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CONJUNCTIVE WATER USE

THE STATE OF THE ART AND POTENTIAL FOR EGYPT

By:

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EGYPT WATER USE AND MANAGEMENT PROJECT

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ABSTRACT

This report is a review of conjunctive water use - the state of the "art" and potential application to Egypt. It provides some introductory information pertaining to Background, Problems and Outlook on Egypt's water situtation.

It then develops the art and science of conjunctive water use in terms of: Evolution, Definitions and Use, Advantages, Disadvantages, Methodologies, Physical Aspects, River Flows, Water Quality, Economics, Institutional Aspects, Maintenance and Modeling.

Next it deals with some of the specific aspects of conjunctive use as they apply to Egypt including: Factors and Problems, Surface Water Supply, Surface Water Quality, Groundwater, Groundwater Quality, Drainage Water and Reuse, Salinity Due to Waterlogging, Water Budget and Feasibility. pertinent data and analyses that have recently appeared in the Egypt Water Use and Management Project technical reports are included.

Finally some summary comments are provided.

ARABIC ABSTRACT

نبذة

هذا تقرير مراجعة لطريقة استخدام المياة
في مصر ومدى كفاءات الحاليات وامكانية تطويرة
ويحتوى أيضا هذا التقرير على بيانات خاصة
بمشاكل المياة في مصر والأسلوب الصحيح للاستخدام
وكذلك طرق التطوير ثم يبين التقرير المنافع والمضار
والعوامل الطبيعية لحالة سريان المياة في الأنهار
وجودتها واقتصادياتها وامكانية عمل النماذج.
وبعد ذلك يقدم التقرير مواصفات محددة للاستخدام
المياة في مصر وكذلك مشاكل المياة السطحيه وجودتها
وكذلك المياة الجوفية وجودتها ومشاكل الملوحة
الناتجة عن زيادة المياة في التربة وحالة الميزانية
المائية وإن دراسة تحليلية للبيانات المتوفرة موجودة
في التقرير الفنى لمعهد تنظيم واستخدام المياة مع ملخص
وبعض التعليقات.

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INTRODUCTION

Background

Egypt has a rapidly growing population which requires increased - agricultural production. The latter is critically dependent on Egypt's water supply and the management of that resource.

Water development and distribution has been almost exclusively based on surface water of the Nile which has finite limits.

There are lands now within the command area of the distribution systems which are not adequately served. In addition water supplies for undeveloped and new lands must be found.

The development and use of groundwater offers substantial potential as a source of new water, if it is integrated into the total supply through the process of conjunctive water use.

Problems

The specific problems include the following: surface water is limited; new lands must be developed; improved water management, including conjunctive water use, can extend limited water supplies; and present groundwater use has been random in nature and in areas where surface supplies are inadequate or nonexistent and without regard for the source, movement, storage, quality or the interrelationship with surface water.

Outlook

Water planning for Egypt is set forth in the Water Master Plan, (WMP) Main Report and Technical Reports, Phase 1 (1981). Among the WMP reports most relevant to conjunctive water use are: No. 4, Groundwater; No. 7, Water Quality; and No. 11, Water Management Capabilities of the Alluvial Aquifer System of the Nile Valley, Upper Egypt. These include the data base, planning tools and processes for proceeding with the logical development of Egypt's water resources. The bases for these reports are some excellent studies conducted previously be several Water Research Institutes of the Ministry of Irrigation.

It is estimated that the "quality of water that could be withdrawn from the alluvial aquifer without depleting the resource is in excess of 4 milliard m^3 per annum" (WMP, TR 4, 1981). Further, examination of the capability of the alluvial aquifer system of the Nile Valley, primarily by a model study, lead to the conclusion that it is technically feasible to conjunctively use surface and groundwater with "a level of water resource management afforded by temporary dewatering of the aquifer system on an intra-annual basis." It was proposed that an extensive pilot project be undertaken (WMP, 1981).

However, water quality is a major concern. Although the quality of the Nile is still good for all purposes, potential loading of pollutants is increasing rapidly (WMP, TR 7, 1981). Groundwaters are variable and tend to degrade with time and use, particularly where leaching of irrigated land is required or takes place naturally.

CONJUNCTIVE WATER USE

Evolution

The combined use of surface and groundwater resources represents a changing strategy that is gradually evolving in different ways in many parts of the world. Often this changing strategy has been brought about by the amalgamation of local supply areas into the jurisdiction of larger administrative units.

In the United Kingdom, for example, larger administrative units have been formed on the outline of natural river basins (Rofe, 1979). This is the trend of water resources management and development in that country, i.e., toward integrated systems embracing the water resources of at least one river catchment or major subcatchment so that the source components within the system both compliment and supplement each other (Sharp, 1980). An integrated reservoir system results when one or more river system and the catchments are supported by associated storage reservoirs and/or groundwater development to provide a combined system which collectively is able to meet a range of demands both for abstracted supplies and for in-situ purposes.

Three new developments in planning and management of water resources have been responsible for stimulating the concept of conjunctive water use (Yevjevich, 1979). These include: 1) advanced economic analysis which demonstrates the attractiveness of using jointly and simultaneously two or more sources of water: 2) the demand for new water supply sources that will be brought into existing or new distribution systems in order to properly integrate water quantity and quality; and 3) all water resources are already allocated, and therefore, planning and operation through conjunctive use is the only way in which new water demands can be met.

In looking at the history of planning and management of water resources systems, Yevjevich (1979) suggests that there are five evolutionary developments as follows:

1. Single structure, single purpose, single source
2. Multi-structure, single purpose, single source
3. Single structure, multi-purpose, single source
4. Multi-structure, multi-purpose, single source
5. Multi-structure, multi-purpose, multi-source

These illustrate the evolving complexity of water resources systems and the demand for scientific and technological contributions.

These involve not only the physical and technical aspects, but also the social, economic, environmental, and institutional considerations.

In the past, two combinations of conjunctive water use have been given the most attention; namely, surface and subsurface sources of water, and 2) effluent urban and surface sources.

It appears in the future that two additional combinations will evolve; namely 1) subsurface and effluent sources of water, and 2) surface, subsurface and effluent sources. these add to the number of combinations that need to be considered, and in which conjunctive use may be an integral and highly important source requiring additional and new technologies (Yevjevich, 1978).

A large number of possible schemes of combining surface and groundwater exist. Considering only two sources of water, Yevjevich (1978) has proposed four basic schemes which could be extended to others. These include the following:

1. Source and user separated schemes (Fig. 1).
2. Source separated but user integrated schemes (Fig. 2).
3. A uni-directional shift between sources (Fig. 3.).
4. A bi-directional exchange between sources (Fig. 4).

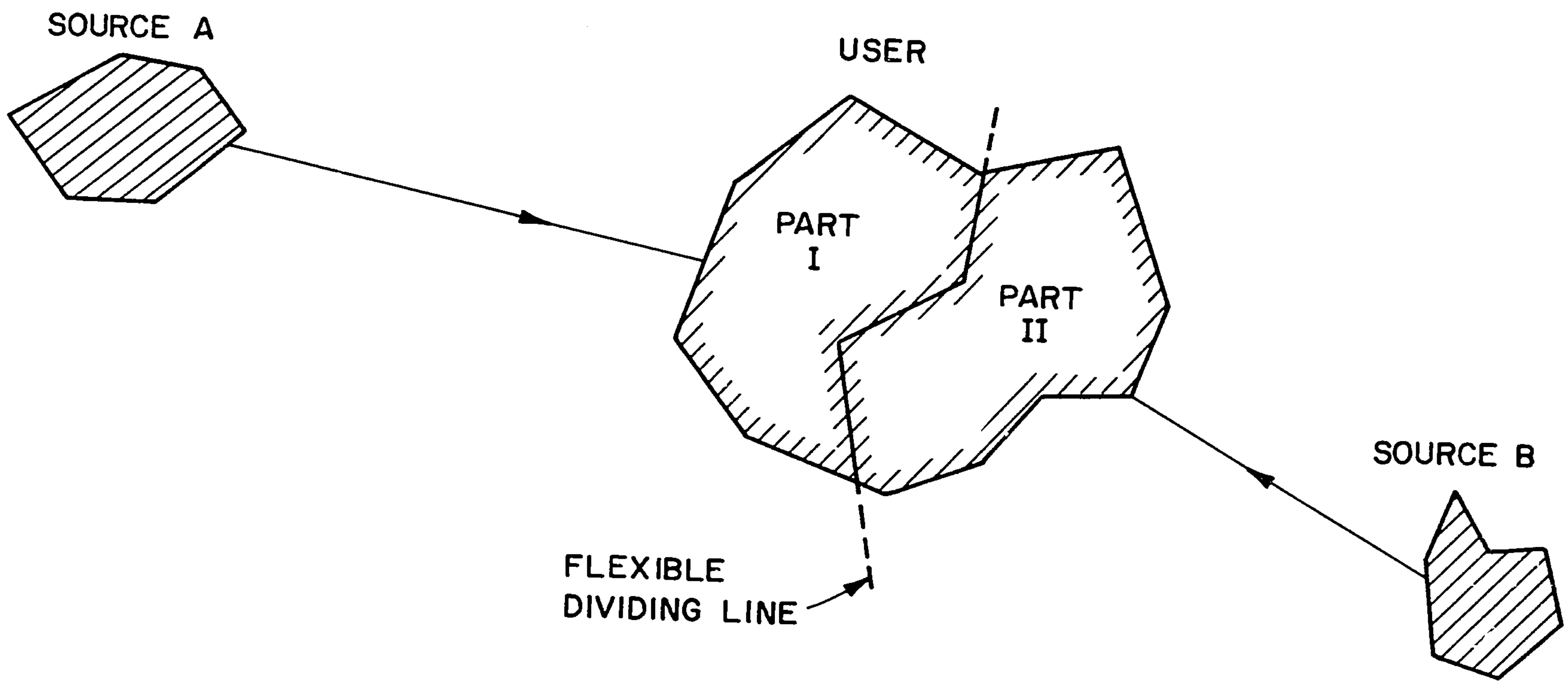

Figure 1. Conjunctive Water Use Of Source and User Separated Scheme
(Yevjevich, 1979)

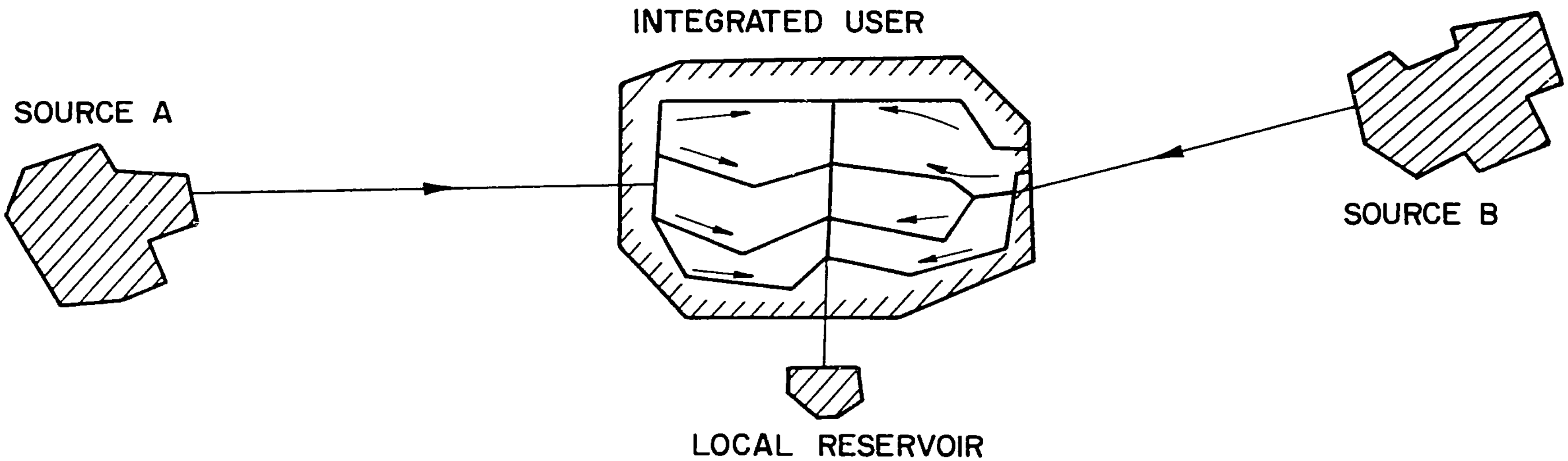

Figure 2. Conjunctive Water Use of Separated Sources cf Water. Integrated By the Users' Distibution System. (Yevjevich, 1979)

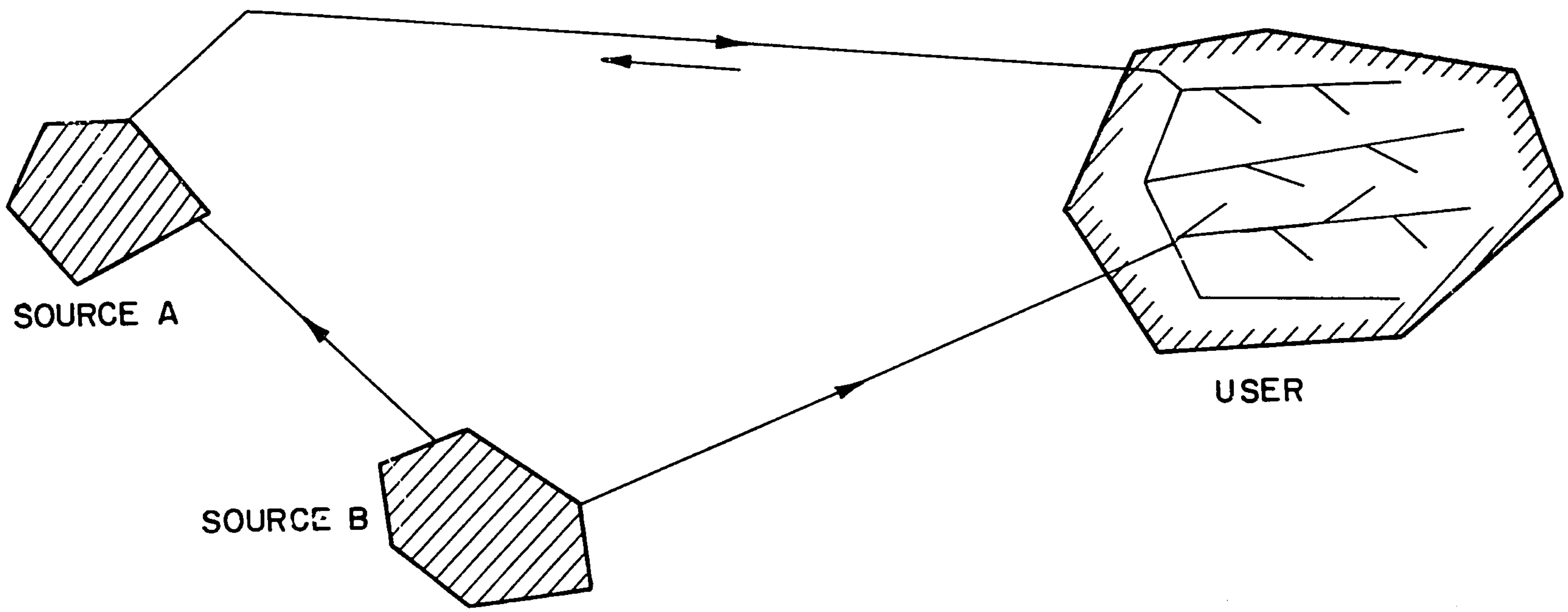

Figure 3. Uni-Directional Shift of Water From Source B to Source A Both By Direct Connection and Via The Users' Network. (Yevjevich, 1979)

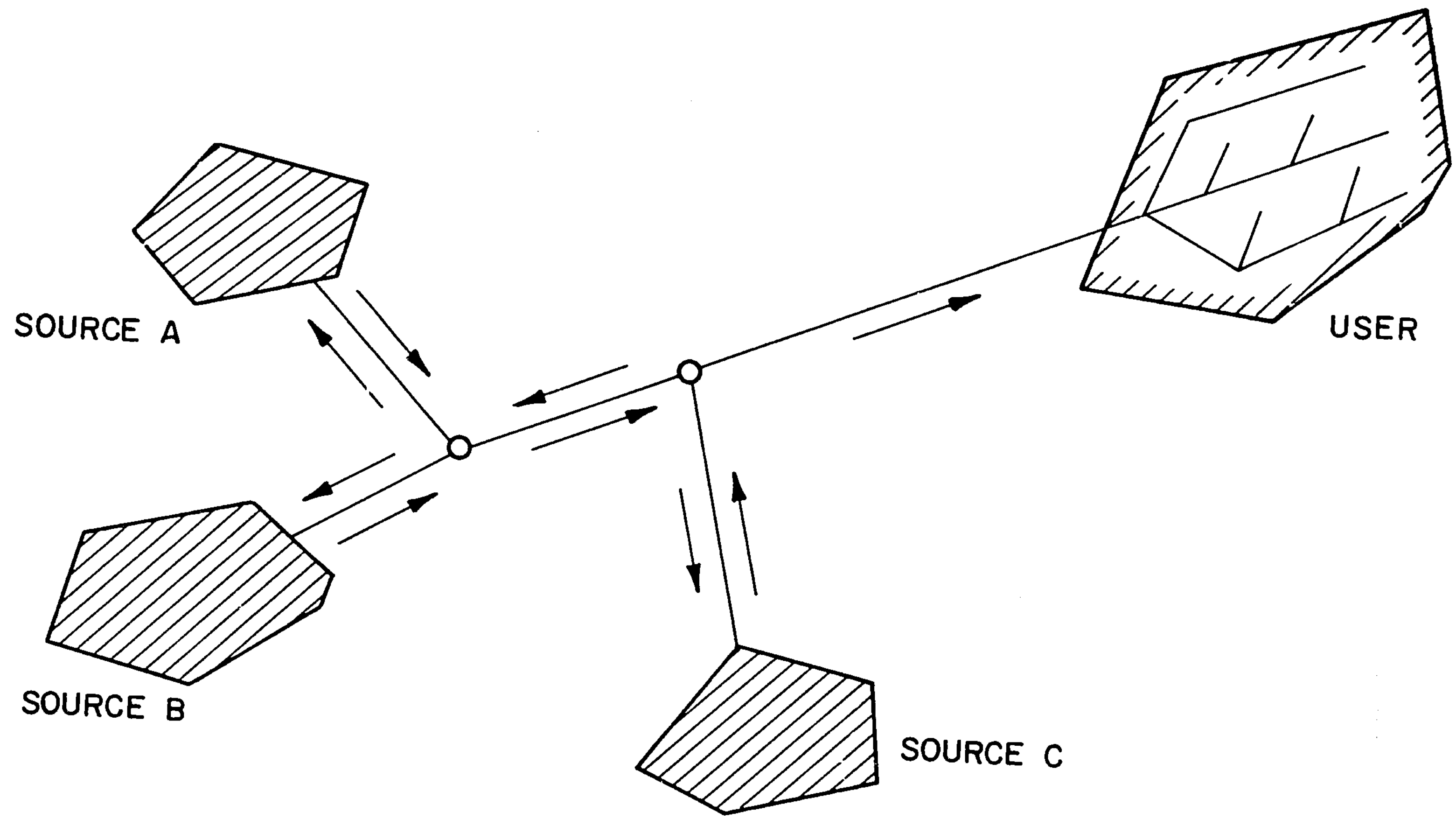

Figure 4. Bi-Directional Water Interchange Between Sources of Water, Before the Water is Supplied to Users, For Purposes of Better Meeting Demand and Storage Requirement and Improving the Water Quality Control (through mixing of waters of different qualities).

(Yevjevich, 1979)

The latter may involve uni-directional or bi-directional shifts through the user's network.

In looking at the multi-source approach to water resources planning and management, conjunctive water use can embody four basic concepts as follows:

1. Physical, i.e., integration of a multi-source components into multi-structure multi-purpose systems.
2. Engineering and scientific methodologies - defining, measuring, analyzing and quantifying the properties of the system and the technology needed in shaping the multi-source component.
3. Regional and system aspects - integration of the water resources systems into the regional systems of energy, agricultural industry, domestic water supply, waste water disposal, environmental protection, transport, recreation and other economic and social activities with proper feedbacks.
4. Social systems integration into the political and social structures which involve legal and health aspects.

Definitions and Use

The use of surface and groundwater together has been identified in several ways, namely: conjunctive (Todd, 1959), combined, integrated, joint, simultaneous, coordinated, multi-source, complementary and optimal use. Other titles included "economic coordination" (Chun, 1963), "economic utilization" (Clendenen, 1954), "optimal conjunctive operation" (Chun et al, 1964) and "integrated water management" (Leonard, 1963).

There appears to be a preference in recent years for the use of "coordinated integrated or combined" over "conjunctive" since these words seem to be better understood by non-technical people and are more self-explanatory.

In addition, conjunctive use is directly or indirectly involved in water resources management studies, or more specifically in groundwater management (Scott and Scalmanini, 1977, 1979).

From a broad point of view, conjunctive use occurs in the concept of multiple sources of water with different characteristics as in the case of groundwater and surface water. It may be, therefore, possible to develop an operating strategy that exploits the differences in the sources. This exploitation strategy has become known as conjunctive water use of groundwater and surface water.

An interesting comparison can be made between the major characteristics of surface and groundwater sources. For example, surface water is available seasonally but usually with some degree of uncertainty as to time and amount available. Surface storage can also be filled rapidly due to floods which are not captured completely, but surface storage reservoirs are subject to losses due to evaporation and seepage.

On the other hand, groundwater is usually available in large aquifers and in large quantities with little variation over time. Less uncertainty is involved in predicting future groundwater availability than in predicting surface water flows. Surface water is much easier to measure than groundwater. Consequently, data on groundwater sources are much less available and lacks verification, thus, increasing the element of uncertainty (MaKnoon and Burges, 1978).

The generalizations expressed in the two preceding paragraphs concerning uncertainty, variations in time and space, etc. are subject modification due to site specific conditions.

A concept frequently used to define conjunctive water use is that of optimality. The optimal utilization of water as a natural resource is then considered essential for the establishment of stable, economic and social structures (Buras, 1963). the term optimal evokes a number of questions. For example: optimal (or best) for whom? Optimal (or, more favorable) to what end? Under what conditions? Questions like these require data and analysis in the context of social and economic constraints and demands.

The conjunctive use of a surface reservoir and groundwater aquifer can be analyzed from the point of view of optimal operation of the system. The groundwater aquifer is considered a reservoir in which part of the stream flow is stored for future use.

An optimal policy can be obtained as a steady-state solution. that is, when the operating rule stays constant irrespective of how many stages remain in the operation of the system. this may also be considered the optimal operations policy for an indefinitely long process because it is not affected by subsequent stages.

In considering optimal management of a groundwater basin, several factors are proposed by Dracup and Hall (1970) as follows:

1. The annual volume of natural recharge which is referred to as the safe yield of a groundwater basin.
2. The volume of groundwater which is capable of being mined.
3. The groundwater basin as a long-term storage reservoir of large capacity.
4. The ability of the groundwater basin to act as a distribution system.
5. The energy requirements for normal and/or modified pumping lifts which will be necessary to respond to fluctuations in water levels.
6. The initial water quality and changes as a function of time and response to a management scheme.

Under optimal coordinated operation of groundwater and surface water, Fowler, (1964) suggests that the unit cost of water supply, storage and distribution can be minimal.

It is suggested that the basic principles of groundwater basin operation that will result in an optimal water resource management for an area are:

1. The surface and underground storage capacities must be integrated to obtain the most economical utilization of the local storage resources and the optimal amount of water conservation.
2. The surface water distribution system must be integrated with the groundwater basin transmission characteristics to provide the minimum cost distribution system.
3. An operating agency must be available with adequate powers to control or cooperate in the control of the surface water supplies, groundwater sites, surface water delivery facilities and the amount and location of where groundwater extraction takes place.

Another concept which has evolved in the coordinated operation of surface and groundwater supplies is by analogy (Fowler, 1964). This analogy is based primarily upon the physical characteristics of the groundwater basins and the surface distribution. They are:

1. The analogy between the surface reservoir and underground storage capacity with a certain volume of water available for storage in both cases.
2. The infiltration rate or a rate of recharge into the groundwater reservoir which is equivalent to the inflow to the surface reservoir.
3. The total combined pumping capacity from the groundwater basin is considered equivalent to the discharge capacity of the surface reservoir(s).
4. The transmission characteristics of the aquifers in the groundwater basin can be compared to the location and delivery capacities of the surface pipeline facilities.
5. The pressure head in the surface distribution system is considered analogous to the piezometric surface or groundwater table of the underground basins.

Generally, the capacities and limitations of the groundwater system are fixed by the physical nature of the system. However, with sufficient capital to underwrite the cost of recharge and pumping facilities, it may be possible to offset these limitations.

According to some experts, the optimal plan of groundwater operation and management will provide for each delivery point (or unit area) water of suitable quality at the desired amount and pressure through the combined use of surface water deliver facilities and groundwater basins at minimum cost or maximum return (Fowler, 1964).

Peters (1972) suggests that management of groundwater resources involves four variables: i.e., the amount and place of extraction and amount and place of recharge. These four variables can be combined in a variety of ways with surface water resources to meet the area's total water demand extending over a long period of time.

Advantages

Experience, physical studies and modeling have provided information on the general advantages of conjunctive water use. They are:

- Provides an unused water resource that can be applied to non or poorly irrigated, undeveloped or new lands.

- Provides water to meet peak crop requirements which may exceed the capacity of existing surface water conveyance systems.
- Could provide vertical drainage obviating the need for extensive tile drainage systems and expensive works required to move the drainage water.
- Provides a method for reuse of drainage water for irrigation.
- Could provide greater flexibility in the release pattern from a reservoir(s) particularly during periods of peak demand and possible short fall conditions.
- Could use off-peak, night energy surpluses and improve the power factor of the electrical transmission system if groundwater pumped could be put into storage in the water distribution system.
- Could be implemented by farmers, if encouraged by appropriate incentive policies.
- Could minimize impacts of contamination and use of potentially dangerous groundwater for domestic use.
- Avoids exploitation of groundwater and minimizes possibility of obtaining brackish water or salt water intrusion.

Advantages that apply specifically to the groundwater system include:

- Little or no loss of water by evaporation.
- Natural reservoir requiring no initial capital expenditure, and the development cost of wells are relatively low.
- A well can be put into operation within days of construction whereas surface work often takes years.
- Use of groundwater is very flexible, i.e., it can be pumped and recharged when needed.
- Providing there is a long-term balance, the aquifer can be overpumped in years of short surface supply, recharged and allowed to recover in years of abundance.

In addition, advantages have been noted by several investigators to apply to specific situations. Examples follow.

Fowler (1964) indicated that: when surface storage facilities are limited or subject to large evaporation losses; the underground storage capacity can be used to advantage; when the groundwater system is limited by low tansmissibility between point of recharge and locations of water demands, the groundwater systems can be supplemented by pipeline and surface storage facilities; and within the service area where adequate surface distribution facilities exist but there is inadequate regulatory storage capacity, a well field can be developed to economically meet regulatory water requirements.

Peterson (1968) suggested that besides rapid development potential, capital costs of groundwater development may be of the order of 10 times less than those for surface water.

Peters (1972) noted that conjunctive water use may contribute to a variation in timing of a project that has not been constructed. Delay of construction of an import project would probably entail greater use of groundwater prior to construction, with possibly increased recharge of developed surface water after construction. So, a number of different dates for project completion would reveal the most advantageous completion date where various plans are compared economically.

Experience in England and Wales (Sharp, 1980) indicates that under favorable conditions it is possible to realize considerable savings in the costs of water resources, development and operation by conjunctive water use, and also assist in the conservation of such resources for all purposes by:

- greater efficiency in development of sources
- economics in development of new sources
- sources of differing characteristics complementing each other
- operational flexibility
- improved reliability in periods of drought
- improved reliability in emergencies.

<u>Disadvantages</u>

In a similar way, experience and studies reveal that conjunctive water use has disadvantages. some of these include:

- Involve substantial investment capital and operating costs.
- Could contribute to short and long term degradation in groundwater quality.

- Could produce excessive drawdown, either short or long term.
- Would require additional energy sources for pumping.
- Would not have widespread application.
- Would require a management scheme of locating and operating wells in an optimum manner.
- Could produce land subsidence with adverse effects on the minimum slope of water conveyance systems and drainage canals.

Also, disadvantages have been noted for specific conditions. Examples follow.

Downing (1974) and other have noted there is a possibility surface settlement may occur as a result of groundwater development in a confined aquifer. If the aquifer is confined by a compressible clay, any lowering of the piezometric level will cause the effective weight of the clay to increase and settlement will result. this may take a few years or, in case of thick impermeable clay, tens of years to develop fully.

Peters (1972) pointed out that the greater disadvantage of groundwater as a resource is its position as a natural receptacle of liquid born wastes from the land surface and the physical rate limitations of recharge and extraction.

Where recharge water is subject to pollution, Rofe (1971) suggests that the treatment of recharge water must be effective and reliable to remove suspended and organic matter and toxic pollutants, when present, in order to guard against the transmission of water born diseases.

Methodologies

Conjunctive water use is approached with a variety of methodologies. The choice may be dependent upon objectives, water sources and amount, reliability of data, crisis situations, funds available, and knowledge and skill of technical personnel.

Two types of studies normally involved include physical and modeling studies. The first is the more traditional, whereas the second is more recent and gaining in popularity.

Physical studies should start with a quantitative assessment and determination of the hydrologic characteristics of both the surface and underground systems. Usually the surface system is better defined in terms of data and relationships. Often estimates are made of the groundwater's storage capacity and transmission characteristics when these are lacking. In addition, the behavior of both systems needs to be quantified for inputs and outputs for both and for the interrelationships that exist between the two systems being integrated into one.

The basic concept in establishing behavior is the principle of continuity with the object to establish a balance between inflows and outflows.

In addition to the physical characteristics of a system, other objectives such as economic benefits, changes in water quality, or river flows, subsidence, drainage, etc., should be evaluated within a physical study.

The results and evaluation of conjunctive water use studies based upon the physical approach, are lacking due to the relatively short period of time during which conjunctive water use has become a focal point in water resources management.

Modeling, on the other hand, is an attempt to duplicate the response of the surface and groundwater systems by simulation and optimization. Such an approach has advantages in being able to explore the question of "what if." Modeling studies do require accurate representation of the systems in the form of equations and relationships, and in addition, suitable data describing the system, initial conditions, and constraints. As with physical studies, the literature lacks results and evaluations of the application and impact on modeling studies.

Both physical and modeling studies have value and are of great importance in providing the basis for decisions by those concerned with the logical, rational, and systematic development of water resources.

In the sections that follow, several specific objectives, problems, etc., of conjunctive water use are examined, which suggests that the combination of physical and modeling studies is essential if successful conjunctive water use is to be achieved.

Most of these concentrate on characteristics or impacts of the groundwater system since these are the less well defined and known parts of the total conjunctive water use system.

Physical Aspects

Although there are a large number of physical aspects that must be considered in both the surface and groundwater systems. Several pertaining to groundwater basins and conjunctive water use need particular attention. These include: drainage, subsidence, and artificial recharge.

Drainage/Quality - It is possible that the development of groundwater in a conjunctive use scheme can provide an additional benefit in that it may lower the water table level and provide a degree of drainage not possible with any other conventional drainage system (Stoner, 1980; Peterson, 1968). This benefit is achieved in the form of increased yields over the drained area and control of the salinizing process that normally arises by evaporation from a high water table.

The practicality of providing water table control by an individual framer is highly questionable, if not impossible. It can only be done by some type of operating authority, which has an overview and a responsibility for coordinating the production of wells.

Subsidence - The extended and heavy use of groundwater aquifers may result in subsidence of the surface. This phenomenon has been observed around the world (Downing, 1974) and particularly in California where drops of over 200 feet (6 meters) have been observed. This activity normally occurs as a result of groundwater development in a confined aquifer. When an aquifer is confined by a compressive clay, any lowering of piezometric level will cause the effective weight of the clay to increase and settlement results. This is not an immediately observed reaction, but may take years to decades to develop. The London clay, for example, has settled by up to 0.3 m in London over the past 150 years, due to the lowering of the groundwater levels in the underlying chalk and tertiary sands (Wilson and Grace, 1942). In and about Mexico City, substantial subsidence has occurred, largely due to the compression of soft peats and clays that confine aquifers that have been drawn heavily upon for a water supply (Zeevart, 1957).

The subsidence of the land surface can be a serious problem, particularly where land slopes are very mild. Gradients of canals can be reduced or even reversed, thereby changing the delivery capacity of a system.

Artificial Recharge - Artificial recharge is a means of augmenting the natural movement of surface water into the underground formations. this process is often considered to be an essential feature of coordinated operation of surface and groundwater systems. A variety of methods have been used successfully, and there is reasonable documentation concerning the results and impact (Todd, 1980). the choice of a particular method of artificial recharge is dependent upon, first of all, availability of supplemental water, and then other specific factors such as topography, hydrogeology, soil conditions, and the volume and rates of water to be recharged.

Experience with artificial recharge is worldwide. In California, there are over 200 artificial recharge projects, most of which have been designed and operated to offset overdraft of the groundwater. It is also widely practiced in several parts of Europe.

River Flows

Conjunctive water use schemes must be closely related to river flows, which includes consideration of stage, sediment transport and the interchange between the river and the groundwater system.

In order to derive optimum benefits from groundwater storage and conjunctive use of surface and groundwater resources consideration must be given to providing the water demands and yet maintaining adequate river flows.

In the United Kingdom, Downing (1974) reports that this principle is being developed in planning the optimum development of groundwater on a regional basis in situations where maintenance of adequate flows for amenity benefits and others is of prime concern. Several developments have been proposed which involve taking advantage of the large storage capacity of aquifers and the low rate of groundwater flow. The direct consequence is that the effects of groundwater development are time dependent, reflecting the hydraulic connection between the river and aquifer and groundwater abstraction.

Downing (1974) suggest that the seasonal variation in groundwater flow to a river is dependent upon the temporal distribution of infiltration and a parameter called the aquifer response time - defined as T/SL^2, where T is transmissivity, S is the storage coefficient and L is the distance from the river to an impermeable boundary of the aquifer or to a groundwater divide which is parallel to the line of the river. Aquifers with relatively fast response will show a rapid change in groundwater flow response to infiltration.

Another time dependent factor is the time lag for pumping effects. In many hydrogeologic systems, a well pumping a reasonable distance from a river will not impact or reach the river for several months after pumping has begun (Donald, 1974). Similarly, when the well is shut off it will take considerable time, i.e., days and weeks before the effect will be felt. Consequently, pumping impacts may be spread over a period of several years rather than being limited to a single season., It is true that the major impact would be felt during the pumping period. There will, however, be a residual and long-term influence. When the effects of several seasons of pumping are combined, the total effect of wells which are of considerable distance from a river will approach a constant effect which varies far more with variations in annual pumping than with seasonal variations. Therefore, the impact on the river of the wells, when they are pumped will not be a changing or varying phenomenon. On the other hand, the impact of a well can make a great difference in terms of distance to pumping water levels, and to the farmer who is totally dependent on the pumped water of needs the supplemental water to keep a crop going because of the probability of a crop failure.

In some schemes the approach has been to regulate the river discharge using groundwater storage, so as to provide more even flows throughout the years, and in some cases, at a level approaching the mean discharge (Downing, 1974). The success of such a scheme depends upon taking advantage of the large storage capacity of aquifers and the relatively low rate of movement through the aquifer. The direct consequence of this approach is that the effects of groundwater development are time dependent. Wells have to be located so as to take advantage of the delay between the pumping of groundwater and the reduction in discharge at natural outlets and changes of inflow from the river. The yield of particular pumping scheme from an unconfined aquifer will depend, to a large extent, on the degree of hydraulic connection between the river and the aquifer. This, of course, requires quantification of the hydraulic conductivity between the river bed and the aquifer.

Another concept which has been used to indicate the success of groundwater abstraction when used for river regulation, is to state the net gain to river flow during an abstraction (Downing, 1974). The net gain is defined as:

$$\text{Net Gain} = \frac{\text{Groundwater Abstraction Rate - Reduction of River Flow}}{\text{Groundwater Abstraction Rate}}$$

Reduction in river flow includes both intercepted base flow and any loss through the river bed. A highly successful scheme has net gains near to unity. the minimum net gain acceptable would depend upon the cost o the water yielded by the scheme compared with alternative schemes.

Water Quality

Any coordinated use of groundwater involving yield and storage capacity must include consideration of possible groundwater deterioration over a short and long time period. There are several possible sources and types of deterioration. These include: 1) salt build-up due to percolation of excess irrigation water; 2) poor well construction and abandonment; 3) landfills and other disposal methods; and 4) waste discharges on or near land surface, particularly in known recharge areas.

Yevjevich (1979) suggests it is feasible to conceive conjunctive use of two or more sources of water without a concern for water quality but this would embody an assumption that neither source would have an adverse affect on the use or purpose of the other. However, the neglect of water quality should be an exception rather than a rule.

It is suggested that groundwater basins in all irrigated areas that use groundwater are being slowly degraded with salt (Helweg, 1979). In some cases aquifers are already degraded to the point that they would not be suitable for agricultural production. Helweg believes that a management program to prevent quality degradation must be implemented at the local level.

The deterioration of groundwater quality from salt build-up is a major unsolved problem in managing stream aquifer systems. Helweg (1977) has proposed several strategies for controlling salt build-up as follows:

1. Instead of applying poor quality groundwater in the vicinity of the wells, it is tranferred downstream and applied on land where the groundwater is of lower quality, thereby controlling the increase of salt concentration.
2. Instead of preventing seepage loss in delivery canals, percolation water be used to maintain groundwater quality.
3. Timed releases of return flow remove salts without exceeding the surface water quality constraints.

In schemes that involve the discharge of groundwater into rivers, changes in quality should be examined. For example, the change in temperature and/or physical or biological constituents of the river flow can in turn modify the river ecology.

On a regional basis maintenance of quality may require that water levels be kept as high as possible preventing large drawdowns around producing wells, thereby preventing the disturbance of natural flow lines extending into regions of poor quality water.

Overdraft of an aquifer can result in serious damage physically which can destroy the resource. For example, in Southern California overdraft has resulted in salt water intrusion and consequent deterioration of the aquifer. In this case the rate of water demand is not reversible. Reduction in rates of pumping would stop additional damage, but would not restore the source of water to its original quality.

Economics

Economic studies of conjunctive water use have progressed primarily through models of efficiency and allocation where optimality is an objective. The state of optimally allocating water among present users only, is often referred to as "spatial" allocative efficiency, whereas the state of optimally allocating water among users in different time periods is called "temporal" allocative efficiency (Helweg, 1979).

In general, allocative efficiency is achieved when it is possible to move a unit of water to another user or time period when it would be worth more than the costs of moving it there.

Economists generally employ the term "user cost" to represent the present value of foregone future uses of stored water. Thus, temporal allocative efficiency requires that the user cost of any future time period be equal to the net value of current use. Further, the allocative efficiency is obtained when the discounted marginal net values of water are equal among all users for all time periods. A practical difficulty in this concept is the unknown of future net values.

It is suggested that the incorporation of groundwater basins into an integrated conjunctive use system provides for the most efficient operation of the entire system (Hall and Dracup, 1970). Therefore, economic justification of conjunctive use is obtained. From these, therefore, the most economical plan can be developed. In developing these plans, a primary objective is usually the continued use of groundwater into the indefinite future. This may not, however, account for any possible degradation in water quality. Also experience indicates that only a few combination of plans for coordinated operation are physically feasible.

In California planned utilization of groundwater basins for transmissions and storage in conjunction with surface reservoirs was approached by a method to determine the most economic plan (Chun, 1964). The objective was to formulate the most economical plan for operating the groundwater basin in coordination with surface storage and transmission facilities to meet certain demands. Criteria of analyses of the groundwater system and surface delivery networks were analyzed, and results integrated into a coordinated operational study which would facilitate execution of alternative plans of operation.

The most economical combination of pumping and surface storage facilities was described in terms of a use factor of pumping facilities. For every alternative plan of operation, a schedule of annual groundwater extraction was specified for each operational area. The most economical use factor was determined by dividing the specified average annual pumping rate by the peak hourly rate.

Another aspect of groundwater management economics is the maintenance of groundwater levels to reduce pumping costs. As the water table fall, pumping costs increase so that the water left in the aquifer has a value of the extent that it reduces these costs. The value of water in use, however, must be greater than the value of water in storage for continued pumping to be economically feasible (Hartman, 1965).

Institutional Aspects

The institutional aspects of conjunctive water use are varied and complex. They include the legal, social and political aspects. The key questions in all of these is the right of the individual to freely develop and use the water resource whether it be a surface or groundwater supply. The problem is that in a conjunctive water use system these supplies are part of a common resource that may extend from a small local site to a region or regions that cross many political boundaries with different laws, customs and jurisdictions.

The farmer or an urban water district wants to control their water supply, and high priority is placed on that right. The farmer wants to be able to plant his crop with confidence that it will be irrigated when he believes it needs to be done. He normally operates and maintains his water system more efficiently than a public authority by more frequent attention and follow-up action. Nevertheless, this practice can often lead to exploitation through mining of groundwater, drying up surface supplies or perhaps selling the water at excessively high rates.

In some areas of India and Bangladesh farmers have joined together in cooperatives and successfully operated wells (Stoner, 1980.)

Conjunctive water use imposes new conditions and unknowns on the farmer. He may have difficulty in understanding the source of water supply as part of a larger system that involves two sources; that it is more economical to use one supply at certain times and the other during other periods of time; and that he may be told when and how his source is to be developed and used.

In the concept of conjunctive water use, all supplies are considered as parts of the same system. This does not mean that the traditional concepts of individual ownership of water rights and the administration of the doctrine of prior appropriation is satisfactory for an integrated system. For example, the time lag for the effects of pumping make legal integration and management difficult depending upon the system of water rights and administrative authority.

Maintenance

The best designed and most optimal scheme for conjunctive water use may fail because of a lack of maintenance. Experience shows that a major problem with any groundwater scheme is the maintenance of pumps and motors (Stoner, 1980). These devices are complicated pieces of equipment requiring diagnositc skill and tools. Mechanics with sufficient skill to analyze and remedy them are not easy to find nor to train in adequate numbers. More skilled individuals tend to move on to other more attractive employment opportunities. The private sector creates a demand for trained mechanics and normally pay well.

Replacement parts are a problem too. Often they are not available locally, require complete detailed instructions and accurate written transmission of those details and are delayed months and years in shipment.

Modeling

Modeling as applied to conjunctive water use is an attempt to duplicate the response of the surface and groundwater reservoirs through simulation and optimization. Simulation is a term used to describe the operation of the model and manipulation of results (Prickett, 1975). Optimization is the approach to the best or most favorable condition involving the combination of surface and groundwater supplies.

Conceptually models are powerful tools of management in assessing alternative designs of a conjunctive use system in terms of efficiency and including the physical, economic, social and political constraints on development and use of the resource.

Models, however, do not stand alone. They require data and input developed from physical studies. The potential utility of the model must be weighed against the feasibility of its use. There are not established criteria or rules. In general, the feasibility of a model varies directly with the scale of the system under investigation.

The development and use of models entails an integration of technical expertise in management at one end and scientific investigation and research at the other.

The principal mathematical techniques include linear and dynamic programming, and finite difference and finite element methods.

Modeling objectives vary from strictly hydrologic to economic to resource demand allocation and management.

There are at least four types of numerical models that focus on assessment. These include predictive models, resource management models, identification models, and data manipulation and storage procedures.

The resource management models are intended to indicate courses of action that will be consistent with stated management objectives and constraints. The objectives have to be carefully conceived and based upon the physical situation. The objectives may include maximizing the net economic benefits or minimizing costs for insuring an adequate water supply. these types of models may employ both simulation and optimization in deriving outputs. They normally incorporate economic, technological, political and institutional aspects to the problem even though these are extremely difficult to quantify. According to Bachmat (1980) the usual management model contains four elements: a submodel for finding the most appropriate decision (i.e., location of wells, pumping rates, etc.); a submodel for predicting the outcome of the decision (i.e., water levels, salinity, etc.); a set of rules and constraints on admissible decisions and/or outcomes (i.e., maximum pumping rates, drawdown, salinity, water rights, well regulation, etc.); and a so-called objective function which evaluates a decision (i.e., costs, benefits, yield, etc.)

Conjunctive water use and management models are distinct in considering a variety of muticomponent systems, such as resources, supply use and production, and in addressing management asks at a reasonable level. Most of the models that have been reported in the literature deal with quantity management on either a lumped or distributed parameter basis. A few have treated stream aquifer interactions in addressing coordinated multilevel management. Others have considered quality in either a lumped or distributed system (see Appendix A).

Buras (1963) considered the problem of optimizing releases from a dam and reservoir in combination with pumping from an aquifer. He proposed three problems:

1. The determination of design criteria of the dam and for the groundwater recharge facilities.
2. The determination of the areas to be served by the system.
3. The establishment of an operating policy that specifies the draft on the reservior and the pumpage from the aquifer.

Buras (1963) also suggested that if the groundwater is considered to be a renewable resource, the amount pumped will depend to a large extent on the magnitude of release for groundwater replenishment.

However, the storage capacity of most aquifers exceeds considerably the surface storage available in the same watersheds or catchment. It is not conceivable therefore to have a regulated release from a surface reservoir so large as to replenish an empty aquifer within any one season. Furthermore, the recharge basins necessary for the infiltration of such large quantities of water during a few months is not a practical consideration.

Each water development project is unique and is not always possible to apply the same economic factors or characteristics of one conjunctive operation to another.

On the other hand, experience has shown that it may be possible to develop criteria for one area that is applicable to another within the limitations of similar geographical, physiological and social factors (Doemnico, 1966).

Bachmat (1980) summarizes the contributions of management models as follows:

> "So far the contribution of management models have been primarily in the area of research and development. Regardless of whether a water resources management system is centralized or decentralized, it is obvious that existing management models can, in certain cases, be useful in enhancing management practices and screening decision alternatives. The application of existing management models to real problems will foster the development of better techniques for addressing multiple objectives in nonengineering decision."

In summary, most of the management/conjunctive use models address water supply problems from the engineering point of view. All have restrictions in terms of boundary conditions and dimensions. In short, the methodology of modeling conjunctive use systems is in int infancy.

EGYPT AND CONJUNCTIVE WATER USE

Factors and Problems

Conjunctive use of surface and groundwaters is an option in the management of water supplies of Egypt in some areas. Little is presently known, however, about the extent of such possibilities in a quantitative sense.

There are a multitude of interrelated questions concerning conjunctive water use. Some are amendable to intuitive answers which in most cases appear to be more positive than negative. However, knowledge, data and experience is required through systematic evaluation and examination.

The major physical and technical factors involve the supply and limits of the total water resources of the country. The quality of these resources, hangs that may take place in time, reuse of drainage water, the hydrogeology of the system, and the demands for water placed on the system for all purposes.

Surface Water - The reports of the Ministry of Irrigation, UN/Master Plan for Water Resources Development and Use (1981)*, are a major contribution to the assessment of the water supplies, the demand estimates, and in proposing the potential for conjunctive water use in Egypt.

The Master Water Plan suggests that there are two principal problem areas in establishing the demand for water: first, is the question of optimum supply of water for existing irrigated areas, and second, is the question of the volume of water needed per feddan for the expansion of irrigation in the new areas.

It is clear that there are a number of key data gaps concerning the total assessment of water in Egypt, as well as conflicting figures on the use of water on the old lands and in the projection of water needs for the more sandy desert soils of the new lands.

Egypt is richly endowed with a water supply, and since the construction of Aswan Dam, water has not been a limiting resource in Egypt's agricultural and economic development. Nevertheless, the Nile has a limited supply of water and incomplete reclamation plans (Giorgio, 1981).

Future plans of the Egyptian government call for a massive expansion of irrigated land, approximately 2.8 million additional feddans by the year 2000.

The Water Master Plan (1981) points out that at present there is a critical need for more accurate data on: canal and drainage flows, particularly at control structures; water applied on crops; the conveyance of water and seepage losses; changes in the level of the water table; return flows; crop areas and yields; farm budgets; and other water related information.

Concerning the flow available and current demands for water use in Egypt, the Water Water Plan indicates the following:

Average annual flow available (High Dam)	$55.5 \times 10^9 m^3/yr$
Agricultural Consumptive Use (1976 - old lands)	$19.4 \times 10^9 m^3/yr$
Flow through drainage system to sea or terminal lakes	16.0
Navigation/barrages safety/hydropower	3.8
Municipal/industrial/wastewater (1980)	2.1
Evaporation from river and canals	2.0
Other and unaccounted for	0.7

* Hereafter referred to as Water Master Plan (WMP)

It appears that the only firm figure among the resources listed above, is the water released at the High Dam. The other quantities are estimates and are not the same in all reports.

Surface Water Quality - Water quality is another critical consideration in a conjunctive water use system. There have been no comprehensive water quality studies on Egypt that would serve as a framework for determining the impact of conjunctive and multipurpose development (WMP, TR 7). The limited studies of water quality have been in relatively small parts of the system and have produced useful data and recommendations, but they are not comprehensive in nature.

The overall quality of water in the Nile system is good for all purposes. There is some local pollution and contamination.

The quality in the freshwater canal system is also good, although there is more variation both spatially and temporally. Monthly monitoring of the main canal sources for the three EWUP Project sites for 1982-83 was reported by Assia and Scott (1984) and is given in Table 1.

Table 1. Water Quality of Canal Water (1982-83)

Canals/Site	Electrical Conductivity (EC) - mmhos/cm			Adjusted SAR		
	Irrigation Season Range	Irrigation Season Ave.	Winter Closure	Irrigation Season Range	Irrigation Season Ave.	Winter Closure
Ibrahimi/Abyuha Minya	0.22-0.30	0.24	0.29	1.49-1.84	1.66	1.77
Mansuriya/ Mansuriya	0.30-0.42	0.37	0.39	1.98-3.00	2.45	2.32
Dakalt/Kafr El Sheikh	0.31-0.81	0.41	0.46	1.88-2.69	2.42	2.86

The canals also receive some industrial effluent and domestic sewage from adjacent areas. Further, many canals are major sources of drinking water which further complicates the problem.

Residuals from fertilizers, insecticides, and other organics find their way into the Nile and the canal system. However, very little data is available on the level of the use of chemicals as a function of time and location. Specifically, high levels of mercury, lead, oil and grease was reported in 1977 in the Mahmudia and the Khandaq el Sharkia canals.

Further investigations in 1979 (WMP, TR 7) showed the concentrations of heavy metals was below accepted levels, there was no organic chlorine pesticides present, however, heptachlor and parathion were present and above permissible levels.

There has been some data on the chemical constituents of the Nile since 1919. However, it was not until 1976 that a comprehensive program of hydrochemical data collection and analyses was established in the reaches between Aswan and the Delta barrage. Since that time, collection and sampling has been carried out in accordance with specification standards of the World Health Organization.

As the water moves into the Damietta and Rosetta branches, studies have indicated that there is a slight increase in TDS and electric conductivity from the Delta barrage to the north. There is also an associated rise in chloride and sulfate levels and BOD in both branches, an amount almost double the values found in the water of the Nile upstream from the barrages (WMP, TR 7). Further there is evidence of significant concentrations of oil, grease, nutrients and/or organic chlorine pesticides. Concentrations of heavy metals are generally low. The recent increase and production of organic biomass in the two branches sometimes depresses the DO levels and pH.

Groundwater - The principle groundwater formations suitable for development and management in Egypt are the alluvial aquifer underlying the irrigated agricultural areas of the Nile Basin and the extensive Nubian Sandstone underlying the desert regions.

It is estimated that the yield that could be extracted from these aquifers without depleting the resources is 4 milliard m^3 per year (MWP TR 4, p1).

Current extractions from the Nile basin aquifer is 1.3 and 1.6 milliards m^3/yr, respectively, in the Nile Valley and the Delta.

Recharge to the Nile Valley aquifer is provided primarily by deep percolation of applied irrigation water. The secondary source is percolation from the Nile and from the canals.

The aquifer system of the Nile Valley has two layers with different hydraulic characteristics. The upper layer functions as a semi-confining layer to the underlying aquifer, and it has low horizontal and vertical transmission conductivity. The lower aquifer is largely graded sand with good transmission properties. It intersects the Nile Channel which serves as a sink for groundwater flow from the aquifer since under regulated river flows the water stage in the river is lower than the groundwater levels.

The aquifer system of the Delta also contains two layers that store groundwater similar to the Nile Valley. The lower layer is highly permeable arid varies in thicknesses from 100 to 900 m. It is in contact with the sea, and, therefore, subject to sea water instrusion, depending on a delicate balance between recharge and extraction.

In the Delta, the largest number of wells tap the shallow alluvial aquifer to provide public and private domestic water supplies. Deeper wells extend down to 50-70 meters in depth. At this depth, they generally encounter the graded sand aquifer.

Groundwater Quality - The quality of groundwater varies considerably between regions, i.e., the Nile Valley, the Delta and the desert areas.

In the Nile Valley, the groundwater quality of the alluvial aquifer is of good quality over the entire area. Usually a suitable quality for irrigation and usually for domestic water supply.

Several thousand tube wells are currently operating, some to supplement irrigation water with a larger number to provide domestic water supply. The electrical conductivity ranges between 0.25 and 1.88 mmhos/cm with an average of 0.74 mmhos/cm. The TDS ranges from 160 to 1,706 ppm and averages 475 ppm. The dominate cations are generally mg^{++} and Na^{++}, and the principal anion is HCO_3^-, and relatively high portions of Cl^- are present in some samples. In most samples the carbonate radical is in the form of the bicarbonate ion, and the waters are almost neutral in pH or slightly acid.

A private well located to the west of the EWUP Abyuha project site was monitored for water quality for a period of six months during 1982. Results showed that the electrical conductivity and adjusted SAR ranged from 0.16 to 1.20 mmhos/cm and from 1.68 to 6.41, respectively, and with an average for the six months of 0.65 and 3.67, respectively (Assia and Scott, 1984).

Wells surveyed in the Kafr El Sheikh and Beheira areas indicate that 84% of the shallow wells drawing from the unconfined and confined aquifers were bacterialogically polluted (WMP, TR 4). These water registered total coliform counts of over 5 MPN/100 ml and were as high as 300 MPN/100 ml. Bacterialogical quality tends to improve with the depth of the wells.

The chemical water quality of the Delta is generally reported to be poor, particularly in the upper alluvial aquifers. This is due to the practice of basin irrigation over many years and the accumulation of salt in the upper most layer of the aquifer due to low, downward water movement. With the introduction of perenniai irrigation the rate of arrival of salts in the aquifer's upper level has accelerated. Salinization in the upper layers in some areas has been exacerbated by waterlogging and secondary soil salinization due to the presence of large amounts of water. Areas of high soil salinity are usually underlain by an upper groundwater layer of high salinity, however, the volume of water contained in this uppermost layer is small relative to the large volumes of good quality water in the main lower and larger reservoir.

Water less than 1,000 ppm is normally found south of Tanta. To the north, quantities of 4,000-5,000 ppm are not unusual. Groundwater becomes brackish south of Wadi El-Natrun. Groundwaters are in the range of 1,000-6,000 ppm south of Ismailia Canal to the Cairo-Ismailia Desert road.

Drainage Water and Reuse - Consideraton of drainage water in a conjunctive use system is an important factor. in Upper Egypt all drainage water flows back into the Nile and is reused in irrigation. On the other hand, in the Delta reuse is limited by the increased salinity of the drainage water. Reuse per unit area is much larger in the Southern portion than in the northern portion of the Delta (Volker, 1980). Further, in the western Delta more water is drained off and less is reused due to higher soil salinity and light texture of the soil. In the middle part of the Delta less water is drained, and the reuse percentage is relatively higher.

Reuse of drainage water is an attractive supply option because of relatively low costs. Some drain waters are of good quality and can be used directly. Others of lower quality will require mixing with canal or groundwater. Some are too saline for reuse.

Several senarios for drainage water is subject to several constraints, namely 1) complete reuse of all drainage water is impossible; 2) the salinity of the drainage water; 3) elevation at which drainage water becomes available; and 4) the likely increase in water use efficiency which will reduce the volume of drainage water available.

Reuse on a long-term basis may be risky.

There are three types of drains in the region from Aswan to Cairo: namely, 1) drains that receive runoff from agricultural lands in which the flow is perennial but varying throughout the year. The quality of the water is good and seldom exceeds twice the TDS of the water in the Nile; 2) drains that serve as overflow for the irrigation system. These drains have irregular flow, and the TDS is normally increased only slightly over that of the Nile quality; and 3) drains carrying industrial wastewater. In these drains the discharge is relatively constant year-round, except those serving sugar factories which are closed four months of the year. Quality of the water in these drains is highly variable and generally not good for domestic or agricultural purposes.

Under present conditions it is estimated that approximately 15% ($2.5 \times 10^9 m^3/yr$) of the drainage water of suitable quality is reused but an enormous amount of water (approximately $13.5 \times 10^9 m^3$) is still moving unused to the sea (Volker, 1980).

Objectives for reuse of drainage water must acknowledge the following constraints:

1. Complete reuse is impossible because a substantial portion of the water must be conveyed out to achieve an overall water and salt balance in the Delta.
2. Quality of the drainage water.
3. Location of the drainage water for reuse with respect to the areas of need.

The estimate of drainage water that returns to the Nile between Aswan and Cairo is $2.3 \times 10^6 m^3$.

The quality of the water was monitored in the drains within and adjacent to the three EWUP sites during 1982-83. The results are given below (Assia and Scott, 1984).

Table 2. Water Quality of Drain Waters (1982-83)

Site/Drain	Electrical Conductivity (EC) - mmhos/cm			Adjusted SAR		
	Range	Ave.	Winter Closure	Range	Ave.	Winter Closure
Abyuha-Minya/						
Kom El Zoheir	0.22-0.35	0.27	0.35	1.27- 2.57	1.79	1.59
El Moheet	0.26-0.44	0.36	1.00	1.04- 2.58	2.32	2.25
Mansuriya/ El Moheet	0.70-0.99	0.80	1.06	3.18- 7.08	4.95	6.49
Beni Magdul	0.44-2.77	1.15	4.33	3.17-13.72	6.65	17.57
El Lebini	0.57-1.07	0.77	1.15	2.64- 6.16	4.63	7.29
Abu Raya-Kafr El Sheikh						
Drain 4	0.72-1.36	1.05	5.54	5.24-13.22	8.43	38.15
El Raghama	0.45-2.00	1.13	6.41	4.95-14.20	9.31	39.94
Drain 7	0.79-2.72	1.46	3.73	3.11-27.76	10.95	20.75
Manshia	0.49-2.80	1.48	8.02	2.80-18.78	10.41	36.19
Om Sen	0.58-3.14	1.32	6.14	3.42-28.32	10.06	32.26
Gadalla	1.01-9.30	2.72	7.31	4.95-65.44	18.37	44.60

A substantial increase in salinity occurs when irrigation is stopped in January as a result of a reduction in return flows. Tentatively, it is expected that the quality of the drainage water will be around 800 ppm in contrast to a river salinity of 250 ppm (WMP, 1981).

The elevated values of salinity during winter closure are illustrated by data obtained from drains in and adjacent to the three EWUP sites and shown in Table 2 for closure in 1982.

In the Delta, drainage water is extremely variable in quality. Those in the west have relatively higher salinity. Some drains receive municipal and industrial wastes which degrades the water substantially. In the middle of the Delta drains have water of relatively good quality. Generally, salinity of the water rises sharply in January during the closure.

The quality of salt leaving the drains and pumping stations in deltas is normally three or four times that entering the Delta regions. Some of this increase is probably due to the strong intrusion of salty water from the seas.

Considerable progress has been made by the Drainage Research Institute in examining and analyzing samples of the main drains on a systematic schedule (El-Guindy and Amer, 1979) and on land drainage through a pilot area research project, which involves an economic evaluation of land drainage, water management of rice fields and reuse of drainage water (Amer and van der Zel, 1983).

Studies by the Drainage Research Institute (Amer and van der Zel, 1983) suggest reuse of drainage water is subject to several constraints, namely: 1) complete reuse of all drainage water is impossible 2) the magnitude of the salinity of the drainage water; 3) the elevation at which drainage water becomes available; and 4) likely increases in water use efficiency which will reduce the volume of drainage water available. Therefore, reuse on a long-term basis may be risky.

Some progress has been made on estimating the quantity and required mixing percentage for reuse of the drainage water in the eastern Delta. Results of a mathematical model of the Bahr Hadus catchment area, indicated that except for the period of the irrigation closure, the water of this drain is of moderate quality and can be used if mixed with fresh water in a 1:1 ratio (El-Guindy, 1981).

Salinity Due to Waterlogging - Salinization of the soil due to a high water table and waterlogging is estimated to be taking place in 10% of the irrigated area of the Nile Valley (WMP, TR 11).

Salinized areas are concentrated on the flank of the valley, where the head difference between the upper and lower layers is minimal and natural drainage to the deeper part of the system is restricted. This situation still applies at the upper confined layer's absence in the zone as the vertical gradient through the system is still minimal.

The rate at which water rises from the water table to the soil surface moisture tension, varies with gradient in soil, the depth of the surface to the water table, and the soil type.

On the other hand, the presence of a high water table is a form of subirrigation for large areas of deep-rooted crops. If the high water table is eliminated by extensive dewatering of the aquifer system, and additional demand would be made on the surface supply in order to satisfy the crop water use requirements.

The long-time practice of irrigated agriculture in the valley has left salt in the soil layers which have been leached slowly down to the saturated zone. Such concentrations of salts have accumulated in the upper most layer of the aquifer and have been subject to the mixing process by diffusion which is very slow.

Since construction of the High Dam and the advent of perennial irrigation, the rate at which salts have been accumulating in the upper part of the system has accelerated. This rate has been compounded by waterlogging and secondary soil salinization.

The Egypt Water Use and Management Project (EWUP) has conducted several studies of soil identification, salinity and fertility in the three project areas which have provided important information on the status of salts in the soil and shallow groundwater.

In a random sampling of 10 to 15 percent of the farms in Abyuha, Minya, the soil salinity changed very little with depth (Zanati, et al., 1982) with mean electrical conductivity (EC) values of 0.44, 0.50, and 0.57 mmhos/cm. The sodim absorbtion ration (SAR) was low for most surface soils and increased gradually with depth but remained below 15 in most profiles (A.W.A. Selim, et al., 1983) for depths of 0-20, 20-40 and 40-60 cm. Shallow groundwaters measured in 1982-83 had an average EC of 1.28 mmhos/cm and an adjusted SAR of 11.46 (Assia and Scott, 1984). For most cr s the soil of this area could be considered as non-saline.

In the Beni Magdul and El Hammami areas, Mansuriya, a preliminary soil survey was conducted by EWUP (Dotzenko, et al., 1979) using soil profiles that represented 10 to 15 feddans per profile. Results for soil salinity and sodicity are given in Tables 3 and 4.

Table 3 Soil Salinity, Beni Magdul and El Hammami Areas
(Dotzenko, et al., 1979)

Salinity Scale	No. of Soils	% of soils	Average EC per category
Beni Magdul			
Non-saline > 4 mmhos	43	75	2.1
Moderately saline > 4 -8 mmhos	11	19	5.7
Strongly saline < 8 mmhos	3	6	13.9

Table 3 Soil Salinity, Beni Magdul and El Hammami Areas (Continued)
(Dotzenko, et al., 1979)

Salinity Scale	No. of Soils	% of soils	Average EC per category
El Hammami			
Non-saline > 4 mmhos	71	83	1.8
Moderately saline > 4 -8 mmhos	9	10	5.6
Strongly saline < 8 mmhos	6	7	11.4

Table 4 Soil Sodicity, Beni Magdul and El Hammami Areas
(Dotzenko et al., 1979)

SAR	No. of Soils	% of Category	Average SAR Per Category
Beni Magdul			
Low, < 10	52	91	5.6
Medium < 10-15	4	7	12.7
High, > 15	1	2	23.0
El Hammami			
Low, < 10	66	77	3.6
Medium < 10-15	7	8	12.5
High, > 15	13	15	31.1

Similarily, a limited number of samples were taken to characterize the shallow groundwater. The range and average values are given in Table 5.

Table 5 Quality Characteristics of Shallow Groundwater, Beni Magdul and El Hammami Areas (Dotzenko, et al., 1979)

Factor	Range	Average
Beni Magdul		
EC, mmhos	1.4 to 13.7	5.9
SAR	5.7 to 14.9	10.1
Total Soluble salts, ppm	1065 to 11,100	4690
El Hammami		
EC, mmhos	0.7 to 4.5	2.5
SAR	1.0 to 15.84	5.85
Total Soluble salts, ppm	630 to 3970	1658

These results demonstrated that a significant portion of these areas were subject to increasing to serve salinity and sodicity problems created by high water tables and poor subsurface drainage.

A soil characterization survey of the Abu Raya area based on a sampling density of one profile per 20 feddans revealed three soil series in the EWUP project area (A.A. Selim, et al., 1983). Differences within series were based on salinity, sodicity, water table depth and the presence of gypsum accumulations in the subsoil. The soils generally showed high salinity and sodicity which tended to increase with depth. Results for the two depths are shown in Figures 5 and 6.

Shallow groundwater quality was monitored in nine observation wells on a monthly basis in 1982-83 (Assia and Scott, 1984). A wide range in both salinity and adjusted SAR occurred in response to fluctuations in the high water table. The average EC and adjusted SAR was 2.79 mmhos/cm and 10.58, respectively.

There have been no systematic, analytical or field verification studies to determine the rate of accumulation of salts in the upper layer of the aquifer system.

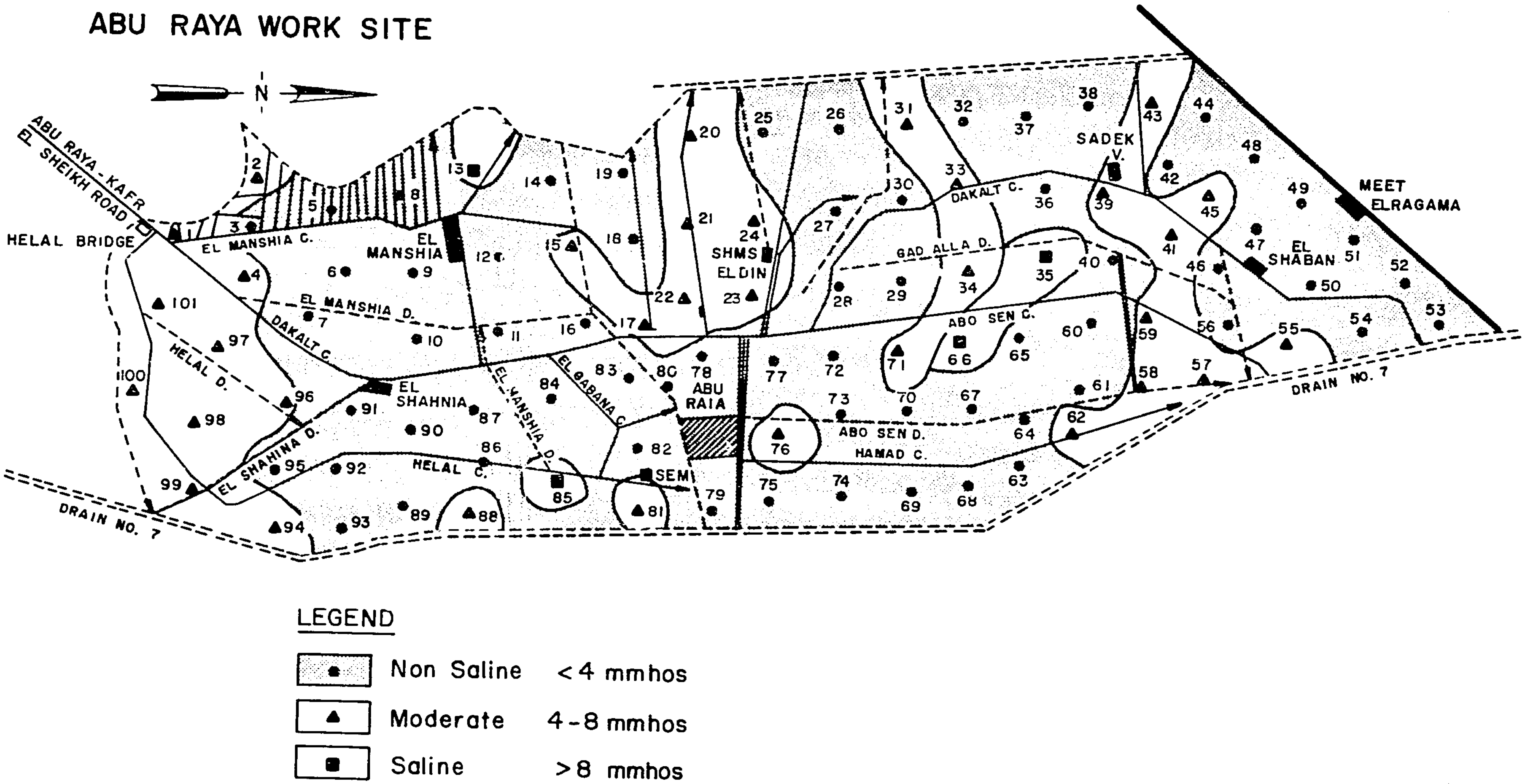

Figure 5. Soil Salinity (EC) Map for 0-25 cm Depth of Abu Raya, Kafr El-Sheikh, Egypt.
(Selim et.al., 1983)

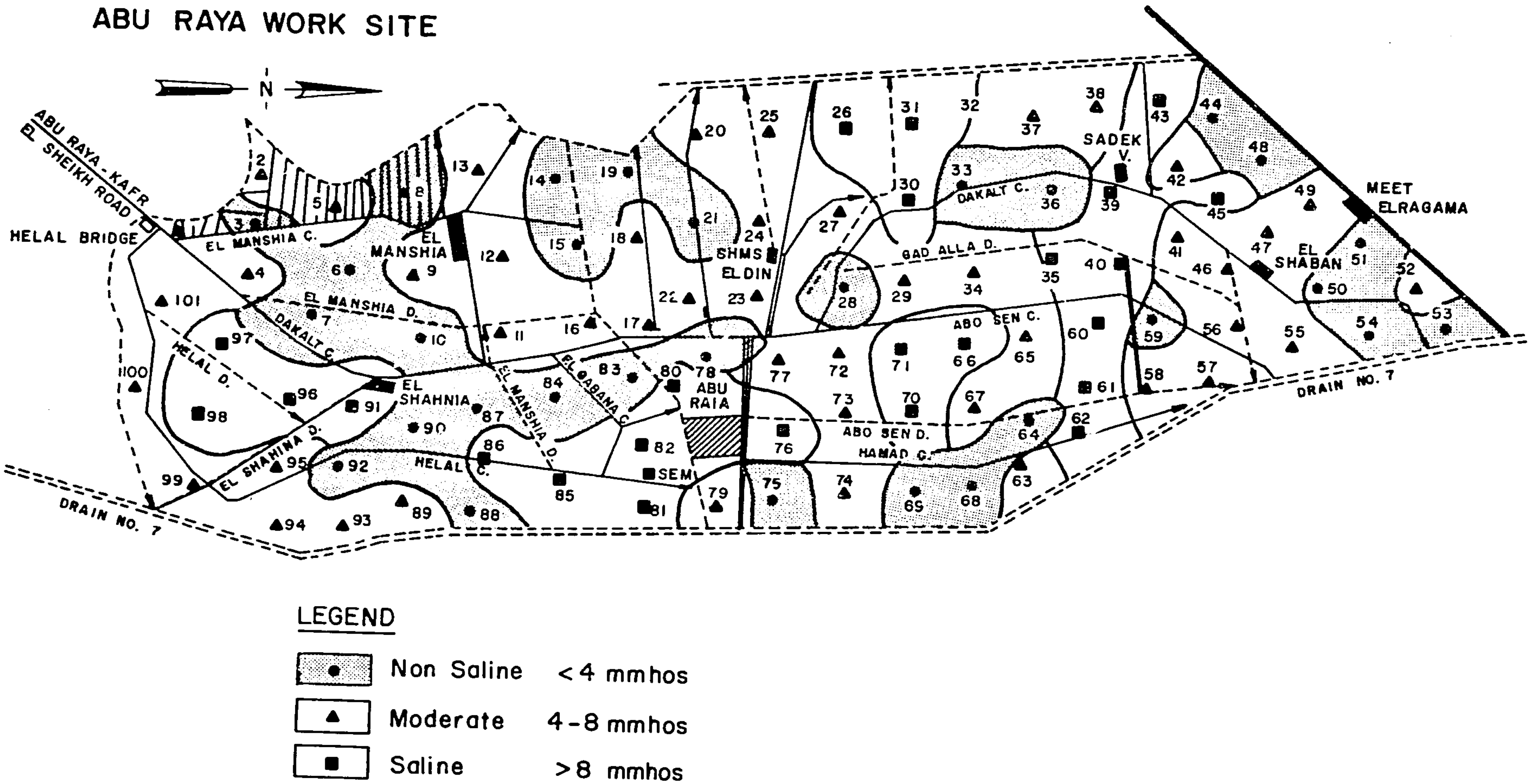

Figure 6. Soil Salinity (EC) Map for Greater than 25 cm Depth of Abu Raya, Kafr El-Sheikh, Egypt (Salim et.al., 1983)

Water Budget

A major contribution to a conjunctive use study is a water budget analysis - an accounting of all water entering, exciting and stored in a region. A water budget determines how much water diverted to or pumped in an area is used beneficially by irrigated agriculture.

The Egypt Water Use and Management Project (EWUP) has compiled water budgets for three small irrigated regions in Egypt and results are reported by Helal, et al., (1984) (Figure 3) for each of the three areas, inflow and outflow components are given including the winter and summer water deliveries and consumption, vertical and horizontal subsurface flows and changes in water storage. In addition, data on the monthly average depth to the water table are given. Typical schematic representations of the magnitude of the various components of the water budget are given in Figure 8 and 9. Conclusions drawn from these studies included the impact of a consistantly high water table, significance of the vertical drainage, negligible amount of horizontal water movement, and seasonal irrigation efficiencies that ranges from 32 to 49% in Abyuha, 50 to 76% in Beni Magdul and 26 to 43% in Om Sen.

Feasibility - The Water Master Plan is the principle source of information concerning the feasibility of conjunctive use in Egypt. The principle thrust of the analysis was to consider the feasibility of the developing wells in the Nile Valley, to provide drainage and supply part of the irrigation water requirement. It is suggested that water be pumped from wells and delivered to the existing surface water conveyance system for use in irrigated agriculture.

Two model studies were developed in the analysis. The first considered an area of 300 Km^2 near El Minya. It considered variables such as the recharge-discharge pattern, aquifer characteristics and vertical flow regime. A second model considered optimization of the well system designed. Variables considered were the size and capacity of the well pumping unit, electrical transmission, pipe conveyance from the wells to canals, terminal stilling basins and energy costs for pumping. Optimization sought the least cost combination of well depths, screen section, length and diameter of surface conveyance height for preselected discharges.

The results obtained from these models demonstrated the technical feasibility of using a well field to provide: a) drainage only; b) "within year regulation;" and c) "over year" regulation.

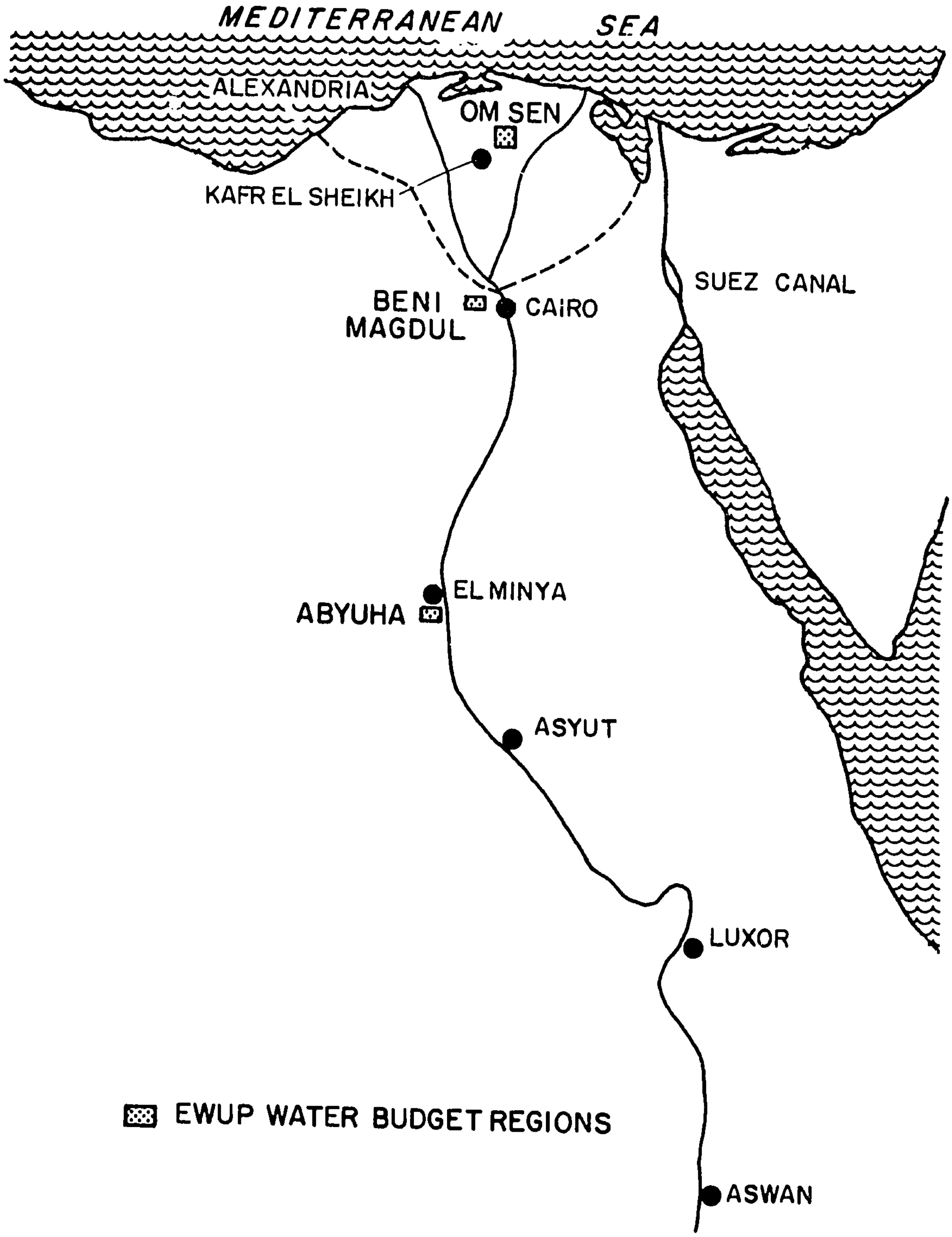

Figure 7. Location Map for EWUP Water Budget Regions (Helal et.al, 1984).

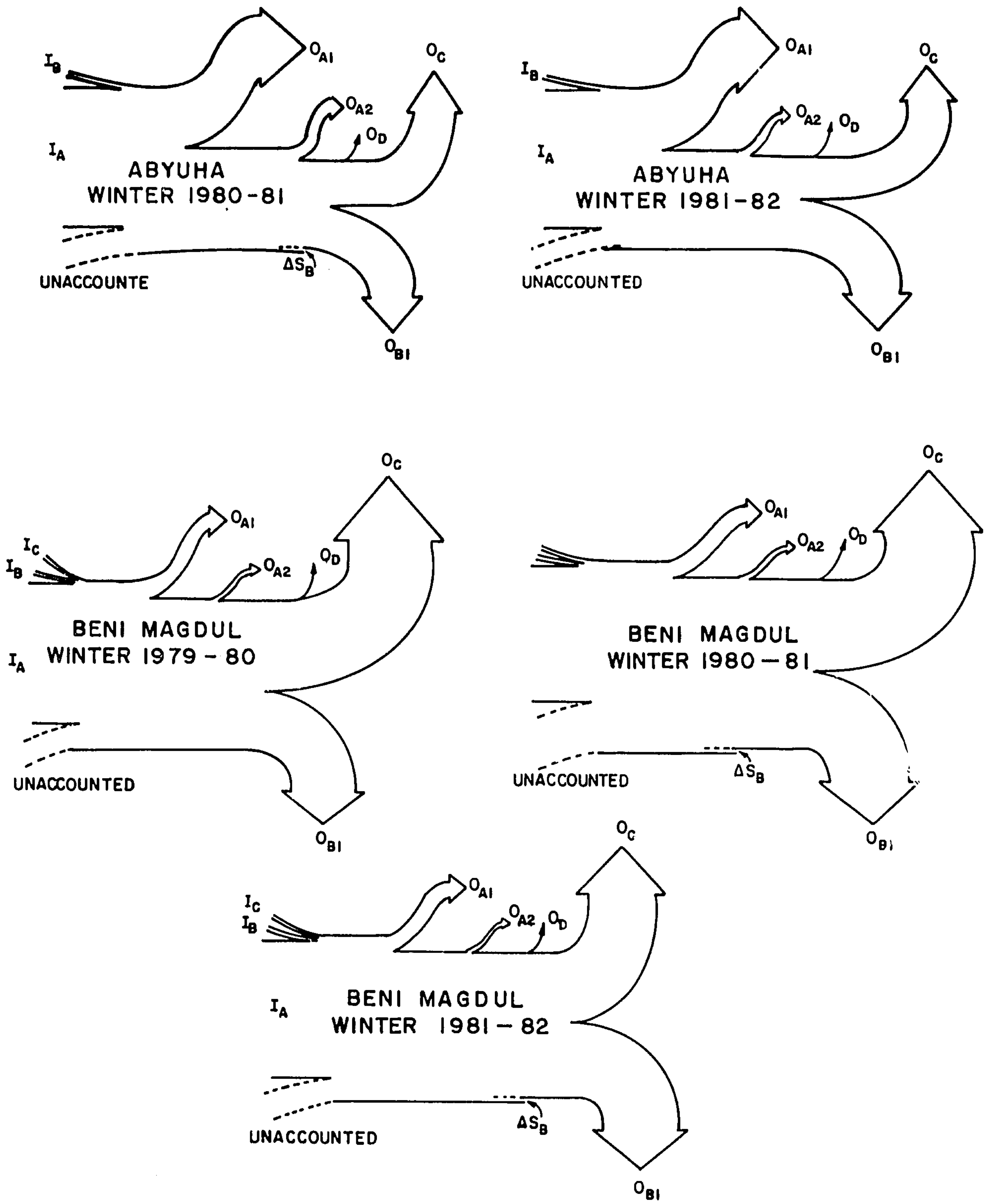

Figure 8. Schematics of Winter Season Water Budgets for Abyuha And Beni Magdul Regions (Helal et.al., 1984).

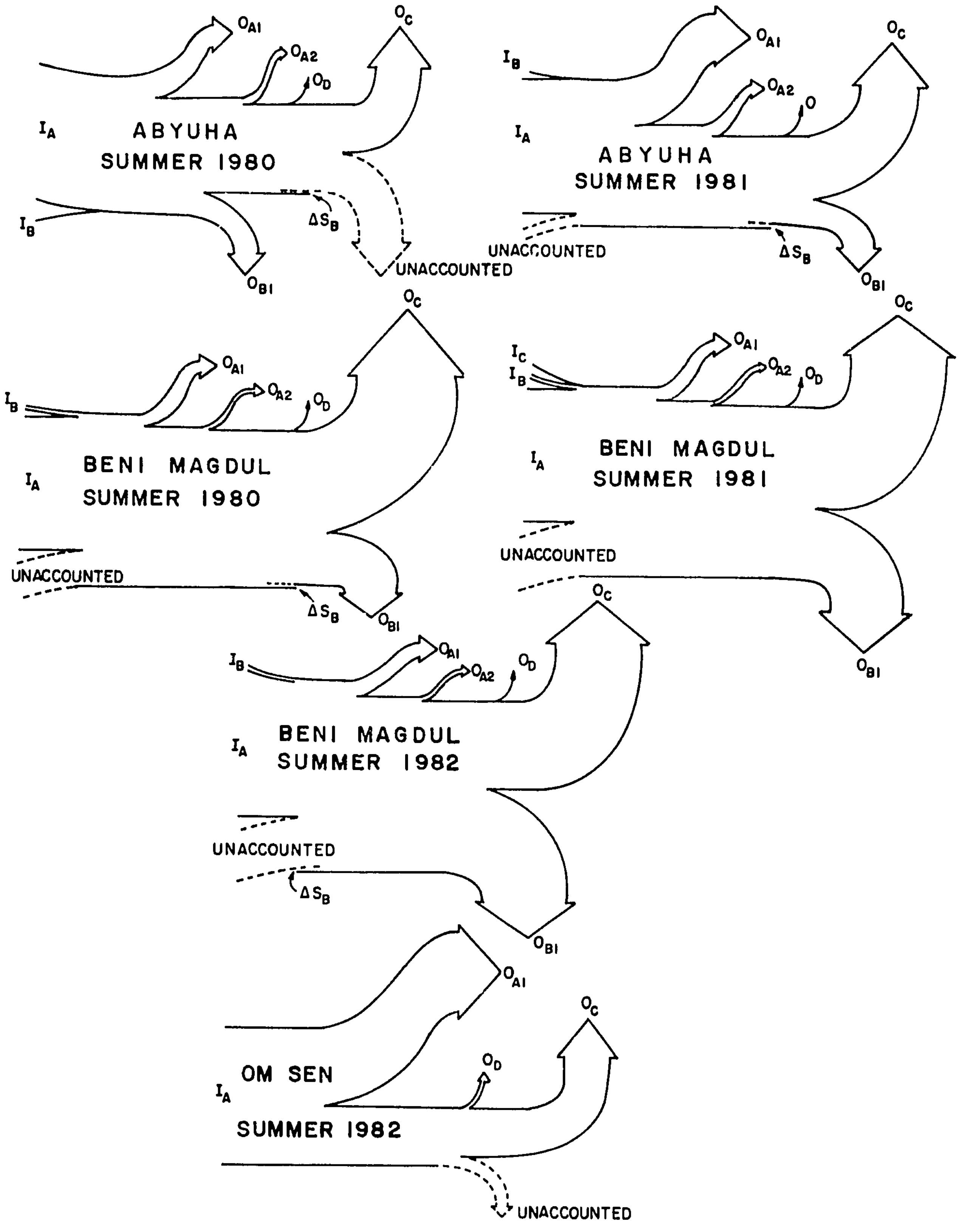

Figure 9. Schematics of Summer SEason Water Budgets for Abyuha, Beni Magdul, and Om Sen Regions (Helal, et.al., 1984).

For the drainage only case, costs of pumping were compared with the drainage. The analysis indicated that the cost of pumping and title drainage was about the same, but the overall benefits of pumping were greater.

In the "within year regulation" model a large pumping capacity (equivalent to 2.92 mm/day over the cultivated area) produced a 2.6 m drawdown but about 50% of the irrigation requirement was met.

In the "over year regulation" model the same large pumping rate was continued for a 10-year period resulting in a drawdown of 18.50 m. Although a four-year period was required for water levels to recover, this case illustrated the tremendous potential for using groundwater as a supplement to surface supplies during periods of shortage and thereby increasing the long-term yield of the system.

Finally, the WMP proposes a major pilot project of groundwater utilization in the Nile Valley alluvium. The potential area for development is from Armant (170 Km downstream of Aswan) to Wasta (850 Km downstream of Aswan). The area has a net cultivated area of 1.3 million feddans. This would be a very ambitious initial undertaking.

SUMMARY

1. In the long term Egypt faces serious problems in the development and management of its water resources.

2. Conjunctive water use of surface and groundwater resources is essential.

3. The state of the are of conjunctive water use has been rapidly evolving in recent years through experience and research and a considerable volume of literature is available on the concept and factors involved. Not much is available on the evaluation of field experience.

Since the Master Plan Report was published in 1981, the Groundwater Research Institute, Ministry of Irrigation, has initiated an intensive field study to test under the feasibility of conjunctive use.

4. There is some basic data available on groundwater resources in Egypt, but considerably more needs to be developed and related to current and future water management practices and plans.

5. The potential for conjunctive water use is technically documented primarily by model studies in the recent report on the Water Master Plan.

6. The principle issues requiring attention are the following:

a. Technical

Groundwater quantity - occurrence, movement and volume available under increased pumping; and relationship to river flows.

Groundwater quality - present status; long-term changes; salinity increases; organic pollutants; heavy metals; nitrates; influence on soils, crops and production.

Drainage - location, effectiveness, quality, influence on salinity and reuse.

Integration of groundwater into surface water distribution system - existing, modified, or new systems; day vs. night pumping; and mixing of supplies.

Land subsidence - influence on land, water conveyance and drainage systems.

Energy - availability, sources, and efficiency requirements.

Well design, construction, maintenance, rehabilitation and efficiency.

Disposal of wastes - location, pollution, control.

b. Economic

Capital and operating costs - wells, pumping, distribution.

Alternatives - incentives and subsidies.

c. Social and Political

Policies - for management of groundwater quantity and quality; water quality goals and standards.

7. Modeling studies are essential but not complete without field experiments and integrated evaluating. In other words, neither physical studies or models are satisfactory without the support, documentation and verification by the other. Both are needed.

8. The study of conjunctive water use in Egypt will require time and adequate resources of personnel and funds.

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APPENDIX A

TABLE A19. Groundwater Management Models—Quantity

Purpose	System: Hydrologic	System: Technologic	State Variables	Decision Variables	Constraints*: State	Constraints*: Decision	Constraints*: Others	Objective Function	Method	Documentation	Availability	Past Applications	Special Features	Identification: Model Number	Identification: Country	Identification: Institution	Identification: Modeler
Distribution of pumpage under given rules	Aquifer Cells		Salinity, Water Level Depth of Seawater Intrusion	Pumpage, Lacking Capacity of pumpage and conveyance	Level of state variables	Operational rules	Total Pumpage (Output from a Lumped Model)		Operational Algorithm	Description (Hebrew)	No	Field: Planning of pumpage distribution	Operational rules depend on priority levels of demand and critical levels of hydrologic monitors. Policy matrix corresponding to the above. Single time step operation. Conjunctive with simulation model.	61-1	Israel	Tahal	Schwartz(73)
Optimal location and operation of wells	Single Aquifer 2D		None	Well location Pumping rate Head		Head (Lower Bound)	Total net pumpage	Sum of heads at node points at each time interval	L.P.	References	Yes	Field (once) Feasibility Study	Simulation within optimization framework. Physical Objective. Solution at each interval used as initial condition for next interval. Static option.	61-2	U.S.	Stanford Univ.	Alley * Aguado (76) Remson
"	Aquifer (homogeneous or heterogeneous)		Head or Drawdown in well	Well location Pumping rate	Drawdown		Total pumpage	Cost	Simulation and curve fitting	Reference + Dissertation (Bostock)	Yes	Hypothetical Examples	Uncertainty in estimating hydraulic conductivity of heterogeneous aquifer. No specific Algorithm for curve fitting. Cost includes construction, replacement, energy and water deficit. Dynamic	61-3	U.S.	Univ. of Arizona	Bostock * Simpson (77) Roeffs
"	Aquifer 2D or 3D	Water supply system	Head	"		Pumping rate, depth, diameter	"	Cost	L.P.	?	?	?	Cost includes Drilling, pumps and surface network. Conjunctive simulation and optimization. Static.	61-4	France	Arlab	Baradat Blanc
"	Aquifer 2D		Head	"	Head (Lower bound)	Pumping capacity (upper bound)	"	Discounted operating cost (concave)	Concave programming, upper linear constraints (TUI Method)	?	?	Hypothetical Case	Discounted operating cost only. Dynamic planning model formulated as a discrete time co[illegible]rol problem.	61-5	U.S.	Cornell Univ.	Willis Newman (77)
Optimal operation of a well field	Single or Multiple Aquifer 2D		Head, Drawdown	Pumping rate	Drawdown			Linear combination of pumping rates	L.P.	Complete	Yes	Field	Influence coefficients computed by simulation as input to optimization. Programmer oriented.	61-6U	France	Ecole de Mines	Levassor (75)

*Reported by Haimes and Das.

From Bachmat, 1980.

TABLE A19. (continued)

Purpose	System			Decision Variables	Constraints			Objective Function	Method	Documentation	Availability	Past Applications	Special Features	Identification			
	Hydrologic	Technologic	State Variables		State	Decision	Others							Model Number	Country	Institution	Modeler (year)
Optimal Operation of a well field	Groundwater 2D Linear	Water Supply	Drawdown or Head	Semi-Annual Pumping Pattern		Well-pumping capacities	Total Pumpage	Cost	Simulation (F.D.) & Optimization - Q.P.	?	?	Hypothetical Case	ATF which relates pumpage (or Recharge) to Drawdown at locations where pumpage (or Recharge) are Decision Variables. Dynamic.	61-7	U.S.	U.S.G.S	Maddock* (72)
Optimal Mining of A Basin	Groundwater Basin 2D Linear	Pumping Wells, Farms (Irrigated)	Water Level	Pumping rate in each time step Irrigated Acreage of crops	Water level below which wells are excluded	Acreage of crops		NET Benefit for Each farm (Annual) Net Benefit for Entire Basin (Long Term)	Simulation followed by L.P. at each time point	Reference	Yes	Research	Steady Recharge. Evapotranspiration. Crop Production Function. Depth-dependent water cost.	61-3	U.S.	U.S.G.S	Bredehoeft Young (72)
Optimal Cropping and Pumping Pattern	Single Aquifer Linear	Irrigated Farm Wells	Drawdown	Pumpage, Acreage of Crops	Drawdown, Acreage	Consumptive use of crops		Net Benefit from Farming	Simulation (response functions) followed by Q. P.	No	No	Model was developed for Research only	Regret Function as a measure of Economic loss given an incorrect decision because of errors in parameter estimation. In combination with Bayesian Decision Technique this function is used to rank data by priority for further data collection. Dynamic. Large storage requirement.	61-9	U.S.	U.S.G.S.	Maddock (73)
Economic Incentives for Efficient Groundwater Management	"	Water Supply, Irrigated Farms	Drawdown	Pumpage, Drawdown, Acreage, Taxation and Rebate Rates	Drawdown	Acreage minimum water requit., pumping capacity		Net Revenue (2 levels) Basinwide & Each Farm	Decomposition Optimization by Q.P.	References Report	Yes	Hypothetical Case	Algebraic Technological Function. Quotas, Taxes, and Rebates. Pumpage below the Quota entitles to a Rebate, Pumpage above the Quota is Taxed. Each Year Taxes are redistributed among users with zero accumulation. Multilevel Optimization and Coordination. LaGrange Multiplier as cost or savings per unit digression from quota. Dynamic.	61-10	U.S.	U.S.G.S.	Maddock* and Haimes (75)

*Reported by Haimes & Das

From Bachmat, 1980.

TABLE A21*a*. Conjunctive Groundwater and Surface Water Management Models: Quantity—Lumped Models

Purpose	System: Hydrologic	System: Technologic	State variables	Statistics	Decision variables	Constraints: State	Constraints: Decision	Constraints: Others	Objective Function	Method	Documentation	Availability	Past Applications	Special Features	Identification: Model No.	Identification: Country	Identification: Institution	Identification: Modeler (year)
Policy planning - Development and Operation	Ground-water & surface water basins	Supply, use and production	Storage. Level of Development	Stochastic replenishment	Capacities Recharge Withdrawal Water Allocation	storage & capacity	allocation Development		Expected discounted net benefit	Stochastic D.P.	Complete (Hebrew) Reference (English)	yes	Field	Part of an integrated planning scheme. Loss due to deficit in supply, compensation for cutback in allocation. Salvage value. Multiple sources and users. **P.d. of state & objective	63-1U	Israel	Tahal	Schwarz (74)
	-	-	Storage	Stochastic input and demand	Pumpage Reservoir site		Site of facilities, supply	Demand	Expected cost of supply	Iterative L.P.	Listing and Description	yes	Research	Given demand. Nonlinear pumping cost. Linear decision rule. Chance constraints. Random parameters	63-2	U.S.	New Mexico Tech	Gelhar (76)
Policy planning - Operation	-	-		Stocastic replenishment and streamflow	Pumpage. Import. Allocation	storage & capacity	Pumping rate		Expected discounted net benefit	Stochastic D.P.	None	no	Field (once)	Value - iterative method for Markov chain. **P.d. of state & objective function.	63-3	U.S.	Montana State Univ.	Burt (62)
	-	-	Storage	Stochastic recharge	Pumpage Allocation		?		-	-	Not specified	unknown	Field (once)	Quadratic benefit function. Interaction between all sources of water	63-4	U.S.	Univ. Illinois	Saleem (69)
	-	-	-	Deterministic	Pumpage & recharge	capacity	Level of supply by higher models	Operating rules	Net benefit	Two: (a)Monte Carlo simulation (b)Monte Carlo linear programing	Hebrew	no	Field (many) Mostly simulation	Synthetic input produced by Monte Carlo methods. Part of an integrated planning scheme	63-5	Israel	Tahal	Gablinger (73)
	Ground-water surface water imported water			-	Source of supply			Demand	Minimum Cost	Out of kilter algorithm	Report	yes	Case study (example)	Network analysis as a screening tool for alternative water supply patterns and structures in a multisource and multiuser system. Shadow prices	63-6	U.S.	Univ. Illinois	Hamdan * Meredith (75)
Policy planning - Operation and pricing		Supply and use	Available water	Deterministic	Pumpage Price of water	supply	price		Net benefit	Segmential unconstrained minimization	?	?	Research	Multiple sources. Relationship between demand, supply and price.	63-7	U.S.	UCLA	Mobusheri* Grant (73)

* Reported by Haimes and Das

** P.d. - Probability density

From Bachmat, 1980.

TABLE A21*b*. Conjunctive Groundwater and Surface Water Management Models: Quantity—Distributed Models

Purpose	System: Hydrologic	System: Technologic	State variables	Decision variables	Constraints: State	Constraints: Decision	Constraints: Others	Objective Function	Method	Documentation	Availability	Past Application	Special Features	Identification: Model Number	Country	Institution	Modeler (year)
Operation of A Stream-Aquifer System under given rules	Inter-connected Aquifer & Stream Evapo-transpiration	Wells, Canals, Reservoirs, Irrigation	Storage	Pumpage Surface Water Delivery to Canals. Reservoir Operation	Capacities	Operational Rules	Prior Appropriation. Interstate Compacts. Demand	Mean Annual Value & Standard Deviation of Supply	Simulation & Accounting	None		Simulations of Water Management Alternatives in River Valleys (Many)	Response Functions. Operational Rules. Programmer Oriented. Dynamic.	A3-8	U.S.	U.S.G.S.	Taylor Luckey (73)
Optimal Water allocation for agriculture from a stream aquifer system	Coupled 2D Groundwater and Stream Flow	Irrigated Agriculture	Stream Flow	Pumpage, Recharge, Downstream supply, Acreage of crops		Surface Water for Irrigation	Maximum Acreage Pumping Capacity, Down-Stream flow, Water rights	Net Benefit From Agriculture	Simulation & L.P.	Reference	Yes	Field (once)	Static and dynamic options. Two Linear Programming Routines. One determines Cropping Pattern. The other allocates available water. Optimal solution not guaranteed as input to optimization is obtained from simulation, instead of simultaneous coupling of the two.	A3-9	U.S.	Resources for future U.S.G.S.	Young Bredehoeft (72)
Optimal Operation of a Stream-Aquifer System under Stochastic Demands	Coupled 2D Ground-water & Stream flow	Irrigated Agriculture	Ground-water level Stream flow	Stream withdrawal, Groundwater pumpage & recharge, Return flow to stream		Transfer from Stream to Aquifer. Reuse	Rights. Satisfaction of expected Demand	Expected Total Discounted Operating Cost	Simulation & Q. P.	Reference	Yes	?	Algebraic Technological Function from Groundwater Simulation. Minimum cost Management Rule. Sensitivity of Discounted expected cost and Operating Rule to the Variation in Parameter Value. Stochastic demand and Drawdown.	A3-10	U.S.	U.S.G.S.	Maddock* (74)
Maximization of yield from a water resource system	Ground Water-2D, Surface Water, Imported Water		Ground Water Levels or their Gradients	Pumpage	Draw-down	Pumping capacity, Annual Pumpage	Minimum Supply, Availability of Imported Water	Total Pumpage over Planning Period	L.P.	?	?	Example	Linear System. Influence Coefficients which are evaluated only for times and location of interest. Maximization of yield as an adequate objective for planning long term Aquifer exploitation when no constraints on budget and demands are considered.	A3-11	Israel	TAHAL	Schwartz* (73)
Optimal Operation of Limited Regional Water Resources by a Decentralized Management System	Ground-water Surface water Linear 2D	Agriculture & Industrial - municipal Water Supply	Head	Regional Authority Decisions: Inter-subregional Boundary Water Levels; Artificial Recharge in Subregions. Pumping Tax Rate. Local Agency Decisions: Flows across Subregional Boundaries Pumpage in Subregion, Import	Water Level, Pumping Capacity	Imported Water, Capacity of recharge Facility. Zero Flow Inter-subregional Boundary Condition	Artificial Recharge Cost Must Equal Tax Revenue Demand (?)	Cost of Water Supply	Decomposition. Simulation, Iterative Two-Level Optimization, Iterative Coordination	?	?	Hypothetical Case	Coordinated Planning Methodology for a Decentralized Water Management in a region Water Supply administered by several local Agencies, each controlling the development and Operation within a subregion, except for inter-subregional Boundary Conditions, Artificial Recharge Rate and Pumping Tax Rate which are controlled by a Regional Authority. The Tax Revenue is spent on an Artificial Recharge Facility for the Region. Decomposition provides for Independent Optimization of each Local Agency's cost Function which is not released to the Regional Authority. Computational efficiency needs improvement.	A3-12	U.S.	Case Western Reserve Univ.	Yu Haimes (74)
Optimal Operation of a large scale System	Multi-Aquifer System Coupled with Multi-Stream System. 2D, Linear	Multiple Users	Ground-water Head. Stream-flow Rate	Groundwater Pumpage. Surface water withdrawal. Artificial Surface water Recharge	Draw-down	Pumping Capacity. Recharge Capacity. Surface water withdrawal	Minimum Demand. Penalty for Depleting Surface Stream	Discounted net Benefit	Decomposition Simulation Optimization Reduced Gradient Coordination	Complete	Yes	Field: Once	Methodolgy for Analyzing a Complex Water Resource System. Algebraic Technological Function for a Multi-Aquifer System. Stream-Aquifer Response Functions. Hierarchy of Simulation Models. Iterative Coordination. Convergence of Hierarchical Coordination Scheme not guaranteed. Computational limitations due to high dimensionality. User oriented.	A3-11	U.S. " Israel Venezuela " "	Univ. " Company Univ. - -	Haimes Das Dreizin Garay Sarkar Beconegra (76)

*reported by Haimes & Das

From Bachmat, 1980.

TABLE A22. Conjunctive Groundwater and Surface Water Management Models: Quality and Quantity

Purpose	System		State variables	Statistics	Decision variables				Constraints			Objective Function	Method	Documentation	Availability	Past Applications	Special Features	Identification			
	Hydrologic	Technologic			Development	Operation	Allocation	Economics	State	Decision	Others							Model Number	Country	Institution	Modeler (Year)
Wastewater Treatment & Water Supply	groundwater & surface water + waste water. Lumped	Supply, use, production treatment	Quantity and quality (chemicals biological)	Deterministic		Pumpage Level of treatment	Source of Supply		Desired quality & quantity			Slack between desired and reached levels of state variables	Mixed integer programming	In French	no	test (once)	Screening model for managing little watershed. St..ic. Multiple sources and users. Multiple choices of sources and treatment levels. Bivalent/integer variables. Solution by standard packages. Calibration of economic parameters.	64-1	France	Ecole de Mines de Paris	Hubert (76)
Wastewater Treatment & Water Supply			As above plus thermal	-	Water works	Mode of supply	-		Quantity & quality of water supply		Reliability level	Slack between planned policy & implementation	Linear programming	In French	no	Planning of river basin management	Lumped. Multiple users sources and modes of supply. Screening model for managing large watershed.	64-2	France	Ecole de Mines de Paris	Hubert (74)
Groundwater Supply and Salinit. Control	Groundwater, 22 Surface water, Imported water.	Agricultural Production. Irrigation.	Groundwater Salinity			Groundwater Pumpage, Surface water Withdrawal, Water Transport	Water Import		Salinity of Irrigation Drainage		Irrigation Demand	Cost	Optimization of Salt Transport by L.P. Followed by Detailed Simulation (Characteristics)	Reference		Once on A Field Case	Salt Transport by Convection and Dispersion Least Cost C[illegible]abination of Distributing Groundwater and Surface Water over the Basin within prescribed Salinity and Irrigation Requirements. Ground and Surface Waters not Connected.	64-3	U.S.	Colorado State University & University of California	Helweg Labadie (76)

<u>From</u> Bachmat, 1980.

AMERICAN EQUIVALENTS OF EGYPTIAN ARABIC TERMS AND MEASURES COMMONLY USED IN IRRIGATION WORK

LAND AREA	IN SQ METERS	IN ACRES	IN FEDDANS	IN HECTARES
1 acre	4,046.856	1.000	0.963	0.405
1 feddan	4,200.833	1.038	1.000	0.420
1 hectare (ha)	10,000.000	2.471	2.380	1.000
1 sq. kilometer	100×10^4	247.105	238.048	100.000
1 sq. mile	259×10^6	640.000	616.400	259.000

WATER MEASUREMENTS	FEDDAN-CM	ACRE-FEET	ACRE-INCHES
1 billion m^3	23,809,000.000	810,710.000	
1,000 m^3	23.809	0.811	9.728
1,000 m^3 /Feddan (= 238 mm rainfall)	23.809	0.781	9.372
420 m^3 /Feddan (= 100 mm rainfall)	10.00	0.328	3.936

OTHER CONVERSION		METRIC	U.S.
1 ardab	=	198 liters	5.62 bushels
1 ardab/feddan	=		5.41 bushels/acre
1 kg/feddan	=		2.12 lb/acre
1 donkey load	=	100 kg	
1 camel load	=	250 kg	
1 donkey load of manure	=	0.1 m^3	
1 camel load of manure	=	0.25 m^3	

EGYPTIAN UNITS OF FIELD CROPS

CROP	EG. UNIT	IN KG	IN LBS	IN BUSHELS
Lentils	ardeb	160.0	352.42	5.87
Clover	ardeb	157.0	345.81	5.76
Broadbeans	ardeb	155.0	341.41	6.10
Wheat	ardeb	150.0	330.40	5.51
Maize, Sorghum	ardeb	140.0	308.37	5.51
Barley	ardeb	120.0	264.32	5.51
Cottonseed	ardeb	120.0	264.32	8.26
Sesame	ardeb	120.0	264.32	
Groundnut	ardeb	75.0	165.20	7.51
Rice	dariba	945.0	2081.50	46.26
Chick-peas	ardeb	150.0	330.40	
Lupine	ardeb	150.0	330.40	
Linseed	ardeb	122.0	268.72	
Fenugreek	ardeb	155.0	341.41	
Cotton (unginned)	metric qintar	157.5	346.92	
Cotton (lint or ginned)	metric qintar	50.0	110.13	

EGYPTIAN FARMING AND IRRIGATION TERMS

fara = branch
marwa = small distributer, irrigation ditch
masraf = field drain
mesqa = small canal feeding from 10 to 40 farms
qirat = cf. English "karat", A land measure of 1/24 feddan, 175.03 m^2
qaria = village
sahm = 1/24th of a qirat, 7.29 m^2
saqia = animal powered water wheel
sarf = drain (vb.), or drainage. See also masraf, (n.)

EGYPT WATER USE AND MANAGEMENT PROJECT

PROJECT TECHNICAL REPORTS

NO.	TITLE	AUTHOR
PTR#1	Problem Identification Report for Mansuriya Study Area, 10/77 to 10/78.	Egyptian and American Field Teams.
PTR#2	Preliminary Soil Survey Report for the Beni Magdul and El-Hammami Areas.	A. D. Dotzenko, M. Zanati, A. A. Abdel Wahed, & A. M. Keleg.
PTR#3	Preliminary Evaluation of Mansuriya Canal System, Giza Governorate, Egypt.	American and Egyptian Field Teams.
PTR#4	On-farm Irrigation Practices in Mansuriya District, Egypt.	M. El-Kady, W. Clyma & M. Abu-Zeid
PTR#5	Economic Costs of Water Shortage Along Branch Canals.	A. El Shinnawi M. Skold & M. Nasr
PTR#6	Problem Identification Report For Kafr El-Sheikh Study Area.	Egyptian and American Field Teams.
PTR#7	A Procedure for Evaluating the Cost of Lifting Water for Irrigation in Egypt.	H. Wahby, G. Quenemoen & M. Helal
PTR#8	Farm Record Summary and Analysis for Study Cases at Abu Raya and Mansuriya Sites, 1978/1979.	F. Abdel Al & M. Skold
PTR#9	Irrigation & Production of Rice in Abu Raya, Kafr El-Sheikh Governorate.	Kafr El-Sheikh Team as Compiled by T. W. Ley & R. L. Tinsley
PTR#10	Soil Fertility Survey in Kafr El-Sheikh, El Mansuriya and El-Minya Sites.	M. Zanati, P. N. Soltanpour, A.T.A. Mostafa, & A. Keleg.
PTR#11	Kafr El-Sheikh Farm Management Survey Crop Enterprise Budgets and Profitability Analysis.	M. Haider & F. Abdel Al
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PTR#21	El-Hammami Pipeline Design.	Fort Collins Staff Team
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MAN.#5	Precison Land Leveling Data Analysis Program for HP9825 Desktop Calculator	T. W. Ley
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MAN.#9	Alphabetical List of Some Crops and Plants with Their English, Egyptian, Botanical & Arabic Names and Vocabulary of Agricultural and other Terms Commonly Used.	G. Ayad
MAN.#10	EWUP Farm Record System	Farouk Abdel Al, David R. Martella, and Gamal Ayad

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