EGYPT'S EXPERIENCE IN IRRIGATION AND DRAINAGE RESEARCH UPTAKE

FINAL REPORT

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LIST OF ACRONYMS

BCWUAs	Branch Canal Water User Associations
CIDA	Canadian International Development Agency
CLEQM	Central Laboratory for Environmental Quality Monitoring
CMRI	Channel Maintenance Research Institute
DBS	Delta Breeding Station
DRP-I	Drainage Research Programme
DWQP	Drainage Water Quality Project
ECRI	Environmental and Climate Research Institute
EMGR	Environmental Management of Groundwater Resources
EPADP	Egyptian Public Authority for Drainage Projects
EWUP	Egypt Water Use and Management Project
GIS	Geographic Information System
GoE	Government of Egypt
GS	Groundwater Sector
HAD	High Aswan Dam
HADSERI	High Aswan Dam Side Effect Research Institute
HDPE	High Density Polyethyelene
HRI	Hydraulic Research Institute
IAS	Irrigation Advisory Service
IIIMP	Integrated Irrigation Improvement and Management Project
IIP	Irrigation Improvement Project
IIS	Irrigation Improvement Sector
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IWRM	Integrated Water Resources Management
MADWQ	Monitoring and Analysis of Drainage Water Quality Project
MALR	Ministry of Agriculture and Land Reclamation
MOH	Ministry of Health
MOI	Ministry of Irrigation
MPW	Ministry of Public Works
MWRI	Ministry of Water Resources and Irrigation
NAWQAM	National Water Quality and Availability Management
NDP	National Drainage Programmes
NRI	Nile Research Institute
NWQMN	National Water Quality Monitoring Network
NWRC	National Water Research Center

NWRP	National Water Resources Plan
PLL	Precision Land Levelling
PVC	Poly-Vinyl Chloride
RDWP	Reuse of Drainage Water Project
RIGW	Research Institute for Groundwater
RNDPS	River Nile Development and Protection Sector
RNPD	River Nile Protection and Development project
SIWARE	Simulation of Water Management in the Arab Republic of Egypt
USAID	US Agency for International Development
WMRI	Water Management Research Institute
WRC	Water Research Center
WUAs	Water Users Associations

UNITS

BCM	Billion Cubic Meter
cm	Centimeter
C^o	Centigrade
feddan	4200 m^2
Kg/ha/yr	kilogram per hectare per year
L.E.	Egyptian pound
lit/sec	liter per second
m	meter
m^2	square meter
m^3 / sec	cubic meter per second
m^3	cubic meter
mil	0.02 mil water
mm	millimeter

ACKNOWLEDGEMENTS

This report has been prepared following a proposal submitted by the National Water Research Center (NWRC) in January 2006 to IPTRID-FAO presenting the approach/ methodology applied by the Center demonstrating the role played by research in formulating and implementing the Ministry of Water Resources and Irrigation (MWRI) policies and practices. The study was carried out by a NWRC team representing the different research activities pursued by the Center under the supervision of the IPTRID technical team.

The authors of the report would like to thank Professor Shaden Abdel-Gawad, President of NWRC, and Mr Carlos Garcés-Restrepo, IPTRID Programme Manager, for the vision and the constructive comments they provided to this study throughout its different stages. Thanks are also due to Ms Edith Mahabir, IPTRID Secretary, for her untiring efforts and commitment in editing the report.

Finally, special thanks are due to the UK Department for International Development (DFID) which provided funds that made this study possible.

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PREFACE

The International Programme for Technology and Research in Irrigation and Drainage (IPTRID) is a multi-donor Trust Tund managed by the IPTRID Secretariat as a Special Programme of FAO. The Secretariat is located in the Land and Water Division of FAO. IPTRID acts as a facilitator mobilizing the expertise of a worldwide network of leading institutions in the field of irrigation, drainage and water resources management.

IPTRID aims at improving the uptake of research, exchange of technology and management innovations by means of capacity development in the irrigation and drainage systems and sectors of developing countries to reduce poverty, enhance food security and improve livelihoods, while conserving the environment. The Programme therefore is closely aligned with the Millennium Development Goals. The IPTRID Secretariat, together with its partners, provides advisory services and technical assistance to countries and development agencies, for the formulation and implementation of strategies, programmes and projects.

The National Water Research Center (NWRC) was established in 1975 to be the research arm of the Ministry of Water Resources and Irrigation (MWRI) to support directly the development and management of Egypt’s water resources system. Since then it has been very active in different branches of water sciences and has put forth significant effort to disseminate its research findings and results as widely as possible through diverse routes. Research carried out by the NWRC institutes has strongly contributed to the outlining and proposing of long-term water resources policies in Egypt, solving the technical and applied problems associated with general policies for irrigation, drainage and water resources, conducting investigations and research in relation to efficient and cost effective means for water resources utilization, and proposing measures for environmentally sound development of the irrigation and drainage system.

Regardless of the mass of research produced and its field applications, there are claims of a gap between research and practice. During the International Water Resources Association Congress in November 2005, Delhi, India, the NWRC organized a workshop titled “30 Years of Research and Development towards Egypt’s Water Resources Management”. At that time, the NWRC was approaching the end of the sixth five-year plan and was still facing research typical cliché accession of research-practice gap. Therefore, it proposed to the congress organizers, namely the NWRC, to allow to show briefly successful examples of research uptake, coming from the Egyptian experience. While going through this exercise, the need for analysis of the water research uptake process in a country like Egypt was experienced. Analysis of Egypt’s long experience, in the field of water resources research, will not only support national water research, but it can also inspire and stimulate water research reform in the surrounding region.

In January 2006, the NWRC, as an IPTRID country partner, together with the IPTRID Secretariat worked on a proposal for an analytical study of Egypt’s experience in irrigation and drainage research uptake. Based on agreed outlines, the NWRC submitted to IPTRID a proposal to present the approach/methodology applied by the Center demonstrating the role played by research in formulating and implementing the MWRI policies and practices. The proposal was in line with the IPTRID mission to focus on the improvement of research uptake, the exchange of technology and management innovations; and hence IPTRID agreed to support the NWRC to conduct a study on the Egypt's Experience in Irrigation and Drainage Research Uptake. Thus, IPTRID and NWRC joined hands to carry out this activity.

In April 2006, a working team of eight national experts from NWRC (Team Leader, Study Coordinator, Senior Researcher and five Junior Researchers) was formed with knowledge and experience on research activities carried out by the NWRC, and the research uptake process that took place over the last thirty years in Egypt. While embedded in the process of identification, analysis and documentation of research uptake in Egypt, it was important to assert that the approach/methodology applied by the NWRC for carrying out research uptake was the ultimate delivery expected from the study. This report reflects the relevance and depth of the applied methodology, the quality of the activities undertaken as well as the importance and weight of the recommendations reached.

IPTRID and NWRC see the Egypt study as a first step in a regional effort that will explore how to enhance the transfer of research knowledge all the way down to the ultimate beneficiaries, namely the farmers.

Carlos Garcés-Restrepo
IPTRID Programme Manager

Shaden Abdel-Gawad
NWRC President

EXECUTIVE SUMMARY

Due to arid conditions, Egypt depends mainly on irrigated agriculture (99.8 percent of the cultivated area) to produce food and fiber for its large mass of population. Therefore, the agriculture sector poses the highest pressure on the water resources system. Seventy-nine percent of the national water requirements go to agricultural sector, while the industry and domestic annual requirements consume 9.5 and 5.0 Billion Cubic Meters (BCM), (14 percent and 7 percent respectively of the national water demand). Egypt's annual water requirements are estimated at 70.0 BCM; if compared with available resources, the result would be a significant deficit. The total annual available water resources are 57.7 BCM; divided into 55.5 BCM of Nile water released from Lake Nasser, 1.3 BCM of effective rainfall and 0.9 BCM of deep groundwater. The per capita share of available water resources in year 2000 was 859 m^3, and this is expected to decrease to 720 m^3 per year by the year 2017. To overcome this shortage, part of the agricultural drainage is reused, besides the use of shallow groundwater and other non-conventional resources.

The Ministry of Water Resources and Irrigation (MWRI) is the official authority in charge of development, allocation and distribution of all conventional and non-conventional water resources of the country. In order to achieve its goals, MWRI has realized the role of research in formulating its policy before even having a formal comprehensive water policy. The research and technical studies date back to the Nineteenth century. Survey research, hydrologic studies and Upper Nile expeditions started as early as 1870.

In 2002, MWRI started to formulate the National Water Resources Plan (NWRP) based on a strategy called 'Facing the Challenge'(FtC) (NWRP, 2005). FtC included measures to develop additional resources, make better use of existing resources, and measures in the field of water quality and environmental protection. The plan has three major pillars: (1) increasing water use efficiency, (2) water quality protection, and (3) pollution control and water supply augmentation.

The water policy development in Egypt faced a number of challenges; mainly the mismatch of water supply and demand that resulted from increasing demands for water in all socio-economic sectors. The rate of demand growth is linked directly to the growth in population and the improvement of the standards of living. In addition, the available water resources in Egypt are limited and the rate of its development is much slower than the rate at which demand increases. This means that the gap between available resources and water requirements is getting wider over time and Egypt will be facing water scarcity in the near future.

The distribution of the water of the Nile River is nearly uniform from Aswan to Cairo with a fairly good quality due to the Nile system of self-purification. Nevertheless, the pollution increases in the two Nile branches towards north as they receive nutrients, organic loads, grease and oils from the intensified agriculture, residential and industrial activities in the Delta region.

Since its establishment as a strong research and development component that would support the MWRI to advance and expedite the implementation of the national water policy, the National Water Research Center (NWRC) produced a significant mass of research in the different branches of water sciences. It spared no effort to disseminate its research findings and results as widely as possible through direct contacts with the research end-users and stakeholders in addition to the international outreach through conferences, workshops and scientific journals. Although the NWRC carried out all of its research in direct support of the development and management of Egypt's water resources system, there are claims of a gap between research and practice. Generally, these claims are not substantiated either by specific examples or thorough analysis of the research uptake process. Therefore, there is a need to examine this typical research-practice gap cliché against consistent analysis framework. The application of referenced analysis framework to specific research programmes will help to dissect the rich experience of Egypt in water research field and its uptake. Revealing strengths and weaknesses in the research uptake process as well as dissemination of the analysis results will contribute to the enhancement of water research uptake process in other countries similar to Egypt.

By structuring NWRC, so that, each of its institutes corresponds to one or more of the Ministry's major departments, authorities or sectors have ensured research influence on policy formulation and action implementation. Such a unique set up has ensured that research influences water policies and actions on the ground. The impact of research has not only accelerated the implementation of the national water policy, but it also contributed in considerable savings to the national economy, increase in food production and public security.

Research knowledge is one of many competing factors influencing policy decisions that can eventually translate into changes in field practices. While better use of research-based evidence in development policy has been covered comprehensively through different, less has been done to close the gap between research and practice or in determining the impact of the research uptake process on end-users or other stakeholders; this study aims to reduce that gap.

With the objective to identify significant research programs and projects carried out by the NWRC during the last three decades that impacted the national water policies and the irrigated agricultural practices in Egypt, the study documents successful cases of direct and indirect research uptake as well as unsuccessful cases. The effectiveness of the NWRC and MWRI's unique set up and relationship, and its impact on the development and implementation of the national policies is analyzed. Reasons for success and failure are identified in terms of intrinsic and externalities. Specific recommendations for increasing the research uptake and improving the process of wide dissemination of research results, especially in countries with similar condition, and for taking corrective measures to enhance and encourage research uptake to irrigation and drainage practices are highlighted.

The development of the logical framework adopted in the study has largely benefited from the inventory of case studies, documents and acquisition of reports as well as the early interviews with stakeholders. The adopted methodology started with the identification of a reasonable number of research projects that qualify for analysis. This step was followed by information collection that had two pillars: acquisition of reports on selected research projects, and consultation with research stakeholders and donors. The third step was basically scripting of the collected information that has bearing on the next step; namely analysis. It included scripting of interviews synthesis, and synopses of case studies.

The process of peer selection of case studies has ended up with seven topics that were considered. These are: Subsurface Drainage; Irrigation; Groundwater; River Nile; Water Quality; Grand Hydraulic Structure; and Weed Control. After a thorough revision of the available reports and a rapid analysis of the seven cases selected first and their thematic relevance to the core of the study, it was decided not to include the two cases of the River Nile and Groundwater. The rapid analysis of the River Nile case showed diverse significant research results that did not materialize in a consolidated impact (national programs and well-delineated national policy). Without doubt, research on groundwater contributed significantly in terms of national policy formulation, but within the context of this study it would have, however, been a redundant example of how research impacted the national policy and practice. It has to be mentioned that both eliminated cases had an important impact on the MWRI institutional reform. They also contributed, partially, to the Water Quality case.

The study has successfully identified the current water research strengths and constraints in Egypt and brought up a number of recommendations for improvement and clear vision on how to go forward.

On strengths, the study concluded that the twinning and partnership between NWRC and MWRI departments and authorities created the enabling environment for successful transfer of interactive research output to field implementation. In addition, the fact that the pioneer staff of NWRC originally worked for MWRI departments and sectors provided them with deep understanding of the practices, problems and potential for development and improvement. Furthermore, most committees formed for addressing specific issues or solving an urgent problem within any sector include members of the Center corresponding institutes. This allows institutes to form a research team, carry out necessary research, and present their research findings to the intended sector, discussing and receiving comments, reevaluating their results and findings, and providing recommendations to MWRI sectors.

On constraints, the study brought up some factors that hamper the effectiveness of uptake process; amongst which is the financial shortage and consequently the elimination of some research and extension activities. The undefined communication channels among researchers, their peers working for MWRI sectors and end users are also other constraints hindering the research uptake process; also the weak awareness creation – not allowing uptake to improve, for instance, periodical brochures, flyers, fact sheets on on-going research activities are rarely produced or disseminated amongst MWRI engineers as well as the general public.

In order to improve the uptake of research, the findings of the study suggest the following:

- Users' involvement at an early stage in defining the research agenda may result in goals being often influenced by short-term considerations and/or immediate policy needs. As interactive research is responsive to users' needs, it should not limit applied research from being predictive and visionary.

- Both quality of research and dissemination of results should be emphasized to encourage research uptake. The research quality is addressed because sound research results lead to better and wider uptake. Therefore, NWRC should strengthen and develop a network of strategic partners and alliances from research institutes and universities (national and international), as well as international water organizations.

- No doubt contract research guarantees full research uptake and generates more funds than interactive research. However, there is a high risk of neutrality being compromised or falling into the consultation trap. Contract research has to be encouraged as additional fund generator.

- The political and institutional context and relationships between different actors are central to the uptake of research. When international donor agencies are sensitive to the national needs and priorities, research results effectively impact decision-making and action.

- Donors need to re-engage and support interactive research, not necessarily through pure research projects. Most of the current national projects supported by donors and lenders do not fit under typical engineering paradigm and require more than consultation. A research and development component, in each project, is an ideal point to engage donors in research activities once again. Furthermore, donors' support to capacity building of research institutes may be sufficient to improve research quality but not sufficient to enhance its uptake. However, capacity building of research users and recipients of its results create the enabling environment of improved research uptake process.

- A comprehensive database for all NWRC research projects, findings and recommendations needs to be established. Such database should be accessible by all NWRC and MWRI staff for their benefit and education.

Finally, the study proposes the way forward taking into account the experience of the NWRC as a unique water research institution in the MENA region to be put as an example for other countries. Similar experiences in Syria (Irrigation Modernization) and Yemen (Irrigation Improvement Project) are qualified for analysis according to the framework suggested in this study.

It calls for making efforts to bring the focus on the core elements of the study and disseminate its outcomes to a number of selected developing countries; promoting effective mechanisms that facilitate the research uptake process, and for formulating a regional dissemination strategy as a follow up of this study with the objectives to regenerate increased interest in the water research industry, enhance its uptake process, and ultimately achieve sustainable use of the regions' limited water resources. The newly-born Arab Water Council (AWC) looks like a good candidate to carry out the dissemination strategy.

1. INTRODUCTION

1.1. Origin of Water Research in Egypt

Due to arid conditions, Egypt depends mainly on irrigated agriculture (99.8 percent of the cultivated area) to produce food and fibre for its large mass of population. The total cultivated area under irrigation is estimated at 8.4 million feddans (one feddan = 4 200 square meters). The average annual cropping intensity reached a value of 1.9 in recent years, which made the agricultural demands amount to 54 Billion Cubic Meters (BCM).

Pressures on water resources of the country come from all sectors of the economy with the highest demand from the agricultural sector. As shown in Figure 1, Egypt's annual water requirements are estimated at 70.0 BCM; if compared with available resources (57.7 BCM), the result would be significant deficit. The per capita share of available water resources in year 2000 was 859 m^3, and expected to decrease to 720 m^3 per year by the year 2017. To overcome this shortage, part of the agricultural drainage is reused, beside the use of shallow groundwater and non-conventional resources.

The Ministry of Water Resources and Irrigation (MWRI) is the official authority in charge of development, allocation and distribution of all conventional and non-conventional water resources of the country. In order to achieve its goal, MWRI realized the role of research in formulating its policy before even having a formal comprehensive water policy. The research and technical studies date back to the nineteenth century. Survey research, hydrologic studies, and Upper Nile expeditions started as early as 1870.

The memorandum titled "Nile control" published by the Ministry of Public Works in 1920, is probably the first documented Egyptian water policy (El-Kadi, 1999). After the completion of HAD, a series of water resources policies had been formulated to improve the management of the available water resources in order to match the current and projected water supply with demands of all sectors. Until 1999, all water policies concentrated on managing the supply side to meet the increasing demands for water and allocate any excess water to land reclamation projects. None of the previous water policies, except the 1999 water policy, took into consideration the use of desalination of seawater or brackish groundwater. Looking to the future and the coming water crises, non conventional kinds of resources may be feasible in the future, due to expected improvement and development of technologies. The Integrated Water Resources Management (IWRM) concept was introduced in the 1999 water policy. Water quality and environmental water related issues started to be mentioned explicitly in water policies.

The memorandum titled "Nile control" published by the Ministry of Public Works (MPW) in 1920, is probably the first documented Egyptian water policy (El-Kadi, 1999). After the completion of HAD, a series of water resources policies had been formulated to improve the management of the available water resources in order to match the current and projected water supply with demands of all sectors. Until year 1999, all water policies concentrated on managing the supply side to meet the increasing demands for water and allocate any excess water to land reclamation projects. None of the previous water policies, except 1999 water policy, took into consideration the use of desalination of seawater or brackish groundwater. Looking to the future and the coming water crises, non conventional kinds of resources may be feasible in the future, due to expected improvement and development of technologies. IWRM concept was introduced in the 1999 water policy. Water quality and environmental water related issues started to be expressed explicitly in water policies.

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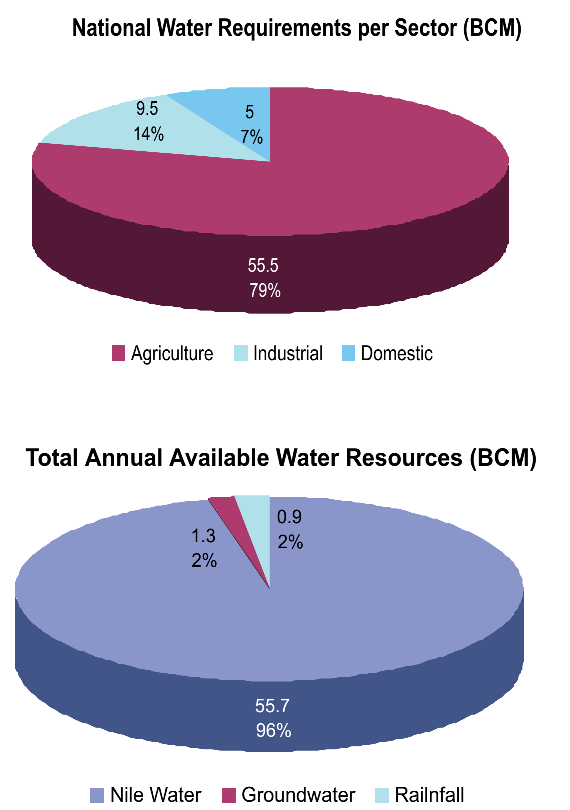
The water policy development in Egypt faced a number of challenges; mainly, the mismatch of water supply and demand that resulted from increasing demands for water in all socio-economic sectors. The rate of demand growth is linked directly to the growth in population and, the improvement of the living standards. In addition to that, the available water resources in Egypt are limited and the rate of its development is much slower than the rate at which demands increase. This means that the gap between available resources and water requirements is getting wider over time and Egypt will be facing water scarcity in the near future.

Figure 1: Water Availability and Demand in Egypt



The distribution of Nile water is nearly uniform from Aswan to Cairo with a fairly good quality due to the Nile system of self purification. Nevertheless, the pollution increases in the two Nile branches towards north as they receive nutrients, organic loads, grease and oils from the intensified agriculture, residential and industrial activities in the Delta region. This continuous decline in water availability, in terms of quantity and quality, requires more stringent measures from all users to achieve more with the limited water available. However, what makes the MWRI mission more exigent is the fact that water sector actions in Egypt are shared among many governmental and non-governmental authorities.

Research is deeply rooted in the activities of MWRI, since its establishment in 1864. Prior to the completion of HAD research took a number of facets including: survey investigations and studies; Nile Basin data collection and hydrologic analysis; hydraulic structure experiments; irrigation water duties; drainage rates; and groundwater. Since the establishment of Surveying Authority in 1878, hydrologic research and studies were carried in one of its divisions, while experiments and measurements were conducted by the different inspectorates of the Ministry. In 1915, a Physical Department was created to conduct hydrologic and hydraulic research. It was headed by one of the pioneer hydro scientists, Dr Hurst, who put the research founding stone in MPW. Three years later, an experimental station was founded in El-Kanater on the banks of Damietta branch (the current premises of ten NWRC institutes). The station was considered as a hydraulic laboratory dedicated for solving field problems faced by the different inspectorates. In 1951, the Experimental Station and Physical Department were inserted under one inspectorate, called Water Research Inspectorate. Evolution of research entities, within Ministry of Irrigation (MOI) departments, continued until HAD was completed.

1.2. Study Rationale and Objectives

The operation of HAD in 1970 confirmed the need to develop a national water policy and adopt a new framework for water resources planning and management. The first national water policy post HAD was approved in 1975. It dictated serious institutional reform to cope with newly emerging issues and advances made in water resources planning and management. In the same year, the Water Research Center (WRC) – later the National Water Research Center (NWRC) – was established to carry out applied research in all water resources development and management aspects. The reason was to create a strong research and development component that could support MWRI [in the Nineteenth century MPW; later MOI and Ministry of Public Works and Water Resources] to advance and expedite the implementation of the national water policy.

Since its establishment, the NWRC produced significant mass of research in the different branches of water sciences. The NWRC saved no effort to disseminate its research findings and results as widely as possible through direct contacts with the research end users and stakeholders as well as international conferences, workshops, and scientific journals. Although it carried out all of its research in direct support to the development and management of Egypt's water resources system, there are claims of a gap between research and practice. Generally, these claims are not substantiated either by specific examples or thorough analysis of the research uptake process. Therefore, there is a need to test this typical research-practice gap cliché against a consistent analysis framework. Application of such framework to specific research programs will help to dissect the rich experience of Egypt in the water research field. Revealing strengths and weaknesses in the research uptake process, as well as, dissemination of the analysis results will contribute to the enhancement of water research uptake process in other countries similar to Egypt.

Research knowledge is one of many competing factors influencing policy decisions that can eventually translate into changes in field practices. While better use of research-based evidence in development policy has been covered comprehensively through different initiatives, less has been done to close the gap between research and practice or in determining the impact of the research uptake process on end-users or other stakeholders; this study aims to reduce that gap.

With the objective to identify significant research programs and projects carried out by the NWRC during the last three decades that impacted the national water policies and the irrigated agricultural practices in Egypt, the study will document successful cases of direct and indirect research uptake as well as unsuccessful cases. The effectiveness of the NWRC and MWRI unique set up and relationship and its impact on the development and implementation of the national policies will be analyzed. The reasons for success and failure will be identified in terms of intrinsic and externalities. Specific recommendation for increasing the research uptake and improving the process of wide dissemination of research results especially in countries with similar condition will be highlighted.

While embedded in the process of identification, analysis and documentation of research uptake, it is of importance to assert that the methodology applied by the NWRC for carrying out research uptake is by itself a key objective of the study. Immediate objectives, however, are the:

1) Comprehensive documentation of Egyptian experience in irrigation and drainage research uptake.

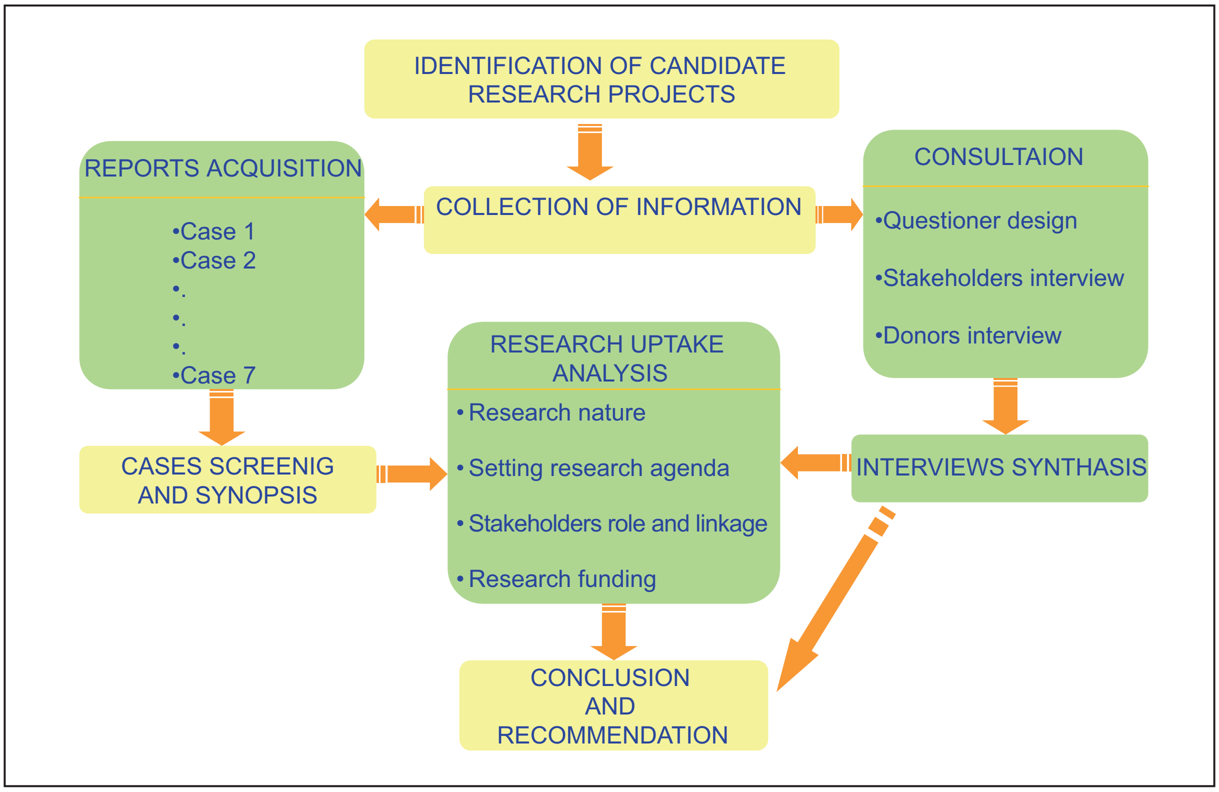
2) Analysis and evaluation of such experience to identify mechanisms and procedures that closes the gap between research and practice.

3) Provision of specific recommendations for taking corrective measures to enhance and encourage the uptake of research results and findings to irrigation and drainage practices.

1.3. Adopted Methodology

The logical framework adopted in the study has been developed according to the inventory of the case studies, documents and acquisition of reports as well as early interviews with the stakeholders. Figure 2 describes, graphically, the adopted methodology and the flow of conducted activities. It starts with identification of a reasonable number of research projects that qualify for analysis. This step is followed by information collection that has two pillars: acquisition of reports on selected research projects, and consultation with research stakeholders and donors. The third step is basically scripting of the collected information that has bearing on the next step; and analysis. It included scripting of the synthesis of interviews and synopses of cases.

Figure 2: Methodology Flow Chart



Before going into analysis, a reference (acknowledged) framework was selected. Finally, the analysis of both the case studies and interviews led to articulation of conclusions and recommendations. It is worth mentioning, that the synthesis of interviews- contributed more directly to the recommendations.

1.3.1. Identification of relevant research

Potential research projects that have impacted the water resources policy and irrigated agricultural practices were identified. In order to reflect the different facets of the research uptake, the following five topics were selected: Irrigation; Subsurface Drainage; Water Quality; Grand Hydraulic Structures; and Weed Control. The selected research projects included those that have resulted in national programs, change in the national water resources policy, or contribution to mega water projects. Good documentation of the research was an important selection criterion.

Irrigation and Subsurface Drainage are the two cases where research resulted in two large scale national programmes: Irrigation Improvement Project (IIP) and National Drainage Programmes (NDP). Both programmes were financed mainly by International donors on grant and loan basis. Research on Weed Control resulted also in national programmes; however, it was fully financed by the Government of Egypt (GoE). The case of Grand Hydraulic Structure has two interesting remarks: the direct research client is not a governmental agency; and the type of research conducted is rather cumbersome and hard to classify.

1.3.2. Instruments

For the five identified cases, synopses were prepared after thorough review of the collected reports on each case. Several reports and documents, especially the final reports, were obtained for each project from the relevant NWRC institutes and NWRC library. Typically, there were more than one report or document for each case; therefore, extracted information was subject to comparative analysis and verification. Some data and information was checked during the interviews.

Based on the selected cases, stakeholder mapping was conducted and a list of interviewees was set up accordingly (**Annex 1**). More than twenty key persons who have direct interaction with the identified projects were interviewed. The interviews were supported by a semi-structured questionnaire to facilitate the interpretation and the consolidation of results (**Annex 2**). Interviewees’ answers were compiled and summarized under three items: observations on research, examples of research impacts (positive and negative), and recommendations to enhance research uptake (**Annex 3**).

The experience of the study team was one of the instruments that have been utilized carefully in this study. Forming the local team from a local supervisor (NWRC President), a coordinator (Institute Director), and a senior researcher (Institute Director) as well as five junior researchers gave the study the relevance and depth. The juniors' experience with three decades of research activities was short. Therefore, they were selected to represent the institutes which were involved in each case study; being staff members in these institutes allowed them to gather the information and documents required for the study. It gave them also first hand accessibility to the contacts of the stakeholders and donors representatives. The long experience of the seniors and then holding of several research directing positions have been reflected in the appraised methodology that have been adopted, the quality of the activities undertaken as well as the importance and weight of the recommendations reached. In turn, the international members of the study team have provided knowledge on similar international experiences that helped the formulation of the theoretical analysis framework and the identification of the diverse case studies as well the recognition of the implicit research impacts.

1.3.3. Analysis

The analysis and evaluation of the research uptake process have depended on two pillars: the interviews and case studies synopsis. These case studies provided diverse examples for research uptake, mostly successful. Diversity was clear in their topics, implementation time, motivation, impacts and involved parties. Therefore, such case studies founded the analysis on a wealth of data and information. Information was obtained from stakeholders’ interviews that gave reflection on the actual effectiveness of the research uptake process. They also pointed out some research results that have not been, initially, found in the documents of the case studies. Such results were incorporated into the presented case studies. The output of the interviews was rather useful in diagnosing the defects or the drawbacks that could make the current research in irrigation and drainage ineffective. It also provided a set of feasible and practical recommendations to enhance the research uptake process.

Analysis and evaluation of research uptake case studies aimed at highlighting successful mechanisms and procedures that closed the gap between research and practice. The effectiveness of NWRC and MWRI partnership in the research uptake, and its impact on the implementation of the national policies was demonstrated. The analysis also spotted some weaknesses that will require further research, more proven results, or better information dissemination. Recommendations and corrective measures, to enhance and encourage the uptake of research results and findings in water resources protection and development practices, were also provided. The role of donors and cross-sectoral partnership in stimulating integrated research activities has been given thorough attention. Different research funding mechanisms were studied and compared in terms of pros and cons. Marginal or indirect role of the national universities in the research uptake has been evaluated.

1.4 Report Structure

This report consists of four chapters, where Chapter 1 describes Egypt's water research origins, the rationale and objectives of the study, and its adopted methodology. Chapter 2 provides some definitions that establish the reference framework that was used to analyze the research uptake case studies. It also outlines the outcome of applying the reference framework to the selected research uptake case studies. Chapter 3 comprehensively describes each case study and its sub-components. It synthesizes their rationale and objectives, the research conducted under each of them and its findings, and the impact that each case has left on the national policy and practice. In Chapter 4, the current water research strengths, problems and gaps are identified. Recommendations and the way forward are furnished in the same chapter; while the list of people interviewed, the structure of the interview and the questionnaire, and the interview synopsis are given in Annexes 1, 2 and 3 respectively.

2. WATER RESEARCH UPTAKE IN EGYPT

2.1. Research Uptake Framework: Definitions

Analysis and evaluation of research uptake case studies has to be referenced to acceptable definitions and acknowledged processes or frameworks that are typically followed to transfer the research findings and results to the practice and end user. It is also needed to establish common understanding and definitions for the terminology utilized, including those taken for granted such as “research”. Box 1 presents an acceptable definition and classification for research that can be applied to water sciences.

In essence, research in water resources protection and development is carried out to improve the practice of water resources policy makers, planners and engineers. It gives professionals better ways to manage water resources. The nature of water resources protection and development is to be purposeful; therefore, the NWRC was established to conduct applied water research. It seeks to advance the practice of water resources protection and development by means such as:

- Discovery of new materials, theoretical models and processes which can enhance the performance, quality, efficiency, cost effectiveness and sustainability of Egyptian water resources systems.

- Increasing the quality of models by which predictions are made thereby improving process understanding.

- Investigating and defining the properties of new or existing materials, systems and resources so that their use can be more appropriate and reliable to the end-user.

- Developing improved design methodologies so that the resultant outcome is more efficient or reliable, or poses less risk to its end-users.

- Improving control and risk management frameworks around particular families of water problems.

Basic research in water resources is defined as scientific investigation and study which may furnish or facilitate potential future practical application, was thought to be left to universities. It includes:

- Research that seeks to build underpinning theoretical and mathematical models that increase understanding of the mechanisms of either water natural or man-made processes or systems.

- Research that seeks to increase understanding of the unique and potentially valuable properties of novel materials or resources.

Box 1: Research Definition and Classification (Adapted from ESRC, 1999)

Research and experimental development comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.

Any activity classified as research and experimental development is characterized by originality; it should have investigation as a primary objective and should have the potential to produce results that are sufficiently general for humanity's stock of knowledge (theoretical and/or practical) to be recognizably increased. Most higher education research work would qualify as research and experimental development.

Research classification:

- **Pure basic research** is to study and investigate on pure science that is meant to increase our scientific knowledge base. This type of research is often purely theoretical with the intent of increasing our understanding of certain phenomena or behavior but does not seek to solve or treat specific problems. In other words, it acquires new knowledge without looking for long term benefits other than the advancement of knowledge.

- **Strategic basic research** is experimental and theoretical exertion undertaken to acquire new knowledge directed into specified broad areas in the expectation of useful discoveries. It provides the broad base of knowledge necessary for the solution of recognized practical problems.

- **Applied research** is scientific effort undertaken primarily to acquire new knowledge with a specific application in view. It is undertaken either to determine possible uses for the findings of basic research or to determine new ways of achieving some specific and predetermined objectives. In other words, it is used to find solutions to everyday problems and develops innovative new technology.

- Experimental development is a systematic process, using existing knowledge gained from research or practical experience that is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

Water basic research does not include the ongoing refinement of risk management or design methodologies, but it includes developing models or knowledge that might lead to substantive rethinking of the methodologies themselves.

Typical research modes that are adopted by research organizations and institutes, in response to socio-political context in which they exist, are presented in Box 2.

Box 2: Research Modes (Adapted from ESRC, 1999)

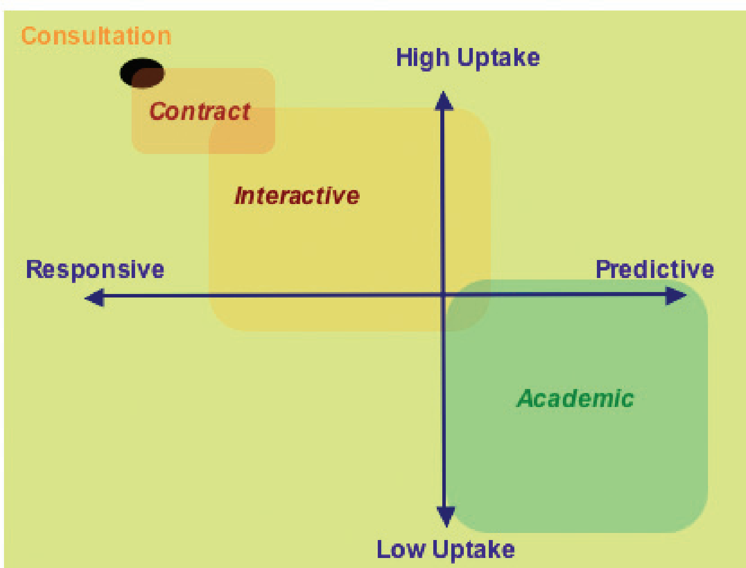
Interactive mode refers to a style of activity where researchers, funding agencies and 'user groups' interact throughout the entire research process, including the definition of the research agenda, project selection, project execution and the application of research insights. Research users may include policymakers, planners, business and governmental or non-governmental organizations.

Academic mode refers to a style of activity where research agendas are defined by academics themselves. Funding mechanisms are driven by academic curiosity, disciplinary values and traditional peer review undertaken by applicants' academic 'peers'.

Contract mode refers to a style of activity where researchers in universities and other institutions already 'interact' directly with users, such as government departments, by accepting contracts to undertake specific pieces of research or by serving in advisory capacities.

Interactive research could be said to blend elements of traditional academic and contract research models, as Shown in Figure 3. However, it is also possible to see it as a distinctive model for research activity in its own right. Interactive research can be distinguished from contract research simply based on the degree of user involvement. While contract research brings researchers into contact with users, it does not meet the definition of interactive research. This is because the research agenda, rather than being jointly determined, is set solely by the 'user'. Goals are often influenced by shorter term considerations and/or immediate policy needs. Therefore, both contract research and interactive research are typical examples of research uptake on the responsive side. On the other hand, academic mode of research is predictive as it is driven by the curiosity of scientists and researchers. Figure 3 demonstrates that this mode of research does not allow for significant research uptake.

Figure 3: Characteristics of Different Research Modes



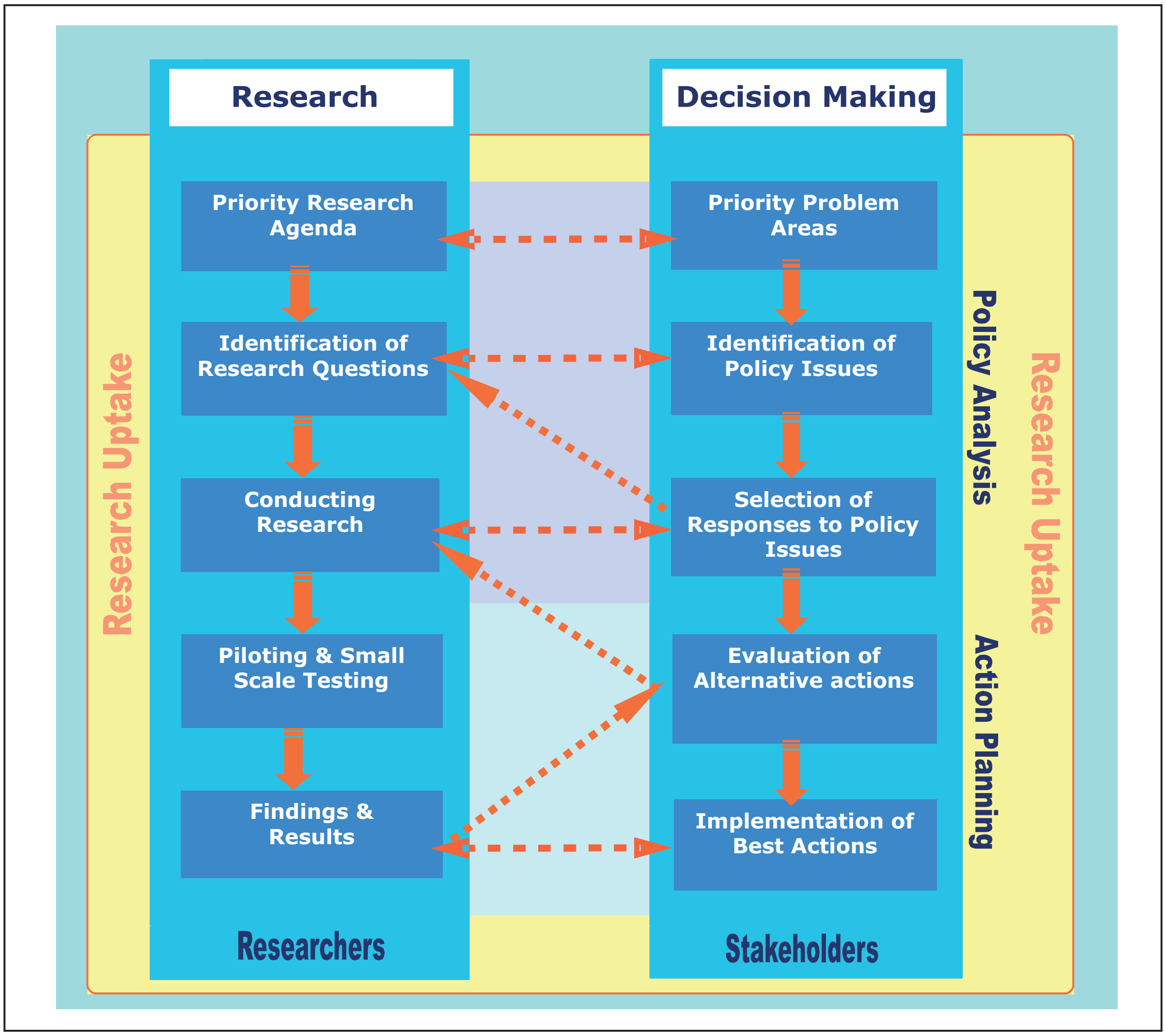
Box 3: Definitions of Research Process-Related Terms (Adapted from ESRC, 1999)

Research user is any entity, representative or organization (governmental or non-governmental) with an interest in the outcome of research**.**

Online research does not exist. Pure basic research, by definition, is always ahead of the society needs and policy requirement. Typically, applied research, either contract or interactive research, follows the issues and problem identification. However, good interactive research may well be conducted ahead of immediate policy needs, which requires considerable visionary researchers and policy makers.

Research versus consultancy which is an assignment commissioned by an organization that knows the answer it wants. Its delivery is typically due according to tight timetables. While research is needed where the answer is not known, or when organizations are under pressure and need to demonstrate that their actions are supported by evidence. Consultancy normally utilizes out-dated research techniques and recycles academic findings freely available in the published literature.

Figure 4: Pathway for Research Uptake (Adapted from IDRC, 2001)



Box 3 provides more definitions and explanations for few terms and issues that will be utilized in the analysis of the research uptake process.

A conceptual framework was developed that represented the pathway for the uptake of research (see Figure 4). Within this framework, two discrete processes go parallel. These are the research and the decision making. The policy analysis and action planning are serially connected elements of the overall decision making process while the research uptake is a perpendicular process that intersects with both research and decision making. The uptake process takes place through the back and forth interactions at multiple stages of the processes.

Research findings and results need not be a single final output at the end of the research process. They may be a series of outputs of a variety of types that occur throughout the research process and inform the next steps in the decision-making process. When the decision making process reaches the step of implementing the best actions, research results are translated into field practice either directly or through research influence on policy formulation. Stakeholders include various groups: national and international research institutions, policy makers, water resources professionals, funding or donating agencies, and end users. Each group has diverse possible contributions to the various stages of the three processes, if they are properly involved.

2.2. Research Uptake Framework: Application to Egypt Experience

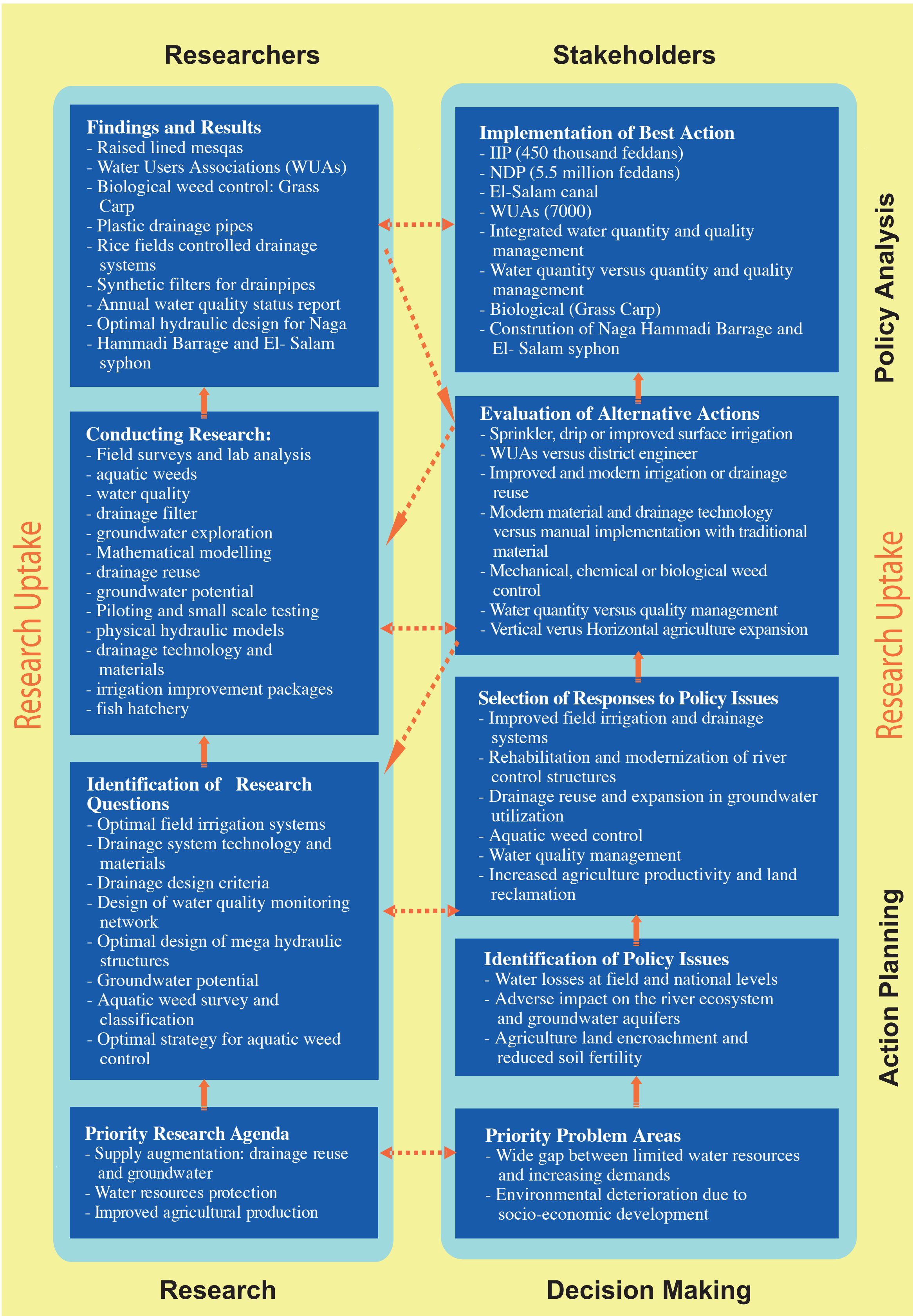
2.2.1. Applied Processes

Research uptake is a very complex process that involves several parties who have different ethos and modes of operation. There are no standard guidelines that make the research uptake effective. In Egypt, the research uptake process was extracted from the analysis of the five case studies. Figure 5 depicts an illustrative application of the theoretical framework for research, decision making and research uptake process as derived from the case studies and their sub-cases.

Since research and decision making are discrete but parallel processes, they are carried out by two distinct bodies within MWRI. NWRC is the body fully responsible for research activities while decision making is the responsibility of MWRI sectors, departments and implementing agencies. The elements of each process are serial connected. For instance, with reference to the decision making process when a national priority area such as the wide gap between limited resources and increasing water demands is identified, at the Cabinet level, a policy issue like high water losses at the field and national level has to be addressed in the national water policy. As a result, drainage reuse, as an immediate response to increase the overall efficiency of the irrigation system and the expansion of groundwater exploitation to augment water supply were considered in the 1975 water policy. As a reflection on the research parallel process, two questions were raised: what was the optimal design for water quality monitoring network and what were the sustainable utilization rates of the different aquifers?

MWRI has founded its 1975 water policy and the consecutive policies on a solid scientific base. As research uptake process is a perpendicular process on both research and decision making processes, research-practice-policy interaction went both ways; as research impacted

Figure 5: Research Uptake Pathway - Application to Egypt Experience



national water projects and policies; they in turn stimulated several research programmes. Water shortages at the Lower Delta led to the drainage water reuse practice which stimulated field surveys and lab analysis to assess the water quality in drains and canals. Research findings and results of these activities made MWRI adopt integrated water resources management principle that embraced both quantity-based and quality-based management alternatives rather sticking to the traditional quantity alternative.

Research findings and results do not need to be a single final output at the end of the research process. Either directly or indirectly the results and findings go into policy and practice. Research on on-farm irrigation efficiency that was carried out through large scale piloting led to the implementation of Irrigation Improvement Project (IIP) in the old lands. It has recommended several physical, institutional and legal interventions that had been applied to more than 450 thousand *feddans*. Recommendations on users' participation became a national policy that resulted in establishment of about seven thousand Water User Associations (WUAs) practicing field water management. More directly, research on subsurface drainage materials and design criteria went to practice by the drainage projects implementing agencies and contractors. More than 5.5 million *feddans* (1 *feddan* = 4 200 m^2) are currently covered by subsurface drainage in accordance with research findings and results. Examples of direct research impacts on hydraulic and structural design of water works and implementation cannot be counted.

For a policy issue like agricultural land encroachment and soil deterioration in old land, reclamation was one of the responses. In the same context, among the best actions the government chose to implement were the two mega rural development projects: Southern Valley Project, and El-Salam Canal. Both projects required the design of sizable non-traditional hydraulic structures that led to physical modelling research activities.

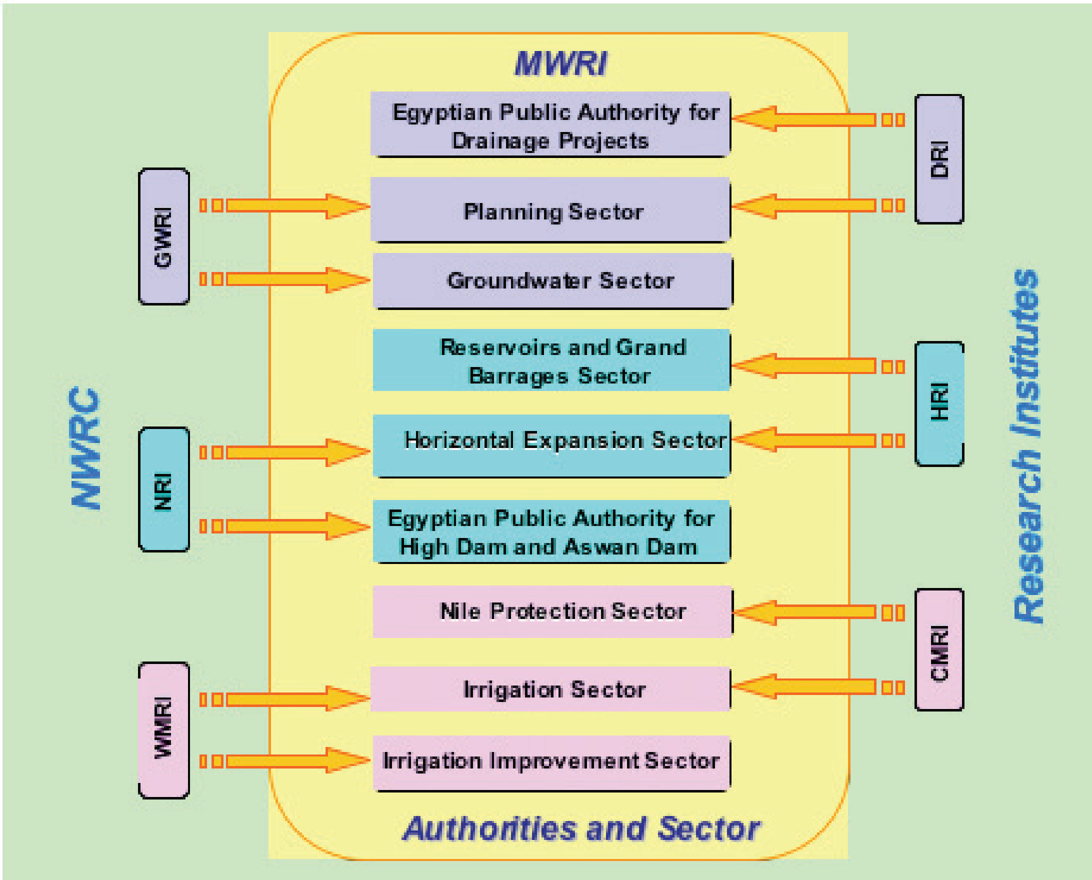
Evaluation of alternative actions may stimulate research as well. When water quality research alarmed decision makers to stop drainage reuse on some main drains, the intermediate reuse was suggested as an attentive action. The resultant research activities has guided the formulation of the current NWRP. On the other hand NWRP, explicitly, calls for research on: new optimal operation rules for HAD, salt and drought tolerant crop varieties, and repeated use of brackish groundwater.

The following analysis, of the research uptake process in Egypt, has been based on four pillars that affect directly or indirectly the research uptake process. These are: institutional context, setting up of research agenda, linkage between researchers and stakeholders, and research funding sources.

2.2.2. Institutional Set-up

The institutional environment has crucial effects on the commissioning and conduct of interactive research. Therefore, the idea behind the establishment of WRC (later NWRC), was to create a strong research and development component that could support MOI (later MWRI) to advance and expedite the implementation of the national water policy. This was associated with an impression, at the national level, that universities cannot support the country's ambitious sectoral development plans through traditional academic research.

Figure 6: Organizational Mapping of NWRC and MWRI



By structuring the NWRC, so that each of its institutes corresponds to one or more of the ministry's major departments or authorities, has ensured research influence on policy formulation and action implementation. Figure 6 illustrates the links amongst the research institutes that carried out the selected cases for this study, with the relevant MWRI sectors and authorities. However, corresponding mapping of the MWRI departments or authorities and the NWRC institutes was not, always, as shown in Figure 6, from the beginning. New sectors and units have been created in response to NWRC intensive research activities and accumulated research findings waiting to be implemented by dedicated departments. Immediate examples are Groundwater (GS), Irrigation Improvement (IIS) and River Nile Development and Protection (RNDPS) sectors and Central Water Quality Unit. Increasing environmental awareness and climate change concerns led in 1995 to the establishment of the most recent NWRC research institute; and Environmental and Climate Research Institute (ECRI).

Currently, NWRC consists of twelve research institutes and two supporting units that read like a list of development needs and problems facing Egypt's water sector. It is structured in a way that each institute corresponds to one or more of the Ministry's major departments or authorities. Figure 6 maps the twelve NWRC institutes to their corresponding MWRI sectors and authorities, based on the direct and obvious links rather than reflecting all existing or potential relationships. Such a unique set up has ensured that research influences water policies and actions on the ground. The impact of research has not only accelerated the implementation of the national water policy, but also contributed in considerable savings to the national economy, increase in food production and public security. The latest techniques which emerged from the research of the NWRC in planning are: design, construction and management of water resources systems which are the day to day practice in the MWRI. The NWRC implements research projects, and provides a wide variety of analytical and advisory services to meet the development requirements of the MWRI and other water related instantiations at the national level. As a national organization, the NWRC is developing in an adoptable manner to the national needs. Nonetheless, it is responsive to the new advances in water since and unite to forms of international cooperation in its field of interests.

2.2.3 Setting Research Agenda

By nature, applied research is a demand driven process. The vision that initiated the NWRC gave it the mandate to be responsive, primarily, to the policy and decision makers in the MWRI. At that early stage and after the establishment of the NWRC, the MWRI was facing serious challenges due to the construction of HAD. With the operation of HAD in 1970, there was need for a new national water policy and to make paradigm shift in water resources planning and management.

The 1975 policy and its successors have raised several non-traditional issues and questions. Although the MWRI has an impressive long history, the available data, information and knowledge were not able to respond to challenging issues and questions. Most of the analyzed case studies were carried out in response to these issues and questions. However, in cases like Subsurface Drainage, Water Quality or Weed Control, where donors and international research institutions were involved, the initiatives did not come directly from the researchers.

The research agenda was neither articulated by policy nor decision makers in the MWRI. In essence, the initiative came from the donors who brought the NWRC institutes with corresponding implementing departments and agencies to formulate research projects and programmes. The process was totally different with respect to the case of Hydraulic Structure Design, which represent the contract mode. In such particular cases the agenda was always very specific and set by an international design firm or consortium. The research objective in each sub case was to confirm the conceptual or preliminary design of a specific hydraulic structure, and optimize its function and performance under different flow conditions.

The current process for research initiation starts with a call from the NWRC President, to the twelve research institutes, to propose a set of research projects under the main themes of water policy. Some institutes, that have direct and good link with their corresponding MWRI entity, reach out and ask corresponding agencies to express their needs and requirement in terms of research and development. The NWRC Vice-President for research work plan affairs collects the proposals for screening and harmonization. In collaboration with the institutes' directors he eliminates conflicts, redundancy, and sometime proposes a joint undertaking of some research projects by multiple institutes. A coherent NWRC research agenda is drafted by the Vice-President, and presented to the heads of MWRI departments, sectors and authorities, in the presence of the twelve research institutes directors. In such a wide meeting the agenda is debated and discussed. It is normal to witness conflicts, controversies and misunderstanding on both sides (researchers and executives) during the meeting. However, the meeting is considered as an internal MWRI affair in which discussions run in a very friendly and open environment. Executives' comments and concerns are incorporated in a modified version of the agenda and disseminated among MWRI sector heads for endorsement. Sometimes a second round of deliberations takes place before the final agenda is routed through its formal upper channels (NWRC Board, His Excellency the Minister).

2.2.4. Researchers-Stakeholders Roles and Linkages

Presented real life cases, either undertaken through interactive or contract research, required collaboration linkage among researchers, governmental agencies, business firms, national and international universities and research centers, people and donors' organizations. Donors in most of the cases played a pivotal role more than just funding the research. Researchers in the research institutes that conducted the case studies had a good understanding of the policy issues. They had a good understanding of water resources professional perspective (working in the governmental implementing agencies) as well as the end users perspective. However, in some sub-cases they could not carry or solicit their results for stakeholders and decision-makers. This may be due to their fear of compromising their integrity; or because they were not good in it.

According to the Egyptian laws, (Agriculture Law, and Irrigation and Drainage Law), the role of MWRI stops at the farm gate, whereas the role of the Ministry of Agriculture and Land Reclamation (MALR) starts. Farmers, therefore, are not the direct end users of MWRI projects. The two exceptions are the Irrigation and the Subsurface Drainage cases. In these two projects, farmers' participation is widely practiced during the implementation. However, during the research phase only selected small farmers were involved through pilot schemes (some of these pilot schemes are 30 years old). In many of MWRI projects and policies, it is very difficult to consider farmers as direct stakeholders. Sometimes impacts of research, which are appreciated by the system operators and managers, are hardly felt by farmers.

The Subsurface Drainage case shows how interactive research can involve a variety of partnerships and collaboration modes throughout the entire research process, from formulating the research questions to communicating and applying the research insights. The partnership between the Drainage Research Institute (DRI) and the Egyptian Public Authority for Drainage Projects (EPADP) is an example to follow. It expedited the implementation of NDP, significantly. However, in other cases the research institutes did not have the chance to create similar partnership. Simply, because when the case study was conducted there was not a corresponding implementing sector in MWRI.

Working with the private sector as opposed to the public sector posed greater difficulties for researchers. This was partially because of differences in culture and in part because researchers were not compatible with industrial approaches and timetables. However, the case study of Hydraulic Structure Design was an exception. The international research community, represented in this case by IHE-Delft, provided the Hydraulic Research Institute (HRI) with both direct and indirect support, so that it reached an international level of accreditation. Such accreditation created a broader contract research market for HRI.

Donors played the role of matchmaker between research institutes and their clients. They made sure that researchers, policy makers, implementing agencies and end users groups interact in developing, executing and communicating research. Such role was demonstrated in the cases of Water Quality, Irrigation and other cases. As funding agencies, donors played undeniable role in the research uptake process to guarantee the cost-effective utilization of their funds. By taking research results to practice and field, donors create more marketing opportunity for their products, instruments and experts. For example, the case of Weed Control and many others witnessed solicitation of foreign consultancies and expertise. Transferring findings and results of Subsurface Drainage sub cases, for installation and maintenance, created a market for the donors' machines, while a case like Water Quality Mentoring furnished a good market for donors' lab instruments and field equipment.

However, donors were sensitive to the country’s own context and needs and established equal partnership with local researchers and professionals. They did not impose “external” agendas, and formulated the research agenda with full endorsement of policy decision makers and researchers. Instead of insisting on the use of external experts to carry out research studies they directed most of the external experts and consultants to capacity building of the national researches and young research institutes. Drainage Research Institute (DRI), Research Institute for Groundwater (RIGW) and Water Management Research Institute (WMRI) are examples of the institutes which received significant help and support from donors who funded their case studies. The capacity building thrust was not limited to the young research institutes, but it was extended to the implementing agencies to ensure better research uptake by policy makers and end users. The idea was that research user should have the capability to interact with the researchers during the whole research process to achieve better management and use of knowledge, and improved communication.

2.2.5. Research Funding

Egypt’s national research funds flow mainly through Ministry of Higher Education and Scientific Research, where water research competes with research in other sectors, such as health, environment, agriculture and others. This puts water resources and irrigation departments at the national universities under financial stress and does not allow them to pursue their applied or basic water research. The NWRC receives its funds through the MWRI. Such separate funding mechanism for water research put an emphasis on water resources protection and development.

With the first comprehensive water policy of 1975, the demand for research leading to action was very high. However, the GoE could not provide enough financial resources for such studies, due to its economic conditions. At that time, national sources of funds were directed to reconstruction, development and economic recovery from the 1973 war rather than research. Most funding sources had given a much lower priority to research compared to tangible developments. Therefore, Egypt had to rely on external sources for funding its water research, without sacrificing relevant research agenda that is effectively linked to its national priority actions. External sources of funding for research have played a crucial role, not only in allowing Egypt to set its own priorities and conduct relevant research, but also in strengthening national expertise and capability.

All presented cases were co-financed by donors and GoE, except for the Hydraulic Structure Design case. A significant part of the Egyptian contribution was in-kind and not in cash. Donors of the different case studies had diverse nationalities: Dutch, Americans, Canadians and International Organizations (World Bank and others) as well. When donors involve large amounts of research funding or intend to support policy changes, they usually demand use of international consultants or imported equipment or instruments, as a condition for loans and grants. Such practice was based mainly on the assumption that the recipient country would benefit more and ensure better-quality and more timely results. Such practice was neither illogical nor without its benefits. Nevertheless, it put the sustainability of efficient research process at risk, owing to the concern that once such external funding sources start to support research they will always be required.

3. RESEARCH UPTAKE CASE STUDIES

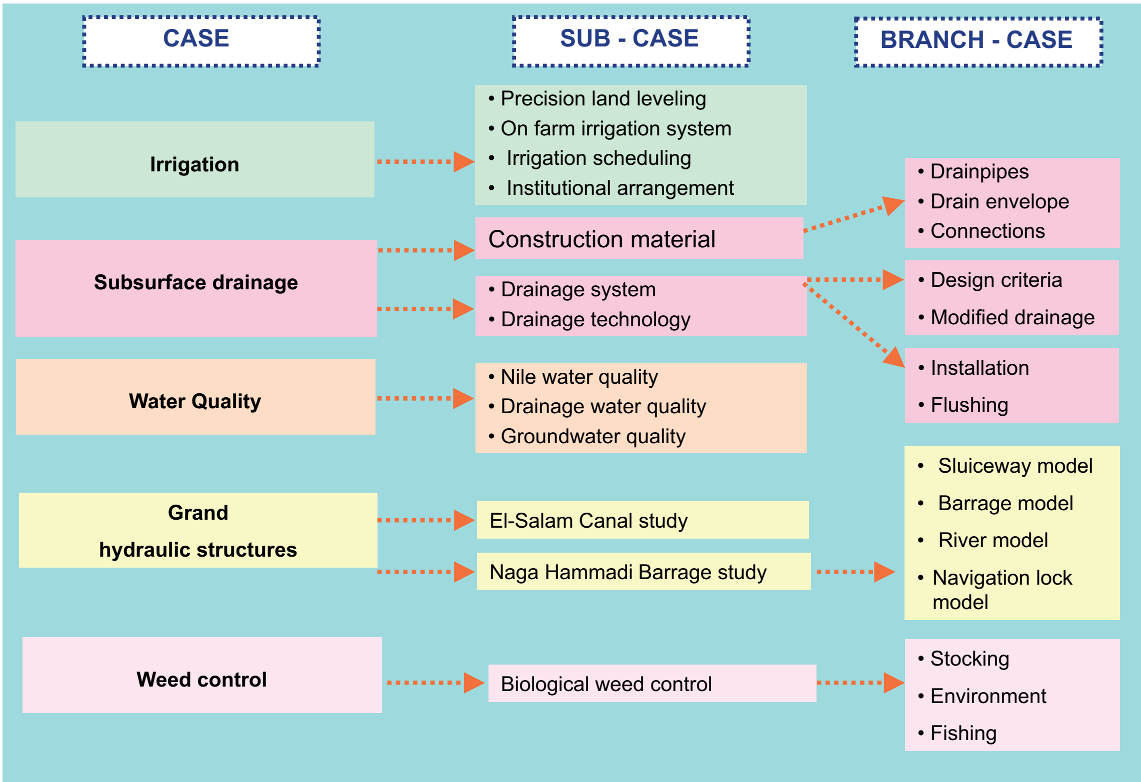
Egyptian irrigation practices experienced radical changes during the Nineteenth century. The old system of basin irrigation and cultivation of one crop per year, which prevailed since the dawn of civilization, has been superceded by perennial irrigation. This has been achieved by Mohammed Ali, who ruled Egypt from 1805-1849. He started and executed an ambitious plan to modernize the Egyptian agriculture. Barrages were constructed across on the Nile in order to regulate its water and provide full control over its flows so as to maximize the profitability and minimize the losses. Since then, Egypt has struggled to cope with the increased irrigation requirements by constructing hydraulic structures and water control facilities along the Nile, including barrages, dams and storage reservoirs. The old Delta Barrages was built in 1861, while old Aswan Dam was erected in 1902, and HAD in 1969.

The operation of HAD in 1970 confirmed the need to develop a national water policy and adopt new paradigm for water resources planning and management. The need for improved field irrigation and drainage systems, at the national level, became more persistent. Urgency for rehabilitation and modernization of control structures on the river itself turned to be a must to save freshwater lost to the sea. Changes of the River Nile ecosystem were observed after the Construction of HAD. Alteration of the water quality, specifically suspended load, led to significant modification in aquatic weed species and behavior. Highly controlled and regulated flows in most irrigation canals created a favorite steady environment for aquatic life. At the same time, more nutrients and chemicals entered the water through increased use of fertilizers in agriculture in addition to domestic and industrial effluent disposal. Therefore, more attention had to be paid to the monitoring and protection of all water resources quality, including groundwater.

The first national water policy, post HAD, was approved by the Parliament in 1975. It dictated serious institutional reform to cope with newly emerging issues and advances made in water resources planning and management. In the same year, the ‘Water Research Center’, WRC (later NWRC) was established to carry out applied research in all water resources protection, development and management aspects. The reason was to create a strong research and development component that could support MOI at that time (later MWRI) to advance and expedite the implementation of the national water policy.

Within the framework of this study, potential research projects that have impacted the water resources policy and irrigated agricultural practices in Egypt have been identified. Seven topics were considered. These are: Subsurface Drainage; Irrigation; Groundwater; River Nile; Water Quality; Grand Hydraulic Structure; and Weed Control. After a thorough revision of the available reports and a rapid analysis of the seven cases selected first and their thematic relevance to the core of the study, it was decided not to include the two cases of the River Nile Development and Protection and Groundwater Management. The rapid analysis of the River Nile Development and Protection case showed diverse significant research results that did not materialize in consolidated impacts (national programmes and well-delineated national policy). With no doubt, research on groundwater contributed significantly in terms of national policy

Figure 7: Schematic Diagram of Selected Case Studies and their Sub-Components



formulation, but within the context of this study it would have, however, been a redundant example of how research impacted the national policy and practice. It has to be mentioned that both eliminated cases had an important impact on the MWRI institutional reform. They also contributed, partially, to the Water Quality case. The schematic diagram of the selected case studies and their sub-components is shown in Figure 7.

3.1. Case Study I: Irrigation Improvement/Egypt Water Use and Management Project (IIP/EWUM)

3.1.1. Rationale and Objectives

The discharge of water from HAD is under full control. The release of water for irrigation is adjusted throughout the year to provide all agricultural lands with sufficient water for different crop requirements. Perennial irrigation has provided new opportunities for more intensive crop production, but at the same time, it has generated new problems. For example, the use of more water (over irrigation) on a relatively fixed area of land has caused water-logging and build up of salts in the soil profile. The challenge was to minimize or solve these problems while fully exploiting the new opportunities for the benefit of the nation.

Egypt Water Use and Management Project (EWUP) during (1979-1984) emerged out of an understanding of the close dependency and interaction between the irrigation water delivery system and the on-farm water management system. The MOI recognized the emerging need for the on-farm water management in addition to its major responsibility of the main system management in order to improve the efficiency and effectiveness of water delivery.

The overall objective of the EWUP was to improve the social and economic conditions of the Egyptian small farmers through development and use of improved irrigation water management and associated practices which increase agricultural production, promote efficient water use and decrease drainage problems. The Project was designed to raise the institutional capacity of the MOI to develop and implement improved on-farm water management programs (EWUP, 1984).

The EWUP aimed at providing experience and knowledge base which can be used to formulate plans for expanded irrigation improvement programs in Egypt. The knowledge and know-how should have been acquired to achieve:

- Improvement of irrigation water management.
- Reduction of the pressure on the field drainage networks.
- Improvement of water availability at various points downstream of the canals and *mesqas*, specially at the tail ends.
- Improvement and renovation of the irrigation networks.
- Crop production increase.

3.1.2. Conducted Research and Findings

The EWUP was one of the most important irrigation projects funded by United States Agency for International Development (USAID) to promote interdisciplinary approaches to deal with both physical and institutional changes in the on-farm irrigation system (Nashed, 1997). It was implemented through the Water Distribution and Irrigation Systems Research Institute, currently the WMRI of the NWRC, in collaboration with the Agricultural Research Center. The Consortium for International Development, with executive offices in Tucson, Arizona, was the USAID contactor for the project.

The project conducted an applied research with small farmers in three representative pilot areas: Giza, Kafr El-Sheikh and Minya. Through the three project sites, the EWUP succeeded in developing methods for on-farm irrigation system improvement together with packages of practices for better on-farm water use (EWUP, 1984).

The first selected site was El-Mansouriya village in the Giza Governorate with a command area of about 1 600 *feddan*s. It represented the fruit and vegetable producing areas serving the Cairo market. The second site was Abu Raya in Kafr El-Sheikh Governorate with a command area of about 6 300 *feddan*s. This site was selected to represent the tail-end part of the irrigation system and rice producing regions. The third site was Abyuha village in El-Minya Governorate to represent Middle Egypt region with different cropping patterns in the Nile Valley with a total area of about 1 200 *feddan*s.

The programme started by studying the Egyptian farming systems which are highly complex due to the mutual effect between physical, economic and social environments. This study was accompanied by a comprehensive analysis of the main characteristics of the water delivery, drainage and groundwater systems. There were four major interventions that were tested by the EWUP to improve on-farm water management. These interventions included a set of precision land levelling, irrigation system design and management, irrigation scheduling, crop management, and innovative institutional arrangements (see Figure 7).

Precision Land Leveling (PLL)

Project activities focused on re-design of the conventional basin irrigation system. In some cases, this resulted in longer and narrower basin configuration. Length of run from field head to tail ranged from 50 to 150 m. The PLL was necessary for successful irrigation of long runs. Thus, it was concluded that the average value for maximum depth of cut within a field was 6.5 cm. It was also recommended that for smallholdings (1 *feddan* or less), consolidation is preferred to provide enough manoeuvring space. The project team managed to provide an estimate of the manpower and equipment requirement to perform the PLL for up to 15 *feddans*. Together with an estimated cost of 14 *L.E./feddan*, it was possible to clearly estimate the pros and cons of the PLL.

Because the PLL minimized field elevation variation, farmers were able to achieve good field coverage with smaller application depths. Drainage of excess water was consequently reduced. In one of the pilot areas, land levelling intervention resulted in application efficiencies of 70 percent and 75 percent for two long basins of 6.3 m x 133 m and 13 m x 50 m, respectively, while application efficiency on six unlevelled farms averaged 61 percent. Land levelling provided soil for maintaining, aligning, elevating and reconstructing channels. On the other hand, construction of long furrows and basins were made possible by the PLL, reduced *saqia*-to-field conveyance channel length and saved water. As a general trend, land leveling and conveyance channel improvements led to higher on-farm irrigation efficiencies. Higher efficiencies decreased irrigation time and reduced water lifting costs. Also, the PLL activities facilitated replacing *mesqas* with farm-access roads and reshaping fields to provide adequate irrigation from remaining *mesqas*.

On-farm Irrigation System

The United States Department of Agriculture-Soil Conservation Service (USDA-SCS) developed level irrigation system design methods for furrows and borders. These methods were adequate for farm irrigation system design at projects sites. It was possible to determine the dependence of on-farm irrigation efficiency on flow rate for borders and desirable results were obtained for flow rates exceeding 2.5 lit/sec per 100 m^2 of border area. It was also possible to estimate Manning roughness coefficient for broadcast small grains to be 0.15 and 0.04 for furrow irrigation.

A comprehensive analysis of the economic feasibility of lining channels in Egypt was conducted. Three typical channel sizes were specified and the lining costs associated with each size were estimated. The total annual cost (June 1983 values) for 2 500 m of size 1 (structural top width of 0.30 to 1.00 m) varied from 1.05 *L.E.*/m^2 (currently one *US $* = 5.5 *L.E.*) for bricks with concrete lining to 4.40 *L.E.*/m^2 for 35 mil (1 mil = 0.025 mm) butyl rubber membrane. For size 2 (structural top width of 1.00 to 3.00 m), total annual cost for 10 000 m of channels varied from 0.93 *L.E.*/m^2 for cast-in-place concrete to 3.53 *L.E.*/m^2 for 35 mil butyl rubber membrane. For size 3 (structural top width of 3.00 to 10.00 m), total annual cost for 5 000 m of channel varied from 1.02 *L.E.*/m^2 for soil cement to 3.41 *L.E.*/m^2 for 35 mil butyl rubber membrane.

Other improvements were introduced and tested in the field condition such as Elevated *mesqas*, renovation of water delivery system to provide gravity flow, and buried pipelines. The EWUP (1984) provided a thorough analysis of the pros and cons of each intervention. The EWUP water budget studies showed that inadequate hydraulic control resulted in water losses to drains of about 30-40 percent of inflow. Therefore, several system renovations were recommended to the canal head-gates, field turnouts and measurement structures.

Irrigation Scheduling and Crop Management

The EWUP experience involved developing irrigation schedules based on prevailing farmers' practices, measured soil water depletion and consumptive use estimates. Constraints to implementing an irrigation scheduling programme were also assessed. Project work at various field sites exhibited that improvement in crop management was required to gain maximum benefit from irrigation system interventions. Crop yields would be increased by implementing solutions to the prevailing crop management problems. Improved agronomic practices included timely sowing of improved crop varieties, adequate plant populations, plant protection against insects and diseases, and proper rate and timing of fertilizer application. These practices, combined with water management, increased crop production. In general, it was observed that higher yields and greater returns from applied water resulted when farmers followed recommended crop and water management practices.

The EWUP studies showed that irrigation should take place at a soil depletion of 40-50 percent of the available moisture in the effective root depth. This was equivalent to a soil water deficit of 7 cm, which was accepted as a guideline for irrigation time. The PLL also led, indirectly, to yield increases. Cropped area was increased through eliminating ineffective, closely spaced, shallow, poorly maintained field drains. Movement of soil from high to low areas in the field and subsequent soil smoothing improved seedbed quality at least for the next crop.

Institutional Arrangements

The introduction of new techniques designed to improve irrigation from the *mesqa* level to the on-farm operation required adoption of an approach that integrates these new techniques with the farmers' present irrigation practices. The EWUP introduced a mechanism called the Irrigation Advisory Service (IAS). It served as a prototype of an advisory service by helping farmers implement a PLL programme, construct on-farm irrigation systems and operate these new irrigation systems. Another radical concept introduced was the WUAs. This intervention

Photo 1: Water User Association and Improved *Mesqas*

stimulated a series of policy changes in MWRI (see Photo 1 for members of Water User Association and improved *mesqas*).

3.1.3. Uptake and Impact

The findings of the EWUP were the basis of the Irrigation Improvement Project (IIP) which was launched in 1988. After being carefully monitored and evaluated by local and international experts, the IIP was considered to be a landmark project that stimulated significant institutional reform and policy changes of the MWRI. The IIP has improved several important components of agricultural production, and water delivery and on-farm water management, in 450 thousands *feddans*. The Egyptian Government has been committed to a long-term improvement irrigation programme, resulting in a series of significant improvement to the water distribution and drainage systems. The IIP aimed at achieving the main goals of the National Master Plan approved by the Cabinet in 1984. Recently, a large World Bank loan is used to finance the Integrated Irrigation Improvement and Management Project (IIIMP) based on the observed and monitored impacts induced by different interventions made under the IIP (IPTRID, 2005).

In 2001, a national study was carried out to update the field survey that was executed in 1998 to determine the level of knowledge and behavior of farmers towards water use (EPIQ, 2001). The study surveyed 2 546 farmers on 317 *mesqas*. The 2001 survey included the same 245 *mesqas* that were surveyed in 1998.

In a recent survey carried out for monitoring and evaluation of the IIP (WMRI, 2007), two samples of farmers were surveyed: 240 farmers in Wassat village, Kafr El-Shiekh governorate and 338 in Mahmoudia village, Beheira governorate. WMRI survey and EPIQ results are reflected in the following sections for each specific IIP measure.

Structural improvements

At the mesqa level, the IIP has effectively reduced the problem of water inequity and supply shortages. This has been achieved through a mix of technical and institutional interventions. These interventions include replacement of the rotational system to continuous flow in combination with gravity flow in raised open mesqa canals or buried pipes operated at low pressure (IPTRID, 2005). Although, continuous flow conditions are not reached, the construction of lined canals and buried pipes has considerably increased conveyance efficiency. Individual pumping has been replaced by a centrally operated pumping system that is managed by members of Water User Associations (WUAs). Notably, the shift from individual to collective pumping has resulted in considerable cost savings in the order of one- third (see Photo 2 for improved delivery systems: radial gates on a hydraulic structure).

According to the preliminary findings of IIP's monitoring and evaluation component, unofficial reuse of drainage water has widely disappeared along improved mesqas. Also, water losses at the tail-ends of the mesqas into open drains were significantly reduced. The positive effect of irrigation efficiency gains at the level of mesqas may be counterbalanced by the loss of the "multiplier effect" of unofficial water reuse at that level; thus creating an opportunity to expand official reuse (Salman, 2005).

Photo 2: Improved Delivery system: Radial Gates on Irrigation Offtake


Photo: WMRI, NWRC

Yet, the effects of the IIP's technical interventions on the performance and functions of existing land drainage are not fully understood. It is assumed that the anticipated effect of improved *mesqa* design, through the IIP interventions, would lead to a decrease in seepage losses, and hence to lower water tables, and reduced drain discharge of the laterals. It was reported that water tables in the improved area have rendered the discharge capacity of drainage systems less effective (IPTRID, 2005).

In EPIQ study (2001), the survey showed that 45 percent of the farmers practiced unofficial drainage reuse due to inadequate canal water. WMRI study (2007) showed that the introduction of continuous flow is still significantly lagging behind other improvement interventions. Continuous flow has been effectively applied only to 18 percent of "Mahmoudia" sample. However, the assessment of farmers' acceptance of the continuous flow showed that all of them were in favour of continuous flow for different reasons. It also indicated that about 83.3 percent of the farmers in Wassat area and 90.8 percent in Mahmoudia area preferred pipeline as improved *mesqa* rather than raised lined *mesqa*.

Socio-economic aspects of the IIP

The appraisal of the socio-and agro-economic effects of improved irrigation suggests that increased availability of water has augmented the productivity of irrigated crops by 12 to 15 percent on average. At the same time, water productivity has increased, which primarily can be attributed to improvements in agricultural production technology. For example, farmers in the project area reported that they had widely adopted the use of short-duration rice varieties. This has shortened the time from transplanting to harvesting by up to four weeks and helped save a considerable amount of irrigation water. The shortening of rice cultivation by four weeks has created a window of opportunity for the cultivation of an additional crop, which would take advantage of the freed land and available water resources. The net effect of water savings through the adoption of short duration rice varieties is hence balanced by the farmers' intensification strategy. It is assumed that improved irrigation has augmented farmers' income, although gains probably fall short of expectations assumed at the project design stage (IPTRID, 2005).

EPIQ study (2001) showed that 75 percent of the sample expressed their interest to join WUAs, while 85 percent were willing to share irrigation improvement costs. In the WMRI study (2007), the increase in crop yield, in the areas where continuous flow was introduced, was significant according to Mahmoudia farmers. Increase in wheat, cotton, maize, and cice were estimated at 10.4 percent, 18 percent, 9.8 percent and 16.9 percent, respectively.

Institutional and legal arrangements

Since the introduction of year-round irrigation in the 1980s, provision of irrigation services at the levels of main and branch canals is the responsibility of MWRI's Irrigation Sector and its Irrigation District Units. The *mesqas* are fully owned and managed by groups of farmers served by the *mesqa*; they were not organized into any formal or informal groups. As a result, Law 12/1984 was issued to regulate the operation and maintenance of *mesqas* and field drains.

Despite the existence of law 12/1984, inequitable water distribution is a common problem along non-improved *mesqas*, and poses a serious constraint to improved water productivity. Inequity of water distribution has led to major conflicts and social unrest among farmers.

Under the IIP, farmers were organized into WUAs that were responsible for water distribution and participation in irrigation costs such as pumping and canal maintenance. In 1994, the irrigation legislation was amended (Law 231/1994) to regulate the establishment and registration of WUAs as a legal entity and to specify their responsibilities. As the owners of pumps, they operate and maintain them and ensure that the costs are covered. More than seven thousand WUAs were established under IIP and other projects. The MWRI has facilitated alternative management models at the branch canal level, including the Branch Canal Water User Associations (BCWUAs) supported by USAID and Water Boards supported by the Dutch Government and similar to those in the Netherlands. The Water Boards Project is currently moving to broaden the domain of water boards to the district level, which includes several branch canals.

Based on the EWUP recommendation irrigation improvement activities have institutionalized under a central administration in 1984. It was later upscaled to become the IIS in 1997. The mechanism through which EWUP suggested improved techniques would be introduced and diffused to farmers became the Central Administration for IAS. The advisory service generally performs two major activities: (1) advises farmers about ways to improve their irrigation practices; and (2) organizes farmers to operate and maintain their watercourses.

3.1.4. Summary

A summary of the rationale and objectives, findings, uptake and impact for the IIP case study is given in Table 1.

Table 1: Summary of Research Uptake Case Study I – Irrigation

Rationale /Objectives:
• Over irrigation on a relatively fixed area of land has caused:
  o waterlogging and build up of salts in the soil profile
  o low field efficiency and ineffectiveness of water delivery
• Emerging need for better on-farm management to improve the irrigation efficiency.
• EWUP's objectives were to:
  o improve the social and economic conditions of the Egyptian small farmers through development and use of improved irrigation water management and associated practices which increase agricultural production
  o promote efficient water use and decrease drainage problems
  o raise the institutional capacity of MWRI to develop and implement improved on-farm water management programs

Sub-Component	Findings	Uptake/Impacts
Precision Land Leveling (PLL)	• PLL minimized field elevation variation: o farmers were able to achieve good field coverage with smaller application depths o drainage of excess water was consequently reduced o reduced *saqia*-to-field conveyance channel length and saved water o with conveyance channel improvements led to higher on-farm irrigation efficiencies • Higher efficiencies decreased irrigation time and reduced water lifting costs.	• Although, continuous flow conditions are not reached yet, the construction of lined canals and buried pipes has considerably increased conveyance efficiency. • Individual pumping has been replaced by a centrally operated pumping system that is managed by members of WUAs. • Shift from individual to collective pumping has resulted in considerable cost savings in the order of one-third. • IIP's monitoring and evaluation component showed that: o unofficial reuse of drainage water has widely disappeared along improved *mesqas* o water losses at the tail-ends of the *mesqas* into open drains were significantly reduced • Positive effect on irrigation efficiency gains at the level of *mesqas* may be counterbalanced by the loss of the "multiplier effect" of unofficial water reuse at that level; thus, creating an opportunity to expand official reuse.
On-farm Irrigation System	• Total annual cost for three typical canal sizes was estimated to analyze the economic feasibility of lining. • Inadequate hydraulic control resulted in water losses to drains of about 30-40% of inflow. • Several system renovations were recommended to: o canal head-gates o field turnouts o measurement structures	

Irrigation Scheduling and Crop Management	• Higher yields and greater returns from applied water resulted when farmers followed recommended crop and water management practices. • Irrigation should take place at: o soil depletion of 40-50% of the available moisture in the effective root depth o equivalent to a soil water deficit of 7 cm, which was accepted as a guideline for irrigation time • PLL made construction of long furrows and basins possible: o cropped area was increased through eliminating ineffective, closely spaced, shallow, poorly maintained field drains o soil smoothing improved seedbed quality at least for the next crop	• Increased availability of water has augmented the productivity of irrigated crops by 12 to 15% on average. • Water productivity has increased, which primarily can be attributed to improvements in agricultural production technology. • Farmers' income has been augmented, although gains probably fall short of expectations assumed at the project design stage.
Institutional Arrangements	• Irrigation advisory service was suggested as a mechanism through which improved techniques would be introduced and diffused to farmers • The radical concept of WUAs was found: o feasible o socially acceptable o operational and replicable o needs legislation	• IIS was established in 1997 under the Irrigation Department of MWRI. • IAS was established in 1999 as a central administration in IIS that advises farmers to: o improve their irrigation practices o operate and maintain their watercourses o organize themselves in WUAs o implement a precision land leveling programme o construct on-farm irrigation systems • In 1984 was issued to regulate the operation and maintenance of *mesqas* and field drains. • In 1994, the irrigation legislation was amended (Law 231/1994) to regulate the establishment and registration of WUAs as a legal entity and to specify their responsibilities. • Currently seven thousands WUAs exist. • MWRI has facilitated alternative management models at the branch canal level, including BCWUAs.

3.2. Case Study II: Subsurface Drainage

3.2.1. Rationale and Objectives

Launching the National Drainage Programme (NDP) in 1970 was associated with the establishment of the EPADP in 1973 and the Drainage Research Institute (DRI) in 1976, as one of the institutes of the National Water Research Center (NWRC). EPADP's original mission was to undertake the design, implementation, operation, maintenance and development of drainage systems at the national level. DRI's mission was to carry out applied research that leads to cost-effective and environmentally safe drainage systems. The idea was to create a strong research and development component that could support EPADP to accelerate the implementation of the national drainage programme. DRI investigated new cost-effective drainage materials, technologies and methods and evaluated their suitability to local conditions.

The Drainage Research Programme (DRP-I) started in 1989 within the framework of Dutch Development Aid, supported by the Advisory Panel Project on Land Drainage that was established jointly by both the Dutch and the Egyptian governments. The most economic and appropriate drainage materials such as plastic pipes and synthetic envelopes were tested in both labs and fields. Pipe connections, manholes, flushing structures and other drainage system components have been subjected to research to improve their quality and construction methods.

DRP-II, which started in 1994, continued research items from the previous programme as well as new research agenda. New design concepts and methods have been developed and investigated to reach optimal design criteria. Quality control methods and equipment have been always subjected to investigation to assure quality of constructed drainage systems. Installation of trenchless technology has been successfully tested in areas with unstable soils as well as in clayey soils. Maintenance equipment and procedures have become another area of interest for research. Drainage of areas with problematic conditions such as areas subject to artesian pressure, unstable soils and areas with rice in the crop rotation has been studied by the DRI.

The DRP was mainly composed of three main research areas. These are: the construction materials, the drainage system, and the drainage technology (see Figure 7). The rationale and objectives, the conducted research and findings as well as the uptake and impact of each research area and its main components are provided in the following sections.

Construction materials

Drainpipes

Installation of subsurface drains started as early as 1942. At that time the installation was carried out manually using clay pipes for laterals, with diameter of 100 mm, plain concrete for small diameter collectors and reinforced concrete for large diameter collectors. Clay tiles were difficult to handle and transport, and had unsatisfactory hydraulic performance due to sediments inflow through the gaps between pipes. However, important developments have taken place since the start of the execution of large-scale sub-surface drainage projects in the 1970s.

These improvements included the introduction of new drainage pipe materials, connections and fittings, and drain envelope materials.

In 1963, plain concrete lateral drainpipes were introduced by EPADP, which created fitting problems between the laterals and the collectors. Also, DRI found that the installation of concrete collector drainpipes in the Nile Delta fringes, where sandy subsoil exists, has been difficult and resulted in a very rapid clogging of the drains.

Drain envelope

Drainage envelope materials increase the efficiency of subsurface drainage systems by protecting drainpipes against soil particles invasion and facilitating the flow of water into drainpipes by creating a more permeable zone around drains. Until 1995, the only envelope material used in constructing subsurface drainage systems was gravel. The application of gravel around the drain has involved quite a few problems. The quality, transportation (geographical availability), application precision, and quality control were weak points in the use of this voluminous costly material as envelope for subsurface drainage pipes.

Connections

In the early 1960s, glazed cross pieces were used to connect lateral pipes (clay tiles or cement) that have small diameter with concrete collector pipes, while buried manholes were applied for large diameter collector pipes. Such connections required not only a laborious installation method but also considerable excavation and dry work conditions. DRI also found that these connections cause intolerable sedimentation problems (Amer et al, 1989). The manholes were constructed before laying collectors at every third or fourth lateral (max distance between manholes 180 m). Excavation to install the manholes was often done manually or by using excavator under wet and unstable soil conditions.

Drainage system

Design criteria

When DRP project started in 1994, four pilot areas were still actively monitored and the data from three of the areas was reviewed to assess the potential for further analysis. The functions of the pilot areas in general were to identify the optimal design criteria. In other words, determine best drain depth, spacing, combination of spacing and depth and the best drain envelope to be used. The pilot research extended to test new systems (modified), and was supported by laboratory testing and computer modeling as well. The research work on drainage design included developing new design concepts and theories and adapting existing techniques to local conditions. DRI investigated and compared both steady and unsteady state spacing equations for pipe drainage design.

Modified drainage system

The implementation of covered drainage in areas with rice in the crop rotation has faced some problems due to the great differences in the drainage rate between rice crop and the other crops. While all other crops need a well-aerated root zone, rice requires ponding conditions throughout its growing season. With the conventional layout of the drainage system and the prevailing cropping pattern, the rice fields usually share the same drains with other crops in a random pattern that changes with the crop rotation.

Drainage technology

Installation techniques

Subsurface drainage installation problems were encountered in the unstable sandy soils at the fringes of the Nile Delta and Nile Valley. These problems were aggravated with the presence of high water table or upward artesian pressure. The collapsing trench walls caused misalignment problems or permanent damage to the drainpipes. The high water table led to an inflow of sediment-rich water into the drainage pipe during construction and caused floating of the plastic drainage pipe. These problems were observed during construction of Haress and Mit Kenana pilot areas. Therefore, the introduction of the trenchless drainage technique in areas with unstable soils was inevitable.

Flushing

Nowadays, jet flushing is a very effective technique for cleaning drainpipes and improving their performance. It removes sediments and obstructions and cleans the perforations of the drainpipes. The large volume of water flushes the loosened sediments to the downstream end of the pipe or the downstream manhole of collector pipes.

A flushing machine consists mainly of a hose and a nozzle with a pump at the other end of the hose. The amount of the flow and the exit pressure at the hose depend on the type of the machine. Two different types of jet flushing machines, high and medium pressure (HP and MP), are used.

Economic evaluation for both types of flushing machines was also conducted to compare the total costs of the two machines under local circumstances. Considering the thickness of the sediments inside lateral drainpipes before and after the flushing process, the sediment removal efficiency achieved by using medium pressure flushing machine was found to be higher than that of the high-pressure machine. The drains flushed with the HP machine regained sediments in the pipe after flushing while this was less with the MP machine.

3.2.2. Conducted Research and Findings

Construction materials

Drainpipes

DRI has contributed to the introduction of new construction materials and methods through testing them in experimental fields and pilot areas of Mashtul, Harrara, Mit Kenana and Haress in the Nile Delta. These pilot areas were selected to represent the three main regions of the

Nile Delta: East, Middle and West. They also have diverse soil conditions and types as well as different cropping patterns. Most of these pilot areas were sizable with area ranging between 160 to 500 *feddans.*

In 1986, DRI introduced the use of plastic tubing for collectors in the Harrara pilot area (Western Delta). Corrugated perforated Poly-Vinyl Chloride (PVC) and High Density PolyEthelene (HDPE) pipes for laterals were tested for both laterals and collector drainpipes. It was found that HDPE pipes float, while PVC pipes sink which makes them advantageous when construction takes place below the water table. The major advantages of plastic drainpipes over clay or concrete pipes are the lower weight per meter length, and the greater length with less joints and connections (DRI, 1986).

Drain envelope

DRI investigated the applicability of the Hydraulic Failure Gradient method for the same purpose, under Egyptian conditions (DRI, 1998). The need for drain envelopes in soils with clay less than 30 percent was confirmed in Abu El-Matamir area (West Delta). It was also found that installation cost of synthetic envelope is 50 percent less compared with gravel cost.

Connections

After the introduction of corrugated plastic PVC laterals in subsurface drainage, DRI searched for cheaper and more practical methods for connecting PVC laterals with concrete collectors. In 1984, an alternative solution for lateral-collector connection and flushing laterals was developed and tested in field experiment. The new connection consisted of one PVC Tee, while for flushing purposes two Tees can be used.

Drainage system

Design criteria

Studies were conducted by DRI in three pilot areas for defining the design criteria. Two pilot areas were located in the Eastern Nile Delta (Mashtul and Mit Kenana) and the third was located in the Western Delta (Haress). Mashtul pilot area was provided with subsurface drainage system in 1980, while the other two pilot areas were provided with subsurface drainage system in 1992. The best drain spacing for Mashtul pilot area was found to be 30 m with 1.2 m drain depth. Haress and Mit Kenana pilot areas (West and East Delta, respectively) represent newly reclaimed land that is subject to high water table and salinity problems. For Haress pilot area it was found that drain spacing of 80 m is more suitable (water table depth is 0.80 m and drain depth is 1.2m). For Mit-Kenana pilot area it was found that drain spacing of 60 m is optimal (water table depth is 0.90 m and drain depth is 1.2m). The results of lateral discharge showed that the design drainage coefficient of 1.5 mm/day and 2 mm/day are better to be used in Haress and Mit-Kenana pilot areas respectively. The implementation of subsurface drainage in such areas needed trenchless machines and pre-wrapped lateral pipes to be used, due to the problems of unstable liquefying subsoil observed during construction with trencher machines.

Modified drainage system

DRI studies from 1977 to 1988 focused on the validity of the modified drainage concept from the point of view of saving Rice irrigation water. It is based on dividing the total drained area to sub areas served by sub-collectors and one collector. An investigation programme was conducted from 1977 until 1979, while during the period 1980-1988, the concept of the modified drainage system was developed and tested in experimental fields at Balakter pilot areas, Behira Governorate.

In general, it was observed that modified drainage saves about 32-48 percent of the irrigation water. Applying irrigation improvement could save 21 percent through lining *mesqas*, using one lifting point, and irrigation scheduling for every farmer. The studies of DRI during the period from 1996 to 2000 confirmed that the application of controlled drainage with IIP could save about 2 500 m^3/*feddan* of Rice irrigation water. Also, saving in irrigation time was 32 percent in the area with IIP during rice season of 1997 (DRI, 1998).

Drainage technology

Installation techniques

In close collaboration with EPADP, DRI executed a Trenchless Drainage Experiment for three months in the summer of 1996 in three areas at the north of Beheira Governorate, West Delta. During installation, a major part of the data collection was devoted to assess the effects of the typical features encountered in small scale irrigation systems on V-Plough drain construction. The observations were divided into two main components: a time/motion efficiency study and an intensive study of all the factors that could affect the net pipe laying rate of the machine. Also, the hydraulic performance of the systems installed by the V-Plough was compared with those laid by the Trencher, as well as installation cost in both cases. The observations were divided in two main components: a time/motion efficiency study and an intensive study of all the factors that could affect the net pipe laying rate of the machine. It was found that the production per hour of the V-Plough was 1.5 times higher than the average production of trenchers of comparable age. The installation costs per kilometer drain with the V-Plough proved to be 17 percent lower than with the trencher (DRP I and II, 2001a). During installation, no difficulties were encountered in any of the soil types and virtually no machine maintenance was needed. However, some disadvantages of the Trenchless technique were observed, such as the fact that not all wet (irrigated) fields could be crossed (approximately 1 percent of all drains), and that visual inspection of the installed drains was not possible.

Flushing

DRI conducted field experiments to evaluate and compare the two kinds of machines, which are used for flushing the lateral drainpipes. The first one was operated under high pressure (HP) (>60 bar at pump), while the second one was operated under medium pressure (MP) (20-40 bar at pump). The experiments were carried out in three different areas in the West of the Delta, namely: Elgorn, Ellawaya and Harrara. Subsurface drainage systems in these areas include different kind of pipes materials and soil types. The obtained results showed almost regular speed of advance and withdrawal for the flushing hose inside the drainpipes in case of using MP flushing machine. While the movement of the flushing hose with the HP flushing machine was irregular with significant reduction in the withdrawal speed of the flushing hose. Flushing efficiency is greatly decreased if the operating pressure for HP machine is dropped to only 25 percent of design pressure during hose withdrawal. The economic evaluation of the two machines MP and HP showed that the total costs of the MP flushing machine are less than the costs of the HP flushing machine by about 33 percent. Manpower, fuel and crop damage costs are the main causes for such difference (DRP I and II 2001b). From the conclusions of this study, it was recommended to use medium pressure flushing machines, particularly in light soil for highly economic and efficient flushing for similar conditions.

3.2.3. Uptake and Impact

Construction materials

Drainpipes

Facilitated installation of corrugated PVC and HDPE pipes in small pilot areas encouraged EPADP to replace all lateral and collector drainpipes. After monitoring hydraulic performance of the plastic perforated drainage systems, DRI proved that their use would be more economic and less problematic under the different prevailing soil conditions in the three Delta regions. Therefore, from 1980 onwards, corrugated PVC pipes and HDPE completely replaced concrete laterals. HDPE is also very well suited for laterals drain and for large-diameter collector pipes. In 1998, EPADP decided that all collector drainpipes should be either PVC or HDPE pipes. Reinforced concrete pipes are still used at the outlet and the flushing inlet of the collectors only.

Drain envelope

After pre-wrapped pipes (with synthetic envelopes) were tested on operational scale, their use was generalized in 1996 by EPADP on large scale projects. They are applied whenever soil conditions (less than 30 percent of clay) require the application of envelope material. Gravel is not applied any more due to its high cost, limited availability and installation problems.

Connections

Tee connections are also used by EPADP to connect corrugated PVC lateral drains with PVC collector pipes. Pre-fabricated standardized manholes were designed and tested by DRI in Mashtul pilot area. EPADP generalized its use to cope with mechanical installation of laterals and collectors which significantly accelerated the NDP construction process (see Photo 3 for the installation of pre-cast concrete manholes).

Photo 3: Installation of Pre-Cast Concrete Manholes


Photo: DRI, NWRC

Drainage system

Design criteria

EPADP adapted the design criteria developed by DRI according to regional characteristics. Recently and according to DRI recommendations, EPADP increased the drainage rate in the northern parts of the Nile Delta to 1.2 mm/day. The minimum spacing between laterals is 30m and the average drain depth varies between 1.3-1.4 m. For rice and non-rice areas, the design drainage rate to calculate pipe diameters is 2 mm/day. EPADP has developed computer aid design software that automated the design process based on the developed design criteria. Geographic Information System (GIS) played the central role in this software. The unsteady state equation requires additional parameters which are very complex to be measured in the field. Therefore, EPADP did not adapt the unsteady state spacing equation in the design process although it was proven to be more economic.

Modified drainage system

EPADP selected El Khawaled area, in Kafr El Sheikh Governorate, as a case study for applying modified drainage system in IIP areas. EPADP prepared two layouts, one as a conventional system and the other as modified drainage, with an increased number of sub-collectors. The results proved that the total costs were increased with 27 percent in case of using modified system. Also, it proved that 43 percent would be saved in irrigation cost; this means that the net return would be about 16 percent to the farmers.

Nevertheless, EPADP did not generalize the application of modified system to other rice cultivated areas in the Delta. Actually, the free unconsolidated cropping pattern prohibited the implementation of the modified drainage system, also the relationship between both the farmers and the institutions of services are not good except the cooperative and IIP members. However, participatory approach that is adopted currently by the MWRI in all water management aspects (irrigation and drainage), may lead to successful implementation and operation of modified drainage system in the future.

DRI carried out a study to evaluate the performance of the controlled drainage system in Balakter area (11 500 *feddan*s) in the Beheira Governorate (DRI, 2002). The results of the study revealed the low level of farmers' awareness with respect to controlled drainage concept and its benefit in water rationalization through rice field consolidation. Controlled drainage system were carried out on 75 sub-controllers which served about 2 250 *feddans* and represented about 22 percent of the total cultivated area in the study area. The total number of land owners, where the controlled drainage was applied, was about 1 550 farmers representing about 4 percent of the total farmers in the study area.

During the period between November 1999 and March 2000, the interdisciplinary study team introduced the concept of controlled drainage in the rice fields to the farmers and encouraged them to consolidate their crops. According to a semi-structured interview which was carried out with the farmers in the pilot area, only 2.25 percent of the farmers agreed to apply controlled drainage in their fields and 1.4 percent rejected the concept.

Drainage technology

Installation techniques

EPADP decided to purchase the Trenchless machine for further testing under typical Egyptian contractor conditions. The average gross production of the V-Plough Trenchless machine was calculated as 615 m/hr (see Photo 4 for the Trenchless Installation Machine). This production was compared with the production data on trenches of the Operational Research Unit.

The machine offered substantial construction savings and seems highly appropriate for application in the fringe areas of the Nile Delta where future drainage construction is taking place, and where typically the problematic soil are present. Currently, EPADP uses V-Plough Trenchless machine in installation of subsurface drainage system at the different Delta areas including those with heavy clay soils.

Flushing

Despite the DRI strong recommendation, EPADP is still using HP flushing machines in maintaining some subsurface systems. This probably because it faces logistic and technical

Photo 4: Trenchless Installation Machine


Photo: DRI, NWRC

problems in modifying more than 300 HP flushing machine, that are currently owned, to medium flushing machine. However, all of the newly purchased flushing machines are MP.

3.2.4. Summary

A summary of the rationale and objectives, findings, uptake and impact for the Subsurface Drainage case study is given in Table 2.

Table 2: Summary of Research Uptake Case Study II – Subsurface Drainage

Rationale/Objectives:
• National Drainage Program was a large scale programme
  o shift from manual installation to mechanical installation.
• Accelerate the implementation of the national drainage program by:
  o investigating new cost-effective drainage materials, technologies, and methods and evaluate their suitability to local conditions
• Optimal design criteria, new design concepts and methods were required especially in problematic areas.

Sub-Component	Rationale/ Objectives	Findings	Uptake/Impacts
Construction Materials	• Clay drainpipes were difficult to handle and transport, and had unsatisfactory hydraulic performance due to sediment inflow through the gaps between them. • Plain concrete lateral drainpipes that were introduced by EPADP in 1963, created fitting problems between the laterals and the collectors. ○ installation of concrete collector drainpipes sandy subsoil has been difficult and resulted in a very rapid clogging of the drains • The application of gravel around the drain has involved quite a few problems: ○ quality ○ transportation (geographical availability) ○ application precision ○ quality control ○ voluminous costly material • Glazed cross pieces were used to connect lateral pipes (clay tiles or cement) that have small diameter with concrete collector pipes, while buried manholes were applied for large diameter collector pipes. ○ required not only laborious installation method but also considerable excavation and dry work conditions ○ cause intolerable sedimentation problems	• HDPE pipes float, while PVC pipes sink which makes them advantageous when construction takes place below the water table. • Major advantages of plastic drainpipes over clay or concrete pipes are the lower weight per meter length, and the greater length with less joints and connections. • Plastic perforated drainage systems proved to be more economic with high hydraulic performance and less problematic under the different prevailing soil conditions in the three regions of the Delta. • Drain envelopes are needed in soils with clay less than 30%. • It was found that installation cost of synthetic envelope is 50% less compared with gravel cost. • New connection consisted of a PVC Tee, while for flushing purposes other Tees can be used. • Pre-fabricated standardized manholes were designed.	• From 1980 onwards, the corrugated PVC pipes and HDPE completely replaced concrete laterals • In 1998, EPADP decided that all collector drainpipes should be either PVC or HDPE pipes ○ Reinforced concrete pipes are still used at the outlet and the flushing inlet of the collectors only • In 1996 EPADP generalized synthetic envelopes use on large scale projects whenever soil conditions (less than 30% of clay) require the application of envelope material • Gravel is not applied any more due to its high cost, limited availability, and installation problems. • Tee connections are used by EPADP to connect corrugated PVC lateral drains with PVC collector pipes • EPADP generalized the use of Tee connection and pre-fabricated manholes to cope with mechanical installation of laterals and collectors which significantly accelerated the NDP construction process.

Drainage Systems	• Developing new design concepts and theories and adapting existing techniques to local conditions. • Identifying the optimal design criteria. o determine best drain depth, spacing, combination of spacing and depth and the best drain envelope to be used in different soil types of the Delta • Under the conventional layout of the drainage system and the prevailing cropping pattern. o the rice fields usually share the same drains with other crops in a random pattern that changes with the crop rotation o high losses of rice irrigation water	• Best drain spacing for old agriculture land in the Middle Delta is 30 m with 1.2 m drain depth. • For newly reclaimed land in West Delta it is better to use drain spacing of 80 m, depth is 1.2 m. • For newly reclaimed land in East Delta it is better to use drain spacing of 60 m and drain depth is 1.2 m. • Results of lateral discharge showed that the design drainage coefficient of 1.5 mm/day and 2 mm/day are better to be used in West and East Delta, respectively. • Modified drainage saves about 32-48% of the irrigation water. • IIP saves 21% through lining *mesqa*s, using one lifting point, and irrigation scheduling for every farmer. • Application of controlled drainage with IIP could save about 2 500 m^3/ *feddan* of irrigation water. o saving in irrigation time was 32% in the area with IIP during rice season • Total costs were increased with 27% in case of using modified system. o it was proved that 43% would be saved in irrigation cost o this means that the net return would be about 16% to the farmers	• EPADP adapted the design criteria developed by DRI according to regional characteristics. o EPADP increased the drainage rate in the northern parts of the Nile Delta to 1.2 mm/ day o minimum spacing between laterals is 30 m and the average drain depth varies between 1.3-1.4 m o for rice and non-rice areas, the design drainage rate to calculate pipe diameters is 2 mm/day (EPADP) o due to application complexity, EPADP did not adapt the unsteady state spacing equation in the design process although it was proven to be more economic • EPADP did not generalize the application of modified system to other rice cultivated areas in the Delta. o the free unconsolidated cropping pattern prohibited the implementation of the modified drainage system

Drainage Technology	• Subsurface drainage installation problems were encountered in the unstable sandy soils at the fringes of the Nile Delta and Nile Valley. o problems were aggravated with the presence of high water table or upward artesian pressure o collapsing trench walls caused misalignment problems or permanent damage to the drainpipes o water table led to an inflow of sediment-rich water into the drainage pipe during construction and caused floating of the plastic drainage pipe	• Average gross production of the V-Plough Trenchless machine was calculated as 615 m/hr. o this production rate was found to be higher when compared with the production data on trenchers	• EPADP decided to purchase the Trenchless machine for further testing under typical Egyptian contractor conditions.

3.3. Case Study III: Water Quality Management

3.3.1. Rationale and Objectives

The population growth and escalated living standards in Egypt have put more stress on both water and land resources. Degradation of these resources, due to heavy socio-economic exploitation, adds up to the water scarcity problem (see Photo 5 for water course pollution). Data were also required on sources of pollution to determine the nature and extent of contamination problems, their severity and causes. Without solid information and scientific research on water quality, pollution severity and impacts, it was difficult to determine what actions had to be taken to control water quality and what effect was likely to result if the proper control and mitigation measures were not taken. Hence the management of Egypt's water resources and the planning of more intensive water reuse called for better collection, analysis and dissemination of water quality data.

The growing demand on fresh water and the realization of the characteristics of groundwater increased the role of the groundwater in the overall water resources management, especially when the deserts have been included. This dictated various changes in the organizational structure, tools, human resources styles (various disciplines), research programme, etc. Therefore, the NWRC took the initiative to integrate water quality management in the MWRI's day-to-day practice.

Formulation of Egypt's water resources policy for the Twenty-first century required a major shift from the classical paradigm used in water resources planning and management to a new innovative approach. Increasing environmental awareness and quality deterioration of the limited fresh water resources necessitate the replacement of water quantity management by quantity and quality management.

Photo 5: Water Course Pollution in the Delta, Egypt

Photo: Wilfried Hundertmark, 2004

The Water Quality Management Programme was mainly composed of three main research areas. These are: the Nile water quality, the drainage water quality, and the groundwater quality (see Figure 7). Complementing the three main areas of research, a fourth programme called the National Water Quality Monitoring Network (NWQMN) started in 1998 with the purpose of rationalizing integrated water quality monitoring activities into a national monitoring programme. The rationale and objectives, the conducted research and findings as well as the uptake and impact of each research area/programme are provided in the following sections.

Nile water quality

The improvement and protection of Nile water quality has been identified as one of the national goals. Therefore and since 1976, the High Aswan Dam Side Effect Research Institute (HADSERI) (currently the Nile Research Institute, NRI) has been given the mandate to undertake various activities in the field of water quality management. Between 1976 and 1979 HADSERI, in collaboration with the Ministry of Health (MOH), produced a set of data on Nile water quality at selected sites along the river from Aswan to Cairo. During the same period NRI was able to determine the physical, chemical and micro-biological characteristics of effluents that were discharged into the river directly at specific locations.

From 1984 to 1986 another set of data was generated as a result of collaboration with the Occupational and Environmental Health Center of MOH. In this period, the Damietta and Rosetta branches were included in the investigation programme. In 1987 and 1989, combined work between HADSERI and the Faculty of Agriculture at Alexandria University focused on the water quality in the two branches as well as the characterization of selected drainage waters. The two collected data sets were sparse in space and time. Data collection campaigns adopted neither a fixed designed monitoring network nor a regular routine programme.

The objectives of the first Nile monitoring network established by River Nile Protection and Development project (RNPD-I) were to:

- serve as general reference for water quality condition in the entire river basin,
- detect stream standards violations and maintain effluents standards, and
- determine the quantitative seasonal variations of the water quality in the River and the point source of pollution.

Drainage water quality

Since 1975, the reuse of drainage water has been adopted as an official policy in Egyptian water resources management practice. The design of reuse schemes was based primarily on water quantity, salinity and the macro-ions in the main drains of the Nile Delta. In 1980, the first formal drainage water quality and quantity programme was initiated through long term cooperation between the Egyptian and Dutch Governments. As a result, in 1983 DRI started the implementation of the Reuse of Drainage Water Project (RDWP) to furnish the responsible authorities with information on the potential locations for reuse of drainage water in irrigation. RDWP aimed also at quantifying the effects of water management alternatives, namely the different quantities of recycled drainage water.

Until 1980, other relevant water quality parameters were given minor attention. There were very few and scattered records on the levels of domestic and industrial discharges except for basic parameters (Biological Oxygen Demand and Suspended Solids). However, such information did not cover all relevant water quality parameters.

The main objectives of the Monitoring and Analysis of Drainage Water Quality Project (MADWQ) were:

- Setting up and implementing an integrated measuring network to monitor drainage water quality in the Nile-Delta and the Fayoum Governorate.
- Application of mathematical models to support drainage water management and maximizing reuse of drainage water of acceptable quality.
- Systematic publication of data and information dissemination.
- Enhancement of NWRC research capacity to respond to external requests for management support in drainage water quality issues.

Groundwater quality

Many groundwater quality problems are already dispersed and may be widespread and frequent in occurrence. Examples include problems associated with the extensive application of chemical fertilizers in agriculture especially in the newly reclaimed areas, leaks in sewers, septic tanks, the aggregate effects of many different point sources pollution in urban areas and natural, geologically related water quality problems. The installation of observation wells started at the beginning of the last century.

The Research Institute for Groundwater (RIGW) of the NWRC received major support during the long cooperation between the institute and the Dutch Government. Since 1983, various programmes have been implemented under the Cooperation umbrella starting by the development and management of groundwater resources in the Nile Valley and Delta project (Phase I from 1983 to 1988, and Phase II from 1987 to 1992).

The Egyptian observation network for groundwater has included about 2 000 wells. The parameters for groundwater quality and quantity are measured from the same observation well.

With the environmental problems, the need for specific observation networks for groundwater such as for fertilizer, sea water intrusion, etc. has increased. One of the activities of the project of Development and Management of Groundwater Resources in the Nile Valley and Delta project (Phase II from 1987 to 1992) was to monitor and control groundwater pollution. This activity aimed at putting the preliminary guidelines for groundwater use and protection with respect to groundwater quality, and indicating some recommendations and priorities for future research.

Information about the present situation provides the water managers with tools for future use of water resources. In addition, policy measures carried out in the past can be evaluated and adjusted if necessary. New developments that threaten the groundwater quality can be identified and policy measures addressing these problems can be decided. The aim of the groundwater monitoring network is to provide decision makers with information about the present and future status of the groundwater quality. In addition, it will be possible to predict changes of the groundwater quality because of different water management policies. Hence, provide information about their effectiveness. If needed, the policies can be adjusted and with the knowledge from the network, different scenarios can be generated.

National Water Quality Monitoring Network (NWQMN)

The Environmental Action Plan of Egypt focused on the need for integrating the existing water quality monitoring networks and programs (Kijkman et al, 1992). Meanwhile, the Government of Egypt had conducted several initiatives, amongst which two initiatives were jointly funded with the Government of the Netherlands and one was funded by the African Development Bank.

The specific objectives of NWQMN were to:

- describe the quality of water entering Egypt through Lake Nasser;
- quantify the seasonal variations of contaminant concentration along River Nile;
- quantify temporal and spatial variations of irrigation water and drainage water as well as the potentiality of drainage water reuse in the Delta and Fayoum area; and
- assess aquifers' vulnerability to pollution and groundwater suitability for different uses in the Valley and Delta as well as the desert.

3.3.2. Conducted Research and Findings

The Water Master Plan project was one of the pioneer projects initiated under the umbrella of the NWRC to achieve its goal. The first main task performed in this project was a nation-wide assessment of the present and potential water resources. Hence, a comprehensive water quality study was carried out, as part of the national water resources assessment task. This study triggered several concerns about the water quality future status and revealed the necessity to begin a water quality monitoring program to all water resources in Egypt.

Nile water quality

In the early 1990s, the Canadian International Development Agency (CIDA) co-financed a large project called RNPD-I. The NRI was the implementing agency on the Egyptian side. One of the main components of RNPD-I aimed at the establishment of a water analysis laboratory and monitoring programme for the Nile River from Aswan to the Mediterranean.

After the establishment of the water analysis laboratory, Nile water quality assessment became the full responsibility of the NRI. The first yield of this laboratory was the set of data collected on the main stem of the river and the two branches, along with potential point sources of pollution in 1990-1991. However, the Agricultural Research Center was contracted to do the analysis for organochlorine pesticides in the water samples. In this programme, priority was given to 13 major sites taking into consideration the barrages, the major industrial areas and the intensive agricultural areas and large cities. Another 22 sites were selected as well as known points along the river in order to fill the gaps between major sites and to represent different stages along the river. In addition, the programme identified 61 wastewater discharge points to be investigated. These points were located at the major agriculture drains and industrial outfalls which are potential sources of pollution into the Nile River and its two branches.

The generated data revealed that the river system received heavy loads of dissolved solids, nutrients, organochlorine pesticides and heavy metals from the investigated agricultural drains and industrial outfalls. However, the loads were diluted by the river flow in such a way that the impact on water quality was generally limited. Nevertheless, some effects appeared at some river sectors especially in the downstream reaches of the main channel and in the Damietta branch.

Water quality of the Rosetta branch was assessed before, during and after the winter closure period. High loads of dissolved solids, nutrients, organic matter, organochlorine pesticides and heavy metals were disposed into the branch via agricultural drains and industrial outfalls. The highest load was from El-Rahawy drain and the industrial outfalls at Kafr El-Zayat. It appeared from the collected data that the pollution loads were diluted by Nile water during the winter closure period so much that their impacts on water quality were masked. Prior to the winter closure period, the impact of pollution showed up and resulted in lowering Dissolved Oxygen and power of Hydrogen levels to reach critical situations. Material balance calculations pointed out that those hazardous chemicals could be accumulated within the aquatic ecosystem and might have concentrated in the food chain. There was a high probability of the need for some water use limitation as a result of water quality deterioration in the Rosetta branch during the low-flow season, which extends for most of the year in that branch.

Based on the experience gained by NRI in the field of the Nile water quality assessment and according to the findings extracted, the following recommendations were made:

- Stream quality assessment should be continued, being one of the important components of any operational environmental quality management system. The management of water quality is not merely a matter of wastewater treatment.

- It is important to have the Nile water quality standards accepted by water quality specialists and the scientific community so that they can be employed to develop a "Status of Nile Water Quality". The existing standard limits and the list of parameters under Art. 60 of the Law 48/1982 should be revised.

- Since it was found that some changes in water quality did occur at locations away from point sources of pollution, the loads of pollutants from non-point sources ought to be estimated in order to be able to formulate concrete cause-effect relationships.

- The existing water quality monitoring programme should be revised with regard to sampling site, time of sampling and parameters to be measured. Priority should be given to the low flow period when the worst water quality conditions are expected.

Drainage water quality

Through the course of RDWP, a monitoring network consisting of 100 sites for measuring the flow and salinity of water in the main drains was established and became fully operational since 1984. In addition, water samples were collected monthly and analyzed to determine the main ions, Total Dissolved Salts and Sodium Adsorption Ratio. The results were linked and integrated with a GIS which can add and overlay other relevant layers of data and information. Annual data was reported in a yearbook distributed by DRI to concerned decision makers.

Simulation models are valuable research tools as they provided better understanding of the various mechanisms (physical, chemical and biological) that control drainage water quality. They have been used for the evaluation of the effect of the different reuse policies on water quality. Therefore, Simulation of Water Management in the Arab Republic of Egypt (SIWARE) model was developed and used as a numerical simulation model to support water management and maximizing reuse of drainage water of acceptable quality (DRI and SC-DLO, 1995).

Afterwards the Governments of Egypt and the Netherlands joined forces again to execute a project called MADWQ project. It started in August 1995 with an original plan to end in August 1998. However, in 1997 it was decided to extend the project period to December 2000 so that the preset objectives could be achieved (Abdel-Gawad, 1997). MADWQ project objectives have been set to meet the needs of the Egyptian decision makers in drainage water quality for the Nile Delta and Fayoum. It was expected that the MADWQ network would provide valuable information on the availability and suitability of the agricultural drainage water for irrigation.

Quality Assurance/Quality Control (QA/QC) procedures that were adopted for the field sampling and laboratory analysis had improved the consistency of the collected information. Continuous monitoring was applied through the implementation of automated water quality stations that enabled the collection of the different water quality parameters on a continuous basis. This has increased the insights into the collected data and provided a means to observe its temporal and spatial variations.

Procedures for entry and screening of water quality data were improved throughout the course of the project. This has increased the reliability of the data and information produced. A database has been implemented for the storage, processing and retrieval of the drainage water quality over a network of minicomputers at DRI. As a result, the accessibility of the water quality data to a wide variety of decision makers had been increased. In addition, the extension of DRI yearbook with water quality data and information has greatly improved the availability of drainage water quality information to the interested governmental institutions (DRI and WL/Delft Hydraulics, 2000).

SIWARE model has been extended by the project to evaluate water quality effects of measures and the reuse potentials. It was contained in a wider computational framework (Delta Decision Support System) along with other models such as the Waste Load Model and the Delft Water Quality Model.

Groundwater quality

During the period from 1990 to 1994, the Government of Egypt and the Government of the Netherlands have executed a project entitled "Environmental Management of Groundwater Resources" (EMGR) project. EMGR project could be considered an integrated type of project. It addresses many interrelated issues, including institutional and managerial aspects, overall water resources management (quantity and quality) and human resources development. The overall objective was to contribute to a more efficient management of Egypt's groundwater resources in strong relation with environmental protection and leading to sustainable groundwater development. One of the main project programmes was dedicated to groundwater quality monitoring network.

Based on the monitoring rounds that have been carried out during the EMGR project period, some important conclusions were drawn. One of the conclusions is that the groundwater quality in the priority areas of the Nile Valley has deteriorated most seriously by land reclamation. The groundwater quality in the central part of the Nile Valley and the Nile Delta is not polluted, but contains high concentrations of manganese due to a reducing environment. When comparing the groundwater quality to Law 48/1982 standards, the majority of the monitored wells showed concentrations that exceeded at least one standard. However, some of the standards were not relevant for determining the suitability of groundwater for specific uses, since the prohibiting parameters can be removed with relatively cheap treatment of the raw groundwater. Therefore, it was recommended to select parameters from the list of standards that can be regarded as 'critical parameters'.

National Water Quality Monitoring Network (NWQMN)

Designing an integrated "National Water Quality Monitoring Network" for Egypt was envisioned together with the Dutch-funded projects. A study, which began in 1995, provided a conceptual design of an integrated national water-quality monitoring network in Egypt (DHV et al, 1996), and additional water quality data from the monitoring and analysis of drainage water quality project (DRI, 2000).

To guarantee homogenous comparable data coming out of the different water quality monitoring activities that takes place within the MWRI, the Central Laboratory for Environmental Quality Monitoring (CLEQM) was established. The investment cost was equally shared by the Egyptian and Canadian Governments through RNPD-II project. The laboratory was an essential step to ensure the production of high quality analytical results for the collected samples from the different water bodies.

NWQMN was established through a CIDA co-financed project called National Water Quality and Availability Management (NAWQAM). The purpose was to rationalize integrated water quality monitoring activities into a national monitoring programme starting from 1998. The NWRC was the implementing agency for the water quality monitoring component of the NAWQAM project through DRI, NRI and RIGW.

Based on these objectives, a considerable amount of research and stakeholders' consultation have been invested to reach the optimal design of the network. Since 1997, samples have been collected on a monthly basis from 158 locations on drains and irrigation canals in the Delta and Fayoum. The number of sites on the Nile main stem and its two branches is 69, where water is sampled twice a year (winter and summer campaigns). RIGW conducts one campaign per year and collects samples from about 218 observation wells. In general, water samples are analyzed in CLEQM for 34 parameters that reflect the different sources of pollutions, namely agriculture, domestic and industrial waste.

Aiming at providing a better understanding of the temporal and spatial variability of the quality of Egypt's water resources, the NAWQAM project has provided technical and financial assistance for the water quality monitoring programme. It also furnished NWRC with a large amount of monitoring instrumentation and laboratory equipment and supported the accreditation of CLEQM (see Photo 6 where water quality is monitored in situ).

Photo 6: In-situ Measurements for Water Quality Monitoring


Photo: DRI, NWRC

The main output of the network is the annual water quality status reports, which is submitted to the senior decision makers of the MWRI. Typically, the Central Unit for Water Quality Management synthesizes the annual status report and puts it in simplified form for wider external dissemination. The data made available over the last decade indicate that the Nile River up to now exhibits excellent water quality conditions. Nile water remains healthy and suitable for present beneficial uses with a few exceptions near Kom Ombo and Cairo. However, both Damietta and Rosetta branches suffer from organic pollution and deficiency of dissolved oxygen. In general, good groundwater quality is prevalent in most monitored locations; more specifically, groundwater in the Nile Valley and Delta has adequate quality to be used for irrigation and drinking with minimum treatment. A few irrigation canals in the Delta and Fayoum suffer from high organic, microbiological pollution and ammonia while almost all Delta drains are receiving agricultural, domestic and industrial discharges that exceed their assimilation capacity and violate the standards.

3.3.3. Uptake and Impact

Public health and environmental degradation concerns were deepened by the pollution threats to the Nile itself, the pressing need to reuse drainage water and expansion of groundwater utilization.

Nile water quality

Some of the findings and recommendations were not implemented such as the revision of the Law 48/1982; however, it is on the government's legal reform agenda. Therefore, a committee of professionals within the Ministry of Water Resources and Irrigation has been formulated to revise and update Law 48/1982. Also, putting some water use limitations for the Rosetta branch during the low-flow season was not possible. However, some investments were made to control pollution loads coming from the El-Rahway drain. The continuation and rationalization of the Nile monitoring programme; and the issuance of an annual status report for all Egyptian water resources, not only the Nile, became a regular management practice. On the organizational side, and due to a recommendation of the RNDP, MWRI has established the Nile River Development and Protection Sector (NRDPS). Its main mandate is to protect the river from all kind of violations including dumping of effluents not in compliance with the Law 48/1982. The early findings and results of RNPD-I contributed to the formulation of the Environmental Action Plan in 1992. With the support provided from NRI monitoring program, the Ministry of State for the Environment was able to implement a far-reaching compliance program for all the industries that discharge their effluents into the Nile.

Drainage water quality

The significant outcome RDWP has brought water quality, in general, on the top of the water resources management agenda in Egypt. Understanding of the current status of water quality and redefinition of problematic areas, provided by RDWP, supported the 1990 water policy. SIWARE was adopted and utilized for the policy formulation, planning development and implementation of Egypt's water resources plan. Although the primary objective of RDWP was to provide assistance in the planning and management of water resources, results of the project were also used in Egypt by other Ministries and authorities. Information furnished by the project was used in the formulation of some chapters in the first Egyptian Environmental Action Plan in 1992.

The SIWARE model has provided insights on the water quality cause and effect relations with respect to drainage system; which has strengthened DRI's role to support MWRI in evaluating strategies and scenarios for the future planning of water resources management. The formulation of recent National Water Resources Plan (NWRP) depended considerably on the Delta Decision Support System.

Groundwater quality

Groundwater is specifically addressed as "waterway", also in the implementation regulations of Law 48/1982, where limits are given for different effluents being discharged in either surface water or groundwater. Compliance with law 48/1982 has generally been weak, partly because of the imposed high standards. Nevertheless, the law forms a firm base for the protection of the Egyptian groundwater resources with respect to direct discharge (for example, by injection through wells).

The groundwater monitoring system in Egypt is an important element of the protection program to continually meet protection objectives and to determine whether, when and how groundwater contamination is controlled. Preventing contamination in the first place is by far the most practical solution to the problem. This can be accomplished by the recent adoption of effective groundwater management practices.

Measures of groundwater protection are commonly based upon the zoning procedure adopted by RIGW. It divides the entire land surface based on the vulnerability of aquifers to pollution and a series of special protection areas for individual sources of supply, in which various potentially polluting activities are either restricted or controlled. The zoning strategy enabled the setting of priorities for groundwater monitoring, environmental audits and pollution control whilst providing a tool for raising public awareness of the importance of groundwater.

According to the findings of the EMGR project, the role of groundwater has been given more emphasis in recent national water policies. Quantitative potential of aquifer systems essentially depend on the protection of groundwater resources. The Egyptian practice of protecting groundwater resources was modified to be based on (i) improved groundwater monitoring and adoption of early warning monitoring strategies, and (ii) setting priorities for action based on assessment of aquifer vulnerability and contaminant loading.

Recently established Groundwater Sector (in 2001), within MWRI, is responsible for the development and implementation of strategies that are applied to a specific groundwater resource under an overall NWRP. Groundwater protection plans and their component measures vary from policy statements outlining broad management objectives to prescriptive regulatory programs, including statutory controls and specific regulations on contaminating activities. Their intent is not limited to influencing decision-making regarding approval of potentially contaminating activities, but extends to control these activities. Groundwater protection plans are directed to minimizing future contamination of groundwater, detecting and managing contamination associated with past or existing activities.

National Water Quality Monitoring Network (NWQMN)

The collected data provided a better understanding of both seasonal and spatial variability of the quality of all water resources including irrigation system. The data provided the basis for the assessment and development of NWRP (NWRP, 2004). The principle of integrated water resources management was highly reflected in Egypt's NWRP for 2017, which paid significant attention to environmental protection. More than 60 percent of the required investment is allocated to pollution control measures. Serious revision of the drainage reuse policy took place due to the deterioration of the main drains quality, which led to halting of 18 mixing pump stations in the Delta. As an alternative policy, intermediate reuse was proposed as well as formulation of drainage reuse guidelines in agriculture to avoid long term impact.

3.3.4. Summary

A summary of the rationale and objectives, findings, uptake and impact for the Water Quality case study is given in Table 3.

Table 3: Summary of Research Uptake Case Study III – Water Quality

<table>
<tr><td colspan="4">Rationale/Objectives:
• Degradation of water and land resources, due to heavy socio-economic exploitation, adds up to the water scarcity problem.
• Concerns about the water quality future status and revealed the necessity to begin a water quality monitoring program to all water resources in Egypt.
○ were deepened by the pollution threats to the Nile itself, the pressing need to reuse drainage water and expansion of groundwater utilization
• Increasing environmental awareness and quality deterioration of the limited fresh water resources necessitate the replacement of water quantity management by quantity and quality management.</td></tr>
<tr><th>Sub-Component</th><th>Rationale/Objectives</th><th>Findings</th><th>Uptake/Impacts</th></tr>
<tr><td>Drainage Water Quality</td><td>• Since 1975, the reuse of drainage water has been adopted as an official policy in Egyptian water resources management practice.
○ furnishing the responsible authorities with information on the potential locations for reuse of drainage water in irrigation
○ Application of mathematical models to support drainage water management, maximizing reuse of drainage water of acceptable quality
• Information on drainage water salinity did not cover all relevant water quality parameters required on sources of pollution.
○ to determine the nature and extent of contamination problems, their severity and causes measures were not taken
○ to set up and implement an integrated measuring network to monitor drainage water quality in the Nile-Delta and the Fayoum Governorate
○ to systematically publish data and disseminate information</td><td>• Increased the insights into the collected data and provided a means to observe its temporal and spatial variations.
• Database has been implemented for the storage, processing and retrieval of the drainage water quality.
○ data screening procedures have increased the reliability of the collected data
• DRI yearbook with water quality data and information has greatly improved the availability of information about the water quality in drains to the interested governmental institutions.
• SIWARE model has been extended to DDSS for the evaluation of water quality effects of measures and the reuse potentials.</td><td>• Support MWRI in evaluating strategies and scenarios for the future planning of water resources management.
○ formulation of recent NWRP depended considerably on Delta Decision Support System
• Cumulative findings and results of drainage water quality programs contributed to the formulation of the Environmental Action Plan in 1992.</td></tr>
</table>

Nile Water Quality	• Improvement and protection of Nile water quality has been identified as one of the national goals.
	• Nile water quality data sets were sparse in space and time.
	  o data collection campaigns adopted neither fixed designed monitoring network nor regular programme
	• Objectives of the Nile monitoring network were to:
	  o serve as a general reference for water quality conditions in the entire river basin
	  o detect stream standards violations and maintain effluents standards
	  o determine the quantitative seasonal variations of the water quality in the River and the point source of pollution
		• The generated data revealed that the river system received heavy loads of pollutants from the investigated agricultural drains and industrial outfalls.
		  o loads were diluted by the river flow so much that the impact on water quality was generally limited
		  o some effects appeared at some river sectors especially in the downstream reaches of the main channel and in the Damietta branch
		• No correlation was found between the wastewater discharge points and the sites where marked changes in water quality parameters did occur.
		  o which leaves no doubt that the river received high loads of pollutants from unidentified sources
		  o data pointed out that nitrate fertilizers are used in overdoses
		• Water quality of the Rosetta branch was assessed before, during and after the winter closure period.
		  o high loads of agricultural pollutants were disposed into the branch via agricultural drains and industrial outfalls
		  o highest load was from El-Rahawy drain and the industrial outfalls at Kafr El-Zayat
			• Some of the findings and recommendations were not implemented such as the revision of the Law 48/1982; however, it is on the government's legal reform agenda.
			• Putting some water use limitations from Rosetta branch during the low-flow season was not possible; however, the government invested in WWTP to alleviate pollution loads coming from El-Rahway drain.
			• Continuation and rationalization of Nile monitoring program; and the issuance of an annual status report for all Egyptian water resources, not only the Nile, became a regular management practice.
			• On the organizational side and due to recommendation of RNPD, MWRI has established the Nile River Development and Protection Sector (NRDPS).
			• Early findings and results of RNPD-I contributed to the formulation of the Environmental Action Plan in 1992.
			  o with the support provided from NRI monitoring program, the Ministry of State for the Environment was able to implement a far-reaching compliance program for all the industries that discharge their effluents into the Nile

Groundwater Quality	• Increased the role of the groundwater in the overall water resources management, especially when the deserts have been included. ○ dictated various changes in the organizational structure, tools, human resources styles (various disciplines), research program, etc. • Groundwater quality problems are already dispersed and may be widespread and frequent in occurrence ○ extensive application of chemical fertilizers in agriculture especially in the newly reclaimed areas, leaks in sewers, septic tanks, the aggregate effects of many different point sources of pollution in urban areas ○ naturally and geologically related water quality problems • To contribute to a more efficient management of Egypt's groundwater resources in strong relation to environmental protection and leading to sustainable groundwater development. ○ to provide decision makers with information on the present and future status of the groundwater quality ○ to predict changes of the groundwater quality because of different water management measures	• Groundwater quality in the priority areas of the Nile Valley has deteriorated most seriously by land reclamation. • Groundwater quality in the central part of the Nile Valley and the Nile Delta is not polluted, but contains high concentrations of manganese due to a reducing environment. • Comparing the groundwater quality to the quality standards, the majority of the monitored wells showed concentrations that exceed at least one standard. ○ some of the standards were not relevant for determining the suitability of groundwater for specific uses ○ it was recommended to select parameters from the list of standards that can be regarded as 'critical parameters' • Zoning comprising division of the entire land surface based on the vulnerability of aquifers to pollution and a series of special protection areas for individual sources of supply, in which various potentially polluting activities are either restricted or controlled. • Annual water quality status reports, which is submitted to the senior decision makers in MWRI. • Data made available over the last decade indicate that: ○ Nile River up to now exhibits excellent water quality conditions. Nile water remains healthy and suitable for present beneficial uses with few exceptions near Kom Ombo and Cairo ○ both Damietta and Rosetta branches suffer from organic pollution and deficiency of dissolved oxygen. In general, good groundwater quality is prevailing for most monitored locations ○ groundwater in the Nile Valley and Delta has adequate quality to be used for irrigation and drinking with minimum treatment ○ few irrigation canals in the Delta and Fayoum suffer from high organic, microbiological pollution, and ammonia	• Groundwater is specifically mentioned as "waterway", also in the implementation regulations of Law 48-1982 (Decree no. 8-1983). ○ limits are given for different effluents being discharged into either surface water or groundwater • Zoning strategy enabled the setting of priorities for groundwater monitoring, environmental audits and pollution control whilst providing a tool for raising public awareness of the importance of groundwater. • The role of groundwater has been given more emphasis in recent national water policies. • Groundwater protection plans are directed to: ○ minimizing future contamination of groundwater ○ detecting and managing contamination associated with past or existing activities • Egyptian practice of protecting groundwater resources was modified to be based on: ○ improved groundwater monitoring and adoption of early warning monitoring strategies

		○ almost all Delta drains are receiving agricultural, domestic, and industrial discharges that exceed their assimilation capacity and violates the standards	○ setting priorities for action based on assessment of aquifer vulnerability and contaminant loading
NWQMN	• Environmental Action Plan of Egypt focused on the need for integrating the existing water quality networks. ○ to guarantee homogenous comparable data coming out of the different water quality monitoring activities that takes place within MWRI • Specific objectives of NWQMN are to: ○ describe the quality of water entering Egypt through Lake Nasser ○ quantify the seasonal variations of contaminant concentration along River Nile ○ quantify temporal and spatial variations of irrigation water and drainage water as well as potentiality of drainage water reuse in the Delta and Fayoum area ○ assess aquifer vulnerability to pollution and groundwater suitability for different uses in the Valley and Delta as well as desert		• Collected data provided a better understanding of both seasonal and spatial variability of the quality of all water resources including irrigation system. • Data provided the basis for the assessment and development of NWRP. ○ a large number of the suggested measures (or already taken) in NWRP are under pollution control or on environmental protection (more than 60 percent of the required investment is allocated to these measures) • Serious revision of the drainage reuse policy took place due to the deterioration of the main drains quality, which led to halting of 18 mixing pump stations in the Delta. • As an alternative policy, intermediate reuse was proposed as well as development of drainage reuse guidelines in agriculture to avoid long term impact.

3.4. Case Study IV: Grand Hydraulic Structures

3.4.1. Rationale and Objectives

Grand hydraulic structures can significantly affect the hydrologic and hydraulic regime of the channel they control; and call for large investments. Because they comprise complicated combinations of different components and elements (civil, mechanical and electrical), their design is not a straightforward or simple engineering exercise; and requires an extensive set of hydrologic, hydraulic and pythametric data. Therefore, mistakes in their preliminary design or unanticipated hydraulic problems are not affordable. Assurance of efficient performance, under different flow conditions, and optimal economic design are compulsory before the implementation. These are only attainable by research through physical modelling simulation and tests.

The Grand Hydraulic Structures Programme was mainly composed of two research areas. These are for the El-Salam Canal project and the New Naga Hammadi Barrage (see Figure 7). The rationale and objectives, the conducted research and findings as well as the uptake and impact of each research area are provided in the following sections.

El-Salam Canal project study

In an effort to cope with the increasing need for food production, Egypt took great strides towards the expansion beyond the boundaries of the Nile Valley. Several mega projects were planned to exploit available opportunities to establish new communities so as to achieve an overall improvement of the old valley's environment and conditions. The El-Salam Canal project is one of those efforts that aim at using the available water resources together with the agriculture drainage water to establish new communities in that part of the Sinai Peninsula. Such mega projects typically require a set of sizeable non-traditional hydraulic structures. In the case of El-Salam canal, a large siphon was required to transfer water, under the Suez Canal, from the Nile Delta to Sinai.

In 1992, the Hydraulics Research Institute (HRI) of the NWRC was assigned by the MWRI to conduct a hydraulic study of the proposed El-Salam Canal siphon under the Suez Canal. The function of the siphon is to carry a peak flow of 160 m^3/sec under the Suez Canal in order to supply irrigation demands in the Sinai Peninsula. The main purpose of this study was to check and test the hydraulic performance of the siphon as designed by Halcrow Ltd of England, an international consulting firm (El-Dessouky, 1993). This performance includes approach flow distribution, head loss, trash-racks design, vortex formation, submergence availability, rip-rap stability, and effect of surge wave created by downstream pump station apart.

New Naga Hammadi Barrage study

The operation of HAD and the downstream barrages provided full control of the Nile river flow. The elimination of annual floods has resulted in river bed degradation of up to 2 meters in fine to medium grained sand of the Nile Valley and consequently lowering of tail-water levels downstream of the old barrage. As a result, the designed safety factors of the old barrage stability have decreased slightly below the acceptable limits. In response to this, the MWRI decided to replace the existing old barrages along the Nile River. The replacement plan started with the construction of the new Esna barrage, followed by Naga Hammadi barrage which is currently under implementation. The Assiut barrage and new Delta barrages are considered for replacement in the MWRI's long term plan.

The new Naga Hammadi barrage, including a hydropower plant, is constructed at 3.2 km downstream of the old barrage. The morphological conditions at the selected site were rather unusual for constructing a large barrage with its auxiliary structures. These limiting conditions were: (i) narrowing the river at the construction location and having a tight bend around Dom Island with stream velocities higher than usual in the Nile, and water depths of about 8.5 m at the mean discharge; (ii) selected site for the new barrage was located at the inflection between the narrowing right hand bend and the subsequent wider left hand bend downstream Dom Island; and (iii) project components could not be constructed at the narrow river bend within the bed of the river, large excavation was required on the right bank. In addition, a temporary canal is needed to divert river flow during the four years of construction (see Photo 7 for the construction of new Naga Hammadi barrage).

The design of the new barrage includes three main components: (1) low head hydropower plant, (2) sluiceway, and (3) navigation lock. River discharges of up to 1 670 m^3/sec were planned to pass through the hydropower plant, subject to the constraint that the head pond level

Photo 7: New Naga Hammadi Barrage

Photo: HRI, NWRC

of the new barrage should not exceed the design head pond level of the old barrage (elevation of 65.9 above mean sea level). The sluiceway would operate only when the power plant is not operating, and for relatively short periods during the three high flow months (June to August), with variable discharges of up to 6 000 m^3/sec, or in cases of floods discharged from HAD which had not happened since its operation 30 years ago.

During the period from 1997 to 1999, the Reservoirs and Grand Barrages Sector of the MWRI contracted the International Consortium of Lahmeyer International, Electrowatt and Sogreah to carry out the feasibility study for the new barrage at Naga Hammadi (PIU, 2000). In order to confirm the main design features and optimize flow conditions in the vicinity of the main structures, the consortium has assigned HRI to perform hydraulic model tests to confirm the different design components, optimize the flow conditions in the immediate vicinity of the structures, and assure the stability of river bed and banks (HRI, 1997).

3.4.2. Conducted Research and Findings

El-Salam Canal project study

HRI designed a hydraulic scale model to provide the optimal hydraulic performance of the siphon's inlet and outlet structures. The hydraulic model gave insights into the physical processes which could not be obtained otherwise. Initially, a 1:20 undistorted scale hydraulic model, was constructed at HRI. The model represented 150 meters of the upstream canal, the inlet structure, the four tunnels (the total length of the tunnels was completely not represented), the outlet structure, and 150 meters of the downstream canal. The model was constructed inside a basin, with total dimensions of 12 meters in width, 28 meters in length. Its outer walls were one meter above the floor level. The inflow from the circulating system had a maximum capacity of 0.35 m^3/sec and was distributed across the total width of the basin by means of a multi-port diffuser. Water level was controlled by an adjustable weir at the downstream end of the model.

The canal was formed using sand-cement mortar according to the cross-sections supplied with the siphon drawings. Rip-rap used in the model was formed of gravel and according to the model volume scale. Inlet and outlet structures were constructed from wood and plexi-glass. The plexi-glass was used in the areas where the formation of vortices was expected, to permit flow visualization. Transient parts at the beginning and at the end of each tunnel were represented. Due to the limited area, it was not possible to represent the total length of the tunnels, which is 650 meters. The model represented only 180 meters of the tunnel's length. It was not possible to represent the screen at the same model scale. With scale 1:20 the flow through the screen was found to be laminar, and the bar space of 0.0085 meters has undesirable flow because of high effect of surface tension. It was necessary to have a bigger scale for the screen.

The study on the bigger scale model supported the design of the inlet and outlet structure, as proposed by Halcrow. However, HRI suggested several modifications to the original design of the transition area downstream the outlet structure, up to the rip-rap protected area in order to minimize the eddies and separation in this reach. It was also recommended to remove the anti-scour hump and exclude side emergency spillway, as it would result in additional head loss.

New Naga Hammadi Barrage study

Sluiceway model

A two-dimensional hydraulic detailed flume model (scale 1:20) of the sluiceway bay was built to check the flow patterns upstream and downstream of the proposed structure, and to provide input for further three-dimensional hydraulic scale model testing of the barrage layout. By the detailed model, the discharge capacity and hydraulic performance of the sluiceway were tested with the aim to confirm or optimize the levels of the sluiceway sill and apron, and the extension of the latter. The flume model gave direct insights into the physical processes. Results obtained from the flume tests showed that both apron shapes investigated by the flume tests appear to be acceptable for the Naga Hammadi Barrage. The appropriate apron length, that confines the hydraulic jump to the apron and rip-rap size that is required to achieve stability for a discharge of 4 000 m^3/sec, was recommended.

Barrage model

The Barrage model was a simple river model with fixed bed which, locally covered by rip-rap. The main variants in the model configuration were the proposed composition of the barrage structures after the finalization and the diversion layout during construction. The river reach modelled extended from 800 meters upstream of the new barrage axis to some 1200 meters downstream.

Photo 8: Physical Hydraulic Model of the New Naga Hammadi Barrage

Photo: HRI, NWRC

There were no significant irregularities observed in the approach flow, neither in the vicinity of the powerhouse nor of the sluiceway. The velocity pattern depended mainly on the rate of total flow approaching the barrage structures while the velocity field, in the downstream reaches, was strongly affected by the proportion of discharge from the powerhouse and from the sluiceway.

The tests with a discharge of 1 670 m^3/sec released only from the powerhouse showed that for the specific site conditions, there was clearly a need to separate the navigation lock from the powerhouse so as to avoid cross flow conditions dangerous for navigation. The results also confirmed the need to increase the required rip-rap diameter. The complementary sedimentation test in the upstream reaches of the barrage model carried out with movable PVC-material indicated that possible sediment movement (bed load) would be concentrated in the center of the river section and away from the approach to the navigation lock. As a result, it was not expected that the area in front of the lock entrance would be affected by sedimentation of fine bed load material (see Photo 8 for the physical hydraulic model of the new Naga Hammadi Barrage).

Two main design adjustments were proposed to meet the safety concerns on the vortex formation at the powerhouse: (1) reshaping the separation piers with an elliptic pier face, and (2) and re-locating the pier face towards the intake section to avoid that they induce flow separation in front of the intake section. However, an exposure by some 0.2 meters had to be maintained for the support of the trash racks. Other design adjustments were suggested by HRI concerning the pier length, flow reduction, side slope protection and improvement of navigation conditions.

River model

The main objective of the river model was to assess any possible long term morphological changes of the riverbed, in particular downstream of the New Barrage, which might be caused by the normal annual discharges. The effect of floods have not been taken into consideration, as since existence of HAD river discharges did not exceed 2 460 m^3/sec. An additional objective of the model investigations was the prediction of short term morphological changes which may result from river diversion during barrage construction.

Testing river diversion during barrage construction confirmed that the morphological changes were limited to a distance of less than 2.2 km. Powerhouse operation tests suggested that the best location of the powerhouse is near the left bank. Downstream of the rip-rap protected riverbed the morphological response of the riverbed to the concentration of flow from the powerhouse extends over a distance of 2.7 km. Finally, it was concluded that the construction of a new barrage will not affect the general river morphology of the Nile downstream of Naga Hammadi. Testing the operation of the New Barrage showed that river morphological effects on the river bed were local and do not extend over a distance of more than 3.0 km downstream of the barrage.

Navigation lock model

An undistorted hydraulic model of the first navigation lock chamber (adjacent to the sluiceway) of the New Naga Hammadi Barrage was established at a scale of 1:20. The filling and emptying system consists of a dissipation port below the lock chamber floor and close to the downstream gate, through which the filling discharge enters the lock chamber or through which the water is released when emptying the chamber. The dissipation port is connected to the head pond by a short filling duct and to the tail water by an emptying duct. Each duct is provided with a gate to control the emptying and filling discharges. A design ship was selected in coordination with the River Transport Authority.

Through the various stages of design for the filling and emptying system, the system was optimized and finally successfully tested meeting all acceptance criteria for the operation of the lock. Accordingly, the system was optimized so that the time necessary for filling or emptying under highest water level difference was less than 10 minutes. At the same time, forces on the mooring lines of the ship were safely below the admissible limits of 50 kN. There was also no significant impact of transversal forces on the ships moored next to the dissipation port. Unfavourable flow phenomena such as bulk turbulence and vortex formation above the filling port were avoided so they do not affect ships in the chamber. The arrangement of the dissipation chamber close to the downstream gate causes a slope and translatory waves in the lock chamber during filling and emptying. Therefore, ships have to be moored in the lock chamber during sluicing.

3.4.3. Uptake and Impact

A fundamental question imposes itself here; was research confused with consultation in this case? The answer is actually "*NO*". Such an objective is a legitimate research agenda item in Egyptian water resources system development. None of the hydraulic structures presented in the sub-cases is a typical structure in terms of size, complexity of components and elements, construction conditions or flow regime. Therefore, design of such structures was not a simple straightforward engineering exercise that could be adopted from text books or design manuals.

Optimal design of grand hydraulic structures leads not only to high performance and facilitated operation, but ultimately to better achievement of the overall goals of mega projects they belong to. Facilitated operation of such structure has direct impact on the MWRI field engineers, especially IS engineers. Optimal design also has a direct impact on the safety and maintenance of hydraulic structures; hence, it reduces maintenance cost. Indirectly, the grand structures serve the end users as element of mega projects. The El-Salam canal is intended for reclamation of 640 thousand *feddans*. The beneficiaries of this project are small farmers, newly graduated and large investors, as well. In the case of the new Naga Hamadi Barrage, water availability for farmers is granted in more than 550 thousand *feddans*. In addition to that, improved navigation conditions for touristic vessels are attained; and a small amount of power is generated through the attached low head power house (64 Mega Watt).

El-Salam Canal project study

The siphon original design was modified according to the study results and recommendations were followed during the construction.

New Naga Hammadi Barrage

The four model studies led to a set of conclusions and recommendations which had significant impact and modifications on the design of the sluiceway bay, separation piers, navigation lock, powerhouse and upstream/downstream protection works.

3.4.4. Summary

A summary of the rationale and objectives, findings, uptake and impact of the Grand Hydraulic Structures case study is given in Table 4.

Table 4: Summary of Research Uptake Case Study IV – Grand Hydraulic Structures

Rationale/Objectives:

- Replacement plan started with the construction of the new Esna barrage, followed by Naga Hammadi barrage which is currently under implementation.
- Main barrages mega projects typically require a set of sizeable non-traditional hydraulic structures, because:
  - they comprise a complicated combination of different components and elements (civil, mechanical and electrical);
  - their design is not a straightforward or simple engineering exercise that requires an extensive set of hydrologic, hydraulic and pythametric data;
  - mistakes in their preliminary design or unanticipated hydraulic problems are not affordable; and
  - assurance of efficient performance, under different flow conditions, and optimal economic design is only attainable by research through physical modeling simulation and tests

Sub-Component	Rationale/Objectives	Findings	Uptake/Impacts
El-Salam Canal	• To check and test the hydraulic performance of the siphon as designed by Halcrow Ltd of England, an international consulting firm. o approach flow distribution and head loss, trash-racks design, vortex formation, submergence availability, and rip-rap stability o effect of surge wave created by downstream pump station apart	• Support the design of the inlet and outlet structure, as proposed by Halcrow. • Several modifications to the original design of the transition area downstream the outlet structure, up to the rip-rap protected area in order to minimize the eddies and separation in this reach. • It was recommended to remove the anti-scour hump and exclude side emergency spillway, as it would result in additional head loss.	• Siphon original design was modified accordingly and recommendations were followed during the construction. • Downstream the siphon 440, thousand *feddans* are served.

New Naga Hammadi Barrage	• Designed safety factors of the old barrage stability have decreased slightly below the acceptable limits. o MWRI decided to construct a new Naga Hammadi barrage including a hydropower plant, 3.2 km downstream of the old barrage • To carry out the feasibility study for the new barrage in order to: o confirm the main design features, provided by International Consortium of Lahmeyer International, Electrowatt and Sogreah o optimize flow conditions in the vicinity of the main structures o assure the stability of river bed and banks	• The appropriate apron length that confines the hydraulic jump to the apron and rip-rap size that is required to achieve stability for a discharge of 4 000 m^3/sec. • Two main design adjustments were proposed to meet the safety concerns on the vortex formation at the powerhouse: o reshaping the separation piers with an elliptic pier face o re-locating the pier face towards the intake section to avoid that they induce flow separation in front of the intake section • Other design adjustments were suggested to pier length, flow reduction, side slope protection, and improvement of navigation conditions. • It was concluded that the construction of a new barrage will not affect the general river morphology of the Nile downstream of Naga Hammadi. • Time necessary for filling or emptying under highest water level difference was less than 10 minutes. • Ships have to be moored in the lock chamber during sluicing	• Set of conclusions and recommendations which had significant impact and modifications in the design of the sluiceway bay, separation piers, navigation lock, powerhouse, and upstream/downstream protection works. • Facilitated operation and cheap cost. • 64 MW of power is generated. • Better water availability of 550 thousand *feddans*. • Improved navigation conditions.

3.5. Case Study V: Biological Weed Control

3.5.1. Rationale and Objectives

The problem of the spread of aquatic weeds became so serious that when the NWRC was established in 1975, one of its institutes (currently the Channel Maintenance Research Institute (CMRI)) was dedicated to aquatic weed problems and their management. There is a number of important issues that has to be considered when selecting the most suitable method of aquatic weed control.

In all these situations it is essential to know how the different plant species react to the different treatments in order to judge which will be the most likely to give the desired results. The effect on the efficiency of the treatment under certain conditions of the watercourse such as flow, quality of water and, in the case of herbicide treatments, the rate of dilution downstream of the point of treatment must be borne in mind. The risk of adverse side-effects on other functions of the watercourse, not only at the point of treatment but also downstream, must always be given attention.

Until the 1980s of the last century, only three methods were used to control aquatic weeds in Egypt, either individually or in combination: manual, mechanical and chemical. Traditionally, the control of these weeds was performed with simple tools, but due to the problem of hiring labourers that were willing to go into the water and the growing cost of labour, more efficient tools were developed although the method remained inefficient and expensive. Draglines, hydraulic excavators and mowing boats were often used for mechanical weed control, which requires a high investment, skilled operators and good maintenance. Light equipment, such as tractor-mounted mowing buckets, which could reduce the cost of mechanical maintenance considerably, could not generally be used due to the poor condition of the maintenance roads. The herbicide acrolein (2-propanal) was often used for chemical control as it works quickly. The disadvantages of the application of this herbicide were the high price to be paid in foreign currency, the short effect and the negative side-effects on the environment.

Since its establishment, CMRI carried out a number of field studies to identify the aquatic weed problems (Khattab and El-Gharably, 1982) and to investigate the different methods of weeding in order to recommend the most suitable means from a technical and economic point

Photo 9: Mechanical Weed Control: Harvesting Equipment

Photo: CMRI, NWRC

of view. Assistance was received from the Government of The Netherlands, which provided the MWRI with technical and financial support to prepare a nationwide programme for the control of aquatic weeds. CMRI focused on the local practical considerations such as the accessibility to the weeds. Availability of labour and cost of each operation are factors that must also be taken into account (see Photo 9 for the mechanical weed control practised in Egypt).

3.5.2. Conducted Research and Findings

The Netherlands' support to the water sector was directed to several aspects amongst which is the development of new weed control technologies to replace traditional silt removal and chemical weed control. Four major projects were partially financed by the Government of The Netherlands from 1976 to 2004.

A biological weed control initiative started in 1975 under the Channel Maintenance Project (1975-1978). This initiative was followed by launching a Weed Control Research Programme for the period from 1976 to 1979 to study the various means of controlling aquatic weeds, including consideration of conventional and biological methods with special attention to their ecological impacts. One of these experimental methods was the use of grass carp or white Amur (a fish from the catchment area of the river Amur and some other rivers in Eastern China) (Ilaco, 1985). The Grass Carp Project for the period from 1979 to 1985 studied, therefore, the breeding, raising and management of grass carp. The bilateral Dutch-Egyptian cooperation in the field of biological weed control continued until 2004 including a variety of parallel activities aimed at studying different biological control methods, development, organization and evaluation of various biological weed control methods.

As the application of chemical weed control was completely banned by the Egyptian Government in 1991 due to its health hazards, weed control was mainly done by biological means. The biological control, through the use of grass carp, required organizational structures and physical facilities for the production of fish and its implementation in the field. Both were lacking in Egypt. Therefore, it was proposed to continue the experiments with grass carp on a larger scale and to breed the required fish in Egypt itself. The experiments were carried out as part of the Weed Control Project Phase II (1978) and the Grass Carp Project (1979-1982). Both projects were financed, in-part, by the Government of The Netherlands under the responsibility of the Ilaco and another firm, acting as consultant.

Weed control experiments with grass carp took place in the surroundings of Ismailia and Cairo and led to the conclusion that weeds in Egypt can be effectively controlled with the help of grass carp in a large number of canals and drains. When the experiments showed positive indications, a larger hatchery was constructed along the Nile near El-Kanater. This hatchery, called the Delta Breeding Station (DBS), was constructed within the framework of the Delta Breeding Station Phase I project. The station became operational in the spring of 1982 (see Photo 10 for DBS). Technical assistance was provided for training and management during the first two operational years of the station. Attention was also given to the application of grass carp in the field. Although weed control as such proceeded well, organizational difficulties and technical issues remained. Therefore, the project was extended for two more years.

Photo 10: Delta Breading Station

Photo: CMRI, NWRC

An Agreement was signed in September 1983 between the NWRC and Ilaco to carry out the project extension, in association with CMRI as executing agency. The programme was financed by the Government of The Netherlands. Since the first experiments with grass carp in Egypt, a substantial amount of knowledge has been collected and experience has been gained in the field of practical grass carp application.

Research conducted under the Biological Weed Control Programme focussed on three main areas. These are: the environment, the stocking and the fishing (see Figure 7). The conducted research and findings of each area are provided in the following sections.

Environment

The research conducted on grass carp has shown that as the environmental factors for natural spawning are unfavourable in Egypt, the eggs of the female grass carp only develop up until stage III. The proper conditions which are necessary to reach stage IV and to stimulate the release of eggs and sperm, are not present. Therefore, artificial reproduction techniques are required to produce fry.

It has been reported that grass carp prefer deeper and wider watercourses (NRLO, 1984). However, it was observed in Egypt that the grass carp, especially the smaller fish, migrated to branch canals fairly soon after stocking of a main canal. These branch canals, therefore, need to be fenced. However, fences in the inlets to the distributors and especially in the head regulators become easily blocked by the continuous supply of garbage in the canals. Several types of fences were tried out. All of these did not function well when regular cleaning is not carried out. Therefore, already existing barriers (weirs, etc.) should be put to use as a means to confine grass carp to the designated area.

It was also found that water from the Nile River is very suitable for fish. However, where irrigation canals or drains pass through large population centers, the water quality quickly deteriorates due to pollution by industrial and household garbage (see Photo 11 for water course pollution by household garbage in the Delta). During the normal water supply, the situation has not yet been so poor that the effect has influenced the grass carp; but during the dry period, the behaviour of the fish changed so much that it was very easy to collect the fish from the water. In drains, where the water flow is often slower, the quality of water, especially near population centers, is so poor that only very tough fish species, such as catfish and Tilapia ssp can survive.

Stocking

Concerning the stocking size, it was found that grass carp were produced in March-June and became of stocking size in June-September. They would normally be stocked in the latter period, which is during or at the end of the weed growth period, but after the explosive growth of the weeds in spring. If the grass carp could be kept in the canals during the dry period (January/February) the grass carp would have time to increase in biomass and would probably then be able to control the explosive growth of the submerged weeds in spring (February-April), when the water temperatures are still rather low (15-20°C). However, the results of the large scale stockings showed that it was impossible to keep the grass carp alive in canals affected by the dry period (a period in winter regulated by the MWRI to enable regular cleaning of irrigation

Photo 11: Water Course Pollution by Household Garbage in the Delta

Photo: Roel Slootweg, 2004

channels). In order to control the weeds in spring, it would, thus, be necessary to stock the canals with grass carp kept in reserve during the winter months.

It should be realized, however, that the density could be higher for the spring stocking, but no definite numbers can be given yet, because of the lack of data. Only two spring stockings took place in 1985, one in Mansouriya Canal (59 kg/ha and average weight between 5 and 11 g), and another in the Sennouris Canal (84 kg/ha and average weight between 9.1 and 10.8 g). Both stockings showed that the grass carp had difficulty in controlling the weed explosion in early spring, in spite of the pre-cleaning carried out prior to stocking.

Fishing

Fishing was observed on many occasions and at many different locations. Licensed fishermen used gill and cast nets in both main and branch canals but illegal fishermen often used electric fishing gear and poison, as well as gill nets. They operated mainly in the branch canals aiming for the larger fish leaving the smaller dead fish, including grass carp, behind. The effect on the grass carp population was therefore very destructive. The fishing activities followed a certain pattern, based on the water distribution cycle. Fishing took place in the sections and branch canals during periods with low water-levels. Especially in the branch canals fishing was relatively easy. Eight out of twelve days, these canals normally do not receive any water and the water depth decreases to 0.20-0.30 m making the fish easily visible.

A survey was carried out among the fishermen in one of the Irrigation Districts, namely the Mansouriya area (Ilaco, 1985). It was found that a few lease holders rent the fishing rights for the entire area from the Fishing License Department of the General Authority of Fish Resources Development, which belongs to the Ministry of Agriculture. The lease holders in turn lease their rights to a far larger number of fishermen (sub-license holders) living in a few villages in the area. They asked the sub-license holders for an annual compensation which is to be paid each year. In another area (Fayoum), a license system exists only for fisheries in Lake Qarun. Hardly any fishing occurs in the irrigation network apart from the dry period when the entire population descends on the canals. Similarly, fishing in the Dammietta Governorate is mainly concentrated on the nearby Lake Manzalah, with some fishing activities in the drains. The research suggested few possibilities for cooperation with the legal fishermen and the prevention of illegal fishing were identified and consisted of:

- establishing an official fishermen's cooperative;
- regulating the catches;
- stopping all fishing by withdrawing all licenses (extreme measure); and
- leaving fishermen completely unhindered (extreme measure).

It was generally concluded that the use of grass carp is a cost-effective means for biological weed control. It has been shown that applying biological weed control, rather than mechanical weed control, reduces the costs of maintenance by about 70 percent. CMRI has recommended including the use of the grass carp in the overall maintenance programme of irrigation canals and drainage systems, mainly after stopping chemical control methods since August 1991 for its adverse environmental impacts. Silver carp was used to control the phytoplanktons in ponds, lakes and in slow-moving water such as open drains; however, it fails within the running water. Another type of fish, namely the tilapia, was planted to control the submerged weeds especially as this native fish has an ability to eat aquatic plants and reproduce rapidly. In the meantime, small grass carp could be used to control the phytoplanktons. During the application, the grass carp in combination with mechanical or manual control methods were used in the season of weed infestation.

3.5.3. Uptake and Impact

In 1991, the MWRI adopted a policy to introduce biological weed control with grass carp in the wider canals (bed-width >6 m), which are operated under continuous flow (Kotb et al., 2006). This decision was also based on the fact that this method has less negative environmental side effects compared to other weed control methods, it is relatively cheap and it is a source of protein (equivalent to a maximum of 500 kg/ha/yr). At present, some 2 700 km (equivalent to 13 percent of all irrigation canals with a bed-width larger than 2 m, where biological weed control can be applicable) are under biological weed control.

Maintaining water channels against aquatic weed has a direct impact on the performance of both irrigation and drainage systems. Thus, application of research results on biological weed control has direct implications on farmers and less directly on fishermen. The biological weed control results were not only adopted by Irrigation Sector (IS) and EPADP, but they were extended to the practice of other sectors and authorities of MWRI. The results were transferred to weed control in Lake Nasser and Nile River, which are the responsibility of HAD Authority and the River Nile Development and Protection Sector (RNDPS), respectively. Therefore, more pressure is put on the fingerlings national production.

The MWRI established another breeding station in Aswan to supply the requirements of Upper Egypt governorates where it produces about 4 million fingerlings per year and it is planned to double to production capacity of the breeding station within the next two years. In the meantime, the MWRI supplements its need for fingerlings, which amounts to 35 million fingerlings per year, from other breeding stations owned by the Ministry of Agriculture and Land Reclamation (MALR). Presently, CMRI is involved in setting criteria for biological weed control application since 1998 and the application of biological weed control nationwide and acts as a trouble shooter to solve technical problems at regional level.

3.5.4 Summary

A summary of the rationale and objectives, findings, uptake and impact for the Weed Control case study is given in Table 5.

Table 5: Summary of Research Uptake Case Study V – Biological Weed Control

Rationale/Objectives:

- After the construction of AHD, the problem of aquatic weed spread became very serious
- Research is needed to know:
    - how the different plant species react to the different treatments in order to judge which will be the most likely to give the desired results
    - the effect on the efficiency of the treatment under certain conditions of the watercourse such as flow, quality of water and, in the case of herbicide treatments, the rate of dilution downstream of the point of treatment must be borne in mind
    - the risk of adverse side-effects on other functions of the watercourse, not only at the point of treatment but also downstream, must always be given attention
- Draglines, hydraulic excavators and mowing boats were often used for mechanical weed control; require high investment, skilled operators and good maintenance.
- Light equipment, such as tractor-mounted mowing buckets, could reduce the cost of mechanical maintenance considerably, but could not generally be used due to the poor condition of the maintenance roads.
- Disadvantages of the application of this herbicide were the high price to be paid in foreign currency, the short effect and the negative side-effects to the environment.
- Field studies were carried out to;
    - investigate on the different methods of weeding and to recommend the most suitable means from a technical and economic point of view
    - prepare a nationwide program for the control of aquatic weeds
    - focused on the local practical considerations such as the accessibility to the weeds (availability of labour and cost of each operation are factors that must also be taken into account)

Findings:

- Substantial amount of knowledge has been collected and experience has been gained in the field of practical grass carp application.
    - the environmental factors for natural spawning are unfavourable in Egypt, the eggs of the female grass carp only develop up until stage III
- In Egypt, it was observed that the grass carp -especially the smaller fish -migrated to branch canals fairly soon after stocking of a main canal
    - branch canals need to be fenced and already existing barriers (weirs, etc.) should be put to use as a means to confine grass carp to the designated area
- it was concluded that the situation in the Egyptian watercourses differed considerably from other places in the world and experiments with self-cleaning fences did not give the expected results
    - in drains, where the water flow is often slower, the quality of water, especially near population centers, is so poor that only very tough fish species, such as catfish and Tilapia spp can survive
- The results of the large scale stockings showed that it was impossible to keep the grass carp alive in canals affected by the closure period (a period in winter regulated by the MWRI to enable regular cleaning of irrigation channels).
    - in order to control the weeds in spring, it will thus be necessary to stock the canals with grass carp kept in reserve during the winter months

- It was concluded that the use of grass carp is a cost-effective means for biological weed control.
  - applying biological weed control, rather than mechanical weed control, reduces the costs of maintenance by about 70 percent
- It was recommended to include the use of the grass carp in the overall maintenance programme of irrigation canals and drainage systems.
  - during the application, the grass carp in combination with mechanical or manual control methods are used in the season of weed infestation
- Silver carp was also used to control the phytoplanktons in ponds, lakes and in slow-moving water like open drains however it fails within the running water.
  - Tilapia was also used to control the submerged weeds especially as this native fish has an ability to eat aquatic plants and reproduce rapidly

Uptake/Impacts:

- Stopping chemical control methods since August 1991 for its adverse environmental impacts.
- In 1991, the MWRI adopted a policy to introduce biological weed control with grass carp in the wider canals (bed-width larger than 6 m), which are operated under continuous flow.
- Currently, some 2 700 km (equivalent to 13 percent of all irrigation canals with a bed-width larger than 2 meters, where biological weed control can be applicable) are under biological weed control.
- Biological weed control is applied for the Nile River and Lake Nasser protection and maintenance.
- The MWRI established another breeding station in Aswan to supply the requirements of Upper Egypt governorates.
  - produces about 4 million fingerlings per year
  - it is planned to double to production capacity of the breeding station

4. CONCLUSIONS AND RECOMMENDATIONS

The NWRC implements research projects, and provides a wide variety of analytical and advisory services to meet the development requirements of the MWRI and other water related institutions at the national level. As a national organization, NWRC is developing in a manner compliant with the national needs. Nonetheless, it is responsive to the new advances in water since and untie to forms of international cooperation in its field of interests. NWRC was established in response to real MWRI needs for research and development to face challenges emerged with the construction of HAD, expansion of land reclamation and agricultural projects, and associated changes in the irrigation management practices, in addition to problems encountered when formulating a comprehensive water policy.

After thirty years, it can be said with no doubt that the NWRC research thrust impacted and considerably changed the national water policies as well as practices. The research findings and results led to water projects that are economically, financially, socially and environmentally sound. NWRC has proved its ability to bridge the gap between science and water resources management practice. The impact of research has not only accelerated the implementation of the national water policy, but also achieved savings to the national economy, increase in food production and public safety. Research uptake was present at the social, institutional, and legal dimension, not only on the technical and engineering dimension.

Some of the research impacts were direct and clear on national programmes and policies, such as irrigation improvement program, subsurface drainage program and groundwater planning and management. Others were, however, indirect in some areas, especially in cases related to design and operation problems. NWRC institutes played significant roles as research and development component for MWRI in all the national mega projects. Towards the improvement of water quality management, NWRC played a pioneer role that indirectly impacted the reuse of drainage water and Nile protection policies.

4.1. Strengths

- Twinning and partnership between NWRC and MWRI departments and authorities created the enabling environment for successful transfer of interactive research output to field implementation. Currently, NWRC sets its research agenda in collaboration with MWRI departments and sectors. Such a unique institutional relationship makes the NWRC research agenda always busy and client oriented, and provides MWRI with continuous research, development and consultation services.

- The NWRC Board of Directors include the two most senior officials within MWRI; the Head of the Irrigation Department and the Chairman of the Drainage Authority. Thus, all details related to the research agenda are discussed in their presence, their views and comments are carefully considered; and in many cases their operational experience alters the research agenda dictating ideas for pressing research topics.

- In addition, most committees, formed for addressing specific issues or solving an urgent problem within any sector, include members of the corresponding institutes. This allows institutes to form a research team, carry out necessary research, and presenting their research findings to the intended sector, discussing and receiving comments, re-evaluating their results and findings, and providing recommendations to MWRI sectors.

- The pioneer staff of NWRC originally worked for MWRI departments and sectors. This provided them with deep understanding of the practices, problems and potential for development and improvement. Furthermore, their personal relationship with MWRI engineers facilitated communication and mutual understanding that resulted in progressive cooperation. In most of the research activities carried out, especially field activities (experimental and pilot) the relationship was almost physical. In such cases, MWRI sectors provide experimental fields; allowing field engineers to take part in carrying out research activities. This resulted in practical recommendations that are based on sound scientific approach, for the implementation of large scale national programs and projects.

4.2. Constraints

- The current approach for setting the NWRC agenda is hampered by many factors such as: budget cuts, government changing priorities and frequent ad-hoc assignments by MWRI (typically emergencies). The direct effect, of course, is the elimination of some research uptake and extension activities. Sometimes research projects are cut short before achieving their results; hence, partial research findings cannot be communicated to the end users.

- Financial shortages are the most important factor that hinders the flowing of some research findings to field application.

- Many of NWRC pioneer staff retired during the 1990s. Thus, the good linkage between NWRC and MWRI is currently diminishing. Some of the new NWRC staff are not aware of the mission, assignment and hierarchy of MWRI, leading to deficient transfer of research results to the MWRI engineers.

- One of the main tools in research uptake is documentation. Some of the previously discussed case studies were financed by foreign and international donors. Thus, most of their documentation was in English which is difficult for MWRI engineers or farmers to comprehend and adopt. Also, in some cases, limited documentation material obstructed the research uptake.

- The undefined communication channels among researchers, their peers working for MWRI sectors, and end users are other constraints hindering the research uptake process.

- Field engineers, not only MWRI sector heads, must be brought into research at its early stages to get the feeling of ownership of research outputs. Such a mechanism will allow them to participate in the design and implementation of research activities is lacking. They also do not have the chance to contribute to or comment on the research documents from an operational point of view.

- Awareness is also required to improve research uptake. Rarely periodical brochures, flyers, fact sheets on on-going research activities are produced or disseminated among MWRI engineers as well as the general public.

4.3. Recommendations for Improvement

- Interactive research is an excellent umbrella that has to be clearly adopted. It encompasses a variety of research projects to build wider social relevance into the research process. Research, that involves local people and that is relevant to their situation, enhances the research uptake process and provides greater value to society. However, involving users too early in the definition of a research agenda result in goals being often influenced by short-term considerations and/or immediate policy needs. As interactive research is responsive to users' needs, it should not limit applied research from being predictive and visionary.

- When assessing and evaluating interactive research proposals, 'utility' is an additional criterion that needs to be considered. However, research credibility and quality as measured in classical academic terms remain indispensable from users' perspective. Interactive multidisciplinary research for the natural and social sciences is required. Implications of both are not the same. This is partly because of the differences in ethos and practice between the two domains, and also differences in the pattern of uptake of the respective research findings.

- Both quality of research and dissemination of results should be emphasized to encourage research uptake. The research quality is addressed because sound research results leads to better and wider uptake. Therefore, NWRC should strengthen and develop a network of strategic partners and alliances from research institutes and universities (national and international), as well as international water organizations. Research institutes have to be proactive in submitting joint proposals and conducting joint research projects with relevant partners and alliances. The complexity of the recent water problems and issues calls for NWRC intra-collaboration. Joining forces allow for efficient use of soft and hard resources, exchange of knowledge and experience, more fund generation and improved research quality.

- Contract research brings researchers into contact with users. It does not meet the definition of interactive research. This is because the research agenda, rather than being jointly determined, is set solely by the 'user'. No doubt contract research guarantees full research uptake and generates more funds than interactive research. However, there is a high risk of neutrality being compromised or falling into consultation trap. Contract research has to be encouraged as additional fund generator.

- The political and institutional context and relationships between different actors are central to the uptake of research. When international donor agencies are sensitive to the national needs and priorities, research results effectively impact decision-making and action.

- Donors need to re-engage and support interactive research, not necessarily through pure research projects. Most of the current national projects supported by donors and loaners do not fit under typical engineering paradigm and require more than consultation. A research and development component, in each project, is an ideal point to engage donors in research activities once again.

- Donors' support to capacity building of research institutes may be sufficient to improve research quality but not sufficient to enhance its uptake. However, capacity building of research users and recipients of its results create the enabling environment of improved research uptake process.

- Research findings and recommendations must be suitable for the Egyptian culture and socio-economic conditions. NWRC research agenda has to be responsive to MWRI needs and requirements. Therefore, it should be articulated with full participation of MWRI sectors and departments. The current procedure for research agenda setting does not allow for grassroots participation from these sectors and departments. NWRC researchers have to visit with MWRI field engineers to learn about their difficulties and problems. The participation circle should go beyond MWRI and reach out to other governmental stakeholders and end users such as WUAs and WB.

- A comprehensive database for all NWRC research projects, findings and recommendations needs to be established. Such a database should be accessible by all NWRC and MWRI staff for their benefit and education. It might also be a good idea to put it on the MWRI web site.

4.4. The Way Forward

- NWRC's experience, as a unique and pioneer water research institution in the MENA region, has to be put as an example for other countries. Similar experiences in Syria (Irrigation Modernization) and Yemen (Irrigation Improvement Project) are qualified for analysis according to the framework suggested in this study.

- For other countries to evaluate and promote research uptake activities, various aspects have to be considered including institutional setup, mechanisms of fund and research uptake process.

- An effort has to be put forth to bring the focus on the core elements of the study and disseminate its outcomes to a number of selected developing countries and on promoting effective mechanisms that facilitate the research uptake process.

- A dissemination strategy should be adopted for the follow up of this project in the region with objectives to increase the interest in water research industry, enhance its uptake process, and ultimately achieve sustainable use of the regions' limited water resources.

- The newly-born Arab Water Council (AWC) looks like a good candidate to carry out the dissemination strategy.

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ANNEX 1: LIST OF INTERVIEWEES

Ministry of Water Resources and Irrigation Staff
Dr. M. Bahaa El-Din Saad First Undersecretary, Head of Irrigation Department
Dr. Khalid Tobar General Director, Dams and Grand Barrages Sector
Dr. Fatma A. Attia Manager, Water Boards Project
Dr. Taher M. Hassan Undersecretary of Studies and Projects, Groundwater Sector
Dr. M. Abdel-Khalik Director, Central Water Quality Management Unit
Eng. Abdel-Hafiz Shalaby Sector Head, Nile Protection Sector
Eng. Mohamed Talaat Chairman, High Aswan Dam Authority
Eng. Khalaf Nassef Khalaf Vice Chairman, Egyptian Pubic Authority for Drainage Project
Eng. Samia Sami General Manager, EPADP Information System
Eng. Karima Hanafy Manager, EPADP Decision Making Support Administration
Eng. Wedad Khalaf Undersecretary, EPADP Studies and Design
Eng. Abdullah Domah Team Leader, Irrigation Improvement Project

MWRI Consultants
Dr. Mohamed Hassan Amer Chairman, Egyptian National Committee on Irrigation and Drainage (ENCID)
Eng. Hussien Elwan MWRI Consultant
Dr. Samia El-Guindy Secretary General, Advisory Panel for Egyptian/Dutch Projects (APP)
Eng. Fouad M. Ramadan EPADP Consultant
Dr. Saoud El-Khafif MWRI Consultant
Eng. Adel Hashem Consultant, Irrigation Improvement Project
Donors and International Experts
Mr. Robert Roostee Team Leader, Fayoum Water Management Project
Mr. Morison Team Leader, IIP Project
Dr. Tarek Morad Dutch Embassy
Dr. Wadie Fahiem USAID
Dr. Hany El-Saadany World Bank

ANNEX 2: INTERVIEW STRUCTURE AND QUESTIONNAIRE

Introduction:

- Explain the objectives of the study.
- Explain the purpose and format of your visit:
  - NWRC is doing a study about its projects during the past 30 years. The study will evaluate the benefits, successes and failures of these projects.
  - I am going to ask some questions about your perspectives regarding these projects.
  - How do you evaluate the successes and failures of NWRC projects, as well as how to improve them in the future?
  - The discussion should take less than an hour.

The Questionnaire:

Try keeping the questions moving forward, so the interviewees do not become bored, but give them time to think when necessary. Try to ask for the opinion of the interviewee in private.

Wrap up:

Thank the respondents for their time and attention. Explain that their perspectives will be analyzed along with all the others and that the key points will be used to evaluate the NWRC project successes and failures and will make a real difference in future projects.

Questions:

- Which NWRC projects affected your sector (donors)?
- In which projects did you participate, and in which did you not (donors)?
- How did each of these projects affect water resources planning and management in your sector (stakeholders)?
- How did these projects participate in the evolution, development and improvement of your sector and its activity in water resources planning and management (stakeholders)?
- How was the coordination between your sector, NWRC and other stakeholders during and after the implementation of these projects (stakeholders)?
- How much of the project recommendations were carried out in field practice (stakeholders)?
- Which of the project recommendations worked, and which did not (stakeholders)? Why?
- How can we increase research uptake (stakeholders)?
- What is the effect of donors directing their funds to implementation instead of research (stakeholders)?
- What is the need, and what are the objectives behind each project and why was it launched (both donors and stakeholders)?
- How do you evaluate NWRC performance during project implementation (both donors and stakeholders)?
- What was enhanced/improved by the output of these projects (both donors and stakeholders)?
- How do you evaluate research uptake in practice? And how can we increase research uptake (both donors and stakeholders)?

- What were the inconveniences during implementation (both donors and stakeholders)?
- How do you foresee project sustainability (both donors and stakeholders)?
- How do you foresee the next step (both donors and stakeholders)?
- Effect on agricultural areas (stakeholders)? (if any)
- Effect on natural reserves (stakeholders)? (if any)
- Effect on water resources (stakeholders)? (if any)
- Effect on cultural heritage sites (stakeholders)? (if any)?

Other concerns or further discussion

- What are the positives and negatives of each project (donors)?
- What are the gaps that were not addressed by each of these projects (donors)?
- What are your recommendations for future projects (donors)? *
- What are your suggestions to improve future project coordination (donors)?
- What are the constraints that limit such projects (donors)? And what do you suggest to overcome obstacles (if any)?

ANNEX 3: INTERVIEW SYNOPSIS

Observations:

- During the 1970s and the 1980s research projects were funded by donors with minimal contribution from the Egyptian Government. Whenever the donors' agenda matched the actual national needs strategic research projects were formulated and implemented. In principle, donors usually advocate needs-driven research and push for the implementation of its results and findings. However, they do not finance research projects that have low priority on their agenda, regardless of the national needs.
- At least the last two five-year research plans were prepared by NWRC and have been subjected to two rounds of consultation with the sector and department heads. NWRC assumes that MWRI needs are driven by the bottom-up approach and expressed these concerns during the consultation process. However, this may not be the reality. In many cases the political and physical systems dynamics required abrupt changes in the research agenda which was not robust enough.)
- MWRI sectors and departments are the main, if not the only, clients of NWRC institutes. During the last decade of the previous century, the donors directed their funds towards implementing agencies rather than research institutes. They also coordinated their efforts and donations to GoE in a very restrictive manner. Therefore, and since the 1990's, NWRC shifted a major part of its activities from research to consultation according to client needs, which led to an outdated research agenda with no strategic element. This can be attributed to:
  - the phasing out of donor support for research projects
  - the reduction of NWRC governmental budget allocations
- Some interviewees called upon NWRC to tackle specific and local field problems rather than addressing strategic and national problems.
- Research results and findings are neither well documented nor disseminated. Also, monitoring data on the national scale programs, resulting from research projects (IIP and NDRP), is limited and unreliable. Therefore, some research results can not be confirmed.

Recommendations:

The interviewees believe that the following recommendations have a vital importance to the research uptake process:

- Cooperation protocols have to be signed by NWRC institutes and their corresponding MWRI sectors for data and information sharing, in addition to provision of research and consultation services.

  Some sort of informal protocols exist by default of the institutional set-up of MWRI and NWRC and in few cases formal protocols subsist. However, it is believed that signing formal protocols is a necessary step, but not a sufficient one.
- NWRC research agenda has to be responsive to the MWRI needs and requirements. Therefore, it should be articulated with full participation of the MWRI sectors and departments.

  This is partially taking place at the senior management level.
- The Planning Sector may act as an interface between MWRI sectors and departments and NWRI institutes. Basically, it should identify and define the sector problems and communicate them to NWRC. On the other side, the Planning Sector should transfer the research results and findings to the MWRI departments and follow their implementation.

  It does not seem to be a practical nor feasible solution.

- The NWRC board and institute, and the MWRI sectors and departments should have a complementary management team.

  Currently, the institutes' boards are under formation and they will be activated very soon. Institutes boards' membership is planned to include the heads of the corresponding MWRI sectors and authorities.

- Research plans have to be innovative in meeting short and long-term objectives, and should predict future problems to find solutions ahead of time.

  Theoretically speaking, it is very difficult to set a responsive and predictive research agenda at the same time.

- Research projects should focus on specific problematic areas rather than the strategic national level. Thus, their results can have better applicability and be directed to help field operators and mangers at the local level.

  It is believed that both levels have to be covered in the NWRC agenda.

- Both local and strategic national levels of research are needed.

  It is believed that both levels have to be covered in the NWRC agenda.

- A monitoring and evaluation unit could be established to investigate and evaluate the research quality, cost effectiveness and uptake.

- NWRC has to establish and develop a network of strategic partners and alliances from research institutes and universities (national and international), as well as international water organizations.

- More publicity of the services that can be provided by NWRC is needed. Reaching out, regionally, will open the door open for the NWRC to face new challenges, create an innovative research agenda and secure sufficient funds.

- A comprehensive database for all NWRC research projects, findings and recommendations needs to be established. Such a database should be accessible to all NWRC and MWRI staff for their benefit and education. It might also be a good idea to put it on the MWRI web site.

- Research findings and recommendations must be suitable for the Egyptian culture and socio-economic conditions. Participation of farmers and stakeholders in planning interventions recommended by NWRC researchers guarantees their applicability and sustainability.

- NWRC future research specifically may include:

- Canal development, especially branch canals;

  - Consideration of water duty as a function of time, not an absolute value;
  - Feasibility of developing main canals without developing branch canals;
  - Farmers' behavior within IIP covered areas and evaluation of the implementation results;
  - Evaluation of upstream control gates; and
  - Review and evaluation of the different drainage reuse modes (main, intermediate and local) according to the specificity of each region.

  Most of these topics concentrate on irrigation and drainage and not necessarily fit the national priorities.

Research Uptake Results and Examples:

- Research uptake was obvious in planning and implementing the national mega projects such as El-Salam and Toshka projects. Another example is the significant contrition of the Drainage Research Institute (DRI) to the National Drainage Programme. Its research on construction material, design criteria, installation and inspection machines and controlled drainage are good examples of a successful research uptake process. However, the controlled drainage needs to be implemented on a wider range to cover all rice cultivation areas.
- Generalization of the research results and the experience gained from Fayoum Water Management Project to the national scale is recommended, provided that a number of research gaps are covered. NWRC research, during the last three decades of the previous century on water quality, has influenced the Ministry's policy on monitoring water quality and detecting pollution. As a result, water resources protection is one of three main pillars of the recent water policy. Specific examples of research projects on water quality are:
    - Egyptian-Dutch Advisory Panel Projects (APP) provided the first preliminary design of water monitoring networks at Delta and Fayoum.
    - Studying water and salt balance at Fayoum through APP projects led to modification of the system's operation at Qaroun Lake.
    - DRI with Overseas Development Agency (ODA) conducted a study on the effect of pollution on the northern lakes. The results have alerted the decision makers to the deterioration of the natural wetland at the national level.
    - The Monitoring and Analysis of Drainage Water Quality project (MADWQ) updated APP preliminary designs based on better design approaches and environmental indicators. El-Salam canal and El-Omoum drainage projects made use of the MADWQ-generated data.
    - Currently, the NAWQAM project upgraded and integrated the water quality monitoring networks for the different water bodies in one national water quality monitoring network. Information on the water quality status is utilized by the Central Water Quality Unit to alert the public and interested decision makers.
- NWRC research succeeded in improving the water distribution system, reducing water losses and establishing the Water Board. More than 4 000 *mesqa*s were improved based on EWUP results and findings. However:
    - Application of upstream control gates was a recommendation that was made by an international consultant and not as a research finding.
    - Continuous flow did not work in many canals due to defects of distribution gates and irregular non-uniform cross sections.
    - In general, water saving was not attained however, equity and increased agriculture production were achieved.

The International Programme for Technology and Research in Irrigation and Drainage (IPTRID) is an international multi-donor programme, co-managed by partner organizations, created in 1990 at the request of the International Commission for Irrigation and Drainage (ICID). Its Secretariat, first located at the World Bank, was transferred to FAO in 1998, where it is being hosted, in the Land and Water Division (NRL) as a Special Programme.

IPTRID aims at improving the uptake of research, exchange of technology and management innovations by means of capacity development in the irrigation and drainage systems and sectors of developing countries to reduce poverty, enhance food security and improve livelihoods, while conserving the environment. IPTRID acts as a facilitator mobilizing the expertise of a worldwide network of leading institutions in the field of irrigation, drainage and water resources management.

Together with its partners, the IPTRID Secretariat provides advisory services and technical assistance to countries and development agencies, for the formulation and implementation of strategies, programmes, and projects. During the last ten years, it has been supported by more than twenty international organizations and government agencies. The present Programme is cofinanced by the Food and Agriculture Organization of the United Nations (FAO), the United Kingdom, the Netherlands, France and Spain, the World Bank and the International Fund for Agricultural Development (IFAD).

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