ECONOMIC ASPECTS OF GROUNDWATER DEVELOPMENT FOR IRRIGATION AND DRAINAGE IN THE NILE VALLEY

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ABSTRACT

The cultivated and inhabitable area in Egypt is practically confined to the Nile valley and delta. Although crop yields are high, domestic food has outpaced national food production. Nowadays Egypt imports more than half of its food intake. Egypt strategy to reduce food imports aims at increasing the agriculture production in the traditionally cultivated lands and expanding the cultivaable area through reclamation of new lands on the fringes of the Nile valley and delta.

The major constraints are related to water management. These factors are deficiencies in the irrigation water distribution and land drainage systems in the old lands, and shortages of water supplies to the new lands. Groundwater development is believed to reduce the contraints.

A study on the technical and economic feasibility of groundwater development is carried out in a pilot area in the Nile valley. Results indicate that groundwater abstractions, if properly designed, are technically feasible and economically attractive to the country.

1 INTRODUCTION

The cultivated and inhabitable area in Egypt represents about 2.5 % of its total area, being confined to the Nile valley and delta (see Fig.1). For thousands of years the fertile soils have been cultivated, mainly on the Nile water. National food production was outpacing domestic food demand. In the last few years, due to the regulation of the Nile, crop yields in the Nile valley and delta have increased and cropping intensities have doubled. Neverthless, domestic food demands has outpaced national food production. Nowadays Egypt imports more than half of its food intake.

Egypt strategy to reduce food imports aims at increasing agriculture production in the present cultivated lands (old land) and expanding the agriculture lands (new land), mainly to sandy desert soils on the fringes of the valley and delta. The major factors constraining this strategy are related to water management. These factors are deficiencies in the irrigation water distibution and land drainage systems in the old lands, and shortages of water supplies to the new lands. Development of the groundwater system is believed to reduce these constraints.

This article provides background information about the water supply and drainage systems in the Nile valley of Egypt, and the preliminary findings on the development of groundwater for irrigation and drainage of a case study in the Nile valley.

2 BACKGROUND

2.1 Surface water supply and drainage

For thousands of years Egyptian farmers were practicing non-perennial irrigation on the Nile flood water. Most of the agricultural lands were cultivated and irrigated (flooded) once a year. During the remaining months the water table dropped as a result of evapotranspiration and natural drainage to the aquifer. This eleminated the need for a man-made drainage system.

At the beginning of this century, the regulation of the Nile enabled the gradual intoduction of perennial irrigation. The construction of the High Aswan Dam (HAD) in the early sixties enabled the conversion of all lands in the Nile

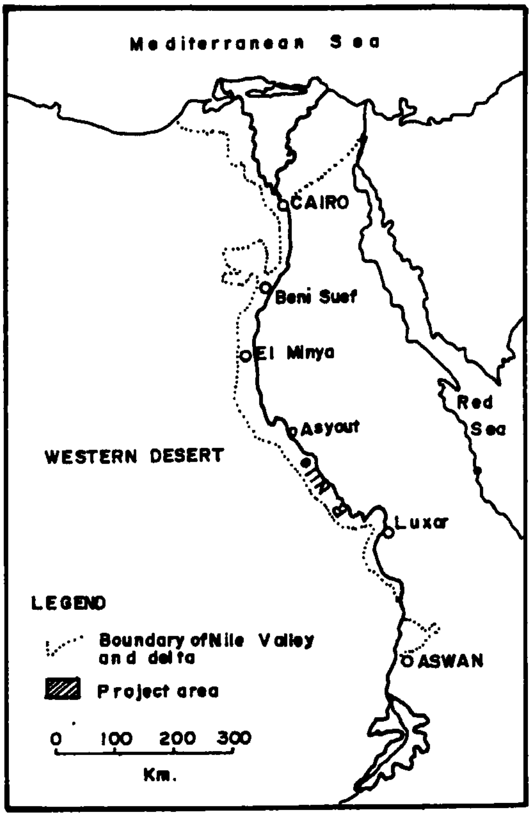

Fig. 1. General location map of the Nile valley of Egypt

valley and delta to perennial irrigation. Under this condition lands are cultivated and irrigated all the year round, thus resulting in an increase in cropping intensity. The time lag in the extension and improvement of the irrigation distribution system to cope with the new irrigation water requirements resulted in deficiencies in its state and, consequently, inequitable water supply in space and time (tail ends of canals and peak season).

Under perennial irrigation, natural drainage to the aquifer could no longer meet with the drainage requirements. Consequently, in extensive areas, the water table rose to levels that caused yield reductions or even total crop failure. In 1970 the Ministry of Irrigation (MOI) started a national plan aiming at supplying all the irrigated lands with tile drainage networks. At present (1987) the irrigated area supplied with tile drains in the Nile valley represents about 50 % of the total area.

2.2 Groundwater supply and drainage system

The groundwater system of the Nile valley consists of the Nile alluvium faulted against limestone or sandstone formations which also form the base of the aquifer (see Fig. 2). The Nile alluvium consists of clay-silt semi pervious layers underlain by the graded sand and gravel water bearing formations (Attia et al., 1983 b). The Nile course cuts into the clay-silt to the aquifer, while the

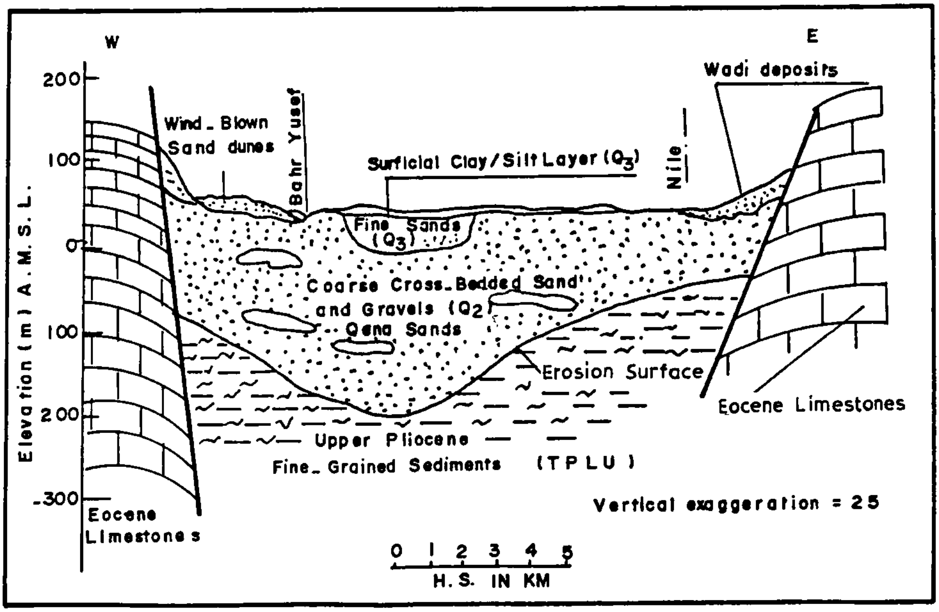

Fig. 2. Lithological cross section in the Nile valley at Minia

irrigation distribution system cuts in the upper clay-silt layers. The vertical hydraulic resistance of the clay-silt formation varies from 100 to 3000 days with a regional average of 500 days. The transmissivity of the aquifer varies from 3000 to 25000 square meters/day (Attia et al., 1986 a).

The total groundwater storage in the Nile valley aquifer is estimated at 200 x 10^9 cubic meters (the capacity of lake Nasser is 130 x 10^9 cubic meters). The aquifer is replenished through deep percolation of subsurface water, which is a result of seepage from irrigation canals and excess irrigation water applied to the lands. The main discharge component is the groundwater return flow to the Nile (Attia et al., 1986 a).

2.3 Water management strategy

The annual surface water released downstream HAD is limited to 55.5 x 10^9 cubic meters, and is fully consumed at present. The overall water use efficiency in the Nile valley is about 60 % (Attia et al., 1986 a). The major component of water loss is subsurface drainage which is either intercepted by artificial drains (wherever existing) or percolates to the aquifer. Wherever drainage networks are absent and groundwater heads are high, the water table builts up resulting in water logging problems.

Water management strategy aims at increasing the overall water use efficiency. This can be attained by reusing drainage water and groundwater. In the Nile valley drainage water is generally pumped back into the Nile and reused downstream. Groundwater is generally pumped by individuals and do not follow a regional plan. This may result in uneconomic schemes and/or the introduction of poor water quality.

3 GROUNDWATER DEVELOPMENT

3.1 General

Groundwater schemes (well fields) may be designed to satisfy irrigation water requirements or drainage requirements. Irrigation wells are generally designed and operated to fulfill irrigation water requirements either solely or in combination with available surface water facilities. Land drainage may be partly fulfilled as a result of pumping. On the other hand, drainage wells are designed and operated to satisfy drainage requirements. Pumped water may be used in irrigation either directly or after being mixed with surface water.

3.2 Economic benefits

Main economic benefits of well fields are land drainage, reuse of groundwater to improve the distribution of irrigation water and seasonal storage of water

Land drainage by wells is generally referred to as "vertical drainage". Vertical drainage requires the presence of a permeable aquifer of sufficient depth and leaky layers of low vertical hydraulic resistance. Groundwater obstractions are accompanied by a drop in groundwater heads and water table levels (Attia et al., 1984 b).

Wells may be located at the tail ends of canals to supplement deficit in surface water or to replace surface deliveries. This would result in saving delivery losses and assuring a better distribution of irrigation water. Moreover, during summer months, a well field may be operated at maximum capacity (abstraction exceeds replenishment). A part of the abstraction is taken from groundwater storage. During the remaining part of the year the well field is operated at a capacity such that replenishment exceeds pumpage.

4 CASE STUDY

4.1 Objectives

The objectives of the study are :

(i) to evaluate the hydrogeologic and economic feasibility of groundwater irrigation schemes ; and

(ii) to develop guidelines for the selection, design, and operation of different groundwater schemes.

4.2 Area description

Fig. 3 shows two areas : (i) the pilot area, where the irrigation pumping scheme is executed and used ; and (ii) the modelled or studied area, where investigations and studies are carried out

The pilot area is located in the central part of the Nile valley at a distance of about 9 km west of the river Nile. The climate is hot, dry and rainless in summer, being mild with some rainfall in winter. Average annual rainfall is less than 20 mm.

Major winter crops are wheat, broad beans and berseems. The predominant summer cops are maize and cotton. An extensive network of irrigation canals distributes the water on a rotation system. The level irrigation method is used for the application of water over the fields.

The surface area under tile drainage is 22 % of the modelled area. The tile drainage system discharges into open collector drains which were constructed at the beginning of this century. The spacing between open collector drains is about 1000 m. These drains discharge considerable quantities of excess irrigation water flowing at the tail ends of the irrigation canals. Drainage water in the modelled area is disposed either by gravity or by pumping into Bahr Yussef (main irrigation canal).

4.3 Hydrogeologic Schematization

Alike most of the Nile valley, the modelled area is schematized by a semi-confined aquifer consisting of Quaternary sands and gravels and is underlain by a virtually impervious layer consisting of fine-grained Pliocene sediments (see Fig. 2). In the flood plain the aquifer is covered by a thin semi-pervious layer consisting of silts and clays. Outside the flood plain the aquifer is unconfined. The valley is bounded on both sides by steep slopes made up of Eocene limestone (RIGW-IWACO, 1986). The maximum thickness of the aquifer occurs in the central part of the valley (250-300 m). Near the river, running along the eastern valley slopess, the thickness of the aquifer ranges from 50 to 100 m . The average hydraulic conductivity of the aquifer is about 70 m/day. The semi-pervious layer overlying the aquifer has an average horizontal and vertical hydraulic conductivity of 0.2 and 0.01 m/day, respectively (Attia et al, 1986a). The river Nile cuts completely through the surfacial semi-previous layer and has a width varying from 500 to 1000 m.

The direction of groundwater flow is to the northeast. The slope of the piezometric head approximates the slope of the land surface (1:10000). In the vicinity of the Nile groundwater flows in an easterly direction at a steeper slope

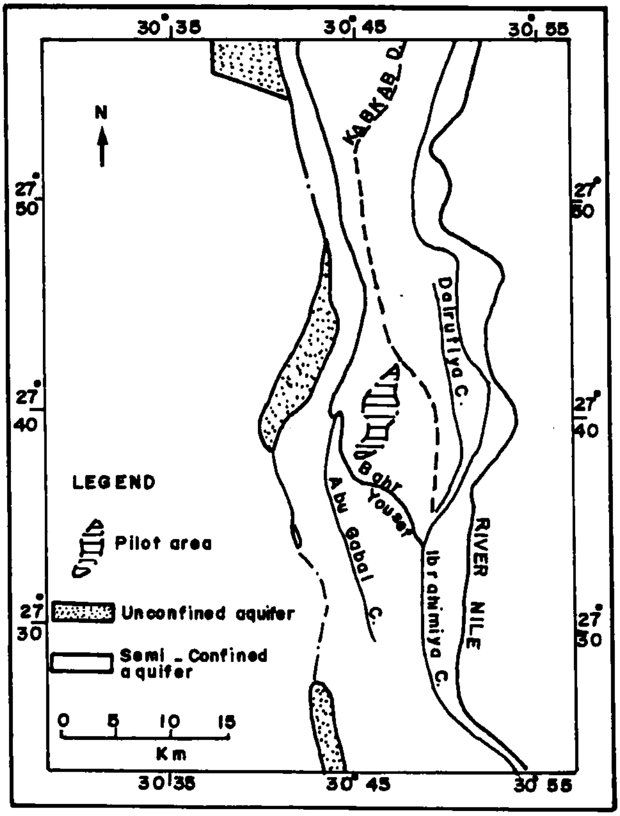

Fig. 3. Location of the pilot area and modelled area

(1:20000) towards the river. The Nile drains considerable quantities of groundwater. The integrated surface water/groundwater system is simulated with the help of the numerical package TRIWACO (RIGW-IWACO, 1986e). Special attention is paid to the simulation of flow of subsurface drainage water from irrigated lands to pipe drains, to open drains and to the aquifer.

Table 1 summarizes the main components of flow as obtained from the water balance computations of the calibrated model. This balance indicates that the major part of the subsurface drainage water is discharge through the aquifer into the river Nilè. As a result of the water balance computation, the leaching fraction (LF) could be estimated. The Lf is defined as the ratio between the amount of subsurface drainage water and the amount of irrigation water. In the flood plain where only open drains are available the value of the LF is found to be about 0.05. This low figure reflects the existing bad drainage conditions in the area.

TABLE 1

Groundwater balance of the modelled area (1985).

Inflow terms	Million cubic meters/day
subsurface drainage water	0.6
seepage from canals and drains	0.4
inflow across southern boundary	0.1
	1.1
Outflow terms	
discharge into tile and open collector drains	0.2
groundwater abstractions	0.1
groundwater discharge into the Nile	0.8
	1.1

4.4 Well field

The well field is designed to satisfy irrigation water requirements on a continuous flow basis for day time irrigation only. It consists of 73 wells (of which 21 wells are standby). The design capacity of each well is 350 cubic meters/hour. The wells are located along the existing canals (farmers requirements). With this well field four operation schemes are investigated. Table 2 presents the groundwater abstractions of the four alternative pumping schemes.

Under alternative "Irr" the well field is operated to fulfill the irrigation water requirements of the pilot area. Under alternatives "Irr+3" and "Irr+5 the well field operation is made according to irrigation water requirements of the pilot area. During 3 or 5 months (peak season) the wells are operated at full

TABLE 2

Aternative operation schemes of the well field

Operation scheme	Pumping rate (1×10^6 cubic meters / year)
Irr	46.5
Irr+3	71.3
Irr+5	91.2
Irr+12	166.0

capacity (24 hours daily). With these two alternatives the seasonal production of groundwater from storage is investigated. Under alternative "Irr+12" the well field is operated 24 hours/day all the year round. This alternative is selected to test the option with most emphasis on land drainage. In the last three alternatives, pumped water exceeding the irrigation water requirements of the pilot area may by transferred to nearby cultivated areas.

5 TECHNICAL FEASIBILITY

5.1 Land drainage and seasonal storage of groundwater

For each of the four pumping schemes, the future drainage conditions and the changes in groundwater storage are calculated with the calibrated TRIWACO model. An area is considered as drained by pumping of groundwater when the water table is kept at a minimum depth of 1.5 m below land surface. The forecasts of land drainage and seasonal groundwater mining are summarized in Table 3 .

Table 3

Forecast of land drainage and seasonal groundwater mining

Aternative pumping regime	Discharge well field	Seasonal production of groundwater from storage		Area drained
	1×10^6 cubic meters per year	1×10^6 cubic meters	months	square Kilometers
Irr	46.5	4	3	70
Irr+3	71.3	22	3	112
Irr+5	91.2	28	5	145
Irr+12	166.0	-	-	271

With the pumping alternatives Irr+3 and Irr+5 about 30 % of the annual discharge of the well field is seasonally produced from strorage during the period of water scarcity. Seasonal changes in storage are mainly due to variations in the water table levels in ares where the aquifer is semi-confined. This indicates that the aquifer can be used for seasonal storage of water (Attia et al, (1987a).

The area drained is found to be considerably larger than the pilot area. For alternative Irr+12 an area of approximately 15 times the pilot area is drained by pumping groundwater from the pilot area. The depth to the water table for alternative Irr+12 is shown in Fig. 4. These data indicate the feasibility of vertical drainage in the Nile valley by concentrated pumping of groundwater from irrigation well fields.

5.2 Suitability of abstracted groundwater for irrigation

Groundwater in and around the pilot area is hydrochemically analysed using different techniques (piper diagrams, equilibrium and correlation diagrams, and geochemical models). The long term water quality of abstracted groundwater is forecasted with the solute transport model STIWACO, combined with a hydrochemical model that takes the different hydrochemical processes in the upper semi-confining layer into account.

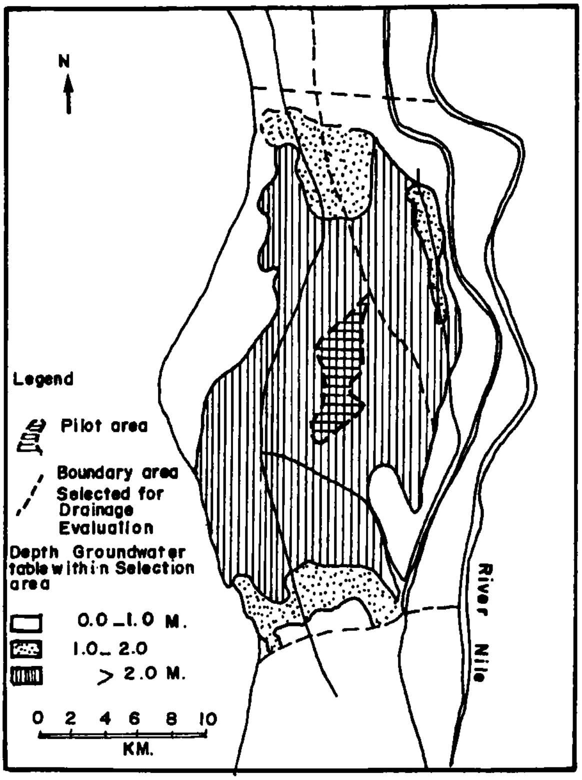

Fig. 4. Land drainage under alternative "Irr+12"

The suitability of the pumped groundwater for irrigation with respect to salinity, hydraulic conductivity, toxicity and miscellaneous effects is evaluated with criteria derived from recent FAO guidelines (FAO, 1976). The results of a 100-year forecast show that no yield decrements are expected and that no problems will occur with the hydraulic conductivity of the soil. Moreover, forecasts show that specific toxiccity and miscellaneous problems are not expected to occur (RIGW-IWACO, 1986e).

6 ECONOMIC FEASIBILITY

6.1 Economic framework

The well field was designed essentially to fulfill irrigation water requirements and farmers needs. Thus, the economic evaluation would be restricted on finding the best way to operate the well field as it is constructed.

The selected criterion to compare mutually exclussive technical alternatives is the "Net Present Value" (NPV) of the project, expressed in economic values. Expenditures are expressed in their present value using a 10 % interest rate.

6.2 Data and assumptions

An economic life of 30 years is assumed for the project. Costs consists of investments of the well field and recurrent costs (energy, maintenance, personnel and replacements). Benefits are for the amounts of groundwater produced from storage and savings on drainage. A shadow price of LE 14/1000 cubic meters of water produced from storage is estimated (WMP, 1981e). Savings on drainage are estimated as the cost (World Bank 1985e) of supplying the area with a horizontal drainage network (assuming that drainage with the well field has an equal performance as tile drainage).

6.3 Calculations and discussion

Table 4 presents the economic present values for the costs and benefits of the involved items. In the first alternative (Irr), with an operation scheme that is made to satisfy irrigation requirements of the pilot area, the net benefit is small but still in favour of the well field. In the other alternatives operation schemes are designed to give more emphasis to land drainage. The resulting net benefit is considerably higher. This is due to the ratio between the net benefits from drainage and water production from storage (8:2). It is obvious that the last alternative (with most emphasis on land drainage) is the most economically attractive scheme to the country.

Financial evaluation of such projects are more important to farmers. Such evaluation requires a thorough investigations on the involved costs and returns to farmers before and after the project (agriculture economy). Such a study is now taking place (Funded by the Ford Foundation). Results are expected in a two-year period, after the project is in operation for at least two seasons.

TABLE 4
Net present economic values of costs and benefits

Economic values L.E. x 10^6 (1 \$ = 2.2 L.E.)	Alternative pumping schemes Irr	 Irr+3	 Irr+5	 Irr+12
Costs				
- installation	6.3	6.4	6.4	6.5
- recurrent	1.3	1.5	1.6	2.5
Total costs	7.6	7.9	8.0	9.0
Benefits				
- saved on horizontal drainage				
- installation	8.2	13.1	14.7	31.8
- recurrent	0.7	1.1	1.2	2.7
- water production from storage	0.6	2.8	3.9	0.5
Total benefits	9.5	17.0	19.8	34.9
NPV (benefits-costs)	1.9	9.2	11.7	26.0

7 CONCLUSIONS AND RECOMMENDATIONS

From the study the following can be concluded:

i) Groundwater development for irrigation may be considered an economic alternative for surface water.

ii) The most economic schemes for the operation of well fields are those giving more emphasis to drainage (vertical drainage). In the selection of well fields, it is recommended to take into consideration the extent of the drained area due to each well field.

iii) Seasonal storage of water in the aquifer should be well investigated before the selection of well fields locations.

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