Institute was created in 1984 and was installed first in Kandy, Sri Lanka, before moving to the capital city, Colombo. The scope of work of the new research organization was extended from irrigation to water and resources and the name was changed to the International Water Management Institute (IWMI).

In 1991, the IWMI became an agency of the Consultative Group on International Agricultural Research and grew to the level of a major agency of that group. The topics on which the IWMI conducted research shifted from irrigation management to global water issues, such as food security and water demand for a long-term horizon (2030 and later 2050) and it pooled efforts with the FAO and the International Food Policy Research Institute to handle these issues. The IWMI greatly contributed to the understanding of the concepts of "efficiency of water use" and "water accounting" in a river basin context and of water productivity.

The International Program for Technology Research in Irrigation and Drainage (IPTRID)

During the International Commission on Irrigation and Drainage (ICID) Congress in Rio, Brazil, in 1990, R. Rangeley, the late President of ICID, warned about the risks of renovating old irrigation systems based on outmoded concepts that will fail again to meet the original objectives. Rangeley suggested that some modernization and innovation to achieve higher standards of performance—both hydraulic and agricultural—were a necessary part of rehabilitation in almost all cases. He concluded that an enormous effort was needed over the following two decades if the necessary measures were to be effective in time to meet demands. A fundamental prerequisite to that effort was research in irrigation and drainage, which in developing countries has been seriously neglected with the result that in many parts of the world agricultural technology has outpaced irrigation and drainage.

The World Bank was very instrumental in the creation of the IPTRID, which was established in 1993 with the support of the Agriculture and Rural Development Department, and specifically with the help of H. Plusquellec, Irrigation Adviser, and W. Ochs, Drainage Adviser. Missions for the identification of ongoing research were organized in several countries—China, India, Mexico, and Mali—with the assistance of experts financed by bilateral donors. These missions included visits to agricultural and civil engineering research organizations.

The missions found that these countries were conducting intensive research on irrigated agriculture (such as crop requirements, salinity of soils, and so on) and on the engineering of large hydraulic structures. The research gaps which were identified included: (1) operation of canal irrigation systems through modernization, (2) maintenance activities, and (3) drainage. These three themes were approved by the ICID. The IPTRID Secretariat comprising a secretary financed by the Bank and experts in the main research themes financed by bilateral assistance from European countries (France, Germany, the United Kingdom, and Spain) was anchored in the Agriculture and Rural Development Department where it was well integrated. Moreover, the IPTRID staff[1] participated in several Bank preparation missions and successfully introduced important research components in Bank projects. In 1996, the IPTRID hosted by the Bank was relocated to the FAO's Land and Water Department.

The International Commission on Irrigation and Drainage (ICID)

The ICID, established in 1950, is a leading scientific, technical, and no-profit international organization. Its membership consists of national committees representing their countries. Meetings of the Executive Councils are organized each year and a Congress every three years. The main themes of each Congress are based on two or three questions. In the initial ICID Congresses, the questions addressed technical topics such as the lining of canals and water control structures.

Progressively, the focus of the questions addressed during the ICID Congresses was oriented toward global issues, such as competition for water, food security, user participation, the environment and the institutions which are crucial in the changing climate and water resources environment, and the increasing population. The ICID is attempting to revitalize the IPTRID through regional nodes known as the International Research Program for Irrigation and Drainage in China and Iran.

The creation of working groups is proposed to the ICID Board during its annual meetings; the working program of these groups should be approved by the Executive Councils. Each working group is expected to work three to five years and present documents to the Board for publication. Since 1999, fewer than 10 publications have been produced of which 2 were on flood risks and 2 on micro-irrigation. The last publication on the rehabilitation of irrigation systems dates back to 1999. Highly specific publications were prepared at the personal initiative of experts (Goussard, Laycock, Montanes, and Plusquellec) and a group of experts (American Society of Civil Engineers).

International Commission on Large Dams (ICOLD)

ICOLD, founded in 1928, was the model organization for the ICID. ICOLD is an international nonprofit, nongovernmental organization dedicated to the sharing of professional information and knowledge of the design, construction, maintenance, and impact of large dams. ICOLD has more than 90 member countries, and its central office is located in Paris, France.

As ICID, ICOLD organizes international congresses every three years and regional events and publishes the proceedings of these events. However, the heart of ICOLD activities is the preparation of technical bulletins. About 30 technical committees have been set up covering all specific subjects. These committees meet for three to five years on a particular subject and produce a state-of-the-art document with recommendations for engineers all over the world.

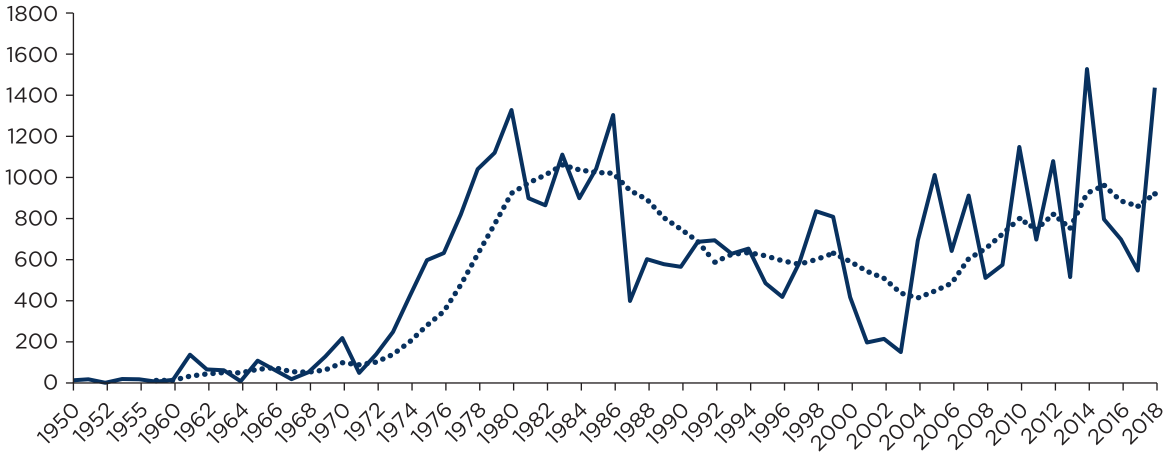
The present committees cover a number of technical topics such as selection of dam sites; seismic aspects of dams; hydraulics for dams; concrete and embankment dams; sedimentation of reservoirs; operation, maintenance, and rehabilitation of dams; as well as nontechnical subjects such as public awareness and education, resettlement due to reservoirs, climate change, and capacity building and dams. About 185 technical bulletins have been published by ICOLD since 1960 of which 70 were during the last two decades. The members of these groups are selected on a personal basis according to their experience on the particular subject.

Note

1. A. Subramanian, T. Brabben, H. Wolters, and F. Gadelle.

Appendix F. Figures and Tables

Figure F.1. IBRD/IDA Annual Commitments to Irrigation and Drainage (nominal $, millions)



Note: IBRD = International Bank for Reconstruction and Development; IDA = International Development Agency.

Table F.1. Regional Distribution of Lending, 1950–2018

Region	Total Lending ($, millions)
Africa	4,229
East Asia-Pacific	14,788
Europe and Central Asia	5,694
Latin America and Caribbean	6,568
Middle East and North Africa	6,005
South Asia	22,175
Total	59,459

Table F.2. Distribution by Decade: Lending ($, millions) and Number of Projects

1950–59	1950–59	1960–69	1970–79	1980–89	1990–99	2000–09	2010–18	Total
Number of projects with irrigation components	6	38	146	151	150	147	180	818
Lending ($, millions)	447	3,550	16,016	17,018	8,698	5,826	7,903	59,459

Table F.3. Projects under the Agriculture Global Practice with an Irrigation Component Exceeding $100 Million

Country	Code	FY	Project Title	% of Irrigation	I&D Amount ($, millions)	Scope
China	125496	FY14	Integrated Modern Agriculture Development	78	156	Civil works, structures, canal lining
Ethiopia	148591	FY14	Second Agricultural Growth Project	44	154	Rehabilitation of 50 small-scale schemes; conveyance, on-farm; water application
Pakistan	145813	FY15	PK Sindh Irrigated Agriculture Productivity Enhancement	65	121.55	Improvement of 5,500 water courses through canal lining with parabolic precast elements
India	158522	FY18	Tamil Nadu Irrigated Agriculture Modernization Project	82	260.76	Rehabilitation/ modernization of 4,800 tanks and 477 diversion barrages
India	160408	FY18	Maharashtra Project on Climate Resilient Agriculture	51	214.2	Postharvest, institutions, adjustment of production systems
Total					906.51	

Note: FY = fiscal year; I&D = irrigation and drainage.

Table F.4. Comparison of Irrigation Lending in India and China, by Decade

	1950–59	1960–69	1970–79	1980–89	1990–99	2000–09	2010–18	Total
Lending ($, millions)								
India	114	321	3,117	6,303	1,689	1,506	1,664	14,713
China	0	0	0	468	1,486	281	391	2,626
Number of projects (no)								
India	1	6	15	27	13	11	13	86
China	0	0	0	4	16	4	8	32

Table F.5. Lending in Constant 2010$, Millions

	1950–59	1960–69	1970–79	1980–89	1990–99	2000–09	2010–18	Total
AFR	-	278	893	628	142	486	1,804	4,229
EAP	146	842	4,811	3,626	2,839	718	1,806	14,788
ECA	-	225	1,944	1,445	334	949	798	5,694
LCR	113	500	1,899	1,817	1,383	440	416	6,568
MNA	75	236	1,815	1,327	1,204	758	591	6,005
SAR	114	1,470	4,656	8,176	2,796	2,475	2,489	22,175
Grand Total	447	3,550	16,016	17,018	8,698	5,826	7,903	59,459
Number of Projects								
AFR	-	2	23	16	18	31	68	158
EAP	2	9	38	28	36	19	27	159
ECA	-	2	13	9	19	32	23	98
LCR	2	7	16	18	18	16	17	94
MNA	1	2	16	23	27	13	13	95
SAR	1	16	40	57	32	36	32	214
Grand Total	**6**	**38**	**146**	**151**	**150**	**147**	**180**	**818**

Note: AFR = Africa; EAP = East Asia and Pacific; ECA= Europe and Central Asia; LCR = Latin America and the Caribbean region; MNA = Middle East and North Africa; SAR = South Asia.

References

Asad, M. 1999. "Management of Water Resources: Bulk Water Pricing in Brazil." Policy Note on Irrigation Modernization, Water Resources Management Team, World Bank, Washington, DC.

ASCE (American Society of Civil Engineers). 2014. *Canal Automation for Irrigation Systems***.** ASCE Manuals and Reports on Engineering Practice no 131. Prepared by the Task Committee on Recent Advances in Canal Automation. Reston, Virginia: ASCE.

Bottrall, A. 1985. "Managing Large Scale Irrigation Schemes: A Problem of Political Economy." Agricultural Administration Unit Occasional Paper 5, Overseas Development Institute (ODI), London. https://cdn.odi.org/media/documents/8142.pdf.

Burt, C. 1999. "Current Canal Modernization from an International Perspective." Proceedings of the USCID Workshop on Modernization of Irrigation Water Delivery Systems, Scottsdale, AZ, October 17–21, 1999. https://digitalcommons.calpoly.edu/bae_fac/66/.

Diemer, G., and F. Huibers, editors. 1996. *Crops, People and Irrigation: Water Allocation Practices of Farmers and Engineers*. London: Intermediate Technology Publications Ltd.

Gardner, W., K. Frederick, H. Adelsman, J. S. Boyer, C. Congdon, D. F. Heermann, E. Kanemasu, R. D. Lacewell, L. MacDonnell, T. K. MacVicar, S. T. Pyle, L. Snow, C. Vandemoer, J. Watson, J. L. Wescoat, and H. A. Wuertz. 1996. *A New Era for Irrigation*. Washington, DC: Committee on the Future of Irrigation, US National Research Council. http://elibrary.pcu.edu.ph:9000/digi/NA02/1996/5145.pdf.

Goussard, J-J. 1993. *Automation of Canal Irrigation Systems*. New Delhi: International Commission on Irrigation and Drainage (ICID).

Habib, Z., and C. Garces-Restrepo. 1993. "Canal Lining Performance Parameters in the Chashma Right Bank Canal Stage-I Irrigation System." In *Proceedings: Workshop on Canal Lining and Seepage*, edited by F. A. Zuberi and M. A. Bodla, 323–44. Lahore, Pakistan: International Waterlogging and Salinity Research Institute.

Hawke, G. 2016. "Keynote Address." Irrigation Australia International Conference, Melbourne Convention and Exhibition Center, May 24–26, 2016.

Horst, L. 1998. *The Dilemmas of Water Division: Considerations and Criteria for Irrigation System Design*. Colombo, Sri Lanka: International Water Management Institute and The Netherlands: Wageningen Agricultural University. https://publications.iwmi.org/pdf/H023588.pdf.

Huppert, W. 2013. "Viewpoint—Rent-Seeking in Agricultural Water Management: An Intentionally Neglected Core Dimension?" *Water Alternatives* 6 (2): 265–75.

ICID (International Commission on Irrigation and Drainage). 2016. “Background Paper—Sub-Theme 3: Key and Smart Actions to Alleviate Hunger and Poverty through Irrigation and Drainage.” Presented at the Second World Irrigation Forum, Chiang Mai, Thailand, November 6–8, 2016. https://www.icid.org/wif2_bg_pap_st3.pdf.

ICID. 2019. “Background Paper—Sub-Theme 1: Enabling Policy Environment for Water, Food and Energy Security.” Presented at the Third World Irrigation Forum, Bali, Indonesia, September 1–7, 2019. https://www.icid.org/wif3_bali_2019/wif3_bg_pap_st1.pdf.

IEG (Independent Evaluation Group). 2019. *World Bank Support for Irrigation Service Delivery: Responding to Emergent Challenges and Opportunities*. Washington, DC: World Bank.

Jones, W. 1995. *The World Bank and Irrigation.* Independent Evaluation Group Studies. Washington, DC: World Bank.

Kadiresan, K., and P. R. Khanal. 2018. “Rethinking Irrigation for Global Food Security.” *Irrigation and Drainage* 67 (1): 8–11.

Keith, George T. 2006. *Water Management in Agriculture: Ten Years of World Bank Assistance, 1994–2004.* Washington, DC: World Bank. http://documents.worldbank.org/curated/en/798841468321266557/Water-management-in-agriculture-ten-years-of-World-Bank-assistance-1994-2004.

Lankford, B. A., I. Makin, N. Matthews, A. Noble, P. G. McCornick, and T. Shah. 2016. “A Compact to Revitalise Large-Scale Irrigation Systems Using a Leadership-Partnership-Ownership ‘Theory of Change’.” *Water Alternatives* 9 (1): 1–32. https://ueaeprints.uea.ac.uk/id/eprint/57333/1/Lankford_et_al_2016_WA_LSIS_ToC_paper_002_.pdf.

Mandri-Perrott, Cledan, and Jyoti Bisbey. 2016. *How to Develop Sustainable Irrigation Projects with Private Sector Participation.* Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/24034.

Mollinga, P. 2003. *On the Waterfront: Water Distribution, Technology and Agrarian Change in a South Indian Canal Irrigation System*. Wageningen University, Water Resources Series. Hyderabad, India: Orient BlackSwan.

Narayanmoorthy, A., and R. Deshpande. 2005. *Where Water Seeps! Toward a New Phase in India's Water Reforms*. New Delhi, India: Academic Foundation.

OECD (Organisation for Economic Co-operation and Development). 2021. “Round Table on Financing Agricultural Water: Summary & Discussion Highlights.” Presented at the Thematic Meeting: Sustainable Use of Water for Agriculture, co-convened with the UN Food and Agriculture Organization, January 27–28, 2021. https://www.oecd.org/water/Summary-Roundtable-Financing-Agricultural-Water.pdf.

OED (Operations Evaluation Department). 1995. *The World Bank and Irrigation.* A World Bank Operations Evaluation Study. Washington, DC: World Bank/Operations Evaluation Department.

OED. 1996. *Irrigation O&M and System Performance in Southeast Asia: An OED Impact Study*. Independent Evaluation Group (IEG) Evaluation Report no. 15824. Washington, DC: World Bank/Operations Evaluation Department.

OED. 1997. "Irrigation in the Humid Tropics: Project Design and Issues in Indonesia and Thailand." An abbreviated version of Bank performance audit reports in Thailand and Indonesia. World Bank, Washington, DC.

Ostrom, E. 1993. "Design Principles in long-enduring Irrigation Systems." *Water Resources Research* 29 (7): 1907–12. Special Section: Water Resources Issues and Problems in Developing Countries.

Plusquellec, H. 2019a. "Overestimation of Benefits of Canal Irrigation Projects: Decline of Performance over Time Caused by Deterioration of Concrete Canal Lining." *Irrigation and Drainage* 68 (3): 383–88.

Plusquellec, H., C. Burt, and H. Wolter. 1994. "Modern Water Control in Irrigation Systems: Concepts, Issues and Applications." World Bank Technical Paper 246, World Bank, Washington, DC. https://documents1.worldbank.org/curated/ru/100291468765601092/pdf/multi-page.pdf.

Plusquellec, H., K. McPhail, and C. Polti. 1990. "Review of Irrigation System Performance with Respect to Initial Objectives." *Irrigation and Drainage Systems* 4 (4): 313–27.

Renault, D., T. Facon, and R. Wahaj. 2007. "Modernizing Irrigation Management—The MASSCOTE Approach." FAO Irrigation and Drainage paper, Food and Agriculture Organization, Rome, Italy.

Sharma, B., and K. Rao. 2009. "Groundwater Externalities of Large Surface Irrigation Transfers: Lessons from Indira Gandhi Nahar Pariyojana, Rajasthan, India." IWMI Conference Proceedings 257992, International Water Management Institute, New Delhi.

Skutsch, J. C. 1993. "The Role of Maintenance in Extending Lining Service Life." In *Proceedings: Workshop on Canal Lining and Seepage*, edited by F. A. Zuberi and M. A. Bodla, 357–70. Lahore, Pakistan: International Waterlogging and Salinity Research Institute.

Trier, R. 2014. "Review of International Experience with Public-Private Partnership in the Irrigation SubSector." *Irrigation and Drainage* 63 (2): 212–20.

Waalewijn, Pieter, Remi Trier, Jonathan Denison, Yasmin Siddiqi, Jeroen Vos, Eeman Amjad, and Mik Schulte. 2020. *Governance in Irrigation and Drainage: Concepts, Cases, and Action-Oriented Approaches—A Practitioner's Resource.* Washington, DC: World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/32339/Governance-in-Irrigation-and-Drainage-Concepts-Cases-and-Action-Oriented-Approaches-A-Practitioner-s-Resource.pdf.

Waalewijn, Pieter, Francois Onimus, IJsbrand de Jong, Remi Trier, Jonathan Denison, Florence Deram Malerbe, Philippe Saura, Etienne Dressayre, Eeman Amjad, and Svetlana Valieva. 2022. *The Irrigation Operator of the Future: A Toolkit*. Washington, DC: World Bank. https://documents1.worldbank.org/curated/en/099537308252239234/pdf/IDU0b823b4db02ab4047f308f4208c4deb4d7e98.pdf.

Winpenny, J., S. Trémolet, R. Cardone, J. Kolker, B. Kingdom, and L. Mountsford. 2016. "Aid Flows to the Water Sector: Overviews and Recommendations." Working Paper, World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/25528.

World Bank. 1985. "Irrigation Design and Management: Experiences in Thailand and Its General Applicability." Technical Paper 40, World Bank, Washington, DC. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/721831468764960973/irrigation-design-and-management-experience-in-thailand-and-its-general-applicability.

World Bank. 1994. *World Development Report 1994: Infrastructure for Development*. New York, NY: Oxford University Press.

World Bank. 2004. *Water Resources Sector Strategy: Strategic Directions for World Bank Engagement*. Washington, DC: World Bank.

World Bank. 2005. *Shaping the Future of Water for Agriculture: A Sourcebook for Investment in Agricultural Water Management*. Washington, DC: World Bank.

World Bank. 2006a. *Water Management in Agriculture: Ten Years of World Bank Assistance, 1994–2004*. Washington, DC: World Bank/IEG.

World Bank. 2006b. *Reengaging in Agricultural Water Management: Challenges and Options*. Washington, DC: World Bank.

World Bank. 2008. *An Impact Evaluation of India's Second and Third Andhra Pradesh Irrigation Projects: A Case of Poverty Reduction with Low Economic Returns*. Washington, DC: World Bank/IEG.

World Bank. 2018. "Environmental and Social Framework." World Bank, Washington, DC. https://www.worldbank.org/en/projects-operations/environmental-and-social-framework.

World Water Council. 2003. *Financing Water for All*. Report of the World Panel on Financing Water Infrastructure, chaired by Campdessus, written by J. Winpenny. https://www.worldwatercouncil.org/fileadmin/world_water_council/documents_old/Library/Publications_and_reports/CamdessusReport.pdf.

Zimbelman, D. 1987. "Planning, Operation, Rehabilitation and Automation of Irrigation Water Delivery Systems." Proceedings of a Symposium sponsored by the American Society of Civil Engineers (ASCE), Portland, Oregon, July 28–30, 1987.

Further Reading

Technical documents available on the topic of irrigation modernization: automation, modern water control, irrigation management transfer, groundwater.

Ankum, P. 2004. *Flow Control in Irrigation Systems*. Delft, The Netherlands: UNESCO-IHE Institute for Water Education.

Branscheid, V. 1989. *Irrigation Water Management Briefs: 100 Collected Papers*. Rome, Italy: Food and Agriculture Organization (FAO).

Branscheid, V. 1997. *Irrigation Investment Briefs: 13 Collected Papers*. Rome, Italy: FAO.

Burt, C., and S. Styles. 1999. *Modern Water Control and Management Practices in Irrigation: Impact on Performance*. FAO Water Report 19. Rome, Italy: FAO.

Buyalski, C., D. Ehler, H. Falvey, D. Rogers, and E. Serfozo. 1991. *Canal Systems Automation Manual: A Water Resources Technical Publication*. Denver, CO: US Department of the Interior, Bureau of Reclamation. https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/CanalSysAuto1.pdf.

Doorenbos, J., W. O. Pruitt, A. Aboukhaled, J. Damagnez, N. G. Dastane, C. Van den Berg, P. E. Rijtema, O. M. Ashford, and M. Frere. 1992. "Crop Water Requirements." Irrigation and Drainage Paper 24 (1977 revised in 1992), FAO, Rome, Italy.

Facon, T. 1996. "Modernization of Irrigation Schemes: Synthesis of Country Papers." Presented at the FAO Expert Consultation on Modernization of Irrigation Schemes: Past Experiences and Future Options, Bangkok, November 26–29, 1996. https://www.fao.org/3/X6959E/x6959e04.htm#bm4.1.

FAO (Food and Agriculture Organization). 1971. "Automated Irrigation." Irrigation and Drainage Paper 5, FAO, Rome, Italy.

FAO. 1996. "Guidelines for Planning Irrigation and Drainage Investment Projects." Technical Paper 11, FAO Investment Centre, Rome, Italy.

FAO. 1997. *Modernization of Irrigation Schemes: Past Experiences and Future Options: Proceedings of the Expert Consultation: Bangkok, November 26–29, 1996*. Issue 12 of Water Reports. Rome, Italy: FAO.

Foster, S., and T. Shah. 2012. "Groundwater Resources and Irrigated Agriculture—Making a Beneficial Relation More Sustainable." Perspectives paper, Global Water Partnership, Stockholm, Sweden.

Giroud, J. P., and H. Plusquellec. 2017. "Water, Canals and Geosynthetics." In *Proceedings of GeoAfrica 2017, the Third African Regional Conference on Geosynthetics,* vol. 1, 53–112. Casablanca, Marrakech: Comite Marocain des Geosynthtetiques.

Gleick, P. 2000. *The World's Water 2000–2001: The Biennial Report on Freshwater Resources*. Oakland, CA: Pacific Institute for Studies in Development, Environment and Security.

IPTRID (International Program for Technology and Research in Irrigation and Drainage). 1999. "Realizing the Value of Irrigation System Maintenance." Issue Paper 2, IPTRID/FAO, Rome, Italy.

Kraatz, D. 1975. "Small Hydraulic Structures." Irrigation and Drainage Paper 26, FAO, Rome, Italy.

Merrey, D. J. 2015. *An Evaluation of CGIAR Centers' Impact Assessment Work on Irrigation and Water Management Research*. Rome, Italy: Standing Panel on Impact Assessment (SPIA), Consultative Group of International Agricultural Research (CGIAR), and Independent Science and Partnership Council (ISPC).

Moench, M. 2001. "Through a Different Lens: Uncertainty, Variability and the Questions of Groundwater and Food Security." Draft, unpublished.

Moench, M. n.d. "Groundwater and Food Security in India: Evaluating the Implications of Emerging Overdraft Concerns." Draft, unpublished.

Plusquellec, H. 1989. "Script of the Audio-Visual Document: Improving Operation of Canal Irrigation Systems." Economic Development Institute, World Bank, Washington, DC.

Plusquellec, H. 1996. "Guilan, A Successful Irrigation Project in Iran." *Irrigation and Drainage Systems* 10: 95–107.

Plusquellec, H. 2002. *How Design, Management, and Policy Affect the Performance of Irrigation Projects: Emerging Modernization Procedures and Design Standards*. Bangkok, Thailand: Food and Agriculture Organization (FAO).

Plusquellec, H. 2019b. "A Fresh Look at the Debate on the Causes of Poor Performance of Certain Irrigation Schemes: The Complexity of Hydraulic Behavior of Canal Systems." *Irrigation and Drainage* 68 (3): 389–98.

Price, W., W. Field, and J. Goussard. 1999. *Guidelines for Rehabilitation and Modernization of Irrigation Projects*. New Delhi: ICID (International Commission on Irrigation and Drainage).

Ring, L., R. Renwick., J. Prozniak, and E. Wilson. 1999. "Irrigation Infrastructure Rehabilitation in Alberta: A 30-Year Case Study of Government Industry Cooperation." Proceedings from the USCID Workshop on Modernization of Irrigation Water Delivery Systems, Phoenix, Arizona, October 17–21, 1999.

Samad, M., and P. Smidt. 1999. "Management Transfer in Irrigation Systems in Asia: A Review of Selected Country Experiences." Question 49 in the 17th ICID International Congress on Irrigation and Drainage, Granada, Spain, September 11–19, 1999.

Snell, M. 2001. "Lining Old Irrigation Canals: Thoughts and Trials." *Irrigation and Drainage* 50 (2): 139–57.

Stringam, B., D. Rogers, and W. Walker. 1999. "Designing Reliable Canal Automation Systems—Lessons Learnt." Proceedings from the USCID Workshop on Modernization of Irrigation Water Delivery Systems, Phoenix, Arizona, October 17–21, 1999.

Vermillion, D. 1997. "Management Devolution and the Sustainability of Irrigation: Results of Comprehensive versus Partial Strategies." FAO/World Bank Technical Consultation on Decentralization and Rural Development, Rome, Italy.

Wahlin, B., and D. Zimbelman, eds. 2014. *Canal Automation for Irrigation Systems*. Prepared by the Task Committee on Recent Advances in Canal Automation. Reston, VA: American Society of Civil Engineers.

Walker, W. R. 1989. "Guidelines for Designing and Evaluating Surface Irrigation Systems." Irrigation and Drainage Paper 45, FAO, Rome, Italy.

Ward, W. 2019. "Cost-Benefit Analysis Theory versus Practice at the World Bank 1960 to 2015." Journal of Benefit-Cost Analysis 10 (1): 1–21.

World Bank. 1994. *Pakistan—Irrigation and Drainage: Issues and Options.* Washington, DC: World Bank.

World Bank. 1997. *India—National Water Management Project*. Implementation Completion Report. Washington, DC: World Bank.

World Bank. 1998. "Irrigation Development in Eastern Europe and the Former Soviet Union: A Study by V. Branscheid." ECSRE Rural Development and Environment Sector Working Paper No. 3, World Bank, Washington, DC.

World Bank. 2010. *Cost-Benefit Analysis in World Bank Projects*. Washington, DC: World Bank.

World Bank. 2019. *World Bank Support for Irrigation Service Delivery: Responding to New Challenges and Opportunities*. Washington, DC: World Bank.

Zhifang, Xu. 1995. "Irrigation Management Transfer in China." Papers from the Expert Consultation on Irrigation Management Transfer in Asia, Bangkok/Chiang Mai, September 1995, FAO RAP Publication, Rome, Italy.