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Final report

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1 Acknowledgement

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Glossary of Terms

ARC	-	Agricultural Research Center
BCWUA	-	Branch Canal Water User Association
BOD	-	Bio chemical Oxygen Demand
CLAR	-	Central Laboratory for Aquaculture Research
CDIAS	-	Central Department of Irrigation Advisory Services
DO	-	Dissolved Oxygen
ds/m	-	deci Siemens per meter
EC	-	Electrical Conductivity
EGSA	-	Egyptian General Survey Authority
ESP	-	Exchangeable sodium percentage
GPS	-	global positioning system
IIIMP	-	Integrated Irrigation Improvement and Management Project
IIP	-	Irrigation Improvement Project
IIS	-	Irrigation Improvement Sector
LE	-	livre égyptienne (Egyptian Pound)
LR	-	Leaching Requirement
NWRC	-	National Water Research Center
PS	-	Pumping Station
RWS	-	Relative Water Supply
SIWARE	-	Simulation of Water management in Arid REgions
WUA	-	Water User Association
WUO	-	Water user Organization

2 Executive summary

The overall aim of the project is to identify physical and institutional interventions to improve water management using an integrated approach across scales (from farm to main canal levels) and encompassing water quantity–quality interactions. The project's geographical focus is the Nile Delta in Egypt.

The project was originally planned for four years. Due to a policy change announced by the Australian Government in reducing the aid investment in the Middle East and North Africa, including Egypt, the duration of the project was reduced to three years.

The project is operating on four different levels: farm, mesqa (tertiary), meso, and macro levels. At the farm level, three different field experiments were carried out for four growing seasons.

Field experiments were carried out during four cropping seasons (summer 2013, winter 2013/14, summer 2014 and winter 2014/15) to evaluate sustainable interventions to combat degradation associated with salt accumulation. Field trials were conducted with various treatments including application of gypsum, organic matter, bio-fertilizers, ammonia injection, and installation of mole drains. The required datasets (soil, water, and plant) were collected and analyses were completed and concluded that application of soil amendments had a significant effect on crop yields and the physical properties of salt-affected soils.

To understand the linkages between water management practices and salt movements, field experiments were carried out with controlled drainage at different levels. A drainage network was installed at different soil depths to control the water table at the required level to evaluate the contribution of the water table to irrigation and to assess salinity build-up. Significant water savings were achieved by practicing controlled drainage at shallow depths. Controlled drainage at shallow depths is not recommended for use with deep-rooted crops such as cotton.

Parallel to research station work, evaluation trials were conducted in summer 2013, winter 2013/14, summer 2014 and winter 2013/14 at the village of Shabab El-Khergeen to monitor the effect of subsurface drainage combined with mole drains on the productivity of different crops. All field trials were implemented in farmers' plots and compared to their traditional practices. From these experiments it was concluded that introducing the mole drain to heavy clay salt-affected soils improve the efficiency of the wider spacing drainage system. Introducing mole drains resulted in the maximum values of total revenue, net return, and economic efficiency.

Activities at the mesqa level included the following: (1) the detailed monitoring of five collective pump stations (W10 and Abu Mustafa areas), which shed light on water management practices at the local and community level, with a focus on collective action modalities; and (2) a survey of 50 pump stations from the Irrigation Improvement Project (completed by a rapid assessment of 640 stations to check whether they were functioning and still existing), which resulted in an in-depth analysis of the degree of acceptance and efficiency of the IIP project in general and Water User Associations (WUAs) in particular. Many problems were identified such as, mechanical problems and the difficulty to find technical assistance and spare parts; design or construction defects inherited from the implementation of the project; theft of motors; non-implementation of continuous flow in branch canals, which did away with the possibility to see water savings, etc. WUAs were hardly identifiable, at least when looking for formal associations which would perform according to project guidelines and expectations. Yet, with very varied patterns, people organized themselves to operate and maintain the collective pump station, not least because they are often forced to do so by the fact that the mesqa canal has been filled in. The various 'trajectories' of the pump stations were made explicit, revealing how specific and locational characteristics, both physical and social, accounted for a large range of situations, from stations that had never been used, or been abandoned, to cases where some farmers had opted out of the group and reverted to their individual pumps, all the way through stations where pumps had been replaced or electrified. The difficulty to comprehend the diversity of environmental and social conditions pleads for an on-demand project rather than one that is frequently imposed on farmers. Sufficient buy-in from particular groups of farmers has been identified to anticipate the continuation of the Irrigation Improvement Projects in such conditions.

In order to understand gender issues on irrigated agriculture two case studies were carried out in two contrasting areas in the old and the new lands of Lower Egypt, which have strikingly different characteristics in terms of landownership, gender roles, labour supply and demand, irrigation technology, and social control.

Activities at the meso level (~200 ha) have focused on detailed monitoring of an area comprising 12 collective pump stations located between Mares el Gamal canal and its Bashair branch. These pumps were recently installed (IIIMP project) and the way water management practices have changed was documented. The water level and salinity in the canal and 20 pumps were monitored with data loggers to assess the patterns of use of these stations; water quality has also been monitored in the subsurface drainage system, in the soil itself, and at the outlet of the drain which collects return flows from the area. Results illustrate and emphasize the high spatial and temporal variability of sub-surface and superficial drainage water.

A further ongoing activity has focused on the management of branch canals (secondary canals), and in particular the actual and possible roles of branch canal water user associations (BCWUAs). This also links with an (summary) analysis, at a higher level, of the Integrated Water Management Districts recently established in the Meet Yazid command area. Most of the associations were found to be inactive since the initial impulse by the government has not been followed by an empowerment of these associations. Their possible role in water management (e.g. enforcing the rotation) and in constituting an interface between individual farmers and district officers has not been forthcoming. Where this has been the case, to a limited extent, this happened to be linked to the positive attitude of specific ministry officers, but such dynamics are difficult to sustain in a context where staff are rotated.

At the macro level, research activities included: (1) a general survey of salinity in the drainage system, including 300 measurement points, revealing the spatial distribution of salt, the linkages with soil type, the gradient along each canal, and the levels of salinity in the drains from which farmers abstract water. Results clearly show that the accumulation of salts in the northern end of the Delta is due to continued mobilization of salts in the soil profile in that area and to the interception of salty groundwater (upward seepage), much more than to concentration by successive reuses; (2) a general survey on individual pumping from main and secondary drains, concluded that 2000–3000 pumping points were operational, mostly in the area north of Kafr el Sheikh, and (3) a survey on wells revealed that the use of groundwater is much more widespread than previously anticipated (reaching densities of one well per 1.5 ha), that a majority of wells were collective, and that investment was motivated by water shortages, poor water quality, or conflicts. Conjunctive use has implications on crop choice possibilities at the farm level, but may incur changes in water management rules at the system level, and have impact on the overall water balance of the delta and seawater intrusion in the delta aquifer.

Three activities examined aquaculture: the first focusing on the economics of the observed shift between crop cultivation on the one hand and aquaculture on the other, in order to understand the respective dynamics of crop and fish production; the second analyzing in detail the economics of fish production in the aquaculture area; and the third monitoring fish and water management practices and at a higher level, calculating in particular their salt and water balances. The aquaculture sector as a whole is under increasing pressure. The critical factors impacting the sector are high price and low quality of fish feed, poor quality fish fry, poor water quality, lack of access to capital, high fuel costs, and declining fish prices among many others. The variability in economic returns of the various aquaculture systems is also assessed.

Activities related to the understanding of the water and salt balance of the delta, although largely curtailed because of the changes in project duration and funding, have identified the need to better monitor the salt load (electric conductivity) of water samples and the water levels upstream and downstream of the main drainage pump stations (so that volumes pumped out to the sea can be better assessed), and to account for the reuse of drainage water downstream of those pump stations. Another very important component of the water balance is that of the delta aquifer. Based on the available data on the changes of groundwater salinity, it is not possible to ascertain whether there is a de-stocking of the aquifer (i.e. intrusion of saline groundwater) or not. Because of the boom in groundwater use identified it is recommended to improve the monitoring network of both the static water table level and groundwater salinity in the Delta.

3 Background

The Nile Delta covers an agricultural area of approximately 2.5 million ha, irrigated by a dense network of waterways, including 40,000 km of canals that branch off the Nile River and convey water to over 2 million farmers across several nested geographical scales and institutional levels. Intermingled with these conveyance canals are 18,000 km of drains, where water is both partially reused by farmers and pumped back to higher level delivery canals, and eventually conveyed to coastal lakes and the sea. The recycling of drainage water, a deficient or ill-maintained drainage system, and inappropriate in-field management of applied water contribute to salt loading of the system that has significant negative effects on its productivity (Ghassemi et al. 1995). Understanding the causes of, and developing management strategies to address, the issue of salt loads is imperative for the Government of Egypt.

In Egypt in 2006, the annual per capita share of water was 850 m^3 and this figure is expected to drop to 600 m^3 by 2025, a level widely considered below the water poverty level. As agriculture is the major user of water in Egypt, accounting for 85% of national demand, addressing this problem will require a reduction in water diversions to agriculture. This will necessitate significant increases in water efficiencies over a range of scales (i.e. from on-farm to basin).

Raising the efficiency of water management at all levels while also increasing agricultural productivity and conserving the resource base are the most salient objectives of both the National Water Resources Plan 2017 (MWRI 2005) and the Government of Egypt Strategy for Sustainable Agricultural Development 2030. More generally, the project supported several key objectives of the strategy, including: sustainable use of natural and agricultural resources, increasing land and water productivity, raising food security, improving living standards and reducing poverty of rural inhabitants. The modernization of the irrigation sector is a key element of this strategy through improvements in the efficiency of the water conveyance and distribution system, as well as the efficiency of on-farm irrigation.

With a current population growth rate of 2.1%, concern over a growing dependency on food imports and the need to compensate for the loss of highly productive agricultural land associated with urbanization, the Egyptian Government has pursued a strategy of *vertical expansion* (i.e. intensification on existing cultivated land) and *horizontal expansion* into the desert (‘New Lands’), which is predicated upon better management and water savings in the ‘Old Lands’.

Aquaculture has also become an important sector in Egypt in the past 15 years, undergoing spectacular growth and production reached 705,000 t in 2009, valued at US$1.35 billion (FAO 2010), which met two-thirds of the total fish consumption in the country. Aquaculture contributes not only to national GDP and food security but also to job creation. According to FAO (2010), 37,000–43,000 people are running small-scale family fish farms and employ around 25,000 workers. In the past two decades, tilapia fish-farming has had substantial positive effects on the economy of Kafr El-Sheikh Governorate by reducing local unemployment (Radwan 2008). Aquaculture is concentrated on the southern part of the four main lakes and is complemented by capture fisheries in the lakes themselves. Most land suitable for fish ponds in the delta has now been reclaimed, yet the Ministry of Agriculture and Land Reclamation (MALR) plans to increase Egypt’s total aquaculture production to 1 million t by 2017, which means not only ensuring that production can be sustained but also that farming can be intensified.

4 Objectives

The overall aim of the project is to identify physical and institutional interventions that improve water management in the Nile Delta, using an integrated approach across scales (farm to main canal level) and encompassing water quantity–quality interactions.

In order to achieve this aim, the project's specific objectives and associated activities are to:

1. Identify and develop strategies that address institutional and technical barriers associated with the management of main and branch canals and assess the effectiveness of collective action in the functional operation of water user associations (WUAs) at the mesqa (tertiary) and branch (secondary) canal levels.
   1.1. Undertake a comprehensive analysis of both technical and institutional factors that influence the effective management of main and branch canals (in the Meet Yazid main canal command area).
   1.2. Analyze the effectiveness of collective action within WUAs at the mesqa level, in both 'improved' and 'unimproved' conditions.
2. Develop and assess marwa- and farm-level interventions that improve the productivity of diverse farming systems, and that contribute to increased water productivity under saline conditions, while assessing the economic and social dimension of crop choice and water management.
   2.1. Evaluate and demonstrate marwa-level water management interventions.
   2.2. Develop and evaluate sustainable interventions to address degradation associated with salt-affected soils in the northern delta.
   2.3. Undertake a comprehensive assessment of farming systems and the rationale behind farmer crop selection and associated rotations.
   2.4. Undertake a socioeconomic analysis of fish-farming systems in the upper delta.
   2.5. Undertake a cross-cutting survey on the gender dimension of water management at various scales.
3. Build an understanding of the temporal and spatial dynamics of salt at several nested and successive scales (farm, meso, and main canal/drain levels and fishpond area and lake) to understand the linkages between water management practices and salt movement/accumulation.
   3.1. Quantify the salt dynamics under contrasting irrigation and cultivation practices at the plot level.
   3.2. Develop an understanding of salt movement and associated changes in drainage water quality at the meso level.
   3.3. Map the spatial and temporal mobilization of salt across the landscape in order to understand salt dynamics at a larger scale and develop management strategies for its abatement.
   3.4. Quantify the impact of aquaculture water management on water quality and the implications of multiple recycling on salt mobilization.
4. Develop an understanding of the implications of these cross-scale interactions through modeling of the whole central delta, and assess the fraction of water that could potentially be 'saved' and used in the New Lands under constraints of salt management and sustainability of current uses (rice, aquaculture, and fisheries).

4.1. Undertake an assessment on the impacts of a range of interventions when scaled-up on water and salt balances (using SIWARE software for the whole central delta) and test various scenarios.

4.2. Establish an integrated view of the rice/aquaculture/lake complex in terms of water/salt balances in order to define the conditions for the joint sustainability of these systems, and to assess the effective potential for macro-level water savings.

5. Build capacity of decision-makers, water managers, researchers, extensionists, farmers, and other stakeholders through seminars, targeted training courses in Egypt, and formal and informal education and training programs.

5.1. Enhance knowledge, skills, and qualifications of key stakeholders in the study area through degree and non-degree training activities, train-the-trainer courses on participatory techniques, and extension.

5.2. Engage decision-makers to connect them with the knowledge generation process of the project.

5 Methodology

The focus of the study is the Meet Yazid main canal and its associated network of distributary canals and farmers/fishers that manage diverse production systems (Figure 1).

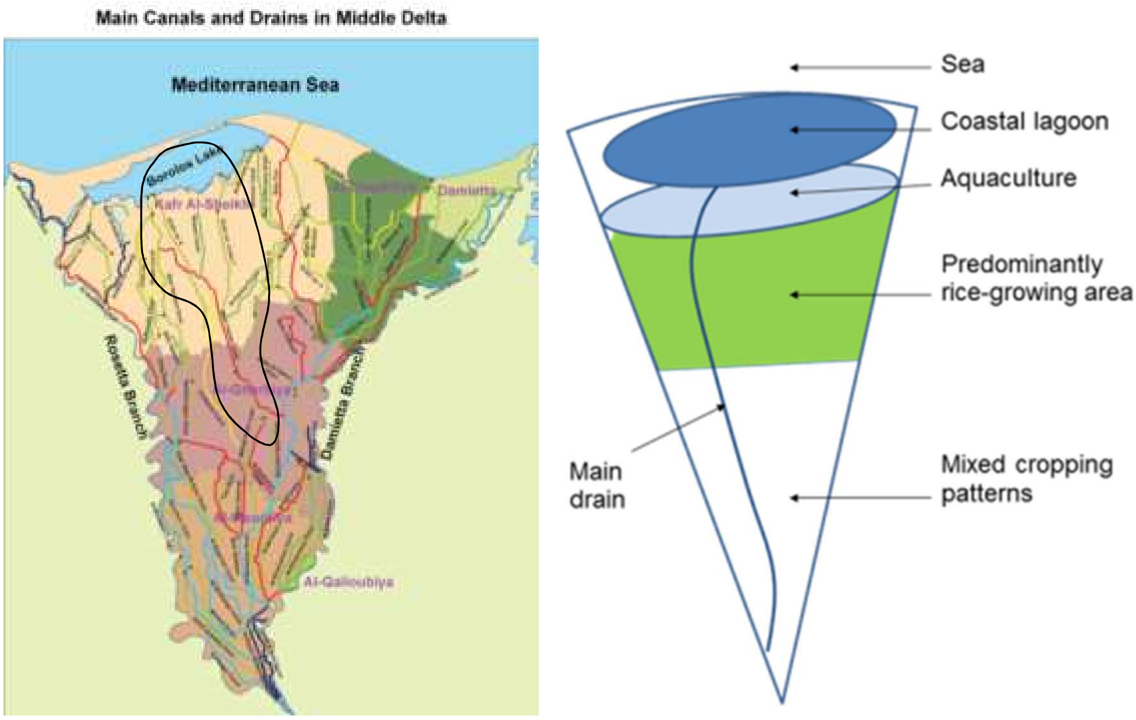

Figure 1: The target distributary canal, Meet Yazid canal, that is the focus of the research activities, and a schematic representation of a delta ‘slice’ and its diversity in production systems

The principal methodologies that were deployed to address the key objectives and associated activity are briefly summarized as follows:

Objective 1: Identify and develop strategies that address institutional and technical barriers associated with the management of main and branch canals and assess the effectiveness of collective action in the functional operation of WUAs at the mesqa (tertiary) and branch (secondary) canal levels.

1.1. Undertake a comprehensive analysis of both technical and institutional factors that influence the effective management of main and branch canals (i.e. the Meet Yazid main canal command area).

M&E of the Irrigation Improvement Project (IIP)/Integrated Irrigation Improvement and Management Project (IIIMP) has shown that the inflow to branch canals is principally related to the characteristics of the canal itself rather than to water demand inside the command area (WMRI 2009, 2010; El-Agha et al. 2010; El-Agha 2011). We studied the management of the Meet Yazid main canal and its 23 associated branch/sub-branch canals, focusing on the interaction between the two provinces concerned (i.e. Gharbia and Kafr El-Sheikh), the characteristics/constraints associated with each branch canal (e.g. length, slope, topography, position in the network, decay of infrastructure and maintenance status, actual/design capacity, tail-end supply from drain, and weed infestation) that influence the way canal head structures are operated (e.g. fully opened, continuously opened but adjusted, adjusted rotations, and fixed rotations), needs and actual water supply, and the interfacing with farmers – through branch canal WUAs (BCWUAs), other institutions, or key individuals.

Activities include interviews with engineers and gate operators; surveys of BCWUAs' and farmers' opinions; collection of data[1] on canal profiles; determination of actual inflow into selected branch canals (and tail spill) (to be partly provided by M&E of the IIIMP project); collection of data on cultivated areas and additional estimates through remote sensing; surveys of a sample of drains to assess the magnitude of groundwater and drain water (re)use in the summer[2]; and analysis of relative water supply (RWS) and first assessment of discrepancies in RWS and in the modes of management of each branch canal.

► Activity 1.1a: Review existing data on canal and water control infrastructures, analyze constraints to management and actual practices, select two branch canals for installation of ultrasonic flowmeters and drains for surveys on water reuse; purchase and install flow meters. Interim report on management constraints and practices.

► Activity 1.1b: Collect land-use data and flow data, survey intensity of drainage water use over a sample of drains, and purchase relevant satellite images on monitored branch canals over two years. Ground truth images and map land use in the whole central delta area.[3] Quantitatively and spatially analyze supply and demand. Final report on management constraints and practices.

High resolution RapidEye satellite images were used in this research. The project area is located in two RapidEye images with a total area of about 9433.8 km^2**.** Eight topographic maps of the project area with a scale of 1:50,000 produced by the Egyptian General Survey Authority (EGSA) were used to collect information for the study area and were geo-referenced by the RapidEye satellite images. ERDAS IMAGINE and ARC-GIS were the main software used in image classification and vector processing. Dynamic SWERI Data Collector system was used in the field work to define and determine the location of the samples for training. Using dynamic GPS, 290 observation points covering the Meet Yazid command area were collected in the field – these points represented the sampling areas of cultivated crops and other features in the study area. The accuracy of the classification was assessed using a confusion matrix. Land use maps were developed for different years and these were used to detect the changes in land use in the Meet Yazid command area.

Flow at the branch canal has been monitored for the historical period and meteorological data has been collated.

► Activity 1.1c: Collect general information on past experiences with BCWUAs in different projects, analyze differences, review literature of case studies, interview key informants, and select a sample of WUAs to be surveyed in detail.

► Activity 1.1d: Carry out comparative surveys on selected BCWUAs, write a synthesis report.

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[1] It is not possible to collect the actual characteristics of, and follow up actual supply into the 23 canals: we will first collect existing information and focus topographic surveys on the canals identified as problematic through interviews with field staff, as well as on the six canals already monitored by the IIP/IIIMP program in terms of actual inflow. We will build on this information and install ultrasonic flowmeters in two additional canals. The assessment of actual requirements is an activity shared with Objective 2.3 (below).

[2] Assessment of actual drainage water use is a 'fuzzy point' of all earlier projects: systematic surveys will be undertaken and completed with information generated at other scales by Activities 1.2 and 3.3, in order to provide novel assessments of this important component of the water/salt balances.

[3] That will be used in Activity 4.1. For this activity only the sub-map for the Meet Yazid command area will be used.

- A literature review of different project experiences in Egypt with the establishment of WUAs, water boards and BCWUAs
- Both in the exploratory survey and the WUA survey (of around 50 mesqa- or pumping station-level WUAs (PS-WUAs), see activity 1.2) the research team then asked questions to farmers, water user representatives, BCWUA board members and water management officials about the working of BCWUAs in the project area
- A focus group discussion was held with BCWUA leaders in Kafr el Sheikh on September, 11 2015
- A number of additional interviews with key-informants, such as Irrigation District staff, IIS-IAS and CD-IAS staff, etc. to contextualize the earlier findings
- A semi-structured survey with a list of key-issues/questions was designed and carried out for a sample of 15 BCWUA cases, mostly in the tail region of Meet Yazid, between October 2014 and February 2015. The questions were mainly qualitative in nature and required full descriptive survey reports. The following set of issues was discussed with the BCWUA representative whom the research team visited in their homes or offices.

1. The historical and organizational trajectory of the BCWUA; Elections and re-elections of Assembly- and Board members of the BCWUA
2. Composition of the board (how many per reach, sectors, women)
3. The role of Central Department of Irrigation Advisory Services (CDIAS)
4. The role of IIP/IIIMP improvement
5. Training
6. Main problems along the BC
7. BCWUA responsibilities in water distribution, maintenance, fee collection, conflict resolution, etc.
8. Frequency and place of meeting, resources (office, records, bank account, money, etc.)
9. Meetings with Project and Irrigation Management Staff
10. Capability BCWUA of acquiring improved service
11. Contributions and effectiveness of BCWUA
12. Law for BCWUAs
13. Future of BCWUA

1.2. Analyze the effectiveness of collective action within WUAs at the mesqa level.

Several projects over the past three decades have worked on establishing WUAs (Abdel-Aziz 2003; Allam 2004; Attia 2003). WUAs are mandatory in the IIP/IIIMP projects because farmers must collectively manage their single-point lifting device. The mesqa level is a crucial scale to understanding water use in the delta. M&E have so far largely focused on the rate of satisfaction of farmers and reduction in the use of drainage water and costs of pumping. However, because abstraction by the collective pumps is the most critical variable in shaping ‘demand’, and eventually water diversions, the project has devoted substantial effort to opening the ‘mesqa black box’ and investigating farmers’ collective action, examining if and how it determines or impacts efficiency and equity, as well as assessing the host of conditions associated with failures and successes of these associations. Actual water management by WUAs (Is water abstraction reduced? Is social capital mobilized? Is long-term maintenance ensured?) is not known in detail and is key to the evaluation of modernization policies based on collective pumps.

The analysis of WUAs’ effectiveness was carried out in four steps:

► Activity 1.2a: First, a review existing data, reports, and articles on the actual management of improved mesqas. Design of a questionnaire for rapid appraisal and choose the sample on which it will be applied. Selection of two mesqas with contrasting features for detailed monitoring.

Existing data, reports, and articles on the management of improved mesqas were collected and reviewed. A synthesis report was issued.

► Activity 1.2b: Second, a sample of 50 WUAs (Figure 2) and associated mesqas spanning key characteristics (e.g. length and area of the mesqa command area, average water availability, and date of establishment) was surveyed. This included a study of the history of the selected associations, their leadership and relationships with other institutions and traditional local authorities, and their functioning regarding the operation and maintenance of pumps, the scheduling of water distribution, conflict management, financial management, and other duties or tasks performed by the association.

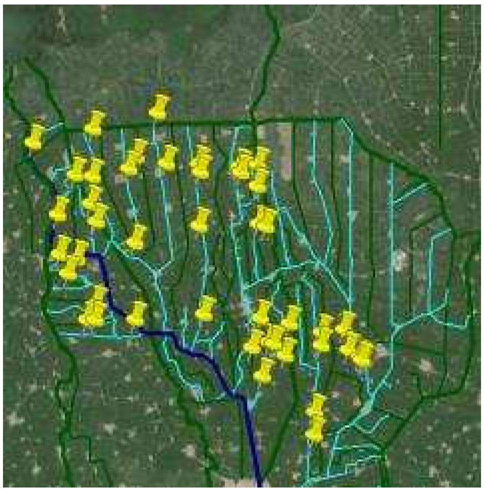

Figure 2: The 50 surveyed pumping stations distributed over Meet Yazid

► Activity 1.2c: Two in-depth studies of two improved mesqas (one study in W10 area, another in Abu Mustafa canal) have been undertaken to understand whether/how technological changes resulted in improved institutional arrangements that together bring about positive outcomes or not (as per IIP/IIIMP projects' expectations and targets).

These two mesqas, with contrasting features, were selected for detailed monitoring of social interactions and daily practices over periods of several months. The focus on water management allowed us to consider in more detail plot size, land use and spatial distribution, physical distribution in the networks of marwas (field-level ditches), reliability and equity, conjunctive use strategies (assessment of the amount of water and salts drawn from canals, drains, and wells), water-use efficiency and productivity, and social interactions between farmers. University students were recruited to help carry out this activity. The work carried out in 2013 and 2014 combined methods of observation, semi-structured interviews, GPS mapping, participatory mapping, and EC measurements.

► Activity 1.2d: *Carry out a study on the collective management of the 'pump sum' in Shalma canal.*

This activity, which was supposed to be done in the last year of the initial project, has been cut

<u>A new activity was added:</u>

A one-page questionnaire was designed to be applied to the largest number of pumping stations possible, taking geo-referenced pictures, and whenever possible filling in the questionnaire. A total of 640 Stations have been visited out of a total of around 1000 in the Meet Yazid area.

The main reason for adding this quite demanding activity was to document the percentage of stations which were not working, where motors had been stolen, or that had been electrified by farmers. This complemented the information from the 50 questionnaires which, by definition, did not address non-working pump stations.

This component (Activity 1.2) provides a key contribution to the evaluation of IIP/IIIMP through the documenting of whether/how efficiency and equity are indeed improved at the mesqa level.

Objective 2: Develop and assess marwa- and farm-level interventions that improve the productivity of diverse farming systems, and that contribute to increased water productivity under conditions of salinity, while assessing the economic and social dimension of crop choice and water management.

2.1. Evaluate and demonstrate marwa-level water management interventions.

Surface irrigation is the main method of irrigation in the Nile Delta. Efficiency and equity depend on how water is able to reach the final user, in particular at the tertiary (mesqa) and quaternary (marwa) levels. Long marwas result in additional losses, however modest, and also, more importantly, in head–end/tail–end disparities and conflicts.

The addition of burried pipes to distribute water from the (improved) mesqa main pipe down to the farm level was tested in the tail-end part of the Meet Yazid area (in the so-called W10 area). The expected benefits in land and water savings, and ease of operation warranted the proposal of a loan by the World Bank, AFD and AusAID.

► Activity 2.1: Assess the W10 pilot project on marwa improvement.

Observations and an analysis of marwa improvement projects were carried out as part of, and combined with, Activity 1.2b (survey of 50 IIP/IIIMP pump stations) and Activity 1.2c (monitoring of two pump stations in W10, equipped with marwa improvements). Results are incorporated in the two respective activity reports.

2.2. Develop and evaluate sustainable interventions to address degradation associated with salt-affected soils in the northern delta.

About 33% of Egypt's irrigated land is salt-affected, and soil salinization continues to increase over time for several reasons including poor irrigation practices, degradation of water quality, and seawater intrusion, which affects most soils in coastal areas. Several treatments and plot-level interventions must be tested to offer farmers a range of possible mitigation techniques. In addition, participatory approaches in developing small-scale farmers' skills and understanding of constraints to technology development and adoption are considered one of the most efficient means to disseminate research findings.

► Activity 2.2a: Conduct research on soil management techniques to combat degradation associated with salt accumulation. Several interventions were compared with no-intervention treatments, including (1) gypsum requirements, (2) organic matter, (3) conservation surface/subsurface tillage, and (4) bio-fertilizers.

A field experiment was conducted at Sakha Agricultural Research Station in Kafr El-Sheikh Governorate in four crop growing seasons to study the effect of soil amendments combined with different sources of nitrogen on growth parameters, yield and yield components of wheat, rice and sugar beet crop grown on a salt affected clayey soil under surface irrigation conditions. Wheat and sugar beet crops were cultivated in the winter season and rice crop during the summer season. All plots received nitrogen fertilizer in different form at a rate of 80kg N/Feddan (1 Feddan = 0.42 hectares).

A randomized complete block design with four replications was used. The treatments were: control, fertilized by urea (C+U), gypsum + ammonia gas (G +Ag), gypsum + bio-fertilizer + urea (G+B+U), gypsum + ammonium sulphate (G+As), gypsum + urea (G + U), gypsum + farm manure + ammonia gas (G + F + Ag) , gypsum + mole drain + ammonia gas + farm manure + bio-fertilizer (G+M +Ag +F + B), gypsum + mole drain + ammonia gas (G + M + Ag), gypsum + mole drain + urea (G + M +U), mole drain + urea (M + U).

Crop yields were determined in ton/ha. Crop growth parameters that included plant height (cm), panicle length (cm), 1000 grain weight (g) and leaf area in cm^2 were collected. Sugar beet root and shoot yields (ton/ha) and its quality were determined. After harvest, samples of grains and straw were dried, milled, and wet digested for determination of N, P, and K. Before the season and after the harvest, soil samples were collected and physical and chemical properties were analysed. Statistical and economic analyses were conducted.

► Activity 2.2b: Evaluate leaching requirements under different conditions of drainage status, sodicity, cropping systems, and also considering the influence of rainfall.

Parallel to research station work, evaluation trials were conducted in summer and winter season at the village of Shabab El-Khergeen (graduates area) for various crops. The selected site was isolated to avoid external factors when monitoring the effect of subsurface drainage combined with mole drains on productivity. Crop rotation was monitored to investigate its impact on soil properties and crop productivity. A well-defined drainage network was designed and installed in the farmers' plots to accurately facilitate the field trials, which included evaluation of subsurface drainage spacing combined with mole drains and gypsum and organic fertilizer application to improve the saline soil condition. All field trials were implemented in farmers' plots and compared to their traditional practices. The experimental design was a randomized complete block with four replicates (Figure 3).

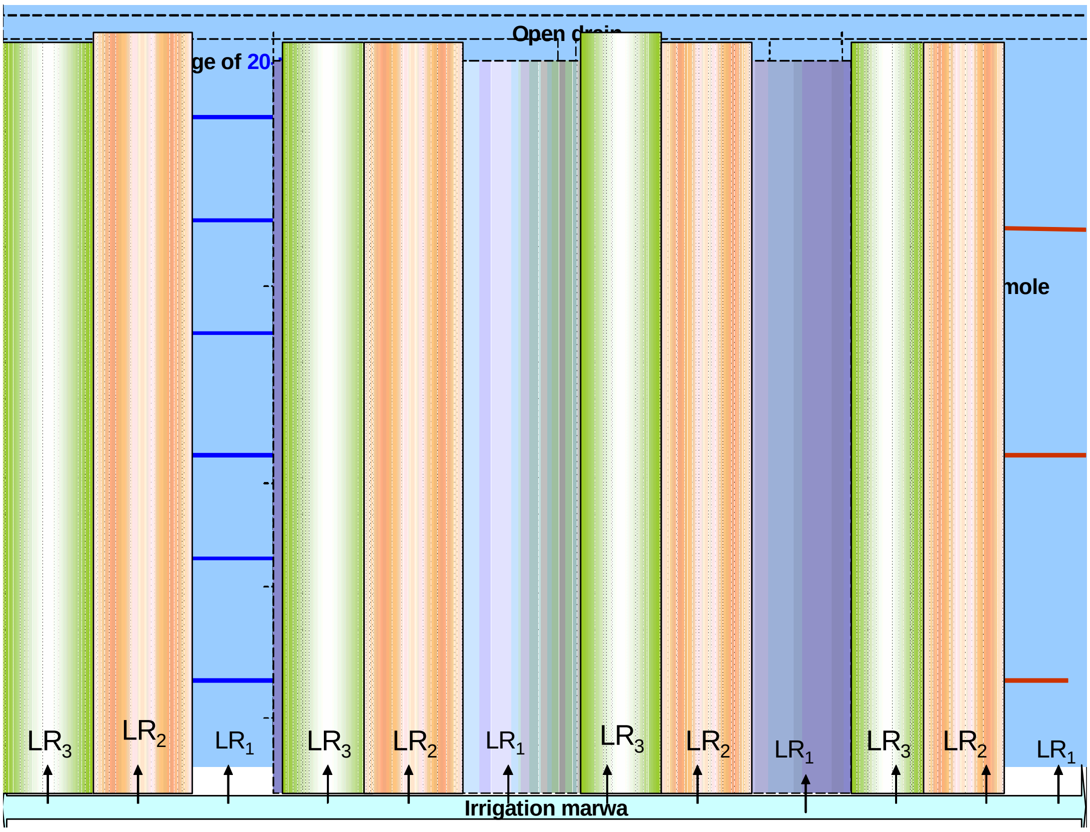

Figure 3. Experimental design

Two tile drains spacing with mole drains were tested as follows:

1) Tile drainage at 20 m spacing between drains and 120 cm depth + mole drains
2) Tile drainage at 20 m spacing between drains and 120 cm depth
3) Tile drainage at 40 m spacing between drains and 120 cm depth + mole drains
4) Tile drainage at 40 m spacing between drains and 120 cm depth

Mole drains spaced at 4 m between the plowed lines were installed at 60 cm depth (Figure 4). Mole drains were installed as a network perpendicular and parallel to the tile drainage.

Three leaching requirements were tried.

1: Traditional irrigation (as used by the farmer)

2: Traditional irrigation + 15% leaching requirements (LR)

3: Traditional irrigation + 25% LR

Data collected includes:

- Applied water (m^3 and dS/m)
- Monitoring of soil moisture content before and after irrigation to calculate leaching requirements
- Water table salinity (dS/m) and level (cm)
- Soil samples (0–15, 15–30, 30–60, and 60–90 cm depth) were collected before crop cultivation to determine some soil chemical and physical properties (Figure 5)
- Infiltration rate using a double-cylinder infiltrometer, and soil hydraulic conductivity (K) using the auger-hole method, were determined before cultivation
- Soil bulk density and total porosity of the different layers of soil profile
- Leaf areas of plants were measured

Rice cv Sakha 102 was transplanted during 1–4 June 2013; sugar beet (cv Pleno) was sown on 28 September 2013; wheat cv Giza 168 was sown on 21 November 2013; cotton cv Giza 86 was sown on 3 May 2014; and rice cv Sakha 102 was transplanted on 28 May 2014. Agricultural practices for all crops were as recommended.

Soil chemical, physical, and hydrological properties were determined at the initial state and after every season. Amounts and salinity of irrigation water applied were measured. Productivities of all crops were determined for the different treatments.

Drain installation

PVC pipes in location

Drain installation

Figure 4. Field setup

Infiltration rate using double ring cylinder infiltrometer

Hydraulic conductivity (K) using the auger-hole method

Soil bulk density

Soil sampling at different depths

Figure 5. Field experiments to measure soil physical properties

2.3. Undertake a comprehensive assessment of farming systems and the rationale behind farmer crop selection and associated rotations (CANCELLED)

The continued evolution of cropping patterns within the Nile Delta has significant implications for land and water use, and livelihoods. These changing patterns and the typology of farming systems is documented at the macro level (secondary data at the delta, province, and study area) and complemented with farm-level surveys and the use of land-use classifications derived from satellite images. Economic rationales under changing policy environments must be made explicit, together with constraints related to (also changing) patterns of water availability in terms of quantity, quality, and timing. This understanding of crop-choice rationales is necessary both to inform scenarios that will be tested in Activity 4.1 and to evaluate the possible impacts of selective policy options (e.g. raising the economic attractiveness of cotton). Data collection includes macro-level economic data on the price structure of inputs and outputs (economic environment) and undertaking a large survey at farm-level. The survey will reveal, in particular, the role of women in crop selection, notably with regard to cash crops, and how they share the benefits (link with Activity 2.5).

► Activity 2.3: Comprehensively analyze the physical, agronomic, and socioeconomic constraints that govern crop choice.

2.4. Undertake a socioeconomic analysis of fish-farming systems in the upper delta.

Fish farming is a significant activity in the lower reaches of the delta and an integral part of the socioeconomic fabric of local communities. Despite the importance of this livelihood activity, it is tellingly often overlooked in studies of land use and neglected in water/salt balances. This project puts aquaculture 'on the map' with a clear evaluation of both its socioeconomic relevance and its adaptation to, and impact on, varying water quantity–quality regimes. The socioeconomic profile of fish-farmers and the level and variability in economic returns from fish production is assessed and compared with competing crop commodities (i.e. rice and sugar beet) for land and water resources.

Structured surveys of individual households were conducted with farmers of aquaculture and field crops to collect data. The study sample consisted of 85 respondents (55 were fish farmers and 30 were dependent on agriculture). A random sample was taken from farmers of fish and field crops. Mobile phones with GPS function were used for the survey to record all the points surveyed.

A detailed socio-economic analysis was carried out for the four main aquaculture systems in the study area consisting of aquaculture system that depends mainly on artificial food and organic manure, aquaculture system that is based on artificial food only, aquaculture system that depends on wastes of food factory and organic manure and aquaculture system with wheat cultivation. The net benefits were estimated after calculating total cost and returns from each of the aquaculture system.

► Activity 2.4: Carry out a socioeconomic study of fish farming in the aquaculture area.

2.5. Undertake a cross-cutting gender analysis of multi-level water management

The research started with a literature review on the role of gender in Egyptian irrigated agriculture. As described above the findings were disappointing. The field research was subsequently carried out in two contrasting case study areas in the old and the new lands of Lower Egypt, which have strikingly different characteristics in terms of landownership, gender roles, labour supply and demand, irrigation technology, and social control. These different conditions change the situation of women who are working in irrigated agriculture. In the old lands of the Nile delta, we selected the W10 area near Kafr el Sheikh and in the new lands we selected a more recently reclaimed Western desert project 'El Bustan' in Nubaria. The study also draws on ethnographic material collected in the latter area between 2010 and 2013.

To construct these two case studies we have used the following research methods: participant observation, semi-structured interviews, a survey, literature study, etc. Participant observation (PO) was particularly important in studying gender relations where people systematically state ideal norms which observation brings into question. As Margaret Mead already observed: “What people say, what people do, and what they say they do are entirely different things”. A research team of two researchers (woman, man) did the PO, compared notes and validated observations on an ongoing basis. Field visits were further used for semi-structured interviews about the role of women in irrigated agriculture with men and women farmers, amongst whom land owners, crop sharers and labourers to answer the question. This later led to designing a survey administered to 400 women and men farmers on gender roles on their farms and the contribution of women to irrigation more generally. We do not intend this sample to be statistically representative. Rather, it allowed us identify and test analytical points about common experiences cutting across divergent household types, age groups, genders, in varying agro-ecological conditions and differing land status.

► Activity 2.5: Carry out a cross-cutting gender analysis of multi-level water management.

Objective 3. Build an understanding of the temporal and spatial dynamics of salt at several nested and successive scales (farm, meso, main canal/drain levels, fishpond area, and lake) to understand the linkages between water management practices and salt movement/accumulation.

3.1. Quantify the salt dynamics under contrasting irrigation and cultivation practices at the plot level.

Detailed controlled drainage studies (Figure 6) were undertaken in order to understand the salt dynamics under rice and associated crops and their impact on soil and drainage water quality. This included the influence of different crop rotations, farm practices, and subsurface drainage status on salt build-up, and the contribution of groundwater to evapotranspiration. Experiments were carried out on research stations in the salt-affected area, and this research will provide key information for the scaling-up at the meso and macro levels. The main objective is to understand the link between particular crop rotations and salinity build-up for varying conditions (levels) of water tables.

Figure 6. Experimental set-up

The experiments started during the summer of 2013 and were carried out in four cropping seasons. The network of drainage was totally changed to achieve better control, with drainage at different levels: 120 cm as control and 40, 60, 80, and 100 cm. Each treatment had three laterals to create a buffering zone to prevent seepage from the neighboring treatments and avoid any interaction between treatments. Soil chemical and physical properties were determined before the experiment and after every season. A network of observation wells was installed to monitor fluctuations in the water table in the experimental site. Activities included the following: records of inflow and outflow, movement of the water table, dynamics of the salt content in the soil profile, and establishment of salt and water mass balances.

► Activity 3.1: Examine and quantify water/salt dynamics in salt-affected plots (on research stations).

3.2. Develop an understanding of salt movement and associated changes in drainage water quality at the meso level.

This activity seeks to understand the water and salt dynamics of a meso-level area (300 feddan) by closely monitoring the quantity and quality of water flows and stocks. This can only be done in an area equipped with collective pumps, so that the number of lifting points is amenable to measurement; and also if drainage outflow is well concentrated in one particular drain. This activity was planned for implementation in summer 2013 but we were not initially able to identify a site suited to such measurements. We eventually found an excellent site in the Mares el-Gamal canal command area that had just been equipped with IIIMP pumps. Researchers from the four institutions worked together on the methodology and setting up the equipment to start monitoring for summer 2014, with the following objectives and tasks:

- Understanding temporal variability of drainage outflow and salt mobilization, to help in understanding the linkages between water management practices and salt movement/accumulation. The monitoring of water and salt dynamics at meso scale will provide a comprehensive understanding of salt movement at this scale.
- Provide insights into the variability in salt mobilization at an hourly/daily time-step as a function of on/off supply rotations and of the current status of subsurface collectors.
- A water and salt mass balance approach was applied to the area considered. The water balance was made precarious by the difficulty of measuring outflows in the drain, with discharge was low and much affected by weeds.
- Assess the performance of the IIIMP pumps and explain variations in management between the 15 pumps. Provide insight on how farmers organize at the very beginning, after commissioning of the pump station.

A network of 18 piezometers was installed to monitor fluctuations in the water table. Data collection includes:

- Water table level every hour in eight piezometers (automatically recorded)
- Soil salinity at beginning, middle, and end of the season
- Ten soil profiles were sampled and analyzed twice at 0–30, 30–60, and 60–90 cm
- Survey of farmer practices in the investigated area, through periodic visits (either during the on or off periods)
- Survey of cropping pattern of summer 2014, winter 2014 and summer 2015
- Twenty-five data loggers monitoring on/off patterns in the electric pumps of pump stations
- Five thermo managers monitoring the use of additional diesel pumps
- Monitoring of water levels and salinity at the head of Mares El Gamal and Bashair sub-branches, providing indications on rotation patterns (hourly recordings)
- Monitoring of water level and salinity in the Bashair drain, at the outlet of the study area (hourly recordings)
- Hourly monitoring of EC in two manholes

► Activity 3.2: Monitor water/salt dynamics at the meso level.

3.3. Map the spatial and temporal mobilization of salt/pollutants across the landscape in order to understand salt dynamics at a larger scale and develop management strategies for its abatement.

Salt concentration in drains, measured by electrical conductivity (EC), reflects soil type, land use, conjunctive water use (i.e. from drains and wells), and effectiveness of subsurface drainage and irrigation practices, along with seepage of groundwater into the waterways. It is necessary to gain an understanding of the spatial and temporal variability of EC in the drainage system over the whole area considered, in order to quantify the relative importance of the aforementioned factors. Drainage water quality is mapped in order to understand spatial heterogeneity. This has been achieved through campaigns of *in situ* EC [together with biochemical oxygen demand (BOD), pH, total dissolved solids, and temperature] measurements through the use of EC meters equipped with a global positioning system (GPS) on primary/secondary canals and drains (with a target 500 measurements), to be collected in two periods of the year (summer and winter).

► Activity 3.3: Undertake campaigns of water-quality measurements in season 1 (with interim report) and season 2 (with final report).

3.4. Quantify the impact of aquaculture water management on water quality and the implications of multiple recycling on salt mobilization.

Little is known about the impact of aquaculture (which, typically, is seldom considered in studies on land use, water use, or control of saline intrusion) on the concentration of salts and overall water consumption. Water management practices at the pond level need to be taken into account in order to understand the key role of the aquaculture area in the overall water and salt balance, an area that acts as a ‘salt-concentrating’ intermediate zone between agriculture and the lake.

Surveys of water management practices at the pond level were undertaken and estimates of rates of water renewal, evaporation, and inflow/outflow quality calculated for a sample of ponds with different types of management. Infiltration was estimated based on comparisons with evaporation in a “Class A” pan that will be measured in parallel. The spatial geographies of salinity flows in the area was identified, with estimates of the share and average salt contents of various inflows from the northern boundary drain (Moheet), the channels connecting with the lake (after pumping stations)[4], and the lake itself – Lake Borullus– as well as return flows. Other water quality parameters such as BOD were also collected. A geographical information system (GIS) based on layers derived from Google Earth, time and location-specific water-quality samples, and survey data were combined to arrive at an overall picture of the functioning of the aquaculture area south of Lake Borullus.

► Water management practices at the pond level were being surveyed and estimates of rates of water renewal, evaporation, and inflow/outflow quality were estimated for the four sampled ponds with different types of management see table.

- Common data collection for all ponds:
  a) Sensors measuring water level and salinity (EC) in the waterway from which water is taken
  b) Sensors inside the ponds to monitor the change in water levels
  c) Water quality device (YSI 5200) to monitor DO, pH, EC, and temperature within the pond. Hourly measurements could be made automatically
  d) Estimating **evaporation** through measuring the evaporation of a Class A pan in the site (daily measurements). A person from the farm was trained and paid for this service, and a water level sensor was added for double checking
  e) Measuring water **inflow** to fish ponds.
  f) The **outflow** is only measured wherever feasible without too much burden. In other cases it will be estimated as the closing term of the balance (all other terms previously being estimated)
  g) Daily management data of each pond e.g. intensity, feed, and fertilizers).

Figure 7: Data collection points in Moheet

Water samples were taken from each pond and analysed for water quality parameters in 2014 and 2015.

► Activity 3.4b: Map waterways and flows, monitor water quality (EC and BOD) in a number (tentatively 10) of selected locations, and identify flows, from and to, the Moheet drain, Lake Borullus, and the connecting channel.

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[4] *The boundary drain (Moheet) has five main stations that pump water out to main channels feeding Lake Borullus after passing through the aquaculture area, from which water is abstracted on its way to the lake (Dumont and El-Shabrawy 2007).*

Figure 8: Mapping water flows in Moheet

This activity recently commenced with identification of the main waterways connecting the fish area with both the lake to the north and the Moheet drain to the south. After this identification, periodic measurements of flows and water quality were conducted.

The spatial geographies of water flows and salinity in the area were identified by:

- Collecting operating data for two years (2012 and 2013) of the pump stations no. 7 and 8, and later in 2014
- Calibrating of pumps in stations 7 and 8 to refine estimates of the volumes of water pumping to the fish area (1,2 of Figure 10)
- Measuring the quantity and quality through:
  a) Installing two ultrasonic (Doppler) flowmeters to measure water discharge to Borullus Lake from drains 7 and 8. (3,4 of Figure 10)
  b) Periodic *in situ* measurements of the flow to Borullus Lake from drains 7 and 8. (3,4 of Figure 10), to control the quality of data from the ultrasonic flowmeters
  c) Measuring EC (sensor) at both the head of drains 7 and 8 just after the pump station
  d) Measuring EC and BOD at the outflow of drains 7 and 8 to the lake (monthly measurement when the pump is working)
- Estimating the return flow to Moheet drain from the fish ponds:
  a) Defining and mapping the area taking water from El-Moheet drain (5,6)
  b) Estimating the amount of water that drains back to El-Moheet drain (periodic measurements of flow of some of these drains to El-Moheet)
- Measuring the water quality (taking samples and defining the location with GPS) in spatial distribution pattern to give a map of the water quality of the fish area
  a) Taking five samples along the El-Arab canal and another five samples along the El-Nasraneya canal and do twice-monthly *in situ* measurement of water quality for the six months of summer
  b) Taking five samples from El-Moheet drain
  c) Taking five samples each from drains 7 and 8 after the pumps, twice-monthly for the six months of summer

These activities recently commenced and will continue during the coming 10 months.

► Activity 3.4c: As mentioned above two ultrasonic flowmeters were bought and installed at the outlet of drains 7 and 8.

Six main drains flow into Lake Borullus. Current flow estimates were based on pump calibration curves that are obsolete and new curves were needed for more accurate measure of outflows. This was done in collaboration with the Mechanical Department of the Ministry of irrigation and water resources. The last five years of pumping records were recalculated based on these new curves and outflows re-estimated. This collaboration was initiated.

Objective 4: Develop an understanding of the implications of these cross-scale interactions through the modeling of the whole central delta, and assess the fraction of water that could potentially be 'saved' and used in the New Lands under constraints of salt management and sustainability of current uses (rice, aquaculture, and fisheries).

4.1. Undertake an assessment on the impacts of a range of interventions when scaled-up on water and salt balances (SIWARE software for the whole central delta) and test various scenarios (CANCELLED).

The scaling-up of the processes and constraints evidenced in other components can be assessed at the system level through a modeling platform. SIWARE (Simulation of Water management in Arid REgions), developed by the Dutch Cooperation and the Drainage Research Institute (DRI), simulates water distribution and drainage at the level of the central delta – see applications in Roest (1999) and El-Ganzori et al. (2000). Elementary units in SIWARE are the branch canal command areas, and the model will be fed with the upgraded and spatially more detailed information obtained by other components of the project on water distribution, drainage water use, and salt dynamics at the meso and macro levels [e.g. soil type, quantity/quality of canal and drain water, cropping patterns (obtained in Activity 1.1), irrigation practices, seepage/capillarity flows, and effectiveness of subsurface drainage].

Additional activities within this component aimed at improving the accuracy and calibration of the model include: 50 canal cross-section surveys (with emphasis on the Meet Yazid canal and its branch canals), surveys on the intensity of pumping from drains in summer (at different representatives locations), surveys on the intensity of groundwater use (along a cross-section), and surveys on the status of the subsurface drainage system (notoriously underperforming due to clogging).

This activity was supposed to involve an Egyptian PhD student (to be selected from NWRC or Universities) to be registered at Wageningen University, where scientists with earlier work on SIWARE/Egypt would have assisted in further development of the software in greater detail, in order to model rotational distribution. But this activity was cancelled.

► Activity 4.1: Prepare input data, calibrate, and run the model to assess scenarios and their outcomes.

4.2. Establish an integrated view of the rice/aquaculture/lake complex in terms of water/salt balances in order to define the conditions for the joint sustainability of these systems, and to assess the effective potential for macro-level water savings (CANCELLED).

Results from the pond management surveys (Activity 3.4a), coupled with a wider study of drainage inflows/outflows (Activity 3.4b), will allow us to quantify the 'salt concentrating power' of the aquaculture area. We will conduct lake-wide surveys of salinity at different times of the year[5] (boat/GPS/EC meters) to assess spatial heterogeneity.[6] These are key missing elements for a proper understanding of the *overall* delta water and salt balances. Coupled with SIWARE, this balance will provide us with a tool to re-evaluate the water/salt balance of the central delta, the sustainability of the lake fisheries under various scenarios, the role of fish ponds in concentrating salts but also in controlling underground seawater intrusion (Kashef 1983; Kotb et al. 2000), and eventually the margin for macro-level water savings, under constraints of water quality. This will lead to a reconsideration of earlier rough attempts to estimate the minimum outflow of the delta (IRG et al. 1998a, 1998b).

This will require the collection of historical data on drainage water quantity and quality (outflow to Lake Borullus), critique/adjustment of data based on new flow measurements by ultrasonic flowmeter after the pumping stations, and surveys of the lake salinity (GPS/EC meter survey and interviews with fishers on observed dynamics) and productivity (secondary data and fisher interviews).

An understanding of the salt dynamics at the delta level will determine the salt balance of the lake and feed into reflections on (1) its ecological sustainability and expected ecological transformations in the case of changed water/salt regimes[7], and (2) the corresponding scope for horizontal expansion through using water 'saved' in the delta. All analyses will be integrated into a revised water balance of the central delta, with a conclusion that may be extrapolated to the delta as a whole.

► Activity 4.2a: Study salinity dynamics in Lake Borullus. This activity has been canceled after shortening of the project.

► Activity 4.2b: Prepare a prospective report on possible future ecological changes in the lake under different scenarios of salinity regimes (consulting with the WorldFish Centre). This activity has been canceled.

► Activity 4.2c: Collect, analyze, and compare the different delta water balances and their components (as well as the hypotheses made) found in the literature. Write report.

Figure 9 presents a summary of the research activities described above and shows how they cover the various nested scales, issues related to the quantitative and qualitative management of water, as well as socioeconomic/institutional aspects. It also illustrates how the different research activities feed into one another: the understanding of salt/water dynamics under varied water/soil management regimes at the farm and meso level are, on the one hand, linked to recommendations to be disseminated to farmers and, on the other, allow a refined modeling of the spatial units considered by the SIWARE model. Macro-level salt dynamics mapping provides hints on heterogeneity and its causes. Likewise the study of mesqa-level water management in three situations (individual pumps, IIP-IIIMP pumping stations, and IIIMP with piped marwa level) will provide understanding of how these interventions modify water abstraction from both canals and drains (and therefore how the model must take such changes into consideration). Last, activities related to the aquaculture area and the lagoon allow for a complete salt/water balance of the central delta.

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[5] Salinity (and exchange between the lake and the sea) varies with the relative magnitude of the drainage outflow with regard to sea level. They are highest at the beginning of the year when drainage outflows are minimal.

[6] The lake receives 'fresh' water from six main drains, with the largest flow from the east, very close to the outlet to the sea.

[7] There is evidence to support the notion that the lake was more saline before construction of the Aswan High Dam (Dumont and El-Shabrawy 2007) and we also need to anticipate associated ecological changes and fisheries potential if this was to happen again.

Levels / issues	Water management (quantity)	Water quality/salts	Socio-economic and institutional aspects
Nation / delta	4.2	4.2	4.2
Main canal	1.1	3.3	1.1
Branch canal	1.1-1.2	3.2	1.2
Mesqa	1.2	3.2	2.3
Marwa, farm	2.1 – 2.2	2.2	1.2-2.3
Boundary drain			
Aquaculture	3.4	3.4	2.4
Lagoon fisheries	4.2	4.2	
Sea			

Figure 9: Integration of research activities across levels and spatial units, and across water quantity, water quality/salt, and socioeconomic/institutional issues

Objective 5: Build capacity of decision-makers, water managers, researchers, extensionists, farmers, and other stakeholders through seminars, targeted training courses in Egypt, and formal and informal education and programs.

This is an overarching component to the project's four research components and is implemented in close coordination and collaboration with the ICARDA–IWMI activities in the country. Enhanced knowledge, skills, and qualifications of key stakeholders in the study area through degree and non-degree training activities was the key focus. With involvement of three universities in the project (Tanta and Kafr El-Seikh locally, and Ain Shams in Cairo), five postgraduate students were engaged in this project. Capacity-building activities are directed at farmers, practitioners, extension agents, students, and scientists to accelerate knowledge and technology uptake.

► Activity 5.1.1: Organize periodic seminars, engaging decision-makers and other stakeholders, including cooperation agencies or donors. It is proposed to have three major meetings at 18, 32, and 46 months when the main results will be presented and debated.

► Activity 5.1.2: Organize focused training courses for the scientists involved in the project to help their professional development, including the following topics:

Several training courses were organized during the life of the project for project scientists and is listed in the section 'capacity building'.

► Activity 5.2: Hold farmers' school, with demonstrations in farmers' fields or in the station on salinity mitigation techniques (linking with Activity 2.2a; other field-demonstrations and on-farm training have been shifted to the CSE project).

Field days were organized in each cropping season and farmer groups are exposed to ongoing experiments in the farm.

6 Achievements against activities and outputs/milestones

	Activity	Partners/ responsibility *name*: *respons. person*	Outputs/milestones	Due date of output/ milestone	New Due date	Status
Objective 1: Identify and develop strategies that address institutional and technical barriers associated with the management of main and branch canals and assess the effectiveness of collective action in the functional operation of water user associations (WUAs) at the mesqa and branch canal levels						
1.1	*Undertake a comprehensive analysis of both technical and institutional factors that influence the effective management of main and branch canal (Meet Yazid area)*					
1.1a		MWRI Cairo, two governorate offices	Data on canal and water control infrastructures collected, branch canals selected, ultrasonic flow meters purchased and installed	January 2013	Completed	**Completed** Ultrasonic flow meters acquired; location shifted from branch canal to main drain exit to Borullus Lake
		WMRI, IWMI	Interim report on management constraints and practices	March 2013		**Completed** An exploratory survey of the whole Meet Yazid area was carried out. An exploratory report was prepared and is available.
1.1b		ARC WMRI, IWMI	Land use data collected, relevant satellite images analysed and groundtruthed over 2 years		Completed	**Completed** RapidEye images were classified using ground truth data collected from 290 sampling points for the years 2014 and 2015. Detected the changes in land use in the Meet Yazid command area.
			Quantitative and spatial analysis of supply and demand. Final report on management constraints and practices	December 2014	December, 2014	**Ongoing** Collected the flow data and meteorological data. Spatial analysis of supply and demand will be carried out and the final report will be prepared by December, 2015.

	Activity	Partners/ responsibility *name*: *respons. person*	Outputs/milestones	Due date of output/ milestone	New Due date	Status
1.1c		IWMI, WMRI, universities	General information and research on past experiences with BCWUAs collected, questionnaire designed, sample defined	January 2015	November, 2014	**Completed** A survey has been carried out and the results are analysed and report is available.
1.1d		IWMI, WMRI, universities	Comparative surveys on selected BCWUAs carried out and understanding of the conditions for success. Synthesis report written	February 2016	May, 2015	**Completed**. Surveys carried out and a synthesis report written
1.2	*Analyse the effectiveness of collective action within WUAs at the mesqa level*					
1.2a		IWMI, WMRI, universities ARC	Available information and research reports on WUAs collected; rapid appraisal questionnaire designed, sample defined, two mesqas selected for detailed monitoring	May 2013	Completed	**Completed** A literature review on WUAs in Egypt was carried out and synthesized into a report
1.2b		IWMI, WMRI, universities, students	Rapid appraisal of a large sample of improved mesqas carried out, to understand the variability in the degree of success and determinants. Report delivered	June 2014	Completed November 2014	**Completed** The report focuses on lessons drawn from surveys conducted in the Meet Yazid canal command area regarding IIP and IIIMP pump stations, with additional observations on on-farm interventions.
1.2c		IWMI, WMRI, universities,	In-depth long-term monitoring of social management of two mesqas and assessment of the problems with collective action; reports delivered	Case 1 Mar 2014 Case 2, Jan 2016	Completed	**Completed** Benefits and difficulties of water management under collective pumps and improved irrigation at different levels is analysed. A Masters student is nearing completion

	Activity	Partners/ responsibility *name*: *respons. person*	Outputs/milestones	Due date of output/ milestone	New Due date	Status
1.2d		IWMI, NWRC, universities	Study on the collective management of the 'pump sum' in Shalma canal carried out in order to understand constraints and social organization in pre-IIP situations; report available	January 2015	Shifted to June 2015	This activity is yet to start
2.1	*Evaluate and demonstrate marwa-level water management interventions*	IWMI, ICARDA, ARC, NWRC	Stock-taking on W10 pilot project in order to highlight the benefits and problems faced with marwa level investments. Guidelines for FIMP loan issued	April 2014	November 2014	**Ongoing** The study was carried out with the involvement of two MSc students. The research use a case study approach, involving various research tools including direct observation, and semi-structured and unstructured interviews. The students are nearing completion.
2.2	*Develop and evaluate sustainable interventions to address degradation associated with salt-affected soils in the northern delta*					
2.2a		ARC, ICARDA	Set of soil amendments and practices tested (over 3 years)	Jan 2015, 2015,2016	June, 2015	**Completed** Field experiments were carried out for four cropping seasons, required data being collected, data analysis completed.
2.2b		ARC, ICARDA	Better knowledge of salt dynamics and water required for leaching soils. Necessary leaching fractions estimated	Jan 2015, 2015,2016	June, 2015	**Completed** Field experiments were conducted in farmers' fields for four cropping seasons and compared to their traditional practices. Data analysis completed and the extension of research findings in progress.

	Activity	Partners/ responsibility *name*: *respons. person*	Outputs/milestones	Due date of output/ milestone	New Due date	Status
2.3	*Undertake a comprehensive assessment of farming systems and the rationale behind farmer crop selection and associated rotations*	ARC, ICARDA, IWMI, universities	Understanding of farmers' constraints with regard to crop choice. Survey carried out and report available	March 2015	March, 2015	This activity has been cancelled due to lack of time.
2.4	*Undertake a socioeconomic analysis of fish-farming systems in the upper delta*	ARC, ICARDA, IWMI, universities	Assess return from fish farming systems and margins for intensification. Survey carried out and report available	October 2014	December, 2014	**Completed**. Socio-economic survey completed, data has been analysed and a draft report is available.
2.5	*Undertake a cross-cutting gender survey*	IWMI, ICARDA, ARC	Gender-sensitivity of water and agricultural management demonstrated. Survey carried out and report available	March 2015	March, 2015	**Completed** Gender survey has been completed and a summary report is prepared.
3.1	*Quantify the salt dynamics under contrasting irrigation and cultivation practices at the plot level*	ARC, ICARDA, univ.	Salt build-up mechanisms studied and report and recommendations issued	Dec 2013, Feb 2015	June 2015; This activity will continue beyond June 2015 using funding from other sources	**Completed** Field experiments were conducted for four cropping seasons. Data analysis completed and a draft report available. The student is nearing completion.
3.2	*Develop an understanding of salt movements and associated changes in drainage water quality at the meso level*	NWRC, ARC ICARDA	Understanding of the temporal variability of drainage outflow at the meso level. Salt mobilisation at the meso level studied in detail at two locations	May 2014, Aug 2015	June 2015; This activity will continue beyond June 2015 using funding from other sources	**80% completed** A suitable location is selected, monitored the land use, groundwater levels, water quality, inflow, soil quality etc. This information will be used to develop a simple mass balance model to understand the salt movements.

	Activity	Partners/ responsibility *name*: *respons. person*	Outputs/milestones	Due date of output/ milestone	New Due date	Status
3.3	*Map the spatial and temporal mobilisation of salt across the landscape in order to understand salt dynamics at a larger scale and develop management strategies for its abatement*	NWRC, IWMI (ARC)	Knowledge on spatial patterns of salt mobilization and movements. Campaigns of water quality measurements in season 1 (with interim report) and season 2 (with final report).	February 2015, Jan 2016	April 2015; This activity will continue beyond life of the project using funding from other sources	**Completed** EC and DO has been monitored spatially along the secondary drains in the Meet Yazid command area during two cropping seasons and analysed.
3.4	*Quantify the impact of aquaculture water management on water quality and the implications of multiple recycling on salt mobilisation*				June 2015	
3.4a		ARC, NWRC, ICARDA, IWMI, universities	Unpack salt and water balances in pond aquaculture. Pond-level water management analysed and report available	June 2014	June 2015 (This activity will continue beyond June 2015 using funding from other sources)	**Activity in progress.** Two fish farms were selected; required equipment's are installed and monitoring is in progress. Activity is delayed due to mal functioning of the water quality measuring device. It is expected that good quality data will be collected during the summer season 2015.
3.4b		NWRC, IWMI	Regional mapping of flows; water quality, water balance of the aquaculture area. Report available	June 2015	June 2015	**Ongoing.** This activity recently commenced and will be continue during the coming 10 months.
3.4c		NWRC	Reassessment of delta outflow records through recalibration of pumping stations' curves. Report available	Nov. 2015 +interim reports	June 2015	**Ongoing** This activity recently commenced and will be continue during the coming 10 months.

	Activity	Partners/ responsibility *name*: *respons. person*	Outputs/milestones	Due date of output/ milestone	New Due date	Status
4.1	*Undertake an assessment on the impacts of a range of interventions when scaled-up on water and salt balances (SIWARE for whole central delta) and test various scenarios*	NWRC, ARC, ICARDA, IWMI	Generate a tool to integrate and upscale salt/water balances at the level of the central delta. Input data prepared, calibrated and the model run to assess scenarios and their outcomes	June 2015	Initiated within the project period and to be continued with proposal to be submitted to WLE.	**This activity was cancelled** because of the exclusion of Egypt from the NUFIC PhD scholarship program of the Netherlands.
4.2	*Establish an integrated view of the rice/aquaculture/lake complex in terms of water/salt balances; define conditions for joint sustainability; assess the effective potential for macro-level water savings*					
4.2a		NWRC, IWMI	Salinity dynamics in the lake are understood. Report produced	October 2015	Use existing data	**This activity is cancelled**
4.2b		Consultant	Prospective report prepared on possible future ecological changes in the lake under different salinity scenarios	October 2015	To be reviewed	**This activity is cancelled**
4.2c		NWRC, IWMI	Different delta water balances (and their hypotheses) in the literature collected, analysed and compared. Report synthesised	January 2014	April 2015; This activity will continue beyond June 2015 using funding from other sources	**Completed**. Close to 10 different sources providing delta water balances have been identified and collected. A delta water balance is carried out based on information available in literature.
4.3		NWRC, ARC, ICARDA, IWMI, universities	Synthesis report available, shedding new light on cross-scale interactions and the complexities of joint water quantity/quality management in the delta	June 2016	June 2015	**Ongoing**. Reports are available for some activities and others in progress.

	Activity	Partners/ responsibility *name*: *respons. person*	Outputs/milestones	Due date of output/ milestone	New Due date	Status
5.1	Periodic seminars, engaging decision-makers and other stakeholders	All partners		Months 18, 30, 46	June 2015	The project team meets once every year to review the progress and communicate findings to and receive feedback from stakeholders.
5.2	Training courses	ARC, ICARDA, NWRC		2014 to 2016	June 2015	**Ongoing**. Several training programs were organised and details are provided in the capacity building section. Five Egyptian students were trained during the life of the project. Several Egyptian project participants attended focussed training programs organised by ICARDA.

7 Key results and discussion

Objective 1: Identify and develop strategies that address institutional and technical barriers associated with the management of main and branch canals and assess the effectiveness of collective action in the functional operation of WUAs at the mesqa (tertiary) and branch (secondary) canal levels.

1.1. Undertake a comprehensive analysis of both technical and institutional factors that influence the effective management of main and branch canals (i.e. the Meet Yazid main canal command area)

► Activity 1.1a

The first six months of the project were dedicated to the collection and analysis of existing data on canal and water control infrastructures, agricultural data, and canal management. An exploratory survey of the whole Meet Yazid area was carried out with interviews of district engineers, gate keepers, and random farmers, addressing agricultural and water management practices. A set of GIS layers was established, with over 1000 geo-referenced pictures available and overlaid in Google Earth.

The wealth of data collected during the survey together with existing reports (notably IIP ones) were synthesized into an exploratory report (more ambitious than initially envisaged), presenting information and reflections on various aspects of agricultural water management. The table of contents of this 122-page report is:

Two ultrasonic flowmeters were planned to installed in selected branch canals. The IIP program already has a database on some of these branch canals and the macro-level analysis is now quite clear. This it seemed much more interesting to use this equipment to measure the outflow of drains 7 and 8 to Borullus Lake (after high diversion by the fish-farming area), thus contributing original and crucial information to understanding of the outflow from the delta to the sea, and as a result to the delta water balance. These two flowmeters were installed and are collecting data, although their calibration has proved difficult and needs to be redone.

► Activity 1.1b: Collect land-use data and flow data, survey intensity of drainage water use over a sample of drains, and purchase relevant satellite images on monitored branch canals over two years.

Rapid eye satellite images for the Meet Yazid command area were procured (for 2013 and 2014) and image processing carried out. Detailed ground-truthing was used to test the accuracy of classification (Figure 10). The results show that about 80% of the studied area is cultivated and about 14% is urban. Major crops in the study area are rice and maize in winter and wheat, clover and onion in summer. One hundred sampling points representing all crop classes were used to calculate the accuracy of classification. The accuracy of classification was assessed using a confusion matrix and the results indicated that the total accuracy of classification was 93%.

Three land use maps for the years 1991, 2007, and 2014 were used to monitor the changes in land use classes in the study area. Change detection analysis has been carried out to analyse the land use change. The results show that about 93% of the land area was cultivated in 1997 and this was reduced to 89% in 2007. Fish farm constitutes approximately 4 to 5% of the total area. Results from change detection analysis suggest that in the last two decades land use in this area has been changing from predominantly agricultural uses to non-agricultural uses (urban areas and fish farms). Approx. 20,000 feddan of agricultural land was converted into urban areas between 1997 and 2014. It is also clear from this analysis that farmers are converting agricultural lands into aquaculture farms possibly due to low irrigation water quality in these areas and economic reasons.

Crop wise maps developed in this activity are very useful in accurately estimating the water demand of the command area. Flow at the branch canal has been monitored for the historical period and meteorological data has been collated. Spatial analysis of supply and demand will be carried out and the final report will be prepared in the next two months.

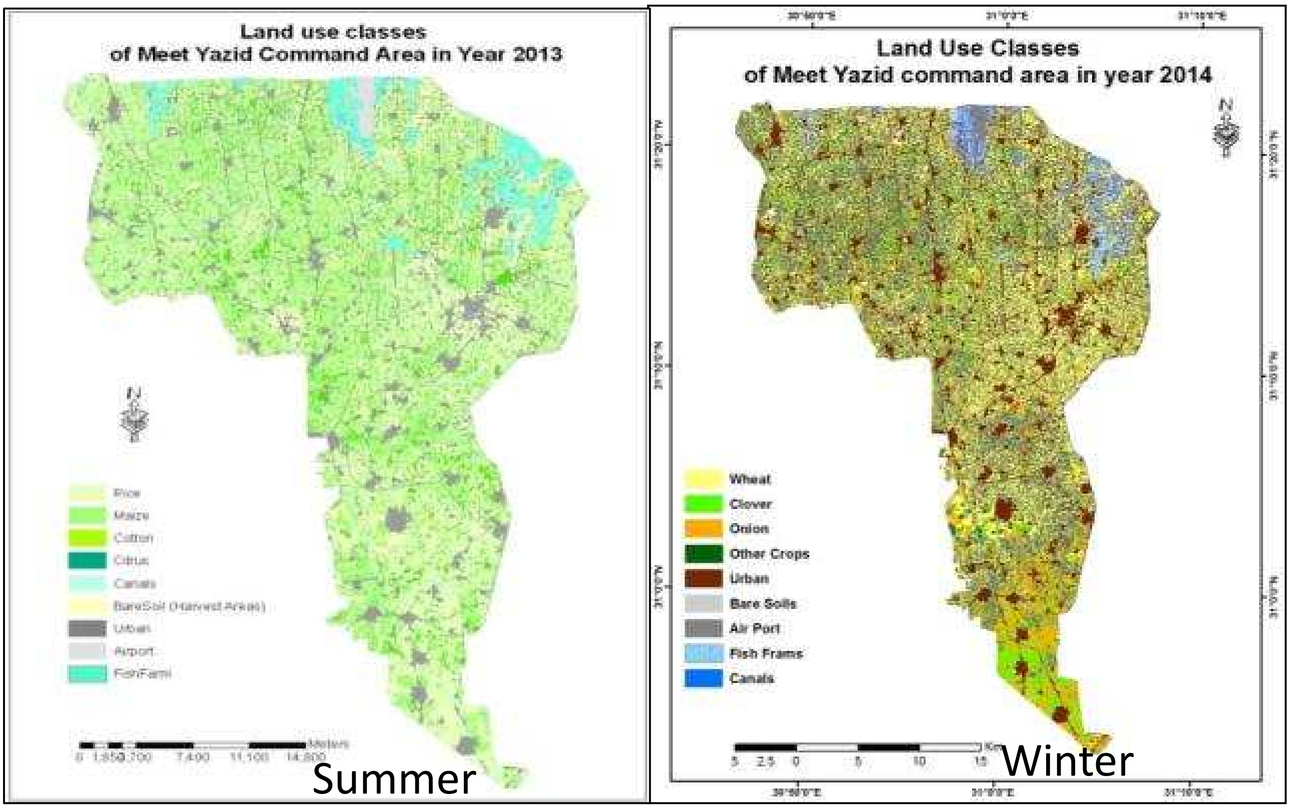

Figure 10: Cropping pattern in the winter and summer season of 2013-14

► Activity 1.1c General information on past experiences with BCWUAs in different projects were collected and analyzed differences, the literature of case studies reviewed, and a sample of WUAs to be surveyed in detail selected. See combined observations with Activity 1.2a below.

► Activity 1.1d: The survey of selected BCWUAs, yielded the following points:

- BCWUA board members were often pre-selected with the idea of promoting IIP/IIIMP among water users, it is therefore not surprising that they were not actively representing farmers in conflicts concerning these improvement projects
- Well-endowed, -educated and -connected men in government, business, and mosques with leadership qualities tend to become BCWUA presidents.

- They often have a good relationship with higher placed irrigation officials, which is beneficial when they want to achieve something for their BC, but complicates matters when they have to make the irrigation sector or the improvement sector accountable for the services that it provides
- The representative basis of BCWUAs is weak as many water users along BCs are not aware of its existence and functions
- The representation of women in BCWUA is not insignificant, but appears more of a token measure, driven by donor pressures
- The amount of effort and money spent on training of BCWUAs does not stand in relation to what BCWUA board members actually remember of it
- Absence of Continuous Flow and the continuation a rotation-system has not strengthened BCWUAs
- There is a weak institutional link between the pump station-WUAs and the BCWUAs, which limits the BCWUA's authority and effectiveness in implementing rotations
- BCWUAs seldom have a significant role in actual water distribution, (i.e. implementing rotations on the BC), and maintenance, which weakens their legitimacy and authority. In some exceptional cases the associations enrolls farmers to check the application of the rotation.
- BCWUA leaders call for a stronger role of district engineers to implement rotations
- Because of the continued absence of a Law that acknowledges BCWUAS as legal entities and other reasons, BCWUA usually do not have much funds, their own office, records, frequent meetings, salaried staff, which weakens their institutional presence and sustainability beyond individual commitments
- BCWUAs have few actual tasks, authorities & activities for which they are responsible and they are therefore ultimately dependent on government staff
- Individual District engineers determine what role, information and support they give to BCWUAs
- Even the BCWUAs or Water Boards identified as success stories, are in spite of international project support, not in a significant way involved in the Operation and Maintenance (O&M) of the BC
- CDIAS efforts have focused on formation and election of BCWUA boards and less on sustaining them, most probably related to its financial structure and support
- The Egyptian Revolution has discontinued many of the institutional efforts to regularly bring together water user representatives and government engineers

In conclusion

- BCWUAs are financially, representationally and institutionally weak organizations, which potentially might but presently do not play a significant role in the O&M of BCs
- Even when a law and additional maintenance responsibilities would strengthen the legitimacy of BCWUAs, it is questionable if this is in time to make them sustainable.

1.2. Analyze the effectiveness of collective action within WUAs at the mesqa level.

► Activity 1.2a: Existing data, reports, and articles on the management of improved mesqas have been collected and reviewed.

A literature review on WUAs in Egypt was carried out and synthesized into a report.

Egypt has experienced a large number of varied projects devoted to farmers' institutional building at different scales, in line with the magnitude and importance of its irrigated sector. Generally, participation of WUOs (water user organizations) in decision-making in water management was found to be "extremely low if not completely absent and a formal procedure for involving WUOs doesn't exist". At the same time the MWRI field-level staff and WUOs show substantial agreement on a much stronger role for the WUOs. This somewhat contradictory statement illustrates that while on the surface, and on paper, all parties see value in a stronger role for WUOs, their low performance generates calls for 'more of it' or for 'strengthening' those already established; rather than discussions on why they did not perform as expected, or on the feasibility of a policy without full legal backing and institutional commitment.

Experience with implementation of WUOs and BCWUAs was characterized by a trial-and-error process involving numerous overlapping and sometimes conflicting institutional-building interventions by various donor-funded projects. There is a clear disconnect between, on the one hand, the enthusiasm shown by donors, aid experts, and some officials convinced of the need for IMT and, on the other, implementation levels where understanding and acceptance of the reform is limited, which "results in misunderstandings, major irritations" (APP 2007). It is apparent that the conceptions of participatory management in circles of decision-making officials of the MWRI are "confused and sometimes contradictory" (APP 2007). While some genuinely believe in the merits of shifting governance, the balance of power and responsibilities, many see participation as a means of increasing the contribution, in-kind or cash, of end-users. There is, however, little evidence that this is actually being realized. It is telling that all the measures meant to instill a higher degree of cross-accountability or transparencies are those that are loosely adhered to, even during the lifetime of the projects.

There are clear disincentives for most staff to fully embrace the logic of management transfer. Transfer is likely to be associated with a loss of prestige, power, legitimacy, and even jobs (Hvidt 1998). For this reason, it is odd to expect that line agencies would support such reforms. Some have raised doubts as to whether the MWRI top management is fully committed to IWRM and water user participation, independent of donor support, when it will significantly change the status quo (IRG, 1998a). With regard to management, there are also difficulties for managers to commit to ensuring a more predictable water supply due to the complexity of water management in the delta. Each level depends on how water is apportioned and distributed at upper levels, which reduces its autonomy in improving supply.

Whatever the reluctance from managers, most development projects also tend to minimize the transaction costs of the collective action requested of farmers, whether in cash, labor, time, or other in-kind contributions (IRG 1998b). In contrast, the expected associated benefits are less than expected because of the lack of substantial improvement in water supply and the minimal shift in decision-making power. Expectedly, the cost/benefit ratio to farmers remains too high and WUOs appear to be barely sustainable. Only when collective management is made unavoidable because of technological choices (notably the IIP and its collective pumps) do WUOs endure in one form or another (usually informally), mostly out of necessity. Similar questions can be raised about the sustainability of BCWUAs or Water Boards at district levels, when tangible benefits, transfer of concrete responsibilities, and legal status are not realized.

► Activity 1.2b: Analysis of WUAs and collective pumps in IIP/IIIMP projects.

First encapsulated in the IIP, launched in 1987 and supported by USAID, turned into a full-fledged program in 1989, expanded by a World Bank/KfW-funded project in 1995, and later in 2006 – and up to the present – expanded into the IIIMP, the idea of introducing collectively managed mesqa-level pumping stations in the delta is nearing 30 years of history. This intervention has been praised as spearheading the 'modernization' of irrigation in Egypt.

Tested, implemented, developed and modified along the last three decades, irrigation improvement projects in Egypt have attempted to respond to a number of identified constraints in irrigation water management. They have proposed interventions concerning the branch canal level (continuous flow, automatic gates, branch canal water user associations...), the mesqa level (collective pump stations), and the on farm or marwa level (distribution networks down to the plot). This activity has focused on lessons drawn from surveys conducted in the Meet Yazid canal command area regarding IIP and IIIMP pump stations, with additional observations on on-farm interventions. It reveals a reality that is frequently quite remote from theoretical design and the benefits expected at the onset, when it was posited that "the IIP is to be understood as a model for the way the government wishes to bring the Egyptian irrigation system in line demands it will be facing by the turn-of-the-century" (Hvidt, 1988). Main conclusions of that activity are as follows:

1. The failure to implement *continuous flow*, “the key and lead technology of IIP” (IRG et al., 1998), has been dealt with through the continued and rather self-serving assumption that it would take time to operationalize it. There has been no attempt to revisit the project assumptions and rationale of IIIMP in case continuous flow would not be forthcoming.

It is also not clear whether the lessons of the failure of downstream regulation -currently not a single automatic gate set up in Meet Yazid command area is functioning-, although its reasons have been somehow identified, have been taken to their logical terms; in particular with regard to what should be done with the structures in place. But it is noted that IIIMP has gone forward while canceling technical interventions at the level of the branch canal and abandoning the idea of continuous flow.

2. The establishment of *Water User Associations* was a cornerstone of the improvement projects, partly because of the intent expressed in the project documents to increase participation of farmers in the design of the improvement itself, as well as in the management of water at the branch canal level. WUAs were expected to be the recipients of communication campaigns and trainings that would allow them to acquire the skills necessary to manage and maintain their collective pumps as well as corresponding financial aspects. Both the revision of the 1984 Law (in 1994) and project documents had established very detailed regulations and instructions about what these associations were expected to do and how they should function.

The survey has revealed a large discrepancy between these formal expectations and reality on the ground. The very existence of a collective pump station makes it inevitable to have a degree of collective organization around what is needed to manage it in a sustainable way. Most farmers, however, did not consider themselves as 'members' of the Association and pointed to the initially designated (rather than formerly elected) board members as the Association's members.

The respective roles of the president, secretary and treasurer of the association, when these existed or had any distinctive activity, were quite different from the roles indicated in the law. Local practices in terms of meetings, decision-making, water management rules, or collection of fees were found to be extremely varied and to reflect local environmental, technical and social conditions (size of the group, area and shape of the command irrigated, position within the branch canal, overall collective and individual pumping capacity, filled in mesqa or parallel mesqa, social cohesion, etc.).

3. Although *Branch Canal Water User Associations* have been formally established in all branch canals, they were found to be by and large non-active. In some cases promises have been made about the establishment of an office, or about the power that these Associations would have in deciding maintenance work and checking their quality at the end of their execution, for example. Since these associations were not really empowered, their board members manifest some frustration regarding this experience. Most farmers ignored the existence of these associations.

4. *Participation of farmers in the design* of the improvement has been moderate. While in some cases farmers have been involved in decisions regarding the number and the position of the valves, for example, in many others the design options have been imposed in the suggestions of farmers disregarded. Likewise, while some individuals of group of farmers have been able to refuse the project, many more felt that it was imposed and that they did not have the possibility to refuse it. The latter case was more frequent in the earlier phases of IIP. Practices of the IIIMP project have improved in this respect.

5. *Water management rules at the pump station level* are in general only agreed upon and applied during the peak of demand in summer, while in the remaining of the year the system is more or less on-demand, with farmers making their request directly to the pump operator. During summer, farmers typically divide their area in sections (defined by a given number of valves), and establish a rotation between these sections with a given number of hours for each of them; in many cases each feddan will then have a fixed time for its irrigation (typically 1.0-1.5 hour). The total time of one full rotation has of course to be compatible with the expected time water will be available in front of the pump station. The rules must be adjusted when water is still available after the full rotation, or when some farmers haven't been served, or when distribution is interrupted by a power cut or a mechanical problem.

6. The detailed analysis of IIP/IIIMP pump stations has revealed a very large diversity of situations, ranging from ones where the pump stations are used to the satisfaction of farmers since the beginning, to others where they have created conflicts or been abandoned altogether. The most striking observation is that *few* pump stations are working with the initial pumps, engines, design areas, and target farmers that were present at the time of implementation. This is not necessarily a problem, as it shows in part that farmers are innovative and able to 'reshape' a given technological innovation so that it fits local conditions.

Pump Station (PS) evolution *'trajectories'* revealed a number of strategies (which can sometimes be combined or happen sequentially), that is fall under five categories: 1) efforts to increase supply availability at the pump level; 2) increasing the abstraction capacity; 3) increasing supply by tapping other sources; 4) improving internal management rules; 5) abandoning the pump station and reverting to individual pumps, sometimes after installing a large diameter pipe to serve as mesqa (Figure 11). 18% of the PS were found to be out of order. In most cases (16% of the total) pump houses were empty, and in a few cases the motors could be seen but were not in working order.

Out of a total of 1288 initial diesel pumps of the 640 surveyed PS, we found 890 diesel pumps (of which 812 were working) and 288 electric pumps (approximately one fourth of the stations). *Electrification* has been popular among farmers, largely because it is cheaper and less burdensome than diesel.

7. Whether a particular farmer tends to be satisfied with the project or not depends on his *perception* of the balance of costs (eg: transaction costs of collective action; replacement cost of stolen motors; investments in additional pumping capacity; costs of increasing water availability, likelihood that costs will have to be recovered, etc.) and benefits (reduced pumping costs, labor, and drudgery; increased equity, etc.). This perception is relative and depends both on the physical location of a farmer's plot, but also on personal characteristics like his income, gender, or his personal perception of equity and drudgery, for example.

These costs are implicitly weighed against benefits. These chiefly include: 1) a better equity of distribution, 2) reduced pumping costs and time for irrigating, and 3) increased easiness of operation and water distribution.

While some pump stations have been working for many years with only minor problems, too many others have been bedeviled by a number of flaws and shortcomings. These include *design issues* (too high inlet pipe; narrow distribution pipe; too low number of valves; poor quality of valves and hydrants; and above all the low capacity of the pumps); *implementation problems* (faulty canal profiles; poor compaction; leaking or broken pipes; unfinished work by the contractor; damage to the subsurface drains, etc.), let alone wider issues related to power cuts or diesel shortages, or thefts and security in general.

Figure 11: Categories of historical trajectories of IIP pumping stations

8. *The availability of water in the branch canal* is the key issue and is overwhelmingly mentioned by farmers, before the question of whether PSs are a good idea or not. In other words, most concur that when water is available in sufficient quantities, the PSs may express their potential in terms of reduction in irrigation time, reduction in labor, and better equity. On the other hand, where and when this is not the case, the PS restricts the amount of water that can be abstracted during the short period of water availability, and therefore leads to conflicts, fragmentation of groups, conjunctive use of canal and drainage water, and intensive use of individual pumps.

9. *Maintenance* needs include running expenditures (e.g. oil for the motors), that are taken care of through the money collected each season from the farmers, and exceptional repairs/ improvements (severe breakdown of the motor; stolen pump that has to be replaced; electrification of the pump station): these give way to a collective decision-making followed by the collection of an ad-hoc per feddan contribution. Financial management in general does not seem to be a problem or to generate lasting conflicts.

10. *Changes in water savings, crop yields or cropping patterns* could not be evidenced from our casual observations as well as from more detailed monitoring and evaluation activities. It was also not obvious that land savings had resulted from mesqas and marwas

being filled in, as in most cases farmers have preferred to enlarge the road or leave the new land uncultivated as a means of avoiding conflicts.

11. A very critical problem that has long been identified is the *theft of pump motors*. Our global survey indicated that 26% of the pump stations had had their motors stolen at least once, of which 22% had their pumps stolen twice and 3% thrice. Theft is chiefly occurring in pump stations with good road access and remote from houses and villages. In some cases motors have been stolen three times and wherever the mesqa has been filled, farmers have no choice other than replacing them at a high cost. Although farmers have demonstrated a lot of creativity to prevent theft or make it more difficult, this scourge should be considered seriously and structural solutions found.

13. Farmers experience frequent problems to access *spare parts* or to repair by themselves a number of shortcomings. This is illustrated by the on-farm interventions of the IIIMP project which, because of the reduced quality of the material used, resulted in leakages. Although the contractor has the obligation to intervene during one year after the handing over of the works by farmers in the case of leakage, in practice it may take so long to obtain such an intervention. Smaller problems, often related to unfinished work, are also reported to them but not resolved, which makes farmers angry and creates unnecessary nuisance or harm to villagers. Some mechanism must be found to ensure 'after sale service'.

14. The overwhelming majority of farmers did not know how much they would *have to pay annually*, and for how long, for the tatweer investment. Although the cost to farmers is individualized and depends on the final design at construction time, the costs range of the proposed improvements should be made clear from the beginning, as a means of building trust. More surprisingly, the financial burden corresponding to the imposition of this payment was very seldom mentioned by farmers as a cause of great dissatisfaction.

15. Because of the formal importance of coming up with adequate internal rates of return, both for the financing and the *economic evaluation of development projects*, the soundness of technical options and the quality of the material employed in construction is sometime negatively affected by the excessive weight given to economic analysis by development banks. The most blatant illustration of that fact, is the unfortunate reduction in the quality of works driven by the will to cut costs to improve the formal economic viability of the on-farm improvement projects associated with IIIMP. This has resulted in countless defects and failures in the distribution network that have angered farmers and undermined the project themselves.[8]

The formal cost-benefit analysis carried out by project planners is of little relevance and farmers are, under certain conditions, eventually ready to pay for a technical innovation that may bring few of the benefits expected but which substantially decreases the drudgery of irrigation at tertiary and farm levels. This conclusion provides a very strong indication that collective (electric or mixed diesel/electric) pump stations, even stripped of promises of continuous flow and other benefits, could be proposed *'on-demand'*, with farmers sorting out whether their particular conditions (including location within the distribution system, physical characteristics, investment capacity, social cohesion, etc.) make such an investment *desirable*.

16. There was clear evidence that there was a *demand for both mesqa and marwa level improvements*, which could fuel a demand driven project, whereby accredited contractors could propose farmers a range of possible improvements. Improvements at the on-farm level would be negotiated directly with the farmers, while construction of collective pumps would be supervised by the Irrigation Improvement Sector (IIS), a crucial control point being the need to keep the installed pumping capacity in line with the area served, in order not to impact downstream areas. The success of these interventions would depend

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[8] *IFAD, which is funding that project, has reverted to its policy and requested higher quality standards.*

on their quality, and so would be in the interests of neighboring farmers in replicate the improvements, as well as of the contractor.

It must be recognized however that not all settings are favorable to the implementation of collective PS. A zoning could be made to prioritize the offers made to farmers; areas with higher demand would include areas along the main canals or along the head reach of branch canals, that have good access to water; areas with long mesqas or marwas, or higher elevation; areas with groups of farmers with good relationships and making up between 25 and 40 feddan, etc. Under the prevailing conditions of distribution by rotation between and within branch canals, the crucial factor is the number of days a PS can expect to have water and therefore to have a pumping capacity high enough to serve the whole area. The attractiveness of the project to farmers is therefore linked to whether they will see their pumping capacity increased. The risk is to see improvement interventions increasing their capacity (by exceeding design capacity and not removing existing pump sumps) in order to gain the acceptance of farmers, which would mean that the gains in equity in the distribution of water at the tertiary level would be paralleled by losses in equity at the secondary level, with the situation of downstream farmers being worsened.

Ultimately, the IIP/IIIMP project is currently being taken forward in a manner that is increasingly remote from the initial hypotheses and expectations. Continuous flow has not been established and there is no evidence of water savings or increases in productivity associated with the project; structural intervention at the branch canal levels have been discontinued and institutional building has been rather modest; official WUAs are frequently disconnected from the way the pump station is managed and maintained in practice; reduction in pumping time and costs at the pump station level have come together with improvements in equity among farmers on the same mesqa, but the project has failed to achieve a more equitable distribution at the branch canal level, and may even have worsened it as the pumping capacity of upstream farmers has generally increased. Individual pumps used to access water from both canals and drains, which should have been discontinued, are still everywhere to be seen. Yet, the improvement of water distribution at the tertiary and, maybe more so, on-farm levels through pressurized pipe networks keeps a degree of attractiveness in certain physical and social settings that have to be determined by the users themselves.

► Activity 1.2c: Detailed monitoring of two mesqas was carried out during summer 2013 in the Abu Mustafa canal area, with the involvement of two MSc students (one Egyptian and one Dutch).

The Egyptian student has continued the research and has selected a set of three pump stations in the same area. The functioning of these pumps was monitored during summer 2014 and data are being analyzed.

The study showed how farmers have re-ordered their water network in an attempt to create a better ‘fit’ between the technology imposed by IIP and their own modes of ordering. Pumping stations have been appropriated and modified to increase their pumping capacity, WUAs have been replaced by a multitude of institutions, and farmers are using drainage water (from both secondary and tertiary drains) through individually operated pumps for supplementary irrigation (See figure below).

The durable relations in this re-ordered network are those that fit best with the mode of ordering of independence and flexibility, and are geared toward dealing with the irregular water supply the mesqa faces. While a system of low collective action and individually owned pumps prevails, the social re-ordering and technical appropriation of the pumping station have partly secured the pumping station’s position in the network. However, a large part of this durability is because removing the IIP infrastructure is very costly. This has however been observed in several mesqas.

The case study clearly demonstrates the unlikely viability of IIP pump stations in situations of low water availability, such as those prevailing in the downstream part of the Abu

Mustafa canal. It is evident that PS designed to operate under continuous flow cannot deliver enough water to farmers under a system of rotation, even though pumps' capacity was over-sized.

Objective 2: Develop and assess marwa- and farm-level interventions that improve the productivity of diverse farming systems, and that contribute to increased water productivity under conditions of salinity, while assessing the economic and social dimension of crop choice and water management.

2.1. Evaluate and demonstrate marwa-level water management interventions.

The study was carried out with the involvement of two MSc students and focused on the mesqas in the Masharqa canal, which supplies three villages, and is located at the tail-end of the Meet Yazid canal in the W10 area. The Masharqa canal has 18 electric pump stations (A1–A6 and B1–B12) along a length of 4.2 km (Figure 12). This area is special in terms of water supply because a major part of the water in the canal is drainage water that is allowed to flow by gravity from the (main) Nashart drain that borders the area on the western side.

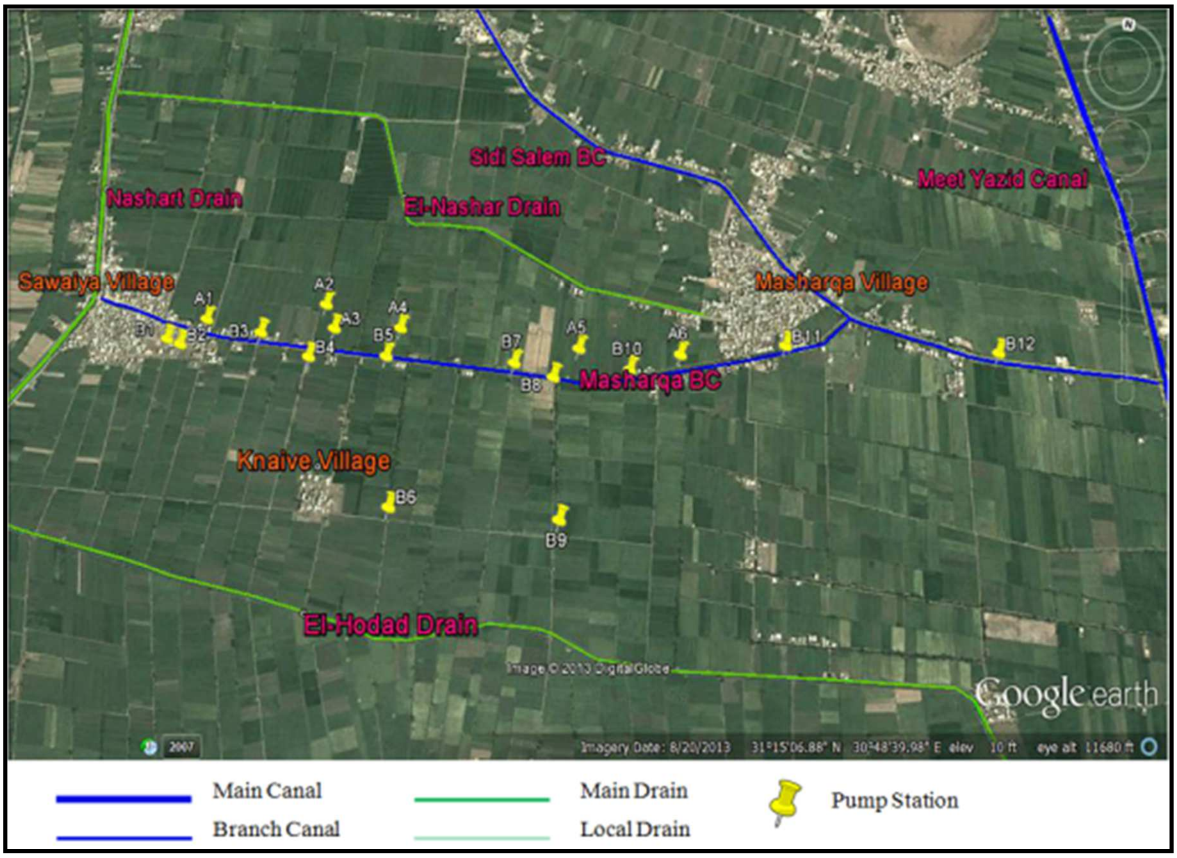

Figure 12: Research Site in W10

The basic aim of the research was to evaluate the socio-technical package with regard to water management practices and the arrangements of farmers around the marwa and mesqa improvements. A case study approach, involving various research tools including direct observation, and semi-structured and unstructured interviews, was taken to understand the micro-level arrangements. A major component of the field work was to observe the daily irrigation practices of farmers along the canal and the mesqas and marwas. The field work was done in three phases as explained below. The survey period (May–July 2013) corresponded to the highest water demand in the year, offering opportunities to study social interactions and coping mechanisms of farmers.

The first part of the field work involved a survey of all 18 PS command areas in this canal to understand the historical trajectories of their use and operations, and was primarily based on semi-structured interviews with 40 farmers. The participants were selected on the basis of their positions along the mesqa. The information was used to create a profile of each pump station.

The second phase involved an in-depth analysis of the water management practices and organizational arrangements of farmers in two mesqas, B4 and B7, selected on the basis of a matrix scoring of the pump station profiles produced by the researchers. Factors such as WUA management, practice of direct pumping from drainage and branch canals, and conflict among farmers were considered for the matrix ranking. The second phase involved observing the flow of water along the mesqas and marwas, and the various micro-interactions around it, and then unstructured interviews with the farmers based on the observations. A third phase attempted to zoom out and look at similarities and dissimilarities in other mesqas based on the observations in B4 and B7.

The report evaluates the impact of the irrigation improvement projects, and also analyzes the factors that shape the water management practices of farmers. It demonstrates that irrigation management practices are shaped by informal organizational and institutional arrangements of farmers, which primarily evolve from socio-political structural relations. The boundaries of water management arrangements are not rigid and often overlap, and are influenced by socio-culturally embedded institutions. It further demonstrates that coping mechanisms of farmers, such as direct pumping from the canal or reusing drainage water, are major factors that shape the equity of water distribution and the efficiency of water use at the lowest levels of the irrigation system. Based on the observations, the report offers a set of recommendations that may improve the adaptability and impact of the improvement projects.

This activity was extended over 2015, as part of the complementary work of the Egyptian MSc student. (Additional sensors were also bought and installed to better monitor water supply and quality).

2.2. Develop and evaluate sustainable interventions to address degradation associated with salt-affected soils in the northern delta.

► Activity 2.2a: Conduct research on soil management techniques to combat degradation associated with salt accumulation.

Combined interventions on soil amendments being implemented include conventional farmer practices: control, fertilized by urea (C+U) compared to gypsum + ammonia gas (G +Ag), gypsum + bio-fertilizer + urea (G+B+U), gypsum + ammonium sulphate (G+As), gypsum + urea (G + U), gypsum + farm manure + ammonia gas (G + F + Ag) , gypsum + mole drain + ammonia gas + farm manure + bio-fertilizer (G+M +Ag +F + B), gypsum + mole drain + ammonia gas (G + M + Ag), gypsum + mole drain + urea (G + M +U), mole drain + urea (M + U).

Field experiments were conducted during summer 2013 and 2014 for rice and winter 2013/14 and 2014/15 for wheat and sugar beet. The required datasets (soil, water, and plant) were collected and are being processed for analyses and reporting.

Summer Season

During summer 2013, the highest rice grain yield of 6.81 ton/ha was observed for the field trial with the application of gypsum combined with ammonia gas and farm manure treatment, while the lowest yield of 3.59 ton/ha was for application of gypsum with ammonia gas (Table 1). Results also indicated that the treatment with G+M +Ag +F + B achieved the highest straw yield; and the lowest straw yield was for application of G+AG. During summer 2014 highest grain yield of 8.44 ton/ha was obtained for the treatment with gypsum combined with ammonia gas and farm manure followed by construction of mole drain at 4m spacing and combined with application of urea (7.43 ton/ha). While, the lowest value was obtained from control treatment fertilized by urea.

The application of soil amendments, installing mole drains, and ammonia injection resulted in decreasing soil bulk density and increasing total porosity values compared with controls; as well as improving the infiltration rate and cumulative infiltration compared with initial values.

The amounts of applied water varied from 9916 m^3/ha for the G+U treatment to 11,063 m^3/ha for the control during 2013 while in 2014 it varied from 10652 m^3/ha (G+B+U) to 13502 m^3/ha (C+U). Concerning the water productivity, data indicated that the highest water productivity of 0.67 and 0.70 kg grain/m^3 during 2013 and 2014 summer seasons was achieved with application of gypsum combined with injection of ammonia gas and farm manure. While the lowest value of water productivity was obtained with control treatment.

Nitrogen, phosphorus and potassium uptake by rice grain and straw as influenced by different soil amendments treatments were analysed. Results revealed that, application of gypsum combined with farm manure and injection of ammonia gas greatly affected the uptake of nutrients in rice grain and straw, followed by application of gypsum and mole drain combined with bio fertilizer, ammonia gas and farm manure. Nitrogen use efficiency in terms of productivity factor clearly showed that the application of gypsum combined with farm manure and ammonia gas injection resulted in a higher value of nitrogen use efficiency (40.88 kg grain/kg N in 2013 and 44.3 kg grain/kg N in 2014) followed by construction of mole drain combined with application urea (40.43 kg grain/kg N in 2013 and 39.0 kg grain/kg N in 2014).

The reduction in soil salinity compared with the initial conditions of different treatments varies between 18% (AG+M+G) and 45% (C+U) in 2013. The highest reduction in soil salinity values was observed for the control treatment may be due to highest amount of irrigation water applied. The G+F+Ag and G+M+Ag+F+B treatments caused decreases in soil sodicity of 47 and 44%, respectively, compared to initial conditions. During 2014, highest reduction of soil salinity of 35% was observed for the control treatment.

The maximum values of total income (LE/ha), net profit (LE/ha), and economic efficiency were obtained with the G+F+Ag in both years. However, the lowest total income and WP values were recorded for the control treatment. The treatment including gypsum, farm yard manure and ammonia gas resulted in a net profit of approx. LE 1526 /Feddan (Approx. $196/acre) in comparison to the control treatment.

Winter Season

During winter 2013/14 and 2014/15, field trials were carried out for two crops: wheat and sugar beet. During both years the G+F+Ag treatments achieved the highest values of wheat grain (6.58 and 6.16 ton/ha) and straw yields (8.48 and 8.26 ton/ha) followed by G+M+Ag+F+B (with mole drain at 4-m spacing). The high yields may in part be associated with the positive effects of incorporating gypsum and other amendments that liberate calcium in the upper portion of the soil profile and improve soil physical and chemical conditions that are conducive for improved plant growth.

The G+F+Ag treatment resulted in the greatest increase in uptake of macronutrients in wheat grain and straw followed by G+M+Ag+F+B (with mole drain at 4-m spacing) treatment in both years. The G+F+Ag treatment resulted in the highest NUE (34.6 kg grain/kg N). Analysis indicated that the highest water productivity of 1.34 and 1.32 kg /m^3 during 2013/14 and 2014/15 winter seasons (wheat crop) was achieved with application of gypsum combined with injection of ammonia gas and farm manure for wheat crop.

Table 1. Rice grain and straw yields (ton/ha) and other parameters as affected by soil amendments treatments during summer season of 2013

Treatments	Rice grain yield (ton/ha)	Rice straw yield (ton/ha)	Amounts of water applied (m^3/ha)	Water productivity of grain (kg/m^3)	Water productivity of straw (kg/m^3)	Nutrients uptake in grains (kg/ha)			NUE kg grain/ kg N	EC (dS/m)	SAR
						N	P	K			
C + U	5.12	8.59	11068	0.46	0.78	72.67	13.33	7.10	30.73	4.18	11.75
G + Ag	3.59	6.76	9640	0.37	0.70	47.26	7.55	6.19	21.55	5.58	12.38
G + B + U	5.28	8.35	9864	0.54	0.85	69.49	7.77	8.66	31.69	5.5	10.72
G + As	4.93	8.21	9988	0.49	0.82	65.41	7.04	7.04	29.59	5.4	10.34
G + U	4.64	8.43	9920	0.47	0.85	62.40	6.63	7.22	27.85	6.42	10.34
G + F +Ag	6.81	8.26	10220	0.67	0.81	100.95	20.59	17.45	40.88	4.84	9.42
G + M +B + Ag + F	5.78	9.42	10663	0.54	0.88	83.83	15.30	11.42	34.69	5.31	9.88
G + M + Ag	4.19	7.26	10321	0.41	0.70	60.72	8.98	6.69	25.15	6.19	11.44
G + M+ U	4.83	8.66	10361	0.47	0.84	64.50	6.90	7.71	28.99	5.21	9.26
M + U	5.07	8.38	10193	0.50	0.82	66.66	6.60	7.46	40.43	6.08	12.69

Table 2. Wheat grain and straw yields (ton/ha) and other parameters as affected by soil amendments treatments during winter season of 2013/2014

Treatments	Wheat grain yield (ton/ha)	Wheat straw yield (ton/ha)	Amounts of water applied (m^3/ha)	Water productivity of grain (kg/m^3)	Water productivity of straw (kg/m^3)	Nutrients uptake in grains (kg/ha)			NUE kg grain/ kg N	EC (dS/m)	SAR
						N	P	K			
C + U	5.77	8.00	5539	1.04	1.44	80.75	15.57	32.88	30.30	4.54	8.88
G + Ag	4.41	7.38	4829	0.91	1.53	77.18	12.35	21.17	23.16	5.35	8.56
G + B + U	6.00	8.21	4902	1.22	1.68	61.74	20.39	29.29	31.50	4.98	8.56
G + As	5.23	7.76	4830	1.1	1.61	77.97	15.70	25.12	27.48	5.14	7.54
G + U	4.64	7.62	4827	0.96	1.58	65.00	18.57	27.39	24.38	5.79	8.5
G + F +Ag	6.59	8.48	4901	1.34	1.73	150.20	29.64	40.84	34.60	5.11	7.02
G + M +B + Ag + F	6.11	8.33	5025	1.22	1.66	91.06	31.17	36.06	32.10	5.08	8.72
G + M + Ag	4.44	7.48	4922	0.9	1.52	62.15	17.39	23.97	23.32	5.65	9.83
G + M+ U	4.46	7.57	5078	0.88	1.49	78.02	19.62	22.29	23.41	5.07	10.12
M + U	5.72	7.86	4917	1.16	1.16	100.10	21.16	32.88	30.04	5.05	10.34

For sugar beet, G+M+Ag+F+B (with mole drain at 4-m spacing) treatment significantly affected sugar beet root yields (41.5 ton/ha in 2013/14 and 40 ton/ha in 2014/15), sugar percentage, and sugar yield during both years. The increase in root yield may in part be due to the use of different N fertilizer sources that have considerable effect on both soil pH and solubility of cations. Results indicated also that ammonia gas was more effective than urea and other N-sources in producing higher yield.

Soil salinity values decreased after harvesting wheat and sugar beet compared with the values obtained after harvesting rice (summer 2013) in all treatments except the control treatment. The highest rate of salt leaching was achieved for the G+M+U treatment.

► Activity 2.2b: Evaluate leaching requirements under different conditions of drainage status, sodicity, and cropping systems, considering also the influence of rainfall.

A field experiment was conducted at the Graduate area, Al-Hamoul District, Kafr El-Sheikh Governorate, Egypt. The soil of the area was clayey in texture. The soil was considered saline sodic as the EC values were > 4 dS/m and the Exchangeable Sodium Percentage (ESP) values are > 15%. Average irrigation water salinity was 0.65 dS/m. Gypsum was initially added to all plots at rate of 8 ton/ha. The experiment was initiated before summer 2013.

Two tile drain spacings with mole drains were evaluated as follows:

D1: Tile drain with 20-m spacing between drains without mole

D2: Tile drain with 20-m spacing between drains with mole

D3: Tile drain with 40-m spacing between drains without mole

D4: Tile drain with 40-m spacing between drains with mole

Mole drains spaced at 4 m between the plowed lines were installed at 60 cm depth. Mole drains were installed as a network perpendicular and parallel to the tile drainage.

Three leaching requirements were tried.

LR1: Traditional irrigation (as used by farmers)

LR2: Traditional irrigation + 15% leaching requirements (LR)

LR3: Traditional irrigation + 25% LR

Rice cv Sakha 102 was transplanted during 1-4 June 2013; sugar beet (cv Pleno) was sown on 28 September 2013; wheat cv Giza 168 was sown on 21 November 2013; cotton cv Giza 86 was sown on 3 May 2014; and rice cv Sakha 102 was transplanted on 28 May 2014. Agricultural practices for all crops were as recommended.

Soil chemical, physical, and hydrological properties were determined at the inception of the study and after every season. Amounts and salinity of irrigation water applied were measured. Productivities of all crops were determined for the different treatments.

Soil chemical and physical properties

At the initial state, soil salinity and sodicity values were high (ECe = 16.70 dS/m and ESP = 19.40, respectively) (Table 3). After implementing the field experiment with rice crop in one season, average soil salinity and sodicity values were reduced (13.62 dS/m and 16.17 for the treatment with mole and 20m drain space, 14.06 dS/m and 17.2 for the treatment with 40m drain spacing and with mole). After four cropping seasons average soil salinity and sodicity were reduced to 11.6 dS/m and 14.8 for the treatment with mole and 20 m drain space (Table 2). The observed reduction in salinity was more pronounced in the surface layers compared to deeper ones. Results indicated in general that the D1, D2, D4 treatments were superior to D3 in reducing soil salinity and sodicity, especially in the surface layers. It is worth mentioning that the high value of leaching fractions (15% and 25% LR) were efficient in reducing soil salinity in comparison to traditional irrigation especially in the top layers (Appendix 1).

Table 3: Average soil salinity (ECe) and sodicity (ESP) values before (initial) and after conducting the field experiment as affected by tested variables.

Parameter	Soil depth (cm	Initial values	20m drain space		40m drain space	
			Without mole	with mole	Without mole	with mole
EC dSm^{-1}	0-15	12.58	7.3	6.6	7.8	6.8
	15-30	15.09	7.9	7.1	11.5	8.2
	30-60	19.16	11.5	10.8	14.4	12.1
	60-90	19.96	21.7	21.7	21.8	21.8
Mean (0-90cm)		16.70	12.1	11.6	13.9	12.2
ESP	0-15	16.71	11.1	10.1	13.8	10.7
	15-30	17.85	12.5	11.0	15.2	13.3
	30-60	21.83	14.6	13.8	17.1	15.9
	60-90	21.23	21.2	21.0	21.9	21.9
Mean (0-90cm)		19.40	14.8	14.8	17.1	15.4

Soluble Na was the dominant cation and chloride the dominant anion. The decrease of salinity and sodicity values can be attributed to the increase of Na^+ ions leaching from the soil profile. The results indicate that drainage spacing of 20 m enhanced drainage efficiency, improved soil physical and chemical properties, and subsequently improved soil structure and hydraulic conductivity, which affected water movement to the drains with its load of soluble salts. Mole drains decreased soil salinity and sodicity only within the mole depth.

Water table depth increased rapidly with elapsed time after irrigation. The drop of water table level was faster with narrow drain spacing. The D1 and D2 treatments were superior to D3 and D4 in reducing water table salinity, especially with 15 and 25% LR. The LR treatments had favorable effects on salinity of the water table. The beneficial effects of LR treatments as well as tile drainage with and without moles were to avoid the harmful stagnation of irrigation water and dissolved salts around the root zone. The high downward water movement was enhanced through cracks and fissures developed by the mole plough blade, and the excess water were partially removed by the mole drains.

Initial basic infiltration rate value was 0.50 cm/h for the traditional irrigation treatment. After four seasons of conducting the field experiment, average basic infiltration rate increased to 0.90 cm/h for treatments with 20 m spacing with mole. Narrow spacing and/or mole treatments were superior to wider spacing without moles in enhancing the infiltration rate. Also, narrow drain spacing with mole treatment was superior in lowering bulk density and increasing porosity in the top 60 cm. LR treatments had no effect on infiltration rate, bulk density, and porosity of soil. Mole drain and LR treatments had no effect on hydraulic conductivity.

Sugar beet (Winter 2013/14)

Drainage treatments significantly affected sugar beet root yield, with averages of 53.0, 58.2, 40.1, and 50.8 ton/ha for D1–D4 treatments, respectively. LR had a minor effect on sugar beet production. Average sugar beet root yields were 48.5, 50.8, and 52.6 ton/ha for LR1–LR3 treatments, respectively. The interaction between 20 m spacing with mole (D2) and both LR2 and LR3 treatments resulted in the highest values of root yield, sugar yield, and quality.

Narrow drain spacing with mole (D2) treatment received the most irrigation water, while the wider drain spacing without mole (D3) received the least. The estimated salts added to the soil from irrigation water were 2.7, 2.7, 2.4, and 2.6 ton/ha for the D1–D4 treatments, respectively, with the LR1 treatment. The corresponding values were 3.0, 3.0, 2.7, and 2.9 ton/ha, for the LR2 treatment; and 3.2, 3.3, 2.9, and 3.2 ton/ha for LR3. The estimated amounts of salts removed from the soil were 19.9, 22.9, 15.9, and 18.7 ton/ha for the D1–D4 treatments, respectively, compared to the traditional irrigation (LR1). The corresponding values were 21.2, 24.2, 16.2, and 19.3 ton/ha for the LR2; and 22.9, 24.7, 16.6, and 20.6 ton/ha for LR3.

Wheat (Winter 2013/14)

The tested treatments had significant effects on wheat grain yield, number of panicles/m^2, and 1000 grain weight. Compared to control, grain yield increased by about 410, 540, 250 and 400 kg/ha for the D1–D4 treatments, respectively. Applying LR had favourable effects on wheat grain yields, which increased by about 290, 380, and 530 kg/ha for the LR1, LR2, and LR3 treatments, respectively.

Narrow drain spacing with mole (D2) treatment received the most irrigation water and added the most salts to the soil from irrigation water. Wider drain spacing without mole (D3) treatment received the least irrigation water and added the least salts to the soil from irrigation water. The estimated removed salts from the soil were 11.1, 14.9, 5.9, and 9.3 ton/ha for the D1–D4 treatments, respectively, with the LR1 treatment. Water table level under the 20 m spacing was deeper than the the 40 m spacing with and without mole drains; and the 40 m spacing with mole drains was deeper to that without mole drains. These results demonstrate the beneficial effect of narrow drain spacing (20 m) with and without mole drains, and wider drain spacing (40 m) with mole drains, in preventing waterlogging in the root zone.

Cotton after sugar beet (Summer 2014)

Narrow drain spacing with and without mole and wider drain spacing with mole were superior to wider drain spacing without mole in enhancing cotton yields. Average cotton lint yields were 778.8, 831.4, 355.2, and 571.4 kg/ha for the D1–D4 treatments, respectively; and correspondingly 1631.8, 1768.9, 994.8, and 1392.9 kg/ha for seed yield. Cotton yields obtained from LR2 and LR3 treatments were higher than for the traditional irrigation treatment (LR1). Introducing mole drains resulted in the maximum values of total revenue, net return, and economic efficiency.

The wider drain spacing without mole (D3) received the least irrigation water and added the least salts to soil from irrigation water, while narrow drain spacing with mole (D2) received the most irrigation water and added the most salts to soil from irrigation water. The estimated amounts of salts removed after three seasons from the soil were 17.4, 20.5, 10.0, and 14.5 ton/ha for the D1–D4 treatments, respectively, with the LR1 treatment. The corresponding values were 18.3, 21.0, 10.3, and 14.8 t/ha for LR2; and 17.9, 20.4, 10.3, and 12.4 ton/ha for LR3.

Rice after wheat (Summer 2014)

There were significant differences in rice grain yield between the proposed interventions. Rice grain yield increased by about 500, 579, 65, and 400 kg/ha for the D1–D4 treatments, in comparison to the control treatment respectively. The corresponding 1000 grain weights were 0.78, 0.76, 0.24, and 0.43 g. Maxima for total revenue, net return, and economic efficiency were for tile drainage at 20 m spacing with mole.

Narrow drain spacing with mole received the most irrigation water and added the highest load of salts to soil from irrigation water, while wider drain spacing without mole received the least irrigation water and added the least salts to soil. The highest drain discharge rates were measured after the planting irrigation. Cumulative drain discharge was higher for D1, D2, and D4 treatments compared to D3 (wider spacing without mole). Under rice cultivation, salinity of drainage water was similar in all treatments. The estimated amounts of salts leached after three seasons were 21.6, 22.2, 15, and 19.2 ton/ha for D1–D4 treatments, respectively.

Sugar beet & Wheat (winter 2014/15)

The average values of root yield being 53.5, 58.1, 40.1 and 49.5 ton/ha for tile with 20 m space supported with mole, tile 20 m space without mole, tile with 40 m space without mole and tile with 40 m space with mole, respectively during winter 2014/15. It can be concluded that that tile drains installed with narrow space (20 m) either with or without moles in addition to the wider drain space (40 m) with mole were more efficient than that with wider tile drain space (40 m) without mole.

For the wheat crop, the observed results in the second winter season (3rd growing season of experimental setup), showed that there were significant differences in the grain yield with various studied treatments and control. Tile drains installed with narrow space (20 m) with mole performed the best followed by 20 m spacing without moles and 40 m spacing with mole. These results verified the importance of tile and mole drainage to improve the saline-sodic conditions and enhancing crop yield.

2.3. Undertake a comprehensive assessment of farming systems and the rationale behind farmer crop selection and associated rotations.

This activity was supposed to be cut after the change in project duration. There was a willingness, however, to carry it out in the second half of 2015. It eventually was cancelled for lack of time.

2.4. Undertake a socioeconomic analysis of fish-farming systems in the upper delta.

Detailed methodology was discussed and established by ARC and ICARDA/IWMI teams, and three questionnaires were developed. The survey includes both the fisheries near Lake Borullus and ‘inland’ fisheries.

For inland fisheries, one questionnaire looked at farms that shifted from crops to fish and another one at farms that shifted from fish to crops. Mobile phones with GPS function were bought for the surveyors of the project to record all the points surveyed. Field work commenced in November 2013. Data has been partly analyzed and a report is being written.

A questionnaire and methodology were designed for Lake Borullus fisheries. The survey was carried out by scientists of the Central Laboratory for Aquaculture Research (CLAR) of ARC during June 2014.

Egypt has the largest aquaculture industry in Africa and it now produce 65% of the country’s fish need, with over 98% produced from privately owned farms. The majority of fish farms in Egypt can be classified as semi-intensive brackish water pond farms and this type of farming suffered a dramatic reduction in numbers during the early 1990s as a result of the competition for land and water. Intensive aquaculture, in earthen ponds and tanks, is now developing rapidly to counteract the reduction in the total area available for aquaculture activity.

The aquaculture sector as a whole is under increasing pressure. Critical factors facing the sector and impacting on profitability can be grouped into those related to inputs, production, and marketing, transportation and sale of product. With regards to inputs, the price and quality of fish feed have had a critical impact on costs and profits. The poor quality of fish fry, lack of available land for expansion in many governorates and short lease periods, poor quality of water, lack of access to capital, high labour cost and the lack of electricity and high fuel costs for generators and vehicles, are all additional problems of considerable importance.

At the production level, critical factors affecting value-chain performance are: poor practices with regard to feed management, farm design and construction, fish health management, and stocking densities, a growing season which is restricted to about 8 months due to the colder weather in the winter months; absence of improved strains of fish that have been shown to have major impacts on production in other countries; and a widespread lack of effective representative organizations for any of the sub-sectors. With regards to the marketing and distribution of fish, the critical factors are: low control of market; declining fish prices in real terms; consumer preference for wild fish and a distrust of filleted/processed products; strongly fluctuating seasonal prices (with declines in prices towards the end of the year coinciding with the major harvesting period); poor fish hygiene and handling practices throughout the value-chain; the lack of any value-addition through processing; the lack of any exports; and in some cases poor road networks impacting on the ability to get fish to markets. Some farmers are shifting from aquaculture to field crops because of the sharp increase in the price of feed, low fish price and non-availability of sufficient water for aquaculture (quantity and quality). The profitability of the fish production can also be increased by improving processing and marketing. Currently, most of the fish produced is for the national market and involves no processing. Little value is thus added to the product which limits the profitability of the sector as a whole. Higher-value production thus requires processing of the fish.

The most common problems faced by rice growers in the region were shortage of irrigation water, higher prices of chemical fertilizers, weakness of extension agencies, and high rental value of agricultural land. Other issues were rising prices of agricultural pesticides, low labor skill during the planting season and harvest, non-availability of chemical fertilizers, unsuitable cultivars, low effectiveness of pesticides, water pollution, and high salinity. The most important problems facing sugar beet farmers were uncertainty of crop weight, high prices of chemical fertilizers, weak extension services and insufficient transport.

An additional socio-economic survey was carried out for the four main aquaculture systems in the study area consisting of systems that depend mainly on artificial food and organic manure (system 1), artificial food only (system 2), waste from factories and organic manure (system 3) and the system with wheat cultivation (system 4). The system which combines aquaculture with wheat cultivation achieved the highest net income per acre ($3300) as well as the highest rate of return in comparison to all other systems (Table 4). In this system farmers use fish ponds for wheat cultivation during winter season when the growing of Tilapia is completed. After harvesting wheat crop, fish farmers add organic manure to the fish pond and fill it with drainage water gradually and transfer fingerlings in May. This system produces two products in one year so it saves liquid money for the fish farmer and achieves high economic efficiency.

The average net return from the system that depends mainly on artificial food and organic manure, artificial food only, wastes of food factory and organic manure were estimated as $1176 (varying from $317 to $ 1950), $1137 (varying from $840 to $1430) and $1036 respectively (Figure 13).

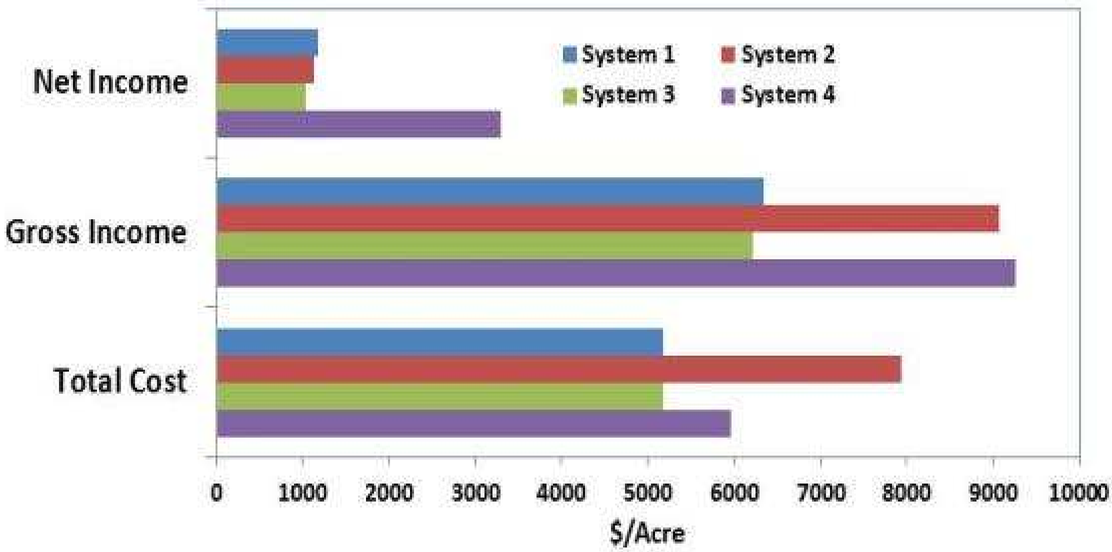

Figure 13: Average total cost, gross income and net income from four different aquaculture system studied.

Table 4. Economical evaluation of aquaculture with wheat cultivation (per feddan).

Item	**Amount (LE)**	**Percentage (%)**
Variable cost		
Wheat seed	155	0.3
Chemical fertilizer	350	0.8
Labor cost	300	0.6
Ploughing	280	0.6
Harvesting	288	0.6
Irrigation	500	1.1
Yearly pond maintenance	1000	2.1
Fingerlings	4450	9.6
Artificial food	20000	43.0
Organic manure	3600	7.7
Labor	1200	2.6
Fuel & energy cost	700	1.5
Equipment maintenance	1000	2.1
Transportation cost	700	1.5
Trader commission 5%	3300	7.1
Total variable cost L.E.	**37823**	
Fixed costs		
Rent cost	5000	10.7
Depreciation	650	1.4
Bank interest on loan	3043.1	6.5
Total fixed cost L.E.	**8693.1**	
Total operating cost (Variable + Fixed)	**46516.1**	100
Total return from aquaculture/feddan, LE	**66000**	
Total return from wheat	**6300**	
Total Return (Fish + Wheat)/feddan, LE	**72300**	
Net Return (LE)	**25784 ($3305)**	

2.5. Undertake a cross-cutting gender analysis of multi-level water management.

This activity consists of an exploratory survey of the gender aspects of agricultural water management in Meet Yazid. Egyptian women constitute only 4% of agricultural landowners. Although women are consequently marginalized from access to water, technology, and other resources, they play an underestimated role in irrigated agriculture. There is an assumption in the literature that Egyptian women are absent from irrigation management, but is this the case in the Nile Delta?

Many scholars argue that women's role in irrigated agriculture is underrepresented in both official statistics as well as in the literature.

Since the role of women in irrigated agriculture is largely invisible, the more explicit question raised in this exploratory phase was: what is the role of women in irrigated agriculture as farmers/users in the larger Meet Yazid region? To acquire a more qualitative understanding of these roles and why they are almost invisible in official statistics required focusing on a particular research area. The W10 area was selected for this research. IIIMP has implemented several of its innovations in this pilot area, including collective pumping stations and piped mesqa and marwa improvements, which may affect women in their irrigation activities.

A few preliminary observations made are synthesized here:

- Landownership: There is a significant difference between the new lands and old lands in female landownership and other conditions.
    - Female graduates received land which in some cases enables or pushes women to enter into what are considered masculine spaces or work, associated with agricultural and engineering technology, heavy physical labour requiring 'muscle', night irrigation and assuming public roles in rural organizations and building networks with government institutions.
    - Female headed households with or without land often have to engage in tasks that are considered masculine: "They do not have men they are working to feed their families"
- Muscle/heavy physical labour:
    - Weeding, *malkh* in rice and other jobs which require muscle are according to the local norms thought to be male jobs
    - Women sometimes do these jobs on their land, but are not hired as labourers or get paid less
    - "Women here have grown muscle. They help their husbands in everything", a female farmer in KFS.
    - Women in the new lands had to farm the land because labour was a constraint and only the nuclear family resettled into the new land. "The woman here is not only a woman but both a woman and a man," explained the wife of a settler
    - Men tend to downplay the role of women in these jobs

- Agricultural and irrigation technology
    - Electrified and pressurized collective pumping stations made it easier for women to irrigate, by opening the valves in the field and sometimes switching on the electrical pump.
    - Jobs that involve the operation of agricultural machinery (e.g. feeding the wheat thresher machine, pesticide spraying) and of individual pumps are considered male jobs, especially when it is associated with danger, risk or indecent exposure (bending or wetting clothes). However, these are jobs that are usually also the better paid labour jobs, to which women do not have access.
    - Being land owners, women in the new lands have received training in operating collective water pumps, changing filters or veterinary medicine, whereas in the old lands women are usually excluded from such training opportunities

- Night irrigation

- o The perception of danger and honour is making it hard for women to irrigate at night. Women are not allowed to walk at night as this is perceived as dangerous and can tarnish their reputations (which belongs to their families and communities).
- o Nevertheless, some women in the new lands do irrigate at night, out of necessity ("She had no older sons. And no husband. She had to irrigate the land by herself,") or because of being the farm manager

- Public roles
    - o World Food Program mandatory requirement of women's participation in public life and women taking public matters related to their lands into their own hands has resulted in women assuming public roles and take positions in agricultural cooperatives and Water Users' Associations. In the old lands, women were less likely to participate in public life. These public roles created experiences, status, mobility and networks for these women to which they are usually excluded.
    - o To become visible in these roles, women also have to 'act as men', to be able to benefit from their position, but this comes at a cost:
        - "You talk to H., you do not feel like she is a woman. She came here farmed her land, farmed with men graduates, and started to behave like men"
        - "I own land in the Old Lands. It is like I own nothing, but here women who own land here have opinion and they know how to get their rights. People listen to them and they know how to talk. Their status is higher than the rest of us here."
        - Female farmer in the new lands: "The way I dress, the way I talk. I do not want the men to underestimate me. I do not feel I am a women when I am in the field. I do not joke; I keep joking to a minimum. "

In conclusion

- The study of gender in Egyptian irrigated agriculture is a relatively young and methodologically challenging field, on which very little has been published in the international literature

- Women are generally not very visible in studies on irrigated agriculture

- "What people say, what people do, and what they say they do are entirely different things", hence survey interviews need to be enriched and triangulated with actual observation of activities and other information sources

- When women adopt 'masculine' roles in irrigated agriculture they need to 'act as a man' to become visible and validated for it, yet this comes at a cost.

Objective 3. Build an understanding of the temporal and spatial dynamics of salt at several nested and successive scales (farm, meso, main canal/drain levels, fishpond area, and lake) to understand the linkages between water management practices and salt movement/accumulation.

3.1 Quantify the salt dynamics under contrasting irrigation and cultivation practices at the plot level.

An Egyptian PhD student is continuing his research and has completed field experiments in four seasons. Data has been analysed for three seasons.

The experiments started during summer 2013 and were carried out in four cropping seasons. Sunflower cv Sakha S3 was sown on 11 July 2013 and harvested on 15 October 2013. Wheat cv Sids 12 and sugar beet cv Nada were planted in raised beds by drill method in November 2013. Rice cv Sakha 177 was sown under flooded paddy conditions and cultivated by transplanting method on 15 June 2014 and harvested on 5 October 2014. Also, cotton cv H10229*86 was sown on 10 May 2014 and harvested on 15 November 2014. Soil chemical and physical properties were determined before the experiment and after every season. A network of observation wells was installed to monitor fluctuations in the water table in the experimental site. Activities included the following: records of inflow and outflow, movement of the water table, dynamics of the salt content in the soil profile, and establishment of salt and water mass balances.

Field experiments were conducted for five control drainage treatments: and 40 cm (T1), 60 cm (T2), 80 cm (T3), 100 cm (T4) and 120 cm as control (T5). Each treatment had three laterals to create a buffering zone to prevent seepage from the neighboring treatments and avoid any interaction between treatments. The main focus of this activity is to evaluate contribution of the water table to irrigation, especially under rice cultivation with control of salinity build-up.

In summer 2013, the 40-cm depth controlled drainage saved 22% of irrigation water, and the 100-cm saved 5%, compared to 120-cm controlled drainage. A shallow water table (40 cm) led to salt accumulation in all soil depths, while the deepest water tables resulted in leaching salts from surface layers of the soil profile. The drop of water table level was faster for levels of 120 cm and 100 cm than shallow levels (40, 60, and 80 cm) for all irrigation cycles. No drainage discharge was noticed for the 40 cm, 60 cm, and 80 cm treatments. The highest rates of drain discharge were for the planting irrigation (first) compared to the other irrigations. The seed yield of sunflower was significantly affected by water table depth treatments. The highest mean yield value 1260 kg/feddan was for the 40-cm treatment, while the lowest value of 1020 kg/feddan was for 120 cm.

Data analysis of winter 2013/14 showed that the lowest amount of irrigation water was applied to the field with controlled drainage at 40 cm depth for both wheat and sugar beet. The highest amount of water storage in the effective root zone and the highest percentage of water application efficiency were also recorded for the 40 cm treatment. Water savings for wheat crop in different treatments were estimated as 338, 240, 165, and 40 m^3/feddan for the 40, 60, 80, and 100 cm water table depths, respectively, in comparison to 120 cm treatment. The results also indicated that the water table at shallow depths led to salt accumulation at all soil depths. The trend was the same for both wheat and sugar beet crops. Results indicated that the soil salinity values for the shallower watertable depth (at 40 cm) were nearly two times the salinity values of the deepest layers. The highest yield was for the 40 cm depth treatment for both crops.

A cotton crop was grown in summer 2014. Controlled drainage at 40-cm depth received the least irrigation water, whereas the most was for 120 cm. Cotton yield was significantly affected by water table depth treatments. The highest mean value of 2961 kg/ha was for the 120 cm depth and the lowest of 1896 kg/ha was for the 40 cm depth. It was concluded that controlled drainage at shallow depths is not recommended for use with deep-rooted crops such as cotton.

3.2. Develop an understanding of salt movements and associated changes in drainage water quality at the meso level.

Water management in twelve IIIMP pump stations, as well as water levels and water quality in canals, drains, and subsurface drainage collectors have been monitored during one year (and monitoring is still going on in 2015).

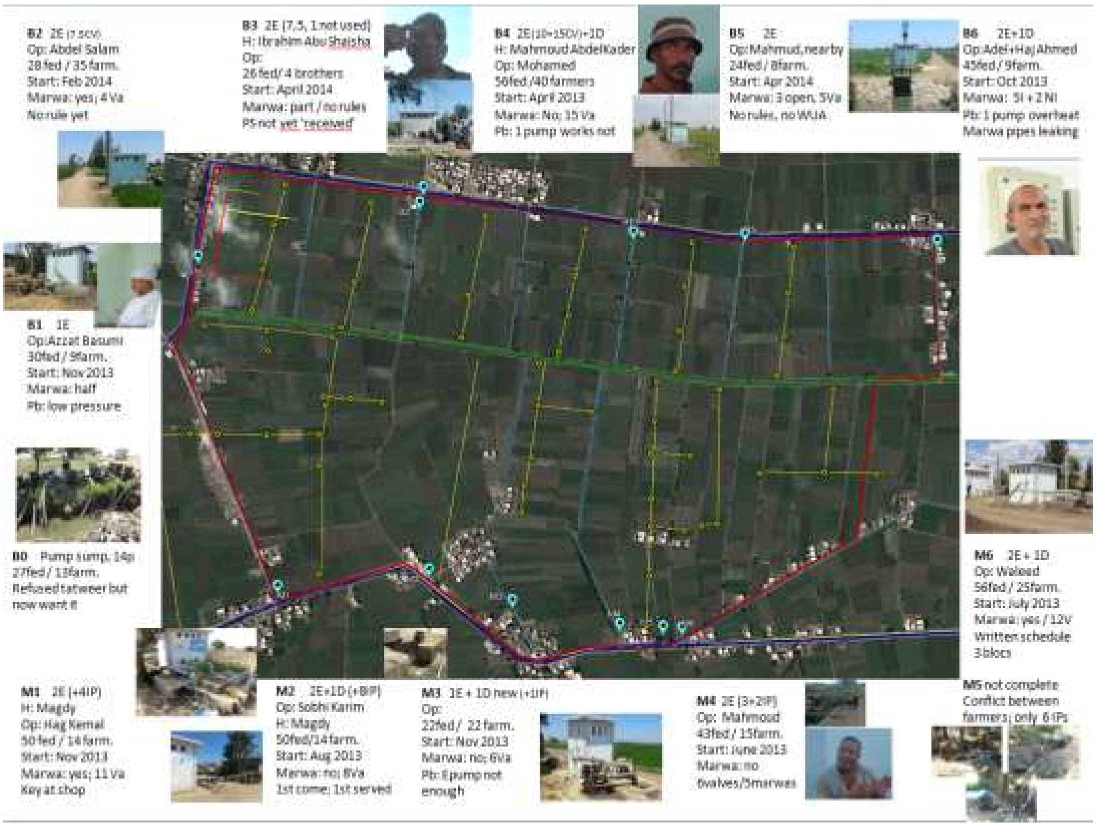

Figure 14: Meso-level research site

EC of irrigation water is around 0.5 ds/m, while EC in the manholes is around three times higher (conductivity of seepage water collected by the subsurface drainage system). This ratio, however, varies from one collector to the other, with higher values in clogged up pipes. Conductivity of the water collected by the second drain, in turn, varies around a mean of 2000 µmhos. This reflects the fact that different collectors might return drainage water with different levels of salinity, depending on the soil type and land use, but also that the water and the drain includes both surface water, water collected by the collectors, and direct deeper seepage (with higher salinity).

Our meso-level area is irrigated with a water of 0.4 ds/m, but the salinity measured in the different manholes of the area varied much more than what was expected. Measurements were made in October 2014 and very high values reflect higher soil salinity (due to both the soil itself and the cropping history), but more importantly the status of the sub-surface drainage itself, as deficient or clogged-up pipes constrain drainage and salt leaching. The variability of drainage water salinity in the collectors varied within a ratio between 1 and 10, which is much more than what one would expect in a rather small area (Figure 15).

Figure 15 also displays the evolution of salinity of drainage water in the Bashair drain during one year. The first striking observation is the huge amplitude of that variability, with EC varying between 1 and 7000 ds/m. Variability is lower in summer, when EC fluctuates around 2 ds/m, which shows that larger amounts of water are applied onto the fields (because of the predominance of rice cultivation) during that season. Also noteworthy is the countercyclical evolutions of EC and water levels (more clearly observed in summer). When the water level drops, indicating a reduction of irrigation operations, EC tends to increase: this shows that the proportion of drainage water that comes from the action of the drain itself (which drains deeper layers of the soil) supersedes the proportion of water coming from a) surface drainage (removal of excess water, for example after land preparation), b) subsurface drainage collectors (which has a lower EC). In winter this correlation is less clear because water levels are always very low (and a flush effect of even a limited irrigation can only be observed on EC, not on water levels).

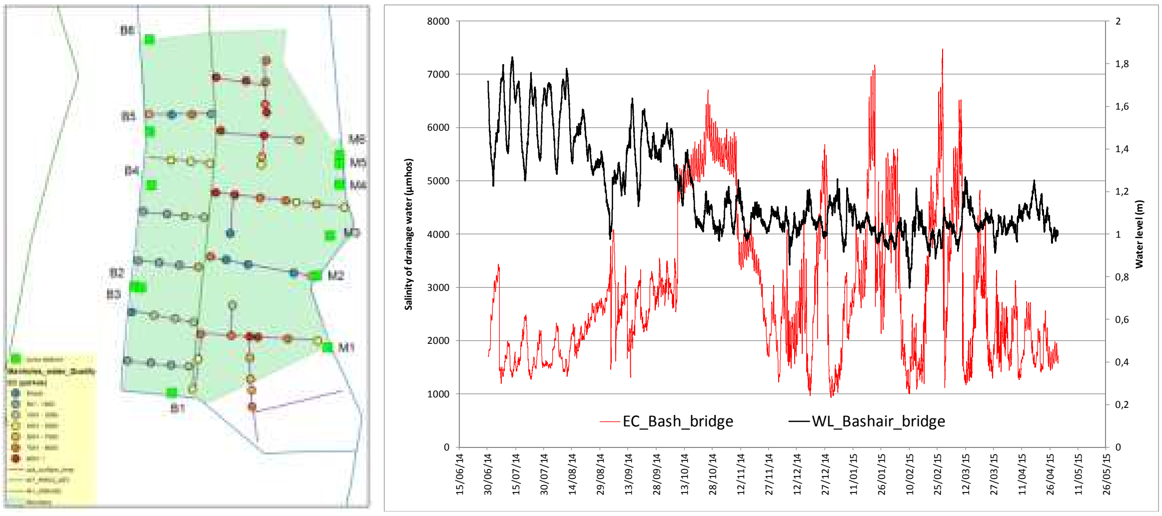

Figure 15: Spatial (manholes) and temporal (drain) variability of salinity

Figure 16 shows the water level in Mares El Gamal canal and at the head of Bashair Branch during one week, in July. The theoretical pattern of rotation appears but with a number of adjustments, showing in particular that Bashair branch can receive some water out of its turn, and that the duration of on and off can be changed according to circumstances.

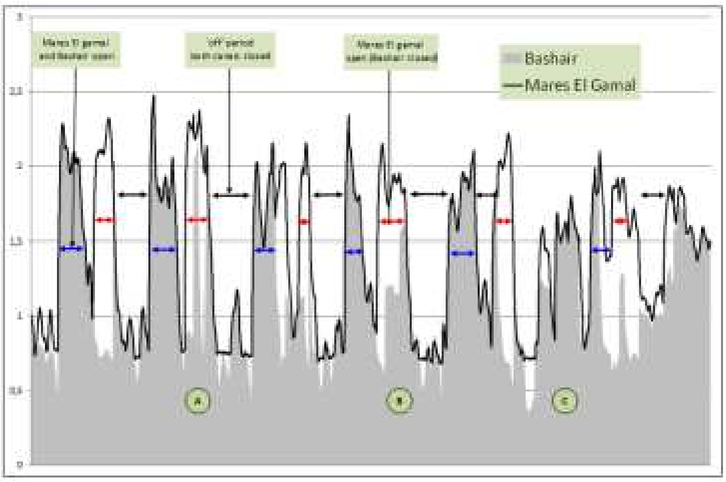

Figure 16. Water levels in Mares el Gamal and Bashair canals (and analysis of rotations)

The survey also provided formation on the operation of pump stations (see full report). For the sake of illustration Figure 17 shows the distribution of pump operations (for one station), according to the starting time (left) and its duration (right). One can observe that the pumps are preferentially operated early in the morning or late in the afternoon, and that over a third of the operations last less than five minutes: this shows attempts by farmers to suck up the remaining ponded water at the bottom of the irrigation canal, as well as situations of overheating.

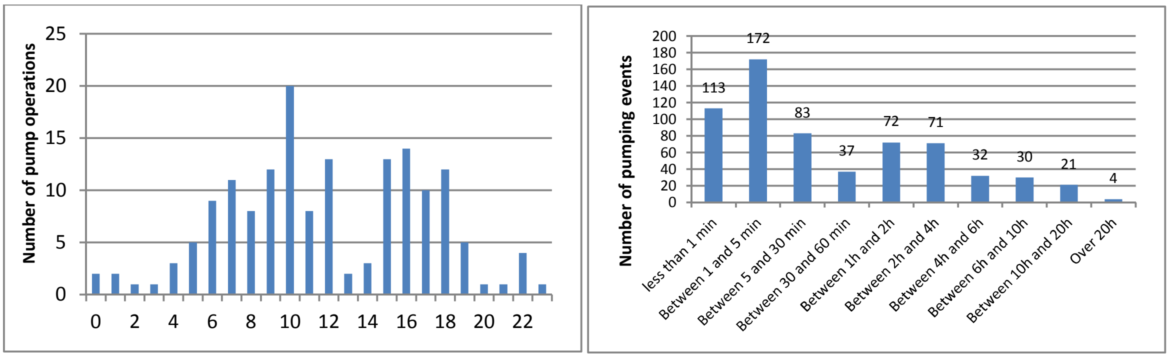

Figure 17. Time and duration of pump station operations

Analysis of all the pump operation records (20 motors + five diesel pumps) is underway for 2015. The results obtained for Bashair PS are shown below. Approximately 20% of the data are missing, because of technical problems with the data loggers, or farmers removing the equipment. The figure shows the result for efficiencies of irrigation of 0.45 for rice and 0.6 for field crops. The final report on this activity will also include an analysis of irrigation efficiency in each pump station. Statistics on the percentage of the time when 'n' (out of 6) PS work together (on each of the two branch) will be calculated, and the differences between pump stations identified and explained.

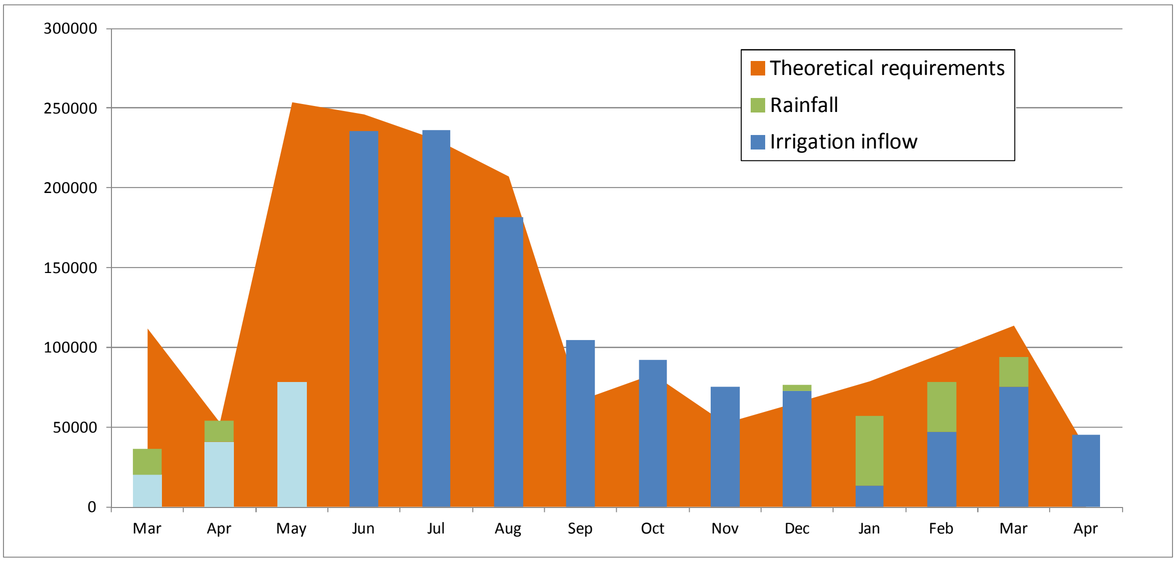

Figure 18: Comparison of water supply and requirements (6 stations on Bashair canal)

3.3 Map the spatial and temporal mobilization of salt across the landscape in order to understand salt dynamics at a larger scale and develop management strategies for its abatement.

Little is known about the spatial generation of salt in the delta because monitoring points are usually at the exit of main drains. This activity consisted in serving most secondary drains in the Meet Yazid command area to document the variability of water quality (EC and DO). One difficulty was that EC in a given location is not constant. Typically, during the off term of the rotation the percentage of water in the drain coming from deep seepage, and therefore being more saline, is higher. We were unable to plan the surveys based on the actual irrigation of the command area, which introduced some bias. The survey's results – based on 482 in situ measurements – are presented in Figure 19, and the following observations can be made:

- A large part of the command area has drains with EC under 1.5 ds/m, which makes water suitable for irrigation.

- The area north of a latitude line going through Riyad shows much higher EC values. We need to distinguish between two areas: (1) the command area of the Abu Mustafa and other canals served by the Deel al Qased branch canal, in the middle of the area, for which drain salinity is good (this is associated with a higher topography and a different soil type, which was why this area was cultivated early on, from the beginning of the 20th century); and (2) the two areas, to the west and to the east, that were reclaimed between the 1960s and 1980s and known to correspond to more saline soils.
- Within the drains of this area, there is a gradient in salinity, with EC increasing toward the north.
- In the north, close to the Moheet drain, salinity is typically over 4 ds/m, making drain water unsuitable for irrigation. This is the water reused by the fish pond area further north.

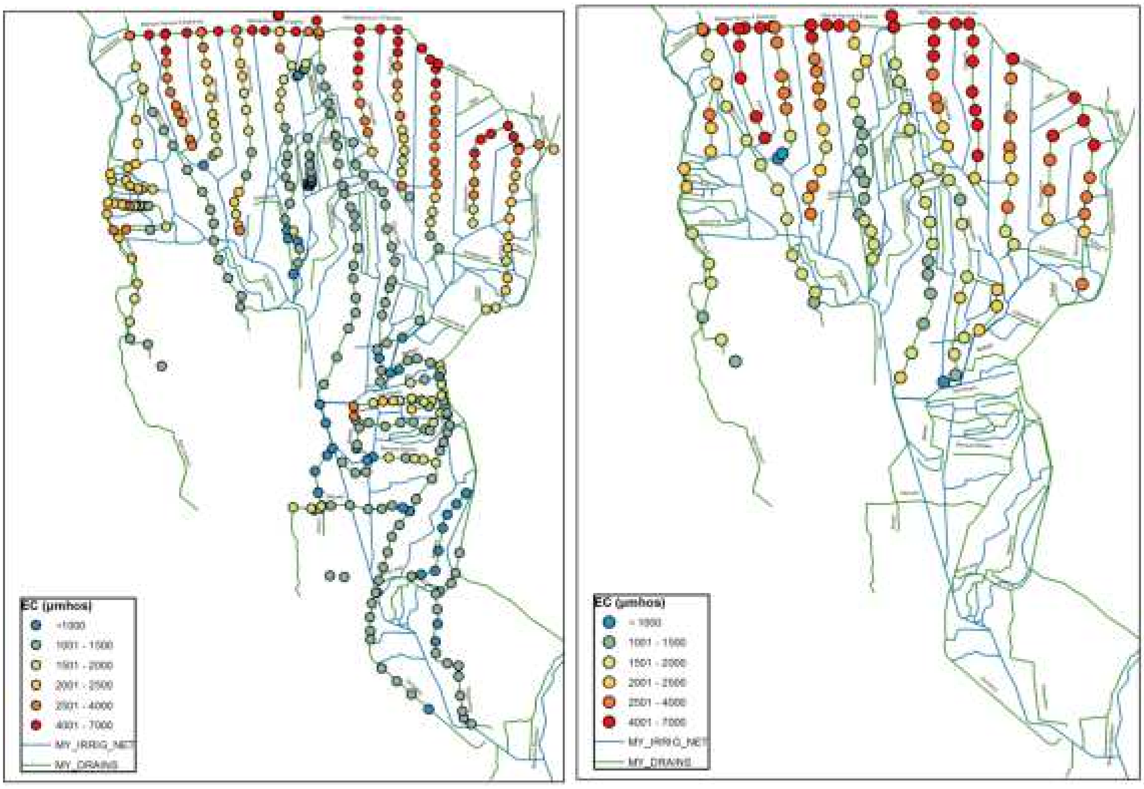

Figure 19: EC at different locations (summer and winter)

This has been repeated during winter 2014/15 (limited to the downstream area on account of the fact that the upstream area has a rather even and good drainage salinity level: 150 measurements in situ). The values of the salinity measured for the winter season show a substantial increase in almost all of the drains compared with the summer season values. If we limit ourselves to the downstream part area surveyed in winter we find that the average EC of drainage water was 3.033 ds/m in winter, against 2.333 ds/m in winter, an increase of 33%. That is due to the fact that the amounts of irrigation and drainage water decrease in winter compared with the summer season. Additionally, lower levels in canals and drains promote the drainage of deeper soil layers, which have a higher salt content. These average values, however, mask the fact that drain salinity in winter can reach very high values in the northern part of the delta.

It is often stated that high levels of salinity in the drainage system is a consequence of multiple reuse across the Delta. Although reuse does increase concentration of salts it appears that this phenomenon is (largely) secondary to that of the production of salt by upward seepage and interception of groundwater in the northern fringe area, which correspond to former marshes areas that have been reclaimed in the past 50 years. This water is both loaded with salts accumulated in the soil profile and originating from seawater intrusion.

This level of salinity is problematic for crop production, although fortunately drain salinity is lowest during summer, at the very time water demand and abstraction from drains are highest.

3.4. Quantify the impact of aquaculture water management on water quality and the implications of multiple recycling on salt mobilization.

► Activity 3.4a: Study water management practices and water budgets of a sample of farms.

To assess the water balance of fish farms, two fish ponds were selected. The two farms take their water from El Arab Drain which takes its water from Drain No. 7. The first fish farm area is about 30 feddans divided into 6 ponds with only one intake and single outlet. The water quantities going in and out from the fish ponds were measured. Evaporation rate was measued using standard Class A evaporation pan installed inside the fish farms and is using water from the same fish farms. Seepage from the farms is also estimated. The water quality sensor installed in the farm was not functioning properly until last season. Therefore the data collected so far is not sufficient to draw concrete conclusion about the water management in the farms. Data collection is in progress now.

This activity has been bedevilled by problems with sensors and batteries, and made difficult by the uneasy access to this distant area. The master student involved will have to repeat the experiment after these problems are solved.

► Activity 3.4b:

This activity recently commenced with identification of the main waterways connecting the fish area with both the lake to the north and the Moheet drain to the south. After this identification, periodic measurements of flows and water quality will be conducted.

The spatial geographies of water flows and salinity in the area are being identified by:

- Collecting operating data for two years (2012 and 2013) of the pump stations no. 7 and 8, and later in 2014
- Calibrating of pumps in stations 7 and 8 to refine estimates of the volumes of water pumping to the fish area (1,2 of Figure 10)
- Measuring the quantity and quality through:
    e) Installing two ultrasonic (Doppler) flowmeters to measure water discharge to Borullus Lake from drains 7 and 8. (3,4 of Figure 10)
    f) Periodic *in situ* measurements of the flow to Borullus Lake from drains 7 and 8. (3,4 of Figure 10), to control the quality of data from the ultrasonic flowmeters
    g) Measuring EC (sensor) at both the head of drains 7 and 8 just after the pump station

These activities have been carried out during summer 2015. Collecting data in such a remote environment has proved to be challenging, in particular because of the question of batteries. Figures 20 below indicates a very high fluctuation of the flow from drains 7 (left) and 8 (right) into Burullus Lake. They also indicate, more surprisingly, that flow values oscillate between positive and negative values. For Drain 7 this means that most of the flow from the pump station on the main drain is diverted to the fish area, with this diversion sometimes exceeding the flow and provoking an influx from the lake. The figure for Drain 8 has some missing data and it's not clear whether there is a drop of the discharge during a April and May, or whether there has been a change in calibration that explain the step observed.

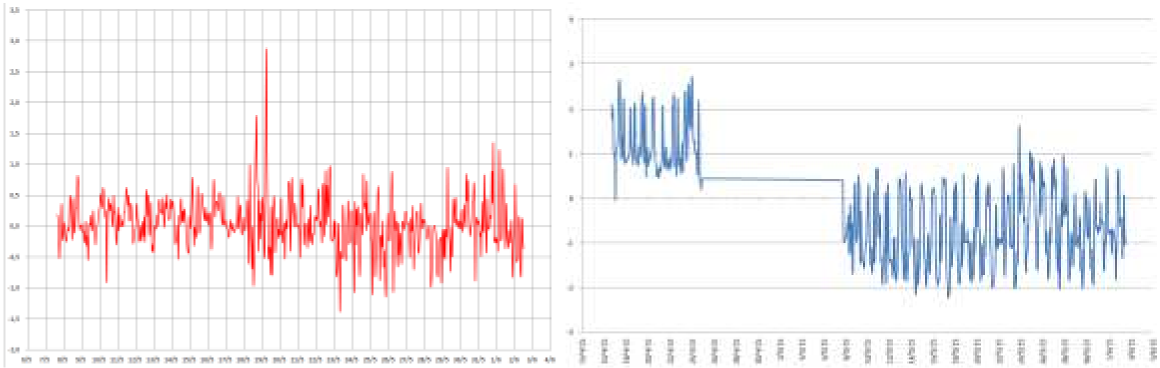

Figure 20: Flow from Drains to Borullus Lake

► Activity 3.4c: As mentioned above two ultrasonic flowmeters were bought and installed at the outlet of drains 7 and 8.

Six main drains flow into Lake Burullus. Three years of pumping records have been collected. Data from Drain 7 shows that the values of the downstream level indicated are often not updated, which in summer creates a substantial discrepancy between the estimated and actual discharges. The volume of water pumped out to the sea is therefore overestimated which points to the need to equip all main drainage pump stations in the Delta with loggers that record hourly values.

Objective 4: Develop an understanding of the implications of these cross-scale interactions through the modeling of the whole central delta, and assess the fraction of water that could potentially be 'saved' and used in the New Lands under constraints of salt management and sustainability of current uses (rice, aquaculture, and fisheries).

4.1. Undertake an assessment on the impacts of a range of interventions when scaled-up on water and salt balances (SIWARE software for the whole central delta) and test various scenarios.

This important activity was cancelled because of the exclusion of Egypt from the NUFIC PhD scholarship program from the Netherlands at the very time of the application of Ahmed Abdallah from the DRI of NWRC, who was thus unable to apply.

Two activities have commenced, however, to enhance the understanding of water reuse at the macro level, with a view of improving the understanding of the water balance of the delta. A first survey estimated the number of individual pumping stations abstracting water from main and secondary drains and identified around 2200 pumps. As expected, and shown in the following map (Figure 21), there is a very high density of wells in the downstream half of the command area. In contrast the secondary drains of the upstream part have few if any pumps. It must be noted that the survey does not consider reuse from drainage water from tertiary drains. In some water-short areas this reuse can be considerable. For example, the command area of one IIP pump station in the Abu Mustafa canal, monitored in Activity 1.2c, is also supplied by a total of 25 individual pumps that abstract water from tertiary drains. In such situations the degree of reuse is extremely high, and so is the efficiency of water use as a result.

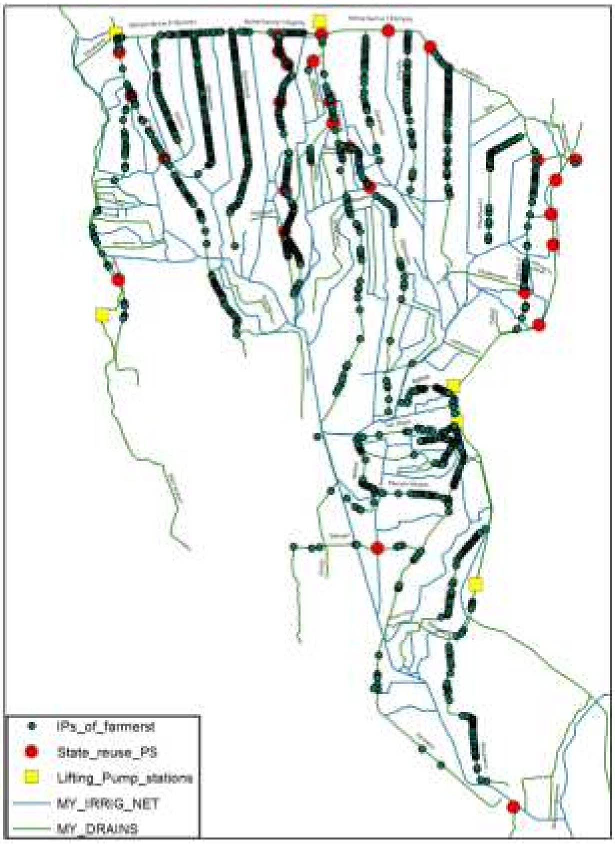

Figure 21: Geo-referenced pumping stations

Another survey examined the number of farmers abstracting water from wells. Although it is well known that wells are used south of Tanta, it was discovered that many wells also exist between Tanta and Kafr el Sheikh (Figure 22). A survey was therefore undertaken to produce knowledge on the dynamics of groundwater in this area, and to ascertain in particular how wells are spatially distributed and whether they are found in the upstream part of the Meet Yazid command area. Very few wells were found in this latter area because of the relatively good supply provided by the Meet Yazid canal in its upstream reach. However, a very high number of wells were found west of its common area. This motivated more systematic survey, given the possible importance of an increase in groundwater use for the water balance of the Delta. A sample of 54 farmers using wells have been interviewed.

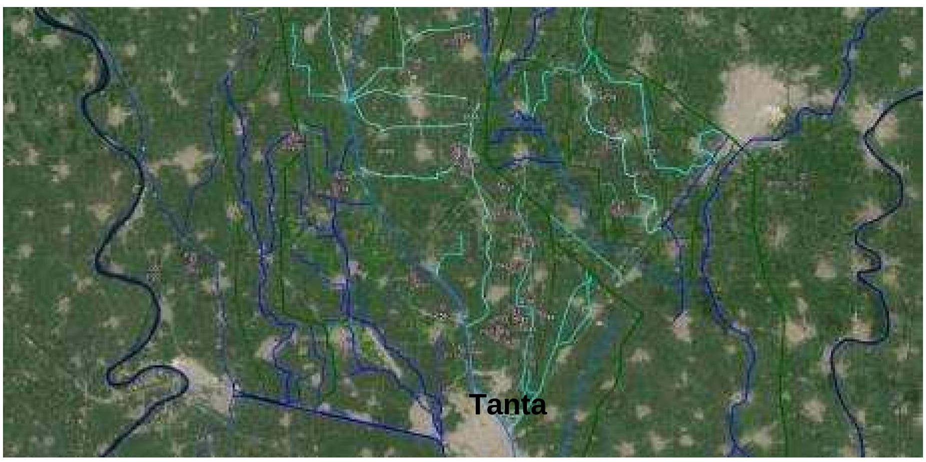

Figure 22: Location of areas visited



Well with suction pump   Tractor-powered pump   Well with electric motor

The intensity of use, trends, drilling and operation costs, in addition to the main drivers behind the use of groundwater by farmers were addressed to give an idea about the current status of this phenomenon. The social arrangements set up by farmers to drill and operate the wells collectively or/and individually were described. The study of the socio-economics of groundwater abstraction in the Delta paints a more complex system of irrigation and conjunctive use than what it has been presented until now. Social informal arrangements between farmers (those with wells and those without) ensure that most farmers can access groundwater. Most of these wells are shared between various farmers: this shows that individual needs are still limited and seldom justify individual investment in a well. The possibility of a shared investment brings obvious economies of scale and allows for the dissemination of wells. With an average investment cost of LE 11,000, a group of over 11 farmers will have individual costs under LE 1000 per person, which is seen as a worthwhile investment if this allows securing water supply to crops.

But pumping from a well requires more energy than pumping from waterways, and costs on average 2 to 3 times more than pumping from the canal, with irrigation durations around twice as long. Those who have to hire a tractor have to face prices which increased recently from 25-30 LE to 40 LE per hour. This is why farmers in general only use their wells when canal water is not available. The survey also found that some wells had a life duration of around 10 years due to clogging up. In this case farmers usually drill another well close to the former one.

This initial review on groundwater in the Nile Delta has also shown that contamination of groundwater by agriculture and more prominently by seepage from domestic and industrial effluents had already attained worrying levels. This may jeopardize the quality of the Nile Delta aquifer in the long run and needs more research and attention. The EC of water was measured whenever possible (i.e. the pump being operated during the time of the interview) to assess salinity variations across the area. Range for EC was 596–2351 mmhos, showing a substantial variability even within a reduced area.

As seen in this preliminary study, groundwater abstraction in the Middle Delta is strongly linked to inadequate and/or untimely availability of surface water in the canals. Users with poor access to canals depend on groundwater as a complement, increasing their water security, especially during peak irrigation times (in summer). This initial study has shown that inadequately maintained canals is also a major driver of the development of groundwater abstraction in the Nile Delta, as well as reduction in water supply (especially for tail-end users in the canal system), and cases of conflicts (with farmers seeking independence from fellow farmers on the same mesqa).

The Nile delta is a highly productive area and ensuring the sustainability of the irrigation system against human inadequate supply and climate change hazards is a high priority. Conjunctive use of water has developed as the main response, with farmers pumping water from all waterways, including drains, but also - and increasingly so- from groundwater, except in the northern part of the Delta where high salinity makes groundwater unfit for use in irrigation. Although well densities can locally be as high as one well per hectare, according to our estimations, groundwater abstraction in times of crisis is still sustainable, despite drops in the level of water and higher pumping costs. Water levels, however, are sometimes close to 8-10 meters, a depth where the use of conventional suction pumps becomes impossible. More intensive use of groundwater might therefore result, in the future, in further investment needs (lowering the pump body, or using submerged pumps).

Studies on the implications of the use of groundwater should be part of the scope of any proposed management scenario for the Delta given the spread of conjunctive use of ground and surface water.

Survey4.2. Establish an integrated view of the rice/aquaculture/lake complex in terms of water/salt balances in order to define the conditions for the joint sustainability of these systems, and to assess the effective potential for macro-level water savings.

► Activity 4.2c:

Close to 10 different sources providing delta water balances have been identified and collected. Analysis of their differences and respective components is no longer part of this project but will be conducted in the future.

However a first analysis of the Delta water balance (illustrated below), combining information from the literature and from this project, provides some important and interesting remarks and conclusions:

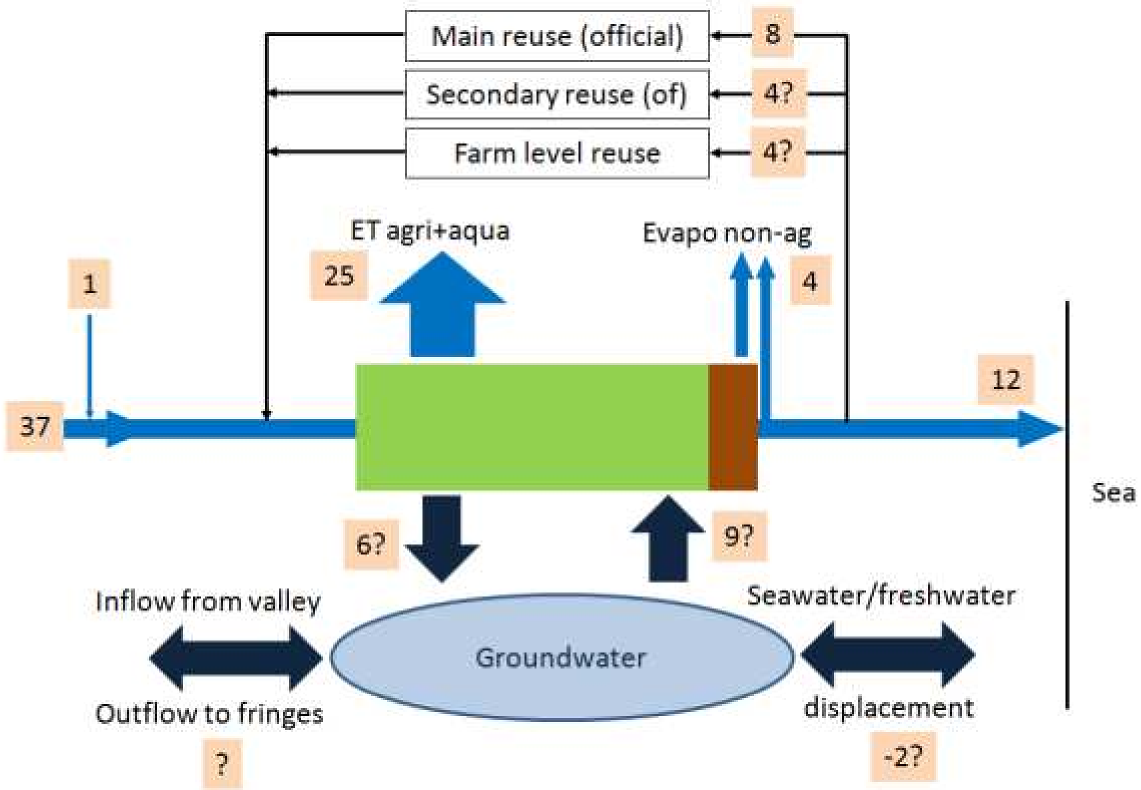

Figure 23: Simplified balance of the Nile Delta (values in Bm3)

- It is not possible to establish an accurate balance of the delta: the accuracy of some terms could be improved
- In particular, the balance of the aquifer remains a fuzzy point
- There is still a large uncertainty on ET consumption and areas cultivated

- Several studies have shown that the outflow (12 Bm^3) could not be reduced under 8-9 Bm^3 which limits possible savings at system level to around 10% of inflow
- Reuse of drainage or groundwater (?) does not add water to the system but eases distribution and improves
- A dam release of –say 52 Bm^3- would probably put outflow at 10 Bm^3 with severe distribution problems (*1988*), and a rush to drains and wells
- In case of prolonged dry spell or reduced inflow to HAD, cutting the rice area should be the first measure to be adopted: it would ease distribution (but reduce return flows). In the long run treatment of drainage water to restart main level reuse PS is a priority.
- The system has by and large reached a balance between supply and demand: further horizontal expansion is not desirable; improving the existing is priority

Objective 5: Build capacity of decision-makers, water managers, researchers, extensionists, farmers, and other stakeholders through seminars, targeted training courses in Egypt, and formal and informal education and programs.

- Three stakeholder workshops were organized during the life of the project.
- Several briefings were made to decision-makers about the project and its progress.
- A 'water policy lunch' attended by 20 high level policymakers has been organized by IWMI on the occasion of its 30th anniversary: this has provided the opportunity to disseminate the main findings of some key activities.
- A special session will be organized on the occasion of the Africa ICID meeting, to be held next March in Aswan, which will be fully devoted to the results of the project. Presentations will reach a large audience of Egyptian as well as African water professionals.
- Seven MSc and PhD students (two at Kafr Sheik University, two at Ain Shams University, one at Cairo University and two from overseas) were trained in this project. The students developed their work plans and conducted research activities in the field – their research activities are add-on activities to the planned research activities. Some are nearing completion.
- A training course on management of salt-affected soil, targeted at young researchers and technicians for up to 25 participants for five days, was organized at Sakha Agriculture Research Station in June 2013.
- A training course on socioeconomics and management of fish ponds, focusing on young researchers and scientists involved in the project was organized in September 2013.
- A member of the field-level intervention attended a four-week water productivity and salinity management training course funded by JICA in Amman, Jordan.
- A half day seminar of the PhD students was organized to evaluate their research progress to date (5th April 2015).
- Fourteen ARC staff members attended the training course on AquaCrop software organized by ICARDA and FAO (2014).
- One PhD student and three staff from NARS attended 3 day training on improving water productivity in irrigated agriculture organized by ICARDA (May, 2015).
- Field days were organized for the farmers in each season.

- A number of informal and on-the-job training programs on the use of equipment to monitor flow, groundwater levels, and salinity were organized by the project team.

Table 4: Student projects

Student Name	Degree	Supervisor	Topic
Mohamed Khattab	PhD	Fawzi Karajeh	Influence of controlled drainage on water saving and soil properties under different crops in north Nile Delta Egypt
Mostafa Ahmed Mohamed Soliman	MSc	Fawzi Karajeh	Water and salt balance of fish farming systems in the north Nile Delta of Egypt.
Samir Salama	MSc	François Molle	Integrated assessment of on-farm water management under improved irrigation system in the Nile Delta, Egypt
Walaa M. Abd EL-Aziz	MSc	François Molle	Water management at mesqa level under collective pump and improved irrigation in Nile Delta, Egypt.
Ala Moosad	MSc	Fawzi Karajeh	Monitoring rate and type of land degradation in the Nile Delta using RS and GIS techniques.
Siraj Dutta	MSc	François Molle	Technical interventions, local organisational and institutional arrangements of farmers: Exploring the factors affecting equitable water distribution in the improved irrigation systems in the Nile Delta, Egypt.
Chis de Bont	MSc	Edwin Rap	Responses to the irrigation improvement project along Abo Moustafa canal, Egypt: *An analysis of water users' re-ordering of the socio-technical water network*

8 Impacts

8.1 Scientific impacts – now and in five years

The project has produced a host of results that have substantially increased our scientific understanding of various aspects of water and salt management in the delta. Among these results, the following should be emphasized:

- About one-third of Egypt's irrigated land is salt-affected, and soil salinization continues to increase over time. The majority of the salt-affected lands are located in the Lower Delta and current situation is serious and threatens not only agricultural sustainability, but also the whole ecological system. Field experiments to evaluate sustainable interventions to combat degradation associated with salt accumulation indicated positive effects of the tested soil amendment treatments on improving soil physical and chemical characteristics, crop yields, decreasing applied irrigation water, and enhancing field and crop water use efficiencies. Therefore the plot-level interventions tested in this project will offer farmers a range of possible mitigation techniques.

- There is usually no single way to control salinity and sodicity, therefore several practices should be combined into a package that function satisfactorily. This package should be field tested under farmer conditions. Experiments to evaluate the effect of tile drain spacing (narrow and wide) with and without mole drains under farmer conditions concluded that introducing the mole drain to heavy clay salt-affected soils improved the efficiency of the wider spacing drainage system. The project will be able to make some recommendations on a package combining physical, chemical and biological interventions, once the collated data are fully analyzed.

- Fish farming is a significant activity in the upper reaches of the delta and an integral part of the socioeconomic fabric of local communities. Despite the importance of this livelihood activity, little is known about the problems faced by aquaculture farmers. This project looked at aquaculture systems in detail and identified the reasons for shifting fish farms to field crops. The variability in economic returns of various aquaculture systems was also assessed. Enhanced knowledge on aquaculture will serve as a basis for the design of further research activities.

- Quantitative analysis of water supply in a number of branch canals allowed a quite detailed description of the rotational system and exploration of the differences between the official rotation and reality.

- The spatial distribution of water quality in the drainage system (limited to salinity), which up to now was isolated to the main control points monitored by the Ministry, was uncovered through an intensive survey of over 300 points. It gives a clear picture of the relationships between soil type and salinity and also of the concentration of salts in the drainage water used for irrigation at different points in the system. This information is very useful in managing the salinity in the future; and in understanding the salt balance of the Delta.

- The magnitude of the reuse from drainage water was also estimated for the first time at this scale by an overall survey of individual pumps set up along drains, as well as bigger public pumps.

- Little is known about water management in the large aquaculture area north of the delta. The project is providing new knowledge on water/salt management both at the pond and regional scales. Together with the data recorded at the pumping stations draining water to the sea, these results with allow a much more elaborate water balance of the central part of the delta.

- Limited knowledge is also available about social processes within WUAs and BCWUAs. The project is providing substantial insight on how these associations work and on the scope for improved participatory management.

Over the next five years, we anticipate that there will be some significant impacts arising from this project. Some of the preliminary reports are among the best studies in their field and these reports will be converted into peer reviewed publications in the next few months. The project has produced the best assessment of the Irrigation Improvement Programs and it is envisaged that the findings of this project will lead to reconsideration of existing policies in the future IIP programs.

8.2 Capacity impacts – now and in five years

Five MSc and PhD students (two at Kafr el Sheik University, two at Ain Shams University, and one at Cairo University) are doing their research under the umbrella of this project. Drs Swelam, Molle and Rap representing the project are serving on the students' supervision teams. The capacity of these young Egyptian scientists has benefitted through their interactions with scientists from ICARDA and IWMI. It is expected that these trained scientists will eventually transfer skills gained to other colleagues and students. Moreover, a wide range of projects currently undertaken by NWRC and ARC is benefitted through the improved capacity of these young scientists.

Several workshops were held to increase the capacity of team members during the life of project. About twenty five young researchers and technicians were trained on the management of salt affected soils. The project scientists have been trained on socio-economic data collection methods and this has significantly improved the quality of the data collected during surveys. One training course on socioeconomics and management of fish ponds, focusing on young researchers and scientists involved in the project was organized.

A significant capacity building impact is that several scientists from the national partners were trained in modeling through this project. Two modeling trainings (Crop Growth Simulation Modeling and Water Productivity Calculator) were organized and several scientists from Agricultural Research Centre and National Water Research Centre were trained on these tools. It is anticipated that scientist's modeling skills will help them to undertake wide range of modeling projects in the future.

Three steering committee meetings involving stakeholders were organized during the life of the project. A number of informal meetings were held with the project stakeholders to enhance the relationship to eventually transfer the knowledge base developed in this project. It is expected that this research will lead to informing policies regarding investment programs in irrigation improvement, extension programs for on-farm salinity management and the role of fish farming at the end of the delta.

Advanced instruments to monitor field soil moisture, flow, groundwater levels, and salinity have been established in the study area and a number of scientists have been trained to operate them.

A member of the field-level intervention team attended a four-week water productivity and salinity management training course funded by JICA in Amman, Jordan.

In the next five years, the main potential capacity building impacts arising from this project are the enhanced capacity of the project participants to undertake inter-disciplinary projects. A further achievement of this project is the inter-institutional collaboration within the Egyptian National Programs and it is expected that National Programs will use this approach in their future research programs. Significant impacts are expected once the skills gained by the project scientists and PhD students are transferred to other researchers.

8.3 Community impacts – now and in five years

8.3.1 Economic impacts

The research actions undertaken in this project has led to better understanding of interconnected processes at various scales. The following economic impacts are expected on adoption of the findings by the farmers:

- Field experiments to evaluate sustainable treatments to reduce degradation associated with salt accumulation were carried out during four cropping seasons. The upscaling of these results to the whole region will lead to significant reductions in production costs, increases in yield, and water savings. An economic analysis of the summer season results yielded a net profit of approx. LE 1526 /Feddan (Approx. $195/acre) for the treatment package including gypsum, farm yard manure and ammonia gas. Widespread adoption of this technology will lead to significant economic benefits.
- Field experiments in the farmers' fields to evaluate the effect of tile drain spacing (narrow and wide) with and without mole drains under farmer conditions concluded that introducing the mole drain to heavy clay salt-affected soils will result in increase in the net returns by LE 260/feddan for rice crop and LE 890/feddan for cotton. Again, increased adoption of this technology over the salt affected areas of Nile Delta will lead to significant economic benefits.
- The project estimated the economic returns of various aquaculture systems and it was concluded that system which combines aquaculture with wheat cultivation achieved the highest net income per feddan as well as the highest rate of return in comparison to all other systems studied.
- The project is providing new knowledge on water/salt management both at the scale of the pond and at regional level, which will lead to improved management of water in the large aquaculture area north of the delta. The results of this research will contribute to enhancing/conserving the potential of fisheries (aquaculture and lake), as well as to determining how, and how much (if any), water can effectively be 'saved' at the delta level and diverted away to expand agriculture.
- The results obtained on the delta water balance as well as on management practices indicate that the delta system is starting to experience stress, which is predominantly due to the complexity of managing such an extended system, notably in the presence of a large area of Rice. It is therefore strongly recommended that efforts should be directed to improving management, in both new lands and old lands, rather than expanding cultivation on both sides of the Delta. This would create increased and undesirable stress on the system, leaving it more vulnerable to possible forthcoming fluctuations in supply, as well as would represent a financial loss to the country that needs to be averted.

In the next five years large scale adoption of on-farm salinity management techniques in the Nile Delta has potential to increase farm profitability and productivity significantly. At the national level, developing appropriate policies for future IIP Projects based on the findings and recommendations of this project will lead to significant economic benefits.

8.3.2 Social impacts

The results of this multi-scale project will have positive impacts at the farm, meso, project, and policy levels:

- At the farm level, the project has recommended a set of technical packages (soil management, drain spacing, leaching requirement, and controlled drainage) to farmers which will lead to increased production and water savings.
- At the meso level, the ineffectiveness of BCWUAs has been documented and explained. BCWUAs need to be empowered by a specific law but it was recognized that this would not be sufficient to ensure a substantial contribution to irrigation management. The ministry needs to rethink its incentive structure to local engineers so that they may be led to co-manage secondary levels with farmers. This may lead to better equity of water distribution between tail- and head-end users, reduction in conflicts and economic disparities between farmers, and ensure better social outcomes.
- At the level of the Irrigation Improvement Projects, the recommendation to make it completely on-demand will deliver a technological package that is more suitable to farmers' varied conditions and requirements and will therefore increase the acceptability and willingness to pay. This would increase the social benefits for farmers generated by the projects' investments.
- At the policy level, the project shed some light on the limited scope for saving water and potentially reallocate it to the New Lands by improving efficiency in the Old Lands. The upper limit of possible improvements that can be achieved (mostly by reducing return flows), do not exceed 10% of the flow entering the Delta (around 3.5 Bm3). In other words the Delta can be seen as functioning with 90% of efficiency, considering the different constraints to its management.

8.3.3 Environmental impacts

The project is producing knowledge on the spatial and temporal variation of salinity in the drainage system, as well as in the fish pond area. Understanding the production and circulation of salts is paramount to assess how these would change in a scenario of drastic decrease in water supply (as might happen due to climate change extreme events or construction of large dams in upstream riparian countries).

- It was shown that the potential increase in drainage water salinity at the edge of the delta (in case water is managed in order to reduce return flows - in particular by reducing the rice area), with a maximum of 40%, would not affect fisheries, since current aquaculture systems can handle such an increase in salinity. The impact on the lagoon ecology would also be positive (better control of weeds and shift towards more valuable marine species) although pollution would also be more concentrated (which calls for the imperative need to increase treatment of wastewater in the delta).
- The research has also shown that the northern fringe of the central Delta is exposed to seepage of salty water, which make it necessary for farmers to grow Rice (or raise fish) at least one year out of two, and even two years out of three in the most critical cases sustaining environmental conditions adequate for agriculture in this part of the Delta means that more water has to be supplied for leaching purposes.
- The development of groundwater use in the Southern and central part of the Delta poses a potential threat to the environment: a massive increase in groundwater abstraction – as has been documented in the project - will result in a de-stocking of the aquifer and increased salinity intrusion from the sea. This means that farmers using groundwater will bring an increased salt load onto their fields, with potential long-term detrimental impacts. The dispositive to monitor the Delta aquifer needs to be strengthened, most notably in the northern part of the Delta.

8.4 Communication and dissemination activities

This project has high impact potential if the generated knowledge is implemented in the whole Nile Delta. Therefore, much effort was put into communication and dissemination activities which included:

Training:

A training course on management of salt-affected soil, targeted at young researchers and technicians for up to 25 participants for five days, was organized at Sakha Agriculture Research Station in June 2013.

One training course on socioeconomics and management of fish ponds, focusing on young researchers and scientists involved in the project, was organized in September 2013. Topics covered were:

- Artificial feeding and its impact on water quality
- Water quality and fish diseases
- Water quality impact on the economics of fish farms
- Problems of harmful algae and their relationship to the aquatic environment
- Pollution and its impact on water management
- The effect of salinity on fish production

A member of the field-level intervention attended a four-week water productivity and salinity management training course funded by JICA in Amman, Jordan.

A training program on crop growth simulation modeling was organized jointly by ICARDA and FAO in August 2014. Fourteen ARC staff and students involved in this project attended this program.

One PhD student and three staff from NARS attended 3 day training on improving water productivity in irrigated agriculture organized by ICARDA.

A number of informal and on-the-job training programs on the use of equipment to monitor flow, groundwater levels, and salinity were organized by the project team.

One training course on socioeconomics and management of fish ponds, focusing on young researchers and scientists involved in the project was organized.

One scientist from ARC attended a one week salinity management training course funded by JICA in Amman, Jordan, 2015.

Field days:

A field day was organized to introduce simple controlled drainage techniques and their role in saving irrigation water without significant yield reduction in every cropping season.

Farmers were introduced to the experimental fields containing different drainage treatments and soil amendment experiments sites in each cropping season. They were convinced by the fact that applying soil amendments and mole drains will improve soil conditions and yield.

A field day was organized for aquaculture farmers on water management practices in April 2014.

A workshop with 20 farmer leaders of selected branch canals was conducted in September 2014. Farmers shared and discussed with project researchers all the different options that could be envisaged to improve water distribution within branch canals. A better understanding of opportunities and constraints by the different participants should be reflected in behaviors and will be fed into recommendations for changes in the project.

Water Policy Lunch:

A 'water policy lunch' attended by 20 high level policymakers have been organized by IWMI on the occasion of its 30th anniversary: this has provided the opportunity to disseminate the main findings of some key activities.

ICID Special Session:

A special session will be organized on the occasion of the Africa ICID meeting, to be held next March in Aswan, which will be fully devoted to the results of the project. Presentations will reach a large audience of Egyptian as well as African water professionals.

Supervision:

Five MSc and PhD students (two at Kfer Sheik University, two at Ain Shams University, and one at Cairo University) are working under the umbrella of the ACIAR Water project. Drs Swelam, Molle, and Rap representing the project are serving on the students' supervision teams.

Publications:

We are planning to publish papers in international peer reviewed journals, research monographs in ICARDA's and IWMI's research report series, conference proceedings targeted at a specialized research community out of this project.

9 Conclusions and recommendations

9.1 Conclusions

The environmental and agricultural sustainability of the Nile Delta is an existential issue for Egypt. The Delta is under threat from degradation as a result of pollution and poor water and salt management. The aim of the project was to identify physical and institutional interventions to improve water and salt management using an integrated approach across scales (field, farm, community, branch canal, main canal) and systems (mixed cropping, rice, aquaculture) encompassing water quantity–quality interactions. The project's geographical focus is the Nile Delta in Egypt. A number of field experiments at the farm, mesqa, and branch canal levels were carried out and some are underway. The following conclusions were drawn from the analysis completed:

- The majority of the salt-affected lands are located in the Lower Delta and current situation is serious and threatens not only agricultural sustainability, but also the whole ecological system. Field experiments to evaluate sustainable interventions to combat degradation associated with salt accumulation indicated positive effects of the tested soil amendment treatments on improving soil physical and chemical characteristics, crop yields, decreasing applied irrigation water, and enhancing field and crop water use efficiencies. Environmental conditions in the northern fringe of the delta demand that rice is cultivated between one year out of 2 and 2 years out of 3).
- Experiments to evaluate the effect of tile drain spacing (narrow and wide) with and without mole drains under farmer conditions concluded that introducing the mole drain to heavy clay salt-affected soils improved the efficiency of the wider spacing drainage system.
- Fish farming is a significant activity in the northern part of the delta and an integral part of the socioeconomic fabric of local communities. Despite the importance of this livelihood activity, little is known about the problems faced by aquaculture farmers. This project looked at aquaculture systems in detail and identified the reasons for shifting fish farms to field crops. It also documented the current difficulties faced by fish farmers, and associated economic profitability. Most of the production is currently for the domestic market and appropriate processing facilities are required to export the product to foreign counties to add additional value to Egyptian aquaculture sector.
- The project estimated the economic returns of four aquaculture systems and it was concluded that system which combines aquaculture with wheat cultivation achieved the highest net income per acre as well as the highest rate of return in comparison to all other systems studied.
- The assessment of IIP has yielded several important conclusions:
    - Widespread design and implementation problems. Difficulty to find spare parts and technical intervention
    - A large number of pumps have been **replaced, stolen, electrified, abandoned**
    - In the absence of continuous flow, water **supply has remained** more or less constant: so has total water abstraction, and drainage water reuse. No water savings can be expected in the absence of continuous flow.
    - WUAs hardly function according to the official pattern, but in most cases farmers have shown to have enough collective resources to handle the

operation and maintenance of the pumps. 18% of the pump stations, however, have been found to be abandoned.
  - Labour requirements, pumping costs, and burden have decreased, but the **overall balance of cost and benefits** varies a lot according to the water situation and the social setting
  - Depending on these conditions **acceptability** of the project varies: it is recommended to make it **fully on-demand**; to find solutions against theft; to provide for maintenance support (trained independent technicians).
  - A major issue is whether the **overall pumping capacity** is increased or not. The **risk** is to increase pumping capacity to make the project acceptable to farmers, to the detriment of tail-end farmers.
  - Given that the benefits drawn are more individual than collective, **a policy question** is whether or how much the government should **subsidize** it.

- The monitoring of 12 IIIMP pump stations yielded several conclusions on the way farmers were adjusting to the new technology. During the three seasons of observation there was a very high rate of mechanical and electrical problems with these pump stations. They were partly dealt with by adding diesel pumps, as well as the individual pumps kept in place by farmers. The efficiency of irrigation at the tertiary level was estimated to be around 55% on average, with lower values for rice and higher values for field crops.

- The efforts to establish branch canal WUAs (BCWUAs) were assessed. The research indicated that these associations were in most cases not playing a significant role in the actual O&M of branch canals. They were from the onset weakened by the lack of financial means and authority, with the water law expected to empower them still under consideration but never passed. Examples of positive relationships between these associations and district engineers were clearly related to specific individuals who were ready to share management responsibilities. However, it was clear that there also was reluctance from field staff to relinquish what they see as their prerogatives and part of their social status. Consequently the lack of buy-in from field staff, and/or incentives to consider new modes of management, explains why the potential for improved O&M has not been realized through the establishment of these associations.

- The spatial and temporal variability of water quality in the drainage systems has been investigated. The results show that salinity of the water collected by the subsurface drainage system varied a lot, notably depending on whether the pipes are partly obstructed or not. The rather high variability of the level of salinity also means that the monitoring dispositive to register the salinity only once a month may not be sufficient and requires more frequent measurement to assess this variability. The mapping of salinity in the drainage systems has also shown that there was a very steep gradient in the direction of the sea. This was attributed to the fact that these are personal area is subjected to up world three-page and intersects a very saline aquifer.

- A dramatic and recent boom in groundwater use in the Southern and central part of the Delta has been identified. The conjunctive use of surface- and groundwater brings a lot of flexibility and security in supply, allowing farmers in particular to grow cash crops. There are however three potentially negative impacts: at the farm level, if this use was to increase further the dynamic level of the water table could drop under 8-10 meters, which would make the use of suction pumps impossible, forcing farmers to costly technological investments. At the system level, managers tend to supply less water to the canals where they know farmers have developed conjunctive use; this means less water, which begets more wells, and also loosens the discipline that needs to be deployed by irrigation engineers to deliver water to all parts of the system. At the macro level, there is a potential impact of widespread groundwater use on the balance of the Delta aquifer, with potential increased salinity intrusion which would reduce water quality, and even jeopardize the use of some wells. A more elaborate monitoring of groundwater conditions and dynamics is needed.

- Examination of the delta water balance has shown that all the terms of the balance were subject to a rather great uncertainty: this is true for the cultivated area, the cropping pattern, consumption by evapotranspiration, how much water is abstracted by farmers from the drains and the aquifer, and also for the volume of water drained to the sea. It was found that the accuracy of the volume pumped out by the pump stations could be improved and that the reuse of water occurring downstream of these stations should be better taken into account. The research showed that the balance of the aquifer was also uncertain, with increased lateral seepage to the new lands using groundwater on the fringes of the Delta. It further demonstrated that the first means of handling potential reduction in supply in the future would be to reduce the rice area: such a reduction, however, would only ease water distribution in the system and would hardly free any water. The actual balance between supply and demand in the Delta makes it undesirable to further expand the cultivation of new lands based on Nile water.

9.2 Recommendations

- At the farm level, the technologies being tested and demonstrated to farmers include soil amendments and mole drains. Adoption of these technologies can improve soils, reduce yield losses due to salinity, and improve farm incomes. *Wider adoption of these technologies requires promotion through government extension agencies*.
- The preliminary work undertaken within this project has indicated that considerable yield increases and water savings can be obtained by controlled drainage technology. Further work is required to *test it in the field* and understand the condition for its uptake by farmers.
- Fish farmers in the Northern part of the Delta operate under a highly uncertain environment as there are restrictions in using both canal and drainage water for fish production in agricultural lands. There is a need to discuss and reconsider the *regulations of drainage water use* for *aquaculture in agricultural lands*, as it is a productive and beneficial use of land and water providing cheap protein to the country's growing population, an activity which the government set as a priority.
- The policy to establish Branch canal water user associations needs to be reconsidered: this policy should be either strengthened by passing of the law on BCWUAs giving them concrete O&M responsibilities and fee collection capacities. This would have to be accompanied with a dramatic effort to raise the awareness and provide adequate incentives to field staff. Or the policy should be discontinued: under the present conditions, the dispositive generates more frustration and lack of trust in the ministry than positive outcomes.
- With regard to Irrigation Improvement Projects the following recommendations are made:
    - improve the participation of farmers in the design of the pump stations
    - control the quality of the equipment and work provided by contractors
    - help to set up independent local entrepreneurs who may intervene in case of mechanical of electrical problems
    - introduce physical devices that make theft more complicated

The corresponding problems are not new and have been observed since the inception of the program, almost 30 years ago; solutions however have not yet been implemented satisfactorily. The research found that *flexibility in proposing the pump stations should include (on-demand) options which make the investment more costly but will satisfy farmers*. There have been attempts to reduce the cost of the pump stations in order to satisfy the economy rationales of the donors. This has proved counterproductive and in many cases farmers have shown clear willingness to pay more if what is offered is adjusted to their needs and requirements. It is not sure however how much of this willingness is due to an anticipation that they might not eventually fully pay for the improvement (as suggested by the rather low cost recovery of IIP).

- A major threat to the continuation of IIIMP is the potential to result in an increase in the pumping capacity of upstream farmers. This is linked to the tendency of engineers to accept farmers' request for a more powerful engine in order to increase acceptability of the project; addition of a diesel pump; individual pumps remaining in place, which together would further compound the lack of equity in distribution between upstream and downstream parts of branch canals. *This project recommends to be strict with the technical design parameters of the pump stations to avoid this situation*.
- A more accurate assessment of the different terms of the Delta water balance is crucial to the understanding of water management in Egypt in general, and to whether further savings are possible (with a corresponding potential expansion of agriculture in the New Lands). *An important recommendation is to strengthen the monitoring system of groundwater in the Delta,* to equip the main drainage pump stations with sensors recording water levels and salinity every day, or every hour (instead of every month). Cheap technology to do this is now available on the market.

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10.2 List of publications produced by project

A number of scientific publications are expected out of this project. To date a number of working reports has been produced which will be converted into journal papers in the next six months.

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APPENDICES

Appendix 1. Effect of different tile drainage and leaching fraction treatments on soil salinity and sodicity among the successive growing seasons.

Treatments		Soil depth (cm)	1st season EC dSm^{-1}	1st season ESP	2nd season EC dSm^{-1}	2nd season ESP	3rd season EC dSm^{-1}	3rd season ESP
20-m spacing without mole	Traditional	0-15	10.32	13.87	7.33	14.02	5.87	12.66
		15-30	13.74	14.25	9.72	14.42	7.51	12.94
		30-60	18.44	18.06	17.62	20.14	14.86	16.85
		60-90	20.41	20.08	19.64	20.47	18.4	17.89
	Average		15.73	16.57	13.58	17.26	11.66	15.09
	15%LR	0-15	9.28	13.57	6.4	13.12	5.88	11.78
		15-30	12.54	14.23	9.56	14.87	7.65	12.94
		30-60	17.86	19.56	15.33	19.01	11.78	14.82
		60-90	19.36	20.86	18.86	19.52	17.85	18.66
	Average		14.76	17.06	12.54	16.63	10.79	14.55
	25%LR	0-15	6.43	13.62	4.38	10.76	3.63	11.22
		15-30	8.39	14.65	6.4	12.76	4.7	12.46
		30-60	15.52	18.67	12.52	17.2	9.36	14.71
		60-90	17.53	19.78	16.52	20.22	14.82	16.82
	Average		11.97	16.68	9.96	15.24	8.13	13.80
20-m spacing with mole	Traditional	0-15	9.28	12.69	5.94	14.26	5.28	11.52
		15-30	11.22	13.54	10.28	14.68	7.46	12.66
		30-60	15.62	17.48	15.87	17.77	13.5	15.24
		60-90	23.54	22.54	18.72	20.08	16.33	17.54
	Average		14.92	16.56	12.70	16.70	10.64	14.24
	15%LR	0-15	8.15	12.34	4.68	11.04	3.75	11.12
		15-30	9.94	15.53	8.84	14.24	5.51	12.31
		30-60	16.35	17.58	12.57	15.75	10.33	14.07
		60-90	21.86	20.26	14.86	19.42	12.45	15.82
	Average		14.08	16.43	10.24	15.11	8.01	13.33
	25%LR	0-15	5.87	12.14	4.97	12.45	4.11	10.23
		15-30	8.5	12.33	6.97	13.86	5.51	12.16
		30-60	14.38	17.37	10.87	15.05	8.25	13.97
		60-90	18.69	20.21	14.88	19.86	12.43	16.52
	Average		11.86	15.51	9.42	15.31	7.58	13.22
40-m spacing without mole	Traditional	0-15	12.04	18.67	8.97	13.66	8.88	13.31
		15-30	16.25	18.57	14.89	15.88	13.8	14.23
		30-60	24.12	24.65	22.91	21.48	20.97	19.56
		60-90	24.89	24.56	23.87	23.08	23.87	20.54
	Average		19.33	21.61	17.66	18.53	16.88	16.91
	15%LR	0-15	8.33	13.14	5.45	12.87	5.16	12.27
		15-30	10.21	15.65	10.42	14.75	8.98	12.25
		30-60	14.46	17.26	16.48	20.14	14.12	18.01
		60-90	17.52	21.82	18.74	21.58	18.79	19.52
	Average		12.63	16.97	12.77	17.34	11.76	15.51
	25%LR	0-15	7.25	12.37	5.08	11.68	5.04	11.44
		15-30	13.94	16.35	7.23	13.64	7.77	13.84
		30-60	13.38	15.52	14.14	18.09	11.22	17.82
		60-90	17.72	19.84	17.16	22.67	18.02	20.14
	Average		13.07	16.02	10.90	16.52	10.51	15.81
40-m spacing with mole	Traditional	0-15	11.18	13.87	6.98	12.88	6.65	12.88
		15-30	13.84	14.88	10.76	13.69	8.72	12.35
		30-60	17.09	20.11	15.84	17.27	13.93	15.85
		60-90	22.86	24.41	21.81	23.45	20.45	18.67
	Average		16.24	18.32	13.85	16.82	12.44	14.94
	15%LR	0-15	7.86	12.21	6.68	12.05	5.86	12.33
		15-30	10.74	13.54	10.64	14.87	8.06	12.13
		30-60	17.85	18.65	15.56	20.88	11.23	15.22
		60-90	21.35	24.26	17.56	20.87	19.34	18.96
	Average		14.45	17.17	12.61	17.17	11.12	14.66
	25%LR	0-15	6.88	12.26	4.85	12.66	5.01	11.4
		15-30	9.18	14.55	6.87	12.88	5.04	12.14
		30-60	10.24	16.54	9.96	17.46	8.55	15.21
		60-90	19.68	20.48	15.75	19.65	15.2	18.24
	Average		11.50	15.96	9.36	15.66	8.45	14.25