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Integrated water resources management for Egypt

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ABSTRACT

Egypt is approaching the point where water demands are exceeding supplies. This situation will necessitate improved decision making for water resources planning. Integrated management represents a unique approach, incorporating both temporal and spatial variations of the problem. To achieve an integrated procedure, efforts are being made to resolve numerous issues ranging from loss of agricultural lands to farmer involvement in the decision-making process. The first part of the paper describes the application of integrated management to water planning and water quality. The second part describes the necessary changes made to the administration structure and the importance of communications in integrated management. The irrigation improvement programme instigated as a result of the integrated approach is already beginning to redress the shortfall in supply by reducing losses. Reorganisation of the operation and the inclusion of the population in the decision-making processes have produced a positive attitude towards water-saving policies. Technical and legal controls have been introduced leading to a significant improvement in system performance and productivity.

Key words | Egypt, environmental impacts, integrated water management, irrigation improvement, water resources, decision support systems

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INTRODUCTION

Egypt has reached a unique juncture; its traditional water resources are fully utilised, whilst demands for water continue to grow in response to the increasing population and rising standards of living. The annual share of water resources per capita is currently 875 m^3 which is below the universally accepted value of 1,000 m^3 for a scarce supply (MPWWR 1997).

Under scarcity conditions, water management tends to create an inevitable overburden on personnel involved in water resources planning. Scarcity is best defined in the technical, economic and social value of water. Failure to recognise the value of water has led to wasteful and environmentally damaging use of this vital resource in many regions worldwide; Egypt is no exception (IMS, MPWWR-USAID 1995).

To meet this challenge, the country has identified four primary objectives to guide its water resources policy (MPWWR 1996). These objectives are:

1. To apply effective water-saving policies.
2. To improve the overall efficiency of the water system.
3. To preserve the water-related infrastructure.
4. To maximise economic growth and employment.

The water resources management methodology that adequately encompasses all the individual and inter-related components is generally referred to as *integrated management*. The Ministry of Public Works and Water Resources (MPWWR) is responsible for water management and is working on three major axes (Abu Zeid 1992):

1. Implementation of the Upper Nile conservation projects to increase the water supply to all riparian countries, thereby raising Egypt's annual share from the current 55.5 billion m^3 to nearly 65 billion m^3 (billion $= 10^9$).

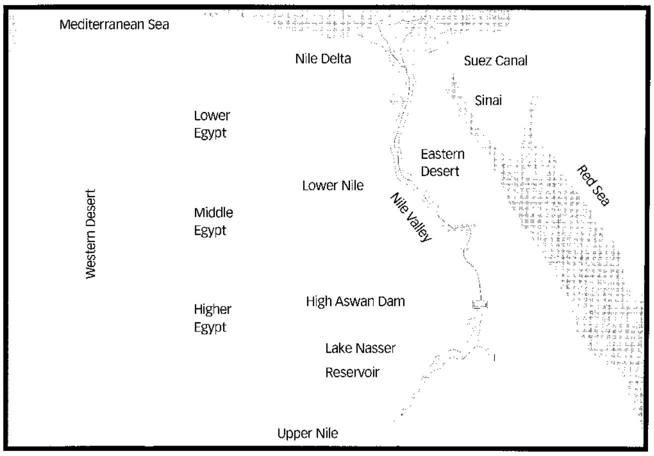

Figure 1 | Map Of Egypt.

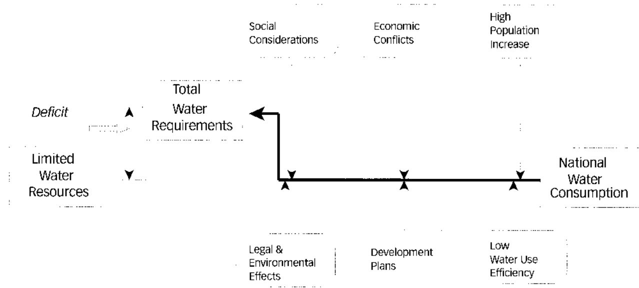

Figure 2 | The current situation in Egypt's water enterprise.

2. Provision of an irrigation and drainage infrastructure, maintenance of the system, and utilisation of modern technology to save water.
3. Establishment of optimum operating rules for Lake Nasser to regulate the varying inflow and match releases with demand patterns.

THE NEED FOR BETTER MANAGEMENT

For effective water resources management it is necessary to identify the key parameters in order to guarantee preservation of the existing water resources. This includes not only skewing the inflating demand to match, as near as possible, the slowly growing supply, but also exploration of additional water resources to fill the anticipated gap between demand and supply (Mott–McDonald International Limited 1993). Management involves ranking of the various demands by allocating different weightings. An essential requirement is to ensure that pollution levels comply with international limits. Figure 1 presents a map of Egypt.

Factors affecting water resources management vary greatly in their style of interaction with the task itself; nevertheless, they all affect the demand quantities, pattern of use, and return flows. Figure 2 shows the current situation in Egypt.

Although Egypt is water secure until the year 2000, the situation will change dramatically afterwards. The water balance drawn for the period 2000–2030 indicates possible severe water shortages if no remedial measures are introduced (Elarabawy *et al.* 1998). This means that water resources will not fulfil the development requirements. However, the low efficiency associated with agricultural and municipal sectors, 70% and 50% respectively, highlights the potential for improvement. Figure 3 presents the water balance for the year 2002, including the anticipated stages of the South Valley Project.

Despite successful efforts to reduce the country's annual population growth rate to below 2%, the per capita water availability could still drop to 500 m^3 by the year 2030 (MPWWR 1993*a*). This would put Egypt on a par with countries more traditionally associated with a natural lack of water resources. Table 1 shows World Bank figures for water resources of various countries illustrating the problem.

The annual land reclamation of 60,700 hectares to match the national food requirement increase requires about 1.0 billion m^3 of additional water resources per year (Abu Zeid 1992). Improved water management is the only foreseeable regime to accomplish this. The New Valley project (Elarabawy & Tosswell 1998) is being implemented in order to expand from the Old Valley, which has become overcrowded, to other areas of Egypt. This important development places additional demands on the limited supply. The schematic shown in Figure 4 illustrates the water system in Egypt.

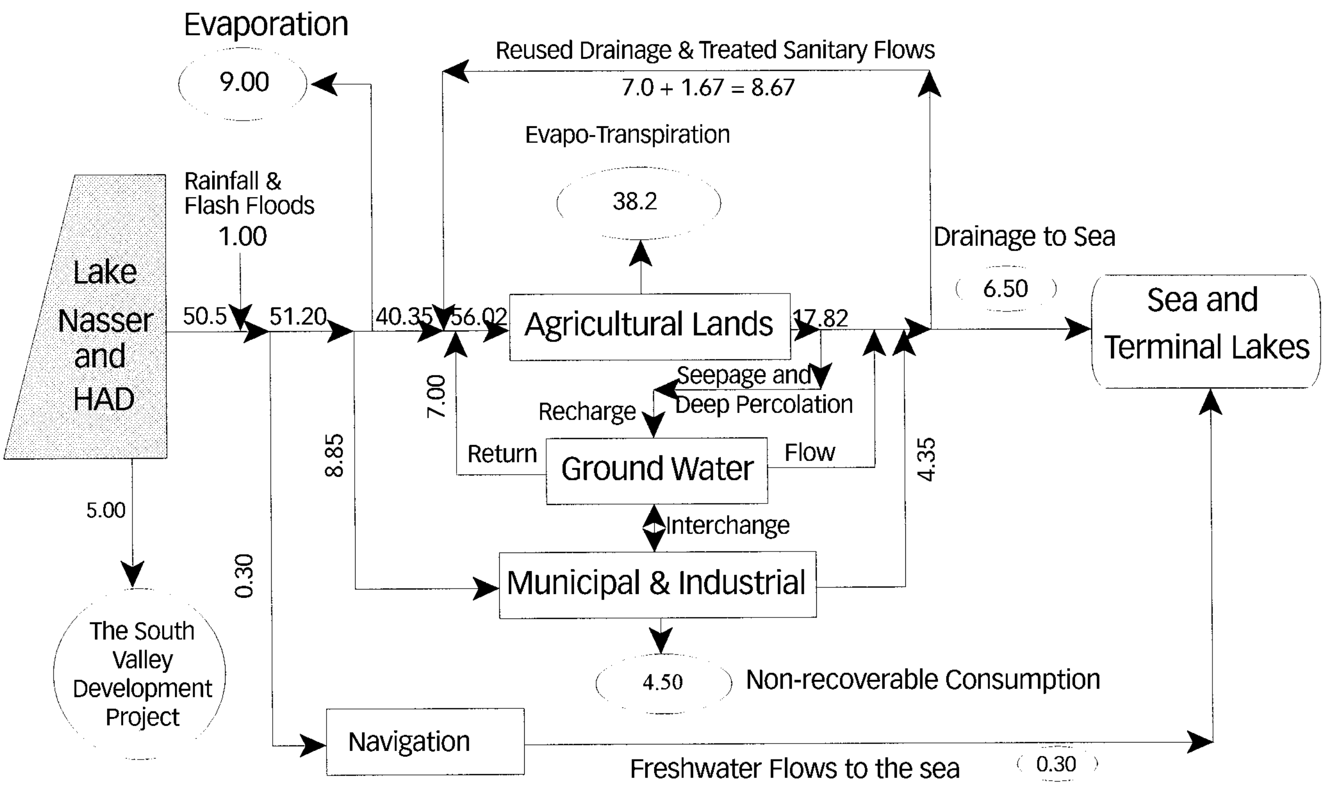

Figure 3 | The water balance for the year 2002, including the South Valley Project (values given in billion m^3).

Insufficient treatment of industrial waste flowing to the Nile and the main canals has led to contamination of a considerable portion of the canal and drain network. Sewage effluents discharging to waterways adversely affect the water quality. Drainage reuse potential is seriously affected by this pollution, thus limiting the water supply. Some reuse mixing stations were closed due to the high pollution levels of drainage water (MPWWR 1991*a*).

INTEGRATED MANAGEMENT APPROACH

To ensure sustainability of the development plans, comprehensive policies and strategies must be established. To achieve an optimal use of the limited water resources in Egypt four principal targets were set (MPWWR 1994):

- Improved irrigation system control.
- Improved policy assessment and planning processes.
- Improved private sector participation in policy making.
- Improved capacity to manage planning and implementation processes.

These were achieved through:

- Raising water use efficiency of the irrigation and drainage system.
- Analysis of cropping pattern choices and establishment of economic water mapping.
- Exploitation of deep groundwater in the deserts.
- Promotion and development of non-conventional water resources.
- Application of sandy soil drainage technology to previously reclaimed lands.
- Enhancement of the existing main system management tools.
- Provision of technical support and maintenance.

Table 1 | Water resources in different countries

Country	Renewable water per capita—1990 (m^3)	Renewable water per capita—2025 (m^3)	Country	Renewable water per capita—1990 (m^3)	Renewable water per capita—2025 (m^3)
Egypt	1,108	621	Cameroon	18,056	7,109
Burkina Faso	3,115	1,237	Gambia	25,581	11,702
Uganda	3,759	1,437	Guinea	39,236	14,977
Senegal	4,802	2,061	Sierra Leone	38,554	16,327
Niger	5,692	2,067	Gabon	141,379	57,143
Benin	5,628	2,105	Mozambique	4,085	1,598
Mali	6,732	2,522	Malaysia	35,213	28,109
Chad	6,919	2,974	Sudan	2,917	1,213

A study (MPWWR 1994) was conducted on the optimal use of the hydrological data matrix for the best utilisation of water resources. A control system was formed in which real-time data recording, processing and analysing, for access by both central and local administrators, is provided through the technique of Meteor-burst signal transmission. (A technique of data transmission where the continuously ionising meteors in the stratosphere are used as media to reflect signals from recording stations to receiving master and sub-master stations.) This telemetry system has led to a significant reduction in water losses and elimination of bottlenecks throughout the scheme.

The strategy adopted for the Nile valley and delta aquifer (MPWWR 1988) relied on the optimum conjunctive use of surface water and groundwater within the national long-term plan. Groundwater abstraction from these shallow aquifers is performed on a seasonal basis; surface water utilisation is employed whilst aquifers are being recharged, the groundwater being utilised to supplement surface water. With this mechanism, the aquifers are functioning as short-term storage reservoirs or conveyance media with minimum losses.

Water losses occur through evaporation, seepage, deep percolation, overflow, evapotranspiration from water weeds, leakage, and navigational fresh water releases. To reduce these losses within the integrated approach several improvements were made. These included:

- The use of pipes instead of lined canals in high-porosity soil.
- Extending the conjunctive use of groundwater and surface water to field level.
- Calibration of control structures on a yearly basis to discount the losses.
- Introduction of modern techniques for water weed control.
- Upgrading the Nile path and reducing, staggering, or eliminating the winter closure to minimise the fresh water released to the sea.

Modern technology was introduced to the water sector to aid planning and implementation of the integrated management approach. This included mathematical models, computer control, satellite imagery, and GIS techniques. Simulation, optimisation, and statistical models have been extensively used as planning tools in this integrated approach (SRP–WRC 1995). The integrated approach is shown schematically as Figure 5.

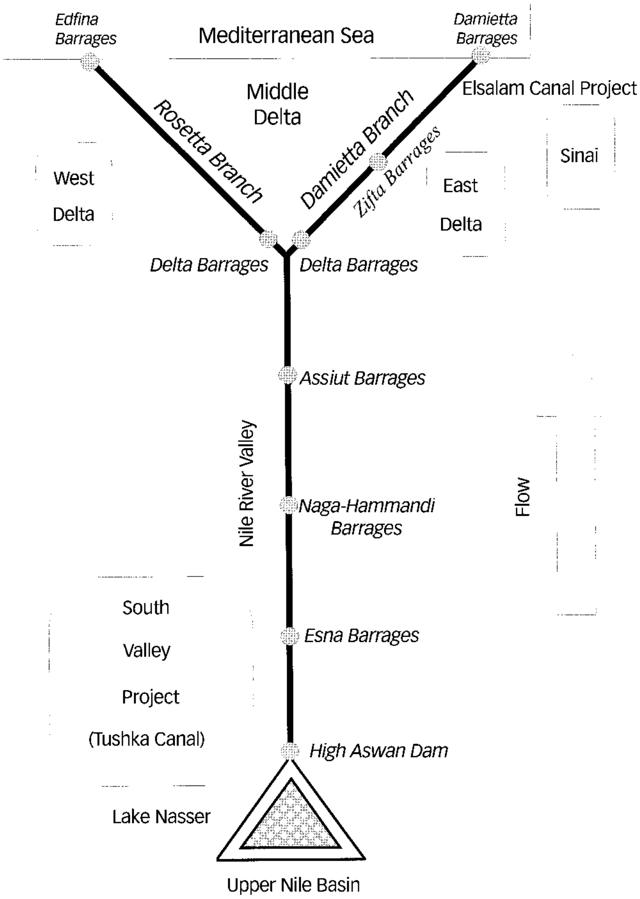

Figure 4 | Schematic diagram of the water system in Egypt.

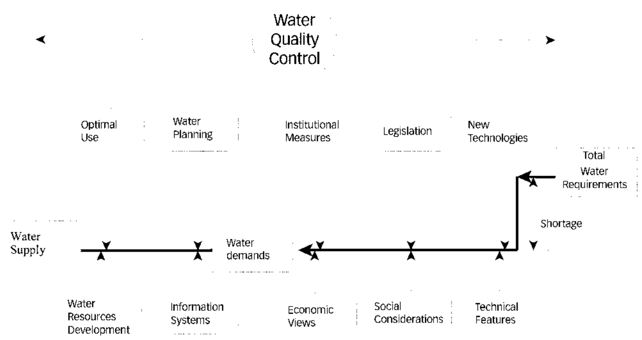

Figure 5 | The integrated water resources management approach.

It was necessary to develop an action plan for more 'user involvement' in decision-making and broader planning of initiatives. The establishment of water boards at the district level encouraged localised planning and decision making. Federations of Water Users Associations (WUAs) were established at the secondary canal level with responsibility for operation and maintenance of delivery canals. The responsibilities and activities of the Water Policy Advisory Units (WPAUs) were identified and communication links established between the WPAUs and MPWWR. Both WUAs and WPAUs include users, MPWWR local engineers and technicians.

WATER PLANNING

The aim of water resources planning is to consider all viable alternatives and therefore include the best plans in the integrated policy. Table 2 shows Egypt's 1996 water balance.

Promotion of water distribution is achieved through a comprehensive plan of branch canals, meskas (field canals), on-farm development works, and the use of mathematical modelling. The development of the Nile River basin through Upper Nile projects is the companion approach via co-operation with other Nilotic countries (Abu Zeid 1992).

Nile flows are entirely dependent on climate and terrain in the Central African Plateau and the Ethiopian highlands. Since the completion of all the Upper Nile development projects is doubtful in the sense that they are all located outside the country's political control (Stoner 1994), other water resources have been included in the development plan such as deep groundwater abstraction in the western desert and Sinai.

To avoid rapid drawdown of deep groundwater aquifers, confined areas (1000–2000 hectares (1 ha $= 10^4$ m^2) are preferable to large ones for the same aquifer. This limits the pumping head and prevents land subsidence due to over-pumping. The budgetary allocations for the irrigation and drainage system operation and maintenance costs were made adequate to ensure optimum standards. The rehabilitation of pumping stations was part of the programme.

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Table 2 | Egypt's 1996 water balance (billion m^3)

	Gross	Net
Available Water (Supply)		
—High Aswan Dam releases	55.5	55.5
—Effective rainfall	0.25	0.25
—Effective flash floods	0.25	0.25
—Utilised ground water	4.35	
—Reused drainage water	4.00	
—Reused wastewater	0.65	
Total	65.00	56.00
Water Requirements (Demand)		
—Agriculture	54.29	38.10
—Municipal	3.21	1.60
—Industrial	7.10	2.00
—Navigation	0.40	0.40
—Evaporation		2.00
—Drainage to sea and terminal lakes		11.90
Total	65.00	56.00

Reserve plans include desalination of both the Mediterranean and Red Sea waters and the extension of treated sewage water utilisation. Sea water desalination is planned for tourist locations and other coastal areas. Solar cells and windmills are used to generate energy for groundwater pumping stations and desalinisation plants to make them fully independent (MPWWR 1997).

Water harvesting through control of flash floods and recycling water within the system as a means of raising the water use efficiency are also included. Non-conventional methods such as sea water and brackish groundwater desalination, and industrial waste treatment and utilisation are practised on a minor scale (MPWWR 1991*b*).

Urban and rural domestic uses consume approximately 1.65 billion m^3 but require about 3.3 billion m^3 per year due to the fact that the conveyance efficiency in this sector is only 50%. If the investment required to execute the plan of reducing the distribution losses to 25% by 2010 and 10% by 2030 is available, the enhancement of the system performance will match the increase in demand keeping the canal diversions unchanged (MPWWR 1991*b*).

Although the net consumption of the industrial sector is negligible, the total diversion required to provide this amount is appreciable (MPWWR 1991*b*). Under the integrated management approach, it was decided that there is no correlation between the increase of industrial production and the increase in water requirements for this sector; all electricity generating plants are designed and located to use sea water for cooling, dry processes are compulsory for new cement factories, and water recycling within industrial units is encouraged (MPWWR 1996).

To minimise the losses in the irrigation and drainage system, control structures were rehabilitated, replaced or added. Some 23% of the water-related investment during the last 10 years was used to construct and modernise nearly 20,000 small control structures and one grand barrage (Esna Barrages). Leakage from old gates was responsible for at least 10% of water losses. Additionally, the wastage due to the restricted head difference on the older structures has been eliminated. Naga-Hammadi barrages will be replaced by 2004 in a plan to rehabilitate all grand control structures on the Lower Nile.

SALT BALANCE

Since water planning and management includes both quantity and quality, it is impossible to verify the national water balance separately from the salt balance. The planner is not only concerned with the balance between supply and demand, but also the balance within a closed system where the water quality continues to deteriorate as the water is reused (MPWWR 1993*b*, 1994).

In order to preserve the scheme, all the salt brought into the system by various agents should be carried out of the system at the end of the planning season (Stoner 1994).

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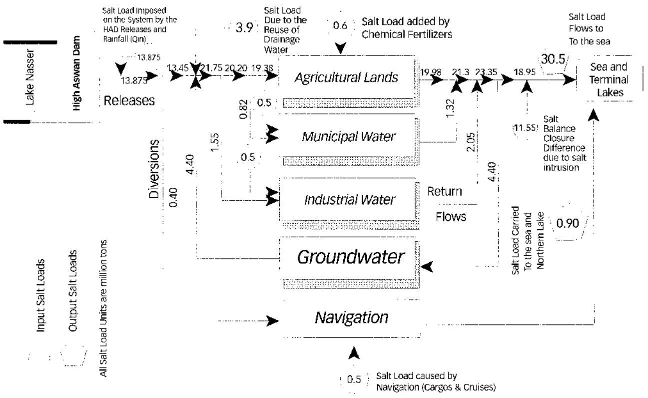

Figure 6 | The salt balance for the system.

This ensures that no harmful material will remain in any component of the system which, if accumulated, could lead to serious impacts ranging from hindering system performance to necessitating its abandonment.

Salt balance imposes some constraints on water policies. For instance, the drainage water released annually to the sea is necessary to maintain the delta salt balance and prevent serious salt intrusion into the northern regions of Egypt (Stoner 1994). A scheme may be rejected because of salt balance problems despite being valid from the water balance viewpoint.

Salt balance is commonly employed as a performance indicator that expresses the degree of mastery accomplished by various policies, the lower the salt load introduced into the system the better the strategy. Consideration of this factor helps the conservation of the system, maximises agricultural production, and improves the efficiency of water resources utilisation. Based on the most reliable current values of the salt loads, the salt balance for the system is as shown in Figure 6 (MPWWR 1993*a*, 1996).

WATER QUALITY

Since both present and future planning must include environmental aspects, the Government of Egypt established a work mission to be responsible for installing, operating and monitoring several water quality control networks.

The mission was responsible for conducting specialised studies on water and soil pollution, suggesting actions for limiting the water pollution and its consequences. This programme, started in 1976, covers surface, drainage and groundwater pollution. Continuous measurements were taken throughout the Nile system for the purpose of evaluating the water quality.

A permanent nationwide water quality monitoring programme was established to warn of sudden drops of water quality at any location within the entire system, regulate quality variations at black spots to meet standards, and identify sources of pollution and the level of treatment required. The rules included in this policy were strictly applied from large reaches to small ditches; latest observations have indicated that the plan is running successfully and that the environmental aspects have greatly improved (MPWWR 1996).

The plan to increase drainage water reuse from the present annual 3.9 billion m^3 to 7.0 billion m^3 by 2000, and then to 8.0 billion m^3 by 2010, necessitates the enhancement of drainage water quality. This is being achieved by the abatement of the concentrated use of pesticides and chemical fertilisers, separation of sewage and industrial effluents from drainage water, and treatment of drainage water before mixing it with fresh water for reuse (MPWWR 1991*a*). Some 50% of the total drainage water is released to the sea to maintain the balance of the delta and prevent salt water intrusion.

MANAGEMENT AND DECISION SUPPORT SYSTEMS

Management and Decision Support Systems (MDSS) play a vital role in the decision-making process. Most developing countries are characterised as data rich and information poor (Deyle 1995). In these countries data may be available, but the quality is questionable. The methodology of the MDSS relies on *familiarisation of domain*—evaluation of relevant parameters based on historical measurements, *observations*—surveying the existing data, and *verification*—field truth surveys.

The MPWWR, supported by the Cabinet of Ministers Information and Decision Support Centre, has initiated the establishment of its Ministry-wide Information and Decision Support Centre. The centre aims to enhance communications between different organisations within the Ministry and also with other Ministries in Egypt. This will include all the available data from the Ministry, incorporate data and information from external sources, and provide integrated decisions (MPWWR 1995).

The MDSS of water shortage, waterlogging and salinity research is a good example of how MDSS can help in local problems. A MDSS, using the major factors that affect the crop relative yield (water deficit, salinity, waterlogging) and interaction with utility modules such as databases, and hydrological and salinity models, was introduced for the promotion of water allocation and planning distribution in the northern delta. The objective of this system was to formulate management strategies by collecting information at primary and tertiary levels to enable the solution of problems related to water shortage, salinity, and waterlogging; generally referred to as irrigation management indices (MPWWR 1996).

The system provided a clear understanding of the problem and facilitated operational control and seasonal management. The flexibility of the system allowed subjective decisions to be incorporated. Relative crop yield in the Nile river delta has averaged 94% for the last 5 years, leading to a 20% increase in total agricultural gross revenue. Rayah (huge canals fed by the Nile and primary feed canals) flows were cut significantly resulting in a 10% water saving. Soil conditions were greatly improved due to elimination of waterlogging and salinity, crop root zone moisture content was kept at a favourable level all year, and the water delivered:water required ratio was maintained at around unity for the entire delta region.

A second example is the MDSS dealing with the water resources management of the entire Egyptian irrigation and drainage system. The management of this highly dentritic scheme (34,000 km of canals and 16,000 km of drains) is a complex task that requires accurate assessment of supply and demand situations.

For this purpose, a real-time MDSS was developed. The system acquires and processes data necessary to support operational decisions, whilst simultaneously accumulating information vital for performance evaluation and development planning. This has enabled central and regional managers to introduce appropriate changes that have not only sustained successful double cropping (cropping intensity of 230% on average) over the past 30 years, but also resulted in significant performance gains in terms of water usage and total agriculture production (MPWWR 1995). Figure 7 locates the water quality black spots and the MSM master and sub-master stations.

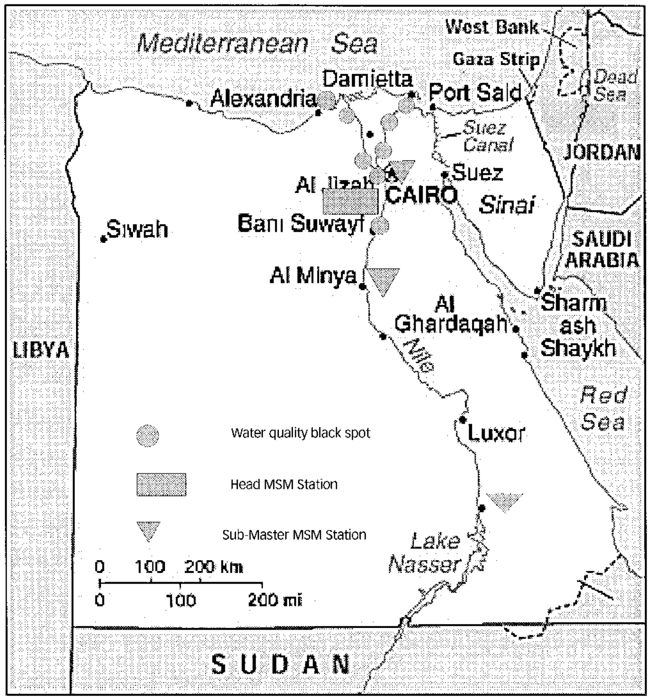

Figure 7 | Location of water quality black spots and MSM stations.

INSTITUTIONAL MEASURES

The MPWWR is the only authority responsible for water resources management in Egypt. To cope with the integrated approach, the organisational structure, administration, and component specialisation had to be modified, and additional units were established (MPWWR

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1995). Moreover, improved co-ordination between the pertinent agencies, decentralisation in decision making and implementation responsibility, adaptation of authority and accountability aspects, and a well-defined monitoring and evaluation structure were introduced.

Human resources development is of key importance, provision of highly qualified personnel capable of tackling the activities was one of the core objectives of the programme. Training was maintained for the period of the programme and will be secured as an on-going activity. A waterways protection unit was established to protect the waterways, banks and hydraulic structures. Pollution levels were greatly reduced after the establishment of this unit.

The MPWWR initiated the Irrigation Improvement Programme (IIP) to increase water use efficiency by constructing elevated lined channels and ditches, pipe networks, distribution networks, and automatic gate control structures. The main accomplishment of the programme was the initiation of the WUAs for each branch canal to arrange the internal rotation of irrigation with technical guidance provided by engineers. The scheme involves farmers in the decision-making process (stakeholder contribution). The programme succeeded in saving 1.0 billion m^3 per year through its application to pilot areas in both the Nile valley and delta, and is expected to save 5.0 billion m^3 per year when applied nationwide (MPWWR 1994, 1996).

ECONOMIC ISSUES

Expenditure on system operation is approximately US$ 760.0 million per year. Over the last 5 years, US$ 250 million was allocated annually for system modernisation. This represents about one-seventh of the total gross domestic investment in 1995. During this period, US$ 0.15 billion per year was expended on operation and maintenance. Some US$ 268 million was spent on tile drainage for the delta old lands. This maintained the high productivity of the land. An investment of approximately US$ 2.3 billion in water-related infrastructure is planned during the next 5 years (MPWWR 1997).

Almost 40% of the total investment allocated for the agricultural sector is spent on land reclamation. This paramount attention to horizontal expansion reflects the concern of the government to increase agricultural production, raise the economic revenue of the agricultural quarter, and offer additional employment for young people. The government has reclaimed approximately 0.84 million hectares since 1952, with an approximate cost of US$ 0.88 billion covering the infrastructure, canals and drains, fertilisers and soil treatment (MPWWR 1986). The 84,000 hectares put in service during 1991–1995 provided direct employment for about 500,000 people, and contributed US$ 177 million per year to the national income.

The cost of reclaiming 1 hectare in sandy soils ranges from US$ 2,120 to 4,900 with an average of US$ 3,510; an additional US$ 143 to 286 is required for normal operation (excluding the cost of cultivation and irrigation). These costs, in addition to the existing scheme costs, are fully funded by the government. Irrigation improvement and rehabilitation of areas is carried out by the government as a loan that is paid back by farmers in interest-free instalments over 5 to 20 years (MPWWR 1996).

Estimation of the cost pertaining to water varies according to the researcher's viewpoint. In 1984, the cost of water was estimated at US$ 2.8 to 5.5 per 1,000 m^3, and in 1995 it was evaluated as US$ 3.0 to 5.9 per 1,000 m^3. The average water requirement per hectare is about 19,050 m^3 per year; the cost of water required for a hectare is US$ 57 to 114 (IMS 1995).

The cost associated with added water is determined via the estimated cost of the new projects to provide additional water resources. Based on the Upper Nile (9.0 billion m^3), drainage reuse (3.0 billion m^3), groundwater exploitation (3.0 billion m^3), treated sewage (1.67 billion m^3), and treated industrial return flows (2.0 billion m^3); the total investment required for the water resources development plan is about US$ 84.0 million (IMS 1995).

The government's determination to locate projects in virgin areas is driven by the fact that only about 4% of the total area of the country is utilised in various human activities. The El-Salam canal project is one of these promising projects to reclaim 0.26 million hectares in the

Table 3 | Economic analysis for crops

Crop name	Seasonal gross revenue (US$/ha)	Net financial revenue (US$/ha)	Net economic revenue (US$/ha)	Economic value added (US$/ha)	Total water use (m^3/ha)	Return value for water (US$/$m^3$)
Sugarbeet	340	162	98	666	6,429	0.10
Clover F	610	562	128	543	3,905	0.14
Clover C	238	205	33	205	2,519	0.08
Wheat	548	478	369	902	3,786	0.24
Maize	448	342	152	724	6,429	0.11
Rice	505	426	26	952	20,953	0.04
Cotton	595	514	519	1,450	7,572	0.19
Sugarcane	1,286	1,286	445	1,085	28,572	0.04
Beans	514	438	95	631	3,214	0.20
Tomatoes	1,726	1,498	1,036	1,864	7,762	0.24
Oranges	866	866	421	1,002	738	0.14
Potatoes	826	645	252	824	6,429	0.13
Sunflower	431	431	138	581	2,381	0.24

Eastern Delta and Sinai regions by mixing drainage water with Nile water in a 1 : 1 ratio (2.0 billion m^3 from each). The New Valley Project is the most recent case.

A free cropping pattern policy was adopted by the government in the past decade in a move towards a free market economy for the purpose of maximising the gross revenues of the agricultural sector. Efforts were dedicated to the promotion of the sector through the increase of crop yield and crop seasons. Greenhouse technology, sprinkler and drip irrigation, and genetic tools have greatly assisted in the increase in production (SRP–WRC 1995).

Table 3 shows the economic-based comparison among the main crops (IMS 1995). In the table: seasonal revenue is the gross farm-gate sale price, i.e. local market price multiplied by the quantity of the crop (and residuals) sold at the farm. Net financial revenue is the return to the farmer after all costs, i.e. the difference between crop (plus crop-byproducts) sales and the costs incurred to produce the crop. Both benefits and costs are calculated in terms of money received or spent regardless of whether the prices are a good reflection of true value or are distorted by taxes and subsidies. This is therefore a market prices based indicator expressing the profit earned by the farmer.

Net economic revenue is the national return from producing the crop, i.e. the economic contribution to the state domestic income based on real values (efficiency prices). Real market prices are distorted by political actions, taxes, subsidies, monopolies, imperfect competition, incomplete or misleading information, fashion, habit and many other factors. Distortion of the market is the reason for economic values to divert from financial values. Economic prices are financial prices adjusted to correct

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for these distortions and arrive at the real values of the products. For example, economic prices take account of employment and rural incomes. So, economic return is basically the financial return at shadow prices. All inputs and outputs are assigned a valuation factor to convert financial values into economic (true or accounting) values, omitting scarcity and bias distortions.

Economic value added is the net economic addition from crop production, taking the tradable components and export/import parity prices into account, i.e. it is the crop production financial impact on the economy measuring the effect on gross domestic and national product. It evaluates the gain to the economy as a result of crop production at border prices, including imports and exports and foreign exchange balance (national opportunity costs). Export crops will therefore have high added value while crops that can be imported at lower than their production costs will have small added value.

Water use is the total water use per hectare, i.e. the total water requirements supplied by canal diversions including land preparation water demands. Return value for water is the economic value added by agriculture (crop production) per unit water withdrawn, dividing the value added by the total water used. Family labour is included as a cost item in crop budgets (World Bank 1992; MPWWR 1996). For more information see Begg *et al.* (1994) and Snell (1997).

An Agricultural Sector Mathematical Model (IMS 1995; MPWWR 1996) was applied to simulate the Egyptian agricultural sector under several irrigation water reduction scales. The fundamental cost of system operation and maintenance was about 3.6% of the total cost of the agricultural sector in 1995. Cost recovery can be calculated by one of four methods; a constant value per hectare, a varying value per hectare based on crop type, a value equalling the cost of water based on crop demand, and a direct cost of water delivered based on actual measurements.

The most useful result of the model application was that the effects of the adoption of the third method is the same as the adoption of the fourth method. This supports the adoption of the crop demand values without the overwhelming cost of the structures necessary for the actual measurements. However, the irrigation improvement programme will reduce water use significantly and actual measurements may be justified in the long term.

Another case was studied where the water consumed by various users was cut by a ratio of between 15% and 30%. Two alternatives were classified for agriculture where the deficit is or is not uniformly distributed amongst the farms. Under the first option, the deficit is fully taken by the farms at the tail ends of the canals while others do not suffer any shortage. The second option presumes that the deficit is equally distributed amongst all users, assigning higher priority to high cash crops. The overall impact on the system was completely different for each option; the second alternative enabled mitigation of the impacts of water deficit at both national and individual levels and also guarantees fairness of profit distribution among the users within the system (MPWWR 1996).

POLITICAL AND MEDIA INCLUSION

Mass publicity was used to bring together governmental targets and people's ambitions. Personal contacts, distribution of booklets, and exhibitions were also utilised. Religious representatives were relied on as messengers of information and concept due to their importance and moral influence on people (MPWWR 1996).

Two factors were considered important in this regard; first, publicising the water policies, accomplishments and projects; and second, achieving participation of the people in solving water-related problems and thus their support for the action required.

The spoken word campaign by advisors through interviews with farmers succeeded in eliminating distorted cropping patterns. This directed the cropping patterns towards the most water efficient and high economic value crops. Close to 47% of the total active female population in Egypt is engaged in agricultural work. The role of rural women was emphasised to address livestock husbandry, agricultural practices, and post-harvest losses (World Bank 1992).

Increasing the knowledge and recognition of environmental aspects amongst the population was a significant part of the integrated programme. This was accomplished through the various media of mass communication. Raising the users' awareness and consciousness of water-related environmental concerns helped reduce pollution (MPWWR 1993*a*, 1994).

Realisation of the importance of the laws that deal with pollution is essential if successful execution of the policy is to be achieved. Individuals as well as companies and factories were well informed of the various methods and precautions that can be used to eradicate pollution (MPWWR 1996).

DISCUSSION

In spite of the powerful programme of population control, Egypt's population is still growing at nearly 2%. This increase, together with the consistent improvement in living standards, affects the use of water. It creates new aspects of demand, increasing the water requirements to levels that necessitate careful water resources planning.

There is some potential for the Egyptian water balance to produce a surplus that fulfils the essential water needs of the vital development plans and projects. However, the water balance for the year 2000 suffers a deficit that will require a large investment and effort to convert into an excess if the essential development plans are not to be hindered.

Although a considerable portion of the water which flows to the drainage system or groundwater shallow aquifers is reused, the fact that it is impossible to use the whole amount reduces the entire system efficiency. Better water distribution was achieved through the structure rehabilitation programme.

Water resources should be linked directly with national development plans. Water needed for each sector has specific attributes that vary according to the type of use. Water quantity, quality, location, temporal variation, and its economic and social return values determine the kind of use within the water scheme. Sectors are prioritised according to the return value of water used and the suitability of the water available. The requirement for drinking water is satisfied in full first as it is essential (Mott–McDonald International Limited 1993).

Both irrigation and drinking water systems have a low efficiency leaving significant room for improvement (Stoner 1994). This can help positively in providing the water needed for projects such as the New Valley Project.

The Upper Nile projects are planned to be completed during the next 30 years. Some of these may face difficulties and thus the water due to be gained as a result of these projects should not be definitely counted on. Continuous monitoring and revision of the Nile catchment development plan should be maintained and milestones should be matched to a dynamic policy response.

Correlating the High Aswan Dam releases with meteorological observations can optimise the use of surface water resources. Deterministic forecasting of rainfall on the catchment (inflow to Lake Nasser) or on Egypt (rainfall or flash floods) can lead to a significant reduction in releases by supplementing part of them (Mott–McDonald International Limited 1993). This will also protect the control structures on the Lower Nile from excessive head balance or gained wedge storage.

Environmental aspects are not a separate part of water resources planning but rather a significant component that must be included. Failure to satisfy the various environmental conditions seriously affects biological, ecological and health aspects, and also adversely affects the usable quantity of the water resource itself. Land resources can be decreased due to these effects.

Water quality is a vital component of development; water quality deterioration affects general health, increases costs, and slows down the development process. The best way to avoid water quality decline is to eradicate the sources of pollution. Scientific research and studies related to water quality have led to a fruitful contribution to the analysis of problems and solutions to them. The direct application of punishment criteria included in the water quality laws has helped significantly in improving water quality.

The use of MDSS, when properly designed and supplied with accurate data, can be of enormous benefit in the decision-making process.

The irrigation improvement programme has led to a noticeable reduction of water use and improvement of productivity, due to the equity provided by the plan in allowing the fields at the far ends of the canals to be adequately supplied. These programmes should therefore continue in the future with performance indicators and assessment criteria.

The Egyptian economy is significantly affected by the agricultural sector; it accounts for about 20% of the national gross domestic production and total exports, and accounts for approximately 36% of employment. In the integrated approach, trade, marketing and agro-industrial development were considered. Farmer organisations and public investment were encouraged to promote initiatives for rural diversification. Public expenditure for agriculture was quantified. Rural financial markets were correlated to water and land issues. Crop competitiveness measures were included in the comprehensive economic and social reform programme to modernise the country.

The cropping pattern is a key factor in reducing water required for agriculture. Reducing the difference between the net revenue for similar summer and winter crops can direct the cropping pattern towards the national interest.

Value added is the increase in the value of goods as a result of the production process. Double counting is avoided by deducting the cost of the inputs at all intermediate stages from the value of the farm's output. Import/export prices are considered to reflect international measures. Price illusion is excluded. Financial return is the actual profit farmers make (gross price less costs, all at market prices).

An agricultural strategy prepared by the World Bank concluded that in Egypt, horticultural crops (fruit and vegetables), cotton and wheat are the most economically viable crops. Sugarcane, rice and berseem (clover) are the least viable crops (World Bank 1992). The inclusion of these findings in the water policies led to conservation and optimal use of the land and water resources, in addition to maximising the contribution of this sector to the national economy.

Tomatoes have an economic added value nine times that of clover. The added value of sugarcane and tomatoes is 3% and 7% of the total national agricultural product, the area cultivated with sugarcane and tomatoes is 4% and 3% of the total arable land, the water demands of sugarcane and tomatoes are 9% and 3% of the total agricultural water demand (MPWWR 1996). This gives a base for comparing the economic viability of crops.

Crop competitiveness is measured by means of Domestic Resource Costs and contribution to the Gross Domestic Product. Domestic Resource Costs are calculated by dividing the economic value of domestic resource input by the economic value added through production. Domestic resources are land, labour, capital and irrigation costs. The economic value added is the shadow priced return of these domestic resources including residual (by-products) returns. A less-than-unity value favours the crop. The net return calculated is a residual return to management, risk and capital. Gross Domestic Product (GDP) measures the output produced by the domestic economy entities regardless of who owns them (government or private sector). Economic revenue is the contribution of the value of production to the GDP excluding the cost of services and subsidies, i.e. real value of the product without profit.

Sugarcane is a perennial crop with high water consumption. If replaced by sugarbeet (a winter crop with low water consumption), the agricultural water requirements will reduce allowing room for horizontal expansion. This can be done gradually to synchronise the replacement of sugar factories to use sugarbeet instead of sugarcane.

Rice is a crop with a high economic value for both the government and the farmer. However, its water requirements are three times that of other crops such as cotton or maize. A minimum area of rice is required to protect the northern delta region from soil and groundwater salinisation and salt water intrusion, as it provides the counteractive hydraulic head that pushes the sea water seawards. This minimum area is of the order of 0.30 million hectares. Restriction of the rice fields to this area conserves water and aids integrated management.

Updating the agricultural property laws to conform with recent changes in society, including some means of regrouping dispersed land units into sizeable blocks, can significantly promote the sector and save water and land lost in unnecessary branching channels.

Better involvement of rural women in the development process, training programmes for women, adult education and literacy programmes, seed technology, widely accessible and reliable databases, plastic cover technology, disease and insect resistance, and primary farm mechanisation were all established within the context of overall rural development.

Given the potential for water shortage over the next 10 years, Egypt has dedicated a sum of US$ 4.4 billion for integrated water resources management.

The integrated management concept addresses the long term prospects for water management in Egypt. The approach is designed to develop realistic projections of water availability and demands, and identify infrastructural and procedural development with the aim of meeting demand and optimising resource allocation.

CONCLUSION

Integration of all relevant factors, issues, and principles in water resources management is essential. Integrated management represents the only foreseeable approach to cope with present and future challenges in water planning.

The integrated management approach not only considers the varying aspects of water planning but also arranges the timing of the solutions. The situation in Egypt is limited supply versus dramatically increasing demands with great potential for saving and development. Reduction of the considerable losses of water can be achieved through technical and institutional means together with exploration to add renewable water to the country's water budget.

The next step is to introduce modern water planning techniques. This allows tight use of the present and future (developed) water resources. Water quality remains a significant constraint. Social considerations constitute a part of the engineering plan in order to guarantee its execution. Institutional modification is necessary for high level performance. Economic and financial views were previously either neglected or considered separately and their inclusion in water planning will support successful implementation.

The legal response provides the environment that encourages users to follow the general strategy of the plan. The use of the media to involve both politicians and the public in discussion of the problems, issues, and plans attracts their essential support. Information systems serve as robust databases for both historical and real-time data necessary for both planning and operation.

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REFERENCES

Abu Zeid, M. 1992 Water resources assessment for Egypt. *J. Wat. Res. Develop*. **8**(2).

Begg, D., Fischer, S. & Dornbusch, R. 1994 *Economics.* Fourth Edition, McGraw-Hill.

Deyle, R. E. 1995 Integrated Water Management Contending with Garbage Can Decision-making in Organized Anarchies. *Wat. Res. Bull*. **31**(3) 387–398.

Elarabawy, M. & Tosswell, P. 1998 An appraisal of the Southern Valley Development Project in Egypt. *J. Wat. Supp. Res. Tech.–AQUA* **47**(4), 1–9.

Elarabawy, M., Attia, B. & Tosswell, P. 1998 Water resources in Egypt: strategies for the next century. *J. Wat. Res. Plan. Mgmt ASCE*, **124**(6).

IMS 1995 *Cost Recovery Study–Final Report.* MPWWR-USAID, Cairo.

Mott–McDonald International Limited 1993 *Water Security Project-Nile Basin Simulation Model.* Revised Final Report, World Bank, UNDP, Cambridge, England.

MPWWR 1986 *Horizontal Expansion Policies in Egypt.* Technical Report, Horizontal Expansion Sector, Cairo, Egypt.

MPWWR 1988 *Hydrogeological Map of Egypt.* Research Institute for Groundwater, Water Research Centre (scale 1 : 2,000,000, first edition).

MPWWR 1991*a Reuse of Drainage Water Project.* Reuse Report No. 30, Main Report, Drainage Reuse Institute, Water Research Centre, Wageningen/Cairo.

MPWWR 1991*b Water Demand, Present and Future Estimates.* Final Report, Planning Sector.

MPWWR 1993*a Drought Study—Final Report.* Water Research Centre – Planning Sector.

MPWWR 1993*b Guidelines on Egypt's Water Resources and Policies through Year 2000.* Water Research Centre—Planning Sector, Cairo, Egypt.

MPWWR, 1994 *General Framework for Water Policy for the MPWWR of Egypt up to Year 2025.* Water Policy Mission, Planning Sector, Irrigation Sector, Water Research Centre, Irrigation Department.

MPWWR 1995 *Contribution of the MPWWR to the National Economy*. Technical Report, Cairo, Egypt.

MPWWR 1996 *Strategy of the Water Resources for Egypt*. Planning Sector, Irrigation Sector, Water Research Centre, Irrigation Department.

MPWWR 1997 *Investment in Water-related Infrastructures: An Overview of Objectives and Future Directions.* Technical Report, Cairo, Egypt.

Snell, M. 1997 *Cost-Benefit Analysis For Engineers And Planners.* Thomas Telford Books.

SRP–WRC 1995 *Strategic Research Programme.* Miscellaneous Reports on M & I—Irrigation Management—Water Resources Development.

Stoner, R. F. 1994 Future irrigation planning in Egypt. In Proceedings of the Conference on *The Nile: Sharing A Scarce Resource* (P. P. Howell & J. A. Allen, eds). CUP, Cambridge, pp. 195–204.

World Bank 1992 *ARE, An Agricultural Strategy for the 1990s*. Report No. 11083-EGT.