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RESEARCH MEMORANDUM

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**ALTERNATIVE WATER MANAGEMENT SCENARIOS FOR SAUDI ARABIA**

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**FEW 344**

# ALTERNATIVE WATER MANAGEMENT SCENARIOS FOR SAUDI ARABIA

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*The socio-economic future of the Kingdom of Saudi Arabia will to a large extent depend on the succesful matching of its extremely limited water resources with demands for water primarily determined by population growth. The paper reviews and roughly quantifies the demand and supply parameters and then proceeds to analyze 4 scenarios for water resources management according to 4 different strategies.*
*The multiobjective approach uses Goal Programming, and the most significant output parameters appear to be the conceptual "water sector cost", and the future rate at which non-renewable groundwater will be mined and exhausted, thereby endangering the Kingdom's water security.*
*The Goal Programming methodology provides decision makers with the necessary and sufficient information to use good judgement in making rational choices from among several water development strategies for the Kingdom, while being aware of the trade-offs involved.*

## 1. Introduction

It has been accepted practice in many developing countries to take it for granted that basic resources, such as air, manpower, water and money, will be available to pursue a given mix of development goals. Occasionally it may have been more expedient to import, or borrow, some of those resources, particularly manpower or money, but nature is always counted on to provide the basic physical framework of national wealth, particularly in terms of land and water.
It now appears that in many areas water may become a powerful, and painful, constraint on economic development. In some countries critical questions about future water availa-

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bility now need to be faced by decision makers. The concept of "water security" is demanding as much governmental attention as the preservation of territorial or economic integrity.
Therefore, it is becoming increasingly important that officials with water management responsibilities have available, and use, resource allocation techniques which are not only easy to understand, but which also provide sufficient and useful information to permit the selection of the "best" water management scenario to satisfy a particular country's objectives.
In the following paragraphs an assessment will be made of the implications of a few selected scenarios of water resources development in the Kingdom of Saudi Arabia. The major constraining parameters will be reviewed, the first one being population, since it determines, directly or indirectly, the nature and scope of society's demands on the available water resources. Thereafter, the resources and uses will be roughly quantified, as well as the costs involved in putting those resources to a beneficial use.
Finally, a few plausible scenarios are examined to evaluate some management options and their consequences.

## 2. Population.

Saudi Arabia is the dominant country on the Arabian Peninsula. In demographic terms it has experienced most of the effects of the regional economic expansion of the past few decades. The country is very lightly populated and the rather sudden growth of the oil-producing sector of the economy attracted many expatriates. Moreover, as a consequence of its custody of two of Islam's holiest shrines the Kingdom yearly receives millions of foreign visitors, some of whom try to prolong their stay for employment reasons.
By 1984 expatriates constituted about 23% of a total population of about 11,000,000 [1]. Figure 1 illustrates the recent growth pattern of the population as estimated by E.S.C.W.A. [2]; the population growth rate for nationals has been found to be in the range of 3.6% [3] to 4.8% [4] per annum, but from a municipal water supply point of view the "total" demand is the one to consider. Therefore, the third curve, based on a 3% growth rate, is proposed as a conceivable compromise for planning purposes only, taking into account an expected gradual reduction in the expatriate segment of the population.

## 3. The Uses.

*- Domestic/Industrial uses.*
The demands placed on the resources by urban dwellers may be categorized as domestic or in-house uses; parallel to those

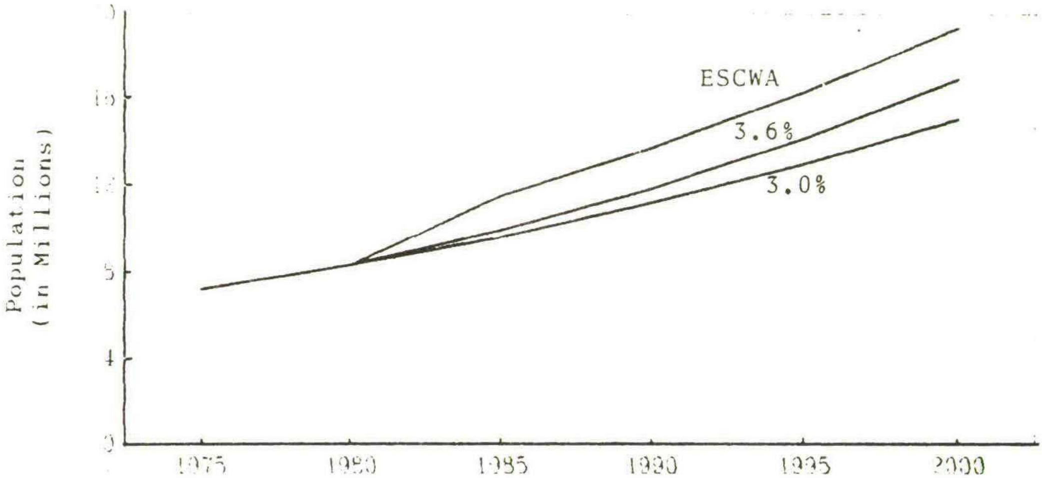


Figure 1. Population growth.

there are other municipal uses, such as industry, firefighting, system leakage, etc. Domestic uses include cooking, cleaning and sanitary needs; such water is normally provided through service connections to a municipal water distribution system and therefore this category also includes most small industrial and commercial establishments, which use the same distribution system. The quality standards applicable to this category are those for potable water, even though many of the specific uses could safely be satisfied with water of poorer quality.

An estimate of 1400 MCMY for the combined Municipal and Industrial uses in 1985 was included in the 4th Development Plan [3], 50% of which will be used here to represent the demands by residences and commercial establishments. This would imply a consumption of about 176 l/cap/day for in-house domestic demand, which is comparable with other localities in the region.

The rate of growth is likely to be close to the net rate of growth of the population, around 3% per annum, unless stringent conservation measures would be enforced.

- *Horticultural Irrigation.*

The use of water for horticultural or landscape irrigation has seen a marked growth in all urban areas of the Gulf States. It is a use that is difficult to quantify because for this category, which is frequently carried out in part by municipalities for the enjoyment of the public, usually no records are required or kept.

A recent case study [5] of a large company headquarters' compound in the Kingdom's Eastern Province suggested that horticultural irrigation may account for as much as 60% of all its "municipal" uses, although this case should not be considered as representative since landscaping standards for that particular community appear to be higher than those of the average local municipality.

In line with the preceding paragraph 50% of 1400 MCMY is assumed to be used for non-productive horticultural irrigation of gardens and parks. The assumption is further made that a gradual awareness of the cost of water will result in a stagnating, rather than a growing, demand in this category.

- *Agricultural irrigation.*

The hydrology, climate and soils of the Kingdom are not generally conducive to the pursuit of agriculture. Date palms, which are fairly tolerant to salinity, appear to thrive regardless of the quality of the water, but the irrigation of most other crops requires water with no more than about 3000 ppm TDS. The Kingdom possesses significant quantities of groundwater of that quality. The development of the agricultural sector was analyzed in a series of detailed Area Resources Surveys, and a summary of those [6] provides a useful insight into the amounts of water actually used for agriculture. More recently the Ministry of Agriculture and Water published statistics for areas under cultivation [7], as well as estimates of crop water requirements in the Kingdom [8]. This permits a fairly accurate assessment of total agricultural water use.

Table 1. Agricultural water requirements (1985).

| Crops<br>- | Area<br>(ha) | Spec.Water Req.<br>(m3/ha/year) | Gross Water Req.<br>(MCMY) |
|---|---|---|---|
| Wheat | 587,400 | 8,000 | 5,874 |
| Coarse Grains | 46,200 | 11,000 | 678 |
| Vegetables | 92,500 | 14,000 | 1,992 |
| Fodder | 145,100 | 32,000 | 5,804 |
| Dates and Fruit | 75,200 | 32,000 | 5,348 |
| TOTAL | 946,400 | - | 19,695 |

A similar total could also have been approximated by utilizing the guidelines for crop water requirements published by F.A.O. [9] with appropriate assumptions, but in view of the site-specific quality of the local observations on which the above table was based it is preferred. A 1980 estimate was calculated, again using statistics from reference [7], whilw projections were based on a 3%/annum growth rate.

## 4. The Resources.

The water resources available to the Kingdom to meet the demands outlined earlier will be discussed briefly under seven convenient headings, together with an attempt at rough quantification.

*- Fossil groundwater.*
Most of the groundwater is derived from storage, primarily from the large primary aquifer systems underlying the Central and Eastern regions of Saudi Arabia. Most of the water in storage is "fossil", deposited in much earlier times, and it has no relation to the current hydrologic regime. It is, therefore, not an "available" resource from a long-term planning point of view. For management purposes its availability is 0 MCMY, although temporary and limited withdrawals are possible.
Its volume has been estimated to be between 337,500 MCM and 500,000 MCM [3], and no serious studies have been published indicating that those estimates may be substantially in error. Many potential problems stand in the way of full utilization of this water, particularly the likelihood that water quality will deteriorate with deeper withdrawals. On the other hand more detailed investigations may yield some additional usable reserves. On balance it appears prudent to

consider 500,000 MCM as a proven reserve, and it was adopted here as being available in 1980.

- *Renewable groundwater.*
The unconsolidated deposits along streambeds, and even some of the primary aquifers referred to above, receive periodic recharge, the magnitude of which has been estimated at 950 MCMY [3]. This renewable portion of the groundwater resource used to be slightly smaller, but it is assumed that from 1985 the effects of the numerous recharge dams in the Kingdom have safeguarded this resource at the level mentioned above.

- *Surface water.*
Only immediately after short intense storms is surface water present in the Kingdom, and its utility derives in part from its contribution to the recharge of the aquifers hydraulically connected to the streambeds, and in part from its availability for diversion and direct spate flow irrigation. The magnitude of this resource has been estimated at about 900 MCMY [3].

- *Seawater.*
The major use of seawater is as the feed water of desalination plants and as such it is in practice not subject to an upper limit. However, since current desalination technology relies almost exclusively on the use of fossil energy, this water resource is also non-renewable and its (temporary) availability is equated to the capacities of the desalination plants. Reference [3] suggests production capacities of 63 MCMY and 400 MCMY for 1980 and 1985 respectively. A plateau of 700 MCMY is assumed for later years.

- *Wastewater.*
After suitable treatment, wastewater is becoming an increasingly appreciated resource; the technology is well tested, but optimum uses require urban surroundings and adequate collection and treatment facilities, conditions which are partially met only in the Riyadh, Jeddah and Dammam urban conglomerates. Reference [3] estimates this resource to amount to 100 MCMY in 1985, and it appears reasonable that its availability will relate to the growth of the municipal demand, as represented by the curve for Total Population in Figure 1. Therefore, values of 119, 143 and 170 MCMY will be used for 1990, 1995 and 2000 respectively.

- *Loss reduction.*
Sometimes it is feasible to reduce, or eliminate, certain natural losses occurring in various stages of the hydrologic cycle. In Saudi Arabia that might include the suppression of evaporation from sabkahs, the capture and storage/recharge of excess surface water, or the interception of subsurface outflows in the form of offshore springs. However, the most promising recharge dam sites have already been utilized, and

other schemes may only yield brackish water. Hence, this category was not taken into account.

- *Imported water.*
From time to time the practicality of water importation has been demonstrated. Conveyance may be by pipelines, open channels, or tanker vessels. The latter approach appears to be the only practical alternative for the Kingdom, and either the back-haul (oil tanker) or shuttle (water tanker) mode could be used. Provided that suitable off-loading facilities are available this resource could be mobilized on rather short notice, and a wide range of foreign supply points is available [10].
Quantification of this resource is essentially a function of the availability of facilities and of a management decision to mobilize the resource. Rather arbitrarily, the amounts of 100, 400 and 1000 MCMY for the years 1990, 1995 and 2000 respectively will be used.
The possibility of constructing a water pipeline from Turkey to both the Eastern Province and the West coast has been mentioned in press reports, but in the face of formidable technical, hydrological, financial and political stumbling blocks this alternative is unlikely to be realized by the end of this century.

Table 2 summarizes the quantification of various Uses and Resources, as described in the preceding paragraphs.

Table 2. Summary of Uses and Resources.

| Year ---> | 1980 | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| USES: | | | | | |
| Domestic/Industrial | 604 | 700 | 811 | 941 | 1,091 |
| Horticultural | 604 | 700 | 700 | 700 | 700 |
| Agricultural | 14,000 | 20,000 | 23,000 | 26,900 | 31,200 |
| RESOURCES: | | | | | |
| Fossil Groundwater | 0 | 0 | 0 | 0 | 0 |
| Renewable Groundw. | 660 | 950 | 950 | 950 | 950 |
| Surface Water | 485 | 900 | 900 | 900 | 900 |
| Seawater | 63 | 400 | 700 | 700 | 700 |
| Wastewater | 86 | 100 | 119 | 143 | 170 |
| Loss reduction | 0 | 0 | 0 | 0 | 0 |
| Imported Water | 0 | 0 | 100 | 400 | 1,000 |
| Deficit | 13,914 | 19,050 | 21,742 | 25,448 | 29,271 |

## 5. The costs.

The process of mobilizing specific resources to satisfy specific demands involves costs for a combination of items, such as acquisition, production, treatment, transportation, distribution, etc. Perhaps the major factor determining cost is the relationship between the quality of the source water and the quality standards to be met for specific uses. For instance, there is a major difference between the treatment cost of groundwater (e.g. 3000 ppm) for agricultural use (e.g. 2000 ppm), and demineralizing seawater (e.g. 50,000 ppm) for domestic consumption (e.g. 500 ppm). These costs are now fairly well established in the Gulf region and average values can be obtained from practitioners in the field or from technical reports; working values are introduced into the planning model in the next section (See Figure 2).

The cost of "producing" fossil groundwater deserves special mention. The very fact that a resource is non-renewable implies that its present use creates a problem for future generations: the "mining" of fossil groundwater today endangers "water security" in the future. This means that the use of the fossil groundwater resource is acceptable only if the present users make adequate provisions to compensate the future users for the economic injury they are bound to suffer. For the purpose of this discussion it is not necessary to examine in detail the various forms those provisions could take, but for the sake of quantification one could envisage that the present users establish a bank account in which they deposit, for each unit volume of water extracted from fossil storage, a certain sum of money or a "penalty". The size of this penalty should be such that its future value, N years later, would be sufficient to permit future generations to produce the same unit volume of water using the then most economically available method. Most likely such future production in the Saudi Arabian context would utilize a combination of desalination and importation.

The following assumptions serve to complete the quantification process:

a) Discount rate: 10% per annum.

b) Year of depletion of fossil groundwater: 2000.

c) Future (2000) alternative production cost: 20 SR/$m^3$.

d) Present extraction cost: 2 SR/$m^3$.

If, within the above framework, today's extractors would set aside 4.31 SR/$m^3$, an amount to be increased continuously as time passes, then future users in the year 2000 and beyond would be able to afford an alternative resource to replace the fossil groundwater, which by that time will have been depleted. The actual 1985 production "cost" would thus be 2 + 4.31 = 6.31 SR/$m^3$, which would gradually increase to 20 SR/m3 in the year 2000. Production costs for the less demanding irrigation uses are assumed to be about 30% lower. Unit costs thus calculated are incorporated in Figure 2.

These production costs actually include other increasing components, since dropping water levels require increased pumping lifts, and increasing salinities require more treatment. However, those aspects have not yet been identified with adequate precision and they are not taken into consideration here.

It appears reasonable, and perhaps even necessary, to include provisions for "social" or "future water security" costs in any planning exercise, because it will give today's decision makers a better and more realistic understanding of the trade-offs inherent in choosing from among alternative development strategies.

## 6. A scenario assessment.

In more humid climates major uncertain determinants in water planning are the stochastic parameters of precipitation and streamflow, and man's decisions are of secondary importance. However, the water sector of Saudi Arabia, depending almost exclusively on man-made extraction and production technology, lends itself conveniently to an exercise in decision-making.
In order to compare a few scenarios the Goal Programming (GP) algorithm is used. This technique is a multiobjective linear programming approach, which requires input data on resources (upper constraints on water availability), on uses (lower constraints on water needs), on costs (unit costs and a budgetary constraint), and on priorities or preferences. The latter represent the decision-maker's concept of which constraints are the more important ones, and the composite of those priorities may be called a "policy" or a "strategy". The output of the GP model presents values for the decision variables, i.e. the allocations of the resources over the uses in order to satisfy to the highest extent possible the priorities specified by the decision-maker. Each set of allocations represents a "scenario", corresponding to a given "policy".
For detailed discussions of the GP technique the interested reader is referred to the textbooks by Lee [11] and Ignizio [12], or to the numerous articles published in the Planning or Operations Research literature. A description of the model formulation used here was provided by de Jong and Al Layla [13].

A base scenario A was formulated according to a policy based on the following major priority components:

- All projected demands need to be met.
- All renewable water resources need to be used in full.
- All water treatment/production facilities need to be used to capacity.
- Water importation may, or may not, be initiated.
- Cost is of secondary importance.
- Any deficits are to be met from mining fossil groundwater.

This scenario was applied to the years 1980, 1985, 1990, 1995 and 2000. Figure 2 illustrates the input data for the year 1985, including qualitative (QC) and quantitative (RC) values for the constraints, priorities (+ or -), and the unit costs (UC) referred to in section 5. It also shows the values of the outputs i.e. the decision variables "$X_i$" and

Emirate The Kingdom or Region — Year: 1985

| DEMANDS OR USES → / RESOURCES ↓ | 8.Domestic/Ind. consumption | 9.Horticultural irrigation | 10.Agricultural irrigation |
|---|---|---|---|
| | QC: 500 | QC: 2000 | QC: 3000 |
| | RC: 700 | RC: 700 | RC: 20 000 |
| | + 1.1 / - 1.5 | + 1.1 / - 1.5 | + 1.1 / - 1.5 |
| 1.Fossil groundwater | | | |
| QC: 3500 / - 4.5 | UC: 6.31 | UC: 6.31 | UC: 7.22 |
| RC: 0 / - 1.2 | $x_1$ = 700 | $x_2$ = 700 | $x_3$ = 17650 |
| 2.Renewable groundw. | | | |
| QC: 1000 / + 1.5 | UC: 3.00 | UC: 2.00 | UC: 2.91 |
| RC: 950 / - 1.1 | $x_4$ = 0 | $x_5$ = 0 | $x_6$ = 950 |
| 3.Surface water | | | |
| QC: 800 / + 1.5 | UC: 2.00 | UC: 1.00 | UC: 1.91 |
| RC: 900 / - 1.1 | $x_7$ = 0 | $x_8$ = 0 | $x_9$ = 900 |
| 4.Seawater | | | |
| QC: 50000 / + 1.5 | UC: 25.00 | UC: 22.00 | UC: 22.91 |
| RC: 400 / - 1.5 | $x_{10}$ = 0 | $x_{11}$ = 0 | $x_{12}$ = 400 |
| 5. Wastewater | | | |
| QC: 10000 / - 1.5 | UC: 6.00 | UC: 4.00 | UC: 2.91 |
| RC: 100 / - 1.5 | $x_{13}$ = 0 | $x_{14}$ = 0 | $x_{15}$ = 100 |
| 6. Loss reduction | | | |
| QC: 2000 / - 1.1 | UC: 4.00 | UC: 2.00 | UC: 2.91 |
| RC: 0 / - 3.1 | $x_{16}$ = 0 | $x_{17}$ = 0 | $x_{18}$ = 0 |
| 7.Imported water | | | |
| QC: 1000 / + 1.1 | UC: 9.00 | UC: 8.00 | UC: 8.91 |
| RC: 0 / - 3.1 | $x_{19}$ = 0 | $x_{20}$ = 0 | $x_{21}$ = 0 |

11.Cost. RC: 0 + 2.1 - 1.4

K85 A

Legend: QC = Quality Constraint (in ppm)
RC = Rate Constraint (in $10^6$ $m^3$/year)
UC = Unit Cost for production (in SR/$m^3$)
$x_i$ = Flow rate, the decision variables (in $10^6$ $m^3$/year)
+ or - = priority for minimizing the deviational variables
The RC for item 11 is expressed in $10^6$ SR/year.

Deviational variables: $x_1^+$ = 19050  $x_{11}^+$ = 149 815

Figure 2. The modelling framework (1985).

any non-zero deviational variables "$d_i$". Figure 2 is in fact an input/output worksheet.

Three other scenarios were examined for the years 1990, 1995 and 2000.
Scenario B stipulated that:

- All demands are reduced by 10%, reflecting the introduction of a modest conservation program.
- Unconventional resources, such as importation, are given more weight.
- The lower limits on the demands are relaxed.

Scenario C put more emphasis on cost, while stipulating a 30% reduction of the demands envisaged sub A, as a result of a stringent conservation effort. However, no underachievement in supply is tolerated and the "technological" resources, such as wastewater, desalinated water and imported water, are to be utilized in full, if necessary.
Scenario D reflects an attempt to return to a "water secure" strategy in 15 years, by eliminating water mining altogether. All other resources are fully utilized, including a fairly high level of importation. The necessary tradeoff in this case is a further reduction of water use for irrigation, of both the horticultural and agricultural types.

In terms of the decision variables the outputs reveal little of interest, but the important parameters are the deviational variables representing the amounts of fossil groundwater to be mined ($d_1^+$), and the total cost of the water sector ($d_{11}^+$). These parameters are plotted in Figures 3 and 4 for the four strategies described earlier.

## 7. Discussion.

### *a) Groundwater mining.*

The most basic question of growing local concern is: How long will the fossil groundwater last? Obviously, this depends both on the volume in storage and on the rate of extraction. In section 5 it was stipulated that 2000 would be the year of depletion, which is in fact an outcome of Strategy A; different strategies will yield different depletion patterns.
The proven magnitude of this storage is a matter beyond the scope of this paper. It involves not only questions of hydrogeology and hydrochemistry, but also of international water law, because water in the major fossil aquifers is shared by several countries in the GCC region. Therefore, the "storage" available to any one of those countries is as much a physical fact as a matter of agreed-upon international allocation.
Water security for the Kingdom will in the final analysis depend both on the selection of a wise strategy for fossil

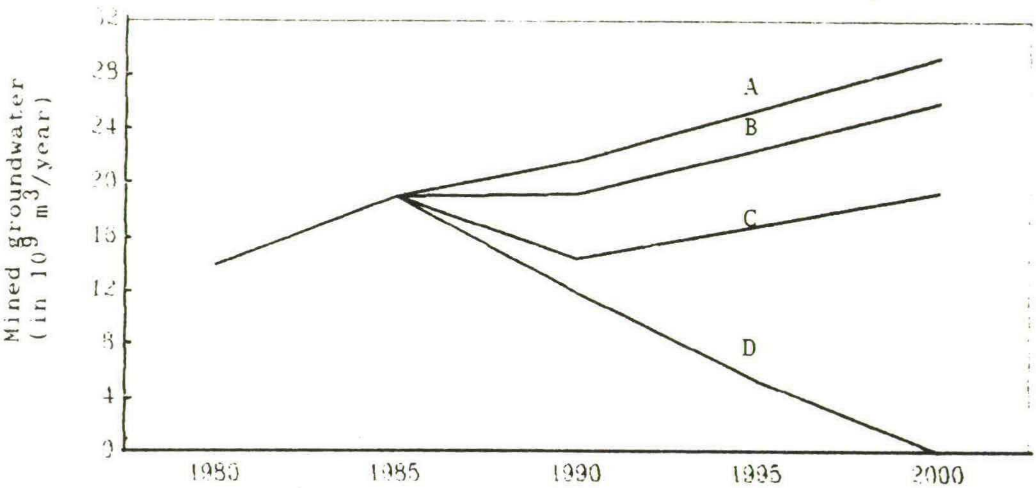


Figure 3. Future trends in groundwater mining.

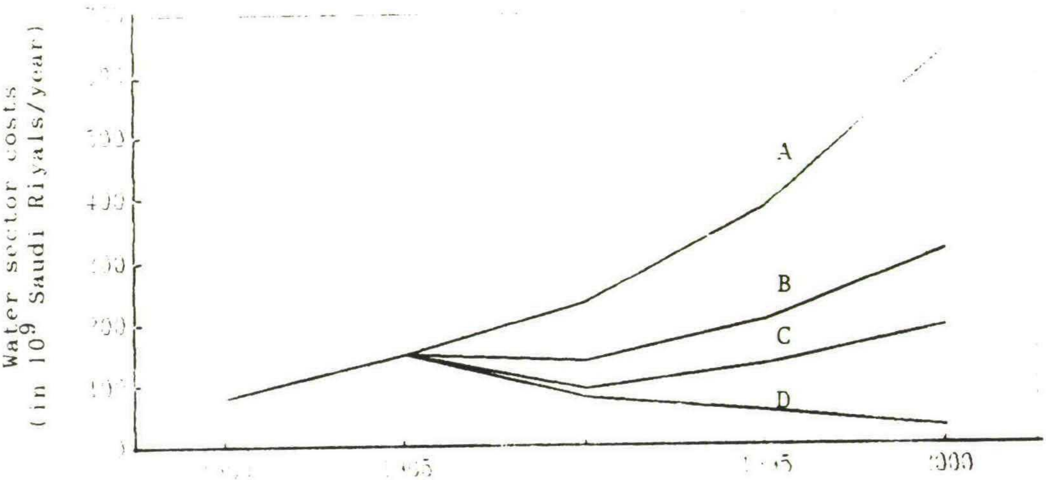


Figure 4. Projections of water sector costs.

groundwater extraction and on a considerable amount of international cooperation.

*b) Water sector cost.*

The grand total of all costs incurred to satisfy the various demands may be called the "water sector cost". Theoretically this figure would be equal to the sum of the budgets of all public and private entities involved in supplying water to various users. In the present context it is more appropriate to view it only as a financial indicator of the impacts of alternative strategies on the economy. As such it serves a useful function by clarifying to the decision-maker the magnitude of the burden on the economy associated with satisfying all perceived water needs.

*c) Unit costs.*

The unit costs for scenario A are shown in Figure 2. For the 3 Fossil Groundwater items those costs were based on a depletion by the year 2000, as assumed in section 5. The other scenarios yielded delayed depletions of the same storage volume, thus reducing the unit costs and hence the total water sector costs.

*d) Agricultural water use.*

It is obvious from the foregoing that the major threat to the Kingdom's water security comes from the rapid increase in the use of non-renewable water for agricultural irrigation. This policy is providing short-term and partial "food security" in exchange for long-term "water security". The GP technique allows for a rapid testing of the trade-offs between those two securities by modifying various priorities.

*e) Conservation.*

Strategies aimed at "water security" are of necessity predicated on the succesful implementation of conservation. It may be desirable to set different target levels for conservation, such as a mandatory 15% reduction and an advisable 15%. The GP model is easily adapted to treat such levels with different priorities.

*f) Interaction.*

The Goal Programming technique is based on the assumption that the user (the Decision-Maker) has selected his priorities in advance. In practice, however, the consequences of various combinations of priorities and strategies may prompt the user to test slightly different alternative approaches. To this end it is useful to test a range of strategies by making minor changes in the stipulated priorities; such a sequence of re-runs approaches a truly interactive modelling exercise.

## Postscript.

In the absence of comprehensive and reliable data a scenario assessment of the type described herein requires of necessity the introduction of personal judgements to fill many gaps with estimates. Professionals involved with strategic planning for Saudi Arabia's water supply may wish to utilize the same approach, while substituting their own judgement and better data.

The GP model runs were performed on an IBM Microcomputer, using the (modified) FORTRAN program listed in reference [11]. The authors are prepared, on request, to make available to interested readers the necessary software and a brief manual with annotated sample inputs and outputs at the cost of reproduction.


## Acknowledgement

Modelling work for this study utilized the facilities of the King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, and the support of Research Project KACST AR-6-134; these resources are gratefully acknowledged.


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