3.2. Case Study II: Subsurface Drainage

3.2.1. Rationale and Objectives

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

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

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

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

Construction materials

Drainpipes

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

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

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

Drain envelope

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

Connections

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

Drainage system

Design criteria

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

Modified drainage system

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

Drainage technology

Installation techniques

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

Flushing

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

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

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

3.2.2. Conducted Research and Findings

Construction materials

Drainpipes

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

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

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

Drain envelope

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

Connections

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

Drainage system

Design criteria

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

Modified drainage system

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

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

Drainage technology

Installation techniques

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

Flushing

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

3.2.3. Uptake and Impact

Construction materials

Drainpipes

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

Drain envelope

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

Connections

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

Photo 3: Installation of Pre-Cast Concrete Manholes


Photo: DRI, NWRC

Drainage system

Design criteria

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

Modified drainage system

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

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

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

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

Drainage technology

Installation techniques

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

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

Flushing

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

Photo 4: Trenchless Installation Machine

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

3.2.4. Summary

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

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

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

Sub-Component	Rationale/ Objectives	Findings	Uptake/Impacts

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

Drainage Systems	• Developing new design concepts and theories and adapting existing techniques to local conditions.
	• Identifying the optimal design criteria.
	  o determine best drain depth, spacing, combination of spacing and depth and the best drain envelope to be used in different soil types of the Delta
	• Under the conventional layout of the drainage system and the prevailing cropping pattern.
	  o the rice fields usually share the same drains with other crops in a random pattern that changes with the crop rotation
	  o high losses of rice irrigation water
		• Best drain spacing for old agriculture land in the Middle Delta is 30 m with 1.2 m drain depth.
		• For newly reclaimed land in West Delta it is better to use drain spacing of 80 m, depth is 1.2 m.
		• For newly reclaimed land in East Delta it is better to use drain spacing of 60 m and drain depth is 1.2 m.
		• Results of lateral discharge showed that the design drainage coefficient of 1.5 mm/day and 2 mm/day are better to be used in West and East Delta, respectively.
		• Modified drainage saves about 32-48% of the irrigation water.
		• IIP saves 21% through lining *mesqa*s, using one lifting point, and irrigation scheduling for every farmer.
		• Application of controlled drainage with IIP could save about 2 500 m³/*feddan* of irrigation water.
		  o saving in irrigation time was 32% in the area with IIP during rice season
		• Total costs were increased with 27% in case of using modified system.
		  o it was proved that 43% would be saved in irrigation cost
		  o this means that the net return would be about 16% to the farmers
			• EPADP adapted the design criteria developed by DRI according to regional characteristics.
			  o EPADP increased the drainage rate in the northern parts of the Nile Delta to 1.2 mm/day
			  o minimum spacing between laterals is 30 m and the average drain depth varies between 1.3-1.4 m
			  o for rice and non-rice areas, the design drainage rate to calculate pipe diameters is 2 mm/day (EPADP)
			  o due to application complexity, EPADP did not adapt the unsteady state spacing equation in the design process although it was proven to be more economic
			• EPADP did not generalize the application of modified system to other rice cultivated areas in the Delta.
			  o the free unconsolidated cropping pattern prohibited the implementation of the modified drainage system

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

3.3. Case Study III: Water Quality Management

3.3.1. Rationale and Objectives

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

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

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

Photo 5: Water Course Pollution in the Delta, Egypt

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

Nile water quality

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

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

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

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

Drainage water quality

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

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

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

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

Groundwater quality

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

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

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

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

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

National Water Quality Monitoring Network (NWQMN)

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

The specific objectives of NWQMN were to:

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

3.3.2. Conducted Research and Findings

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

Nile water quality

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

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

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

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

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

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

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

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

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

Drainage water quality

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

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

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

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

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

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

Groundwater quality

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

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

National Water Quality Monitoring Network (NWQMN)

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

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

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

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

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

Photo 6: In-situ Measurements for Water Quality Monitoring


Photo: DRI, NWRC

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

3.3.3. Uptake and Impact

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

Nile water quality

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

Drainage water quality

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

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

Groundwater quality

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

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

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

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

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

National Water Quality Monitoring Network (NWQMN)

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

3.3.4. Summary

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

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

Rationale/Objectives:

- Degradation of water and land resources, due to heavy socio-economic exploitation, adds up to the water scarcity problem.
- Concerns about the water quality future status and revealed the necessity to begin a water quality monitoring program to all water resources in Egypt.
  - were deepened by the pollution threats to the Nile itself, the pressing need to reuse drainage water and expansion of groundwater utilization
- Increasing environmental awareness and quality deterioration of the limited fresh water resources necessitate the replacement of water quantity management by quantity and quality management.

Sub-Component	Rationale/Objectives	Findings	Uptake/Impacts
Drainage Water Quality	• Since 1975, the reuse of drainage water has been adopted as an official policy in Egyptian water resources management practice. ○ furnishing the responsible authorities with information on the potential locations for reuse of drainage water in irrigation ○ Application of mathematical models to support drainage water management, maximizing reuse of drainage water of acceptable quality • Information on drainage water salinity did not cover all relevant water quality parameters required on sources of pollution. ○ to determine the nature and extent of contamination problems, their severity and causes measures were not taken ○ to set up and implement an integrated measuring network to monitor drainage water quality in the Nile-Delta and the Fayoum Governorate ○ to systematically publish data and disseminate information	• Increased the insights into the collected data and provided a means to observe its temporal and spatial variations. • Database has been implemented for the storage, processing and retrieval of the drainage water quality. ○ data screening procedures have increased the reliability of the collected data • DRI yearbook with water quality data and information has greatly improved the availability of information about the water quality in drains to the interested governmental institutions. • SIWARE model has been extended to DDSS for the evaluation of water quality effects of measures and the reuse potentials.	• Support MWRI in evaluating strategies and scenarios for the future planning of water resources management. ○ formulation of recent NWRP depended considerably on Delta Decision Support System • Cumulative findings and results of drainage water quality programs contributed to the formulation of the Environmental Action Plan in 1992.

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

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

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

3.4. Case Study IV: Grand Hydraulic Structures

3.4.1. Rationale and Objectives

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

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

El-Salam Canal project study

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

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

New Naga Hammadi Barrage study

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

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

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

Photo 7: New Naga Hammadi Barrage

Photo: HRI, NWRC

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

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

3.4.2. Conducted Research and Findings

El-Salam Canal project study

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

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

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

New Naga Hammadi Barrage study

Sluiceway model

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

Barrage model

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

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

Photo: HRI, NWRC

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

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

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

River model

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

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

Navigation lock model

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

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

3.4.3. Uptake and Impact

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

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

El-Salam Canal project study

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