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Water Resources and Agricultural
Development Project

QATAR

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INTRODUCTION

1.1 PROJECT BACKGROUND

Prior to the late 1950s agriculture in Qatar was confined to a few farms and date gardens within the environs of Doha and some of the other main centres of the country, but from about 1958 onward the number of farms increased steadily to reach a total of over 350 by 1967 and in excess of 500 by 1980. This expansion in agriculture has, however, placed a considerable strain on the existing groundwater resources of the country and as early as 1967, a year in which total abstraction is estimated to have exceeded the normal recharge from rainfall, the Government of Qatar began to view with concern this continued over-exploitation of its groundwater resources. At that time, however, there was very little hydrogeological or other data upon which any reliable assessment of the extent of this probable over-exploitation could be made. In late 1971 therefore, Government with the technical assistance of the United Nations Development Programme (UNDP) and the Food and Agriculture Organization of the United Nations (FAO), initiated a project known as 'Hydro-Agricultural Resources Surveys' (QAT/ 71 /501). This preliminary project was brought to a close in 1973 ^{1/} after having established a hydrometeorological and groundwater observation network throughout the country, carried out a geophysical survey and the drilling of 10 exploratory wells, provided an initial quantitative assessment of the hydrological balance of Qatar, completed a soil reconnaissance and land classification survey and limited horticultural trials.

With these basic data as firm foundation, the Ministry of Industry and Agriculture, with the collaboration of the Water Department of the Ministry of Electricity and Water and increased

^{1/} See FAO. Hydro-Agricultural Resources Survey. Report on project results, conclusions and recommendations, Rome 1973. AGL DP QAT/71/501, Technical Report.

technical assistance by UNDP and FAO, initiated a second phase project in mid-1974 and known as 'Integrated Water and Land Use' (QAT/73/007). The objective of this expanded project was to carry out a wide range of studies and investigations arising from the previous project's recommendations aimed at achieving a close integration of the limited groundwater resources with agricultural production, taking into consideration also both present and future possible usage of water for municipal and industrial purposes, and to collect and analyse hydro-agricultural data pertaining to water supply and usage.

Between 1974 and 1977 this second phase project carried out a wide range of observations, investigations, experiments, trials and special studies. The hydrological and groundwater observational networks were modernized and expanded. Intensified observations of run-off, infiltration and recharge were carried out after heavy rainfall and these data supplemented by the drilling of a further 10 exploratory wells. The occurrence and movement of groundwater within Qatar was further evaluated by the introduction of environmental isotope studies, carried out with the collaboration of the International Atomic Energy Agency (IAEA). The boundaries of the freshwater aquifer of northern Qatar was accurately defined by a new geophysical survey. The total groundwater extraction rates for domestic and industrial purposes was determined and renewed agricultural abstraction survey was undertaken.

In the agricultural sector of project activities, a wide range of horticultural trials with local and newly introduced varieties and crops was performed over three consecutive summer and winter season at the Rawdat el Faras experimental station, to test response to improved cultivation practices. Irrigation practices and soil management studies to evaluate crop water requirements and water/yield ratios under improved water and soil management techniques, including drip irrigation trials, were carried out over two consecutive summer and winter seasons at the Barada experimental station. A farm management and production survey was undertaken over an 18 month period which provided basic data on the farming systems of Qatar. Work was initiated into controlled-environment greenhouses.

At the close of project operations in mid-1977^{1/}, the Government of Qatar decided to intensify these joint water resources and agricultural investigations particularly in the light of project results which clearly showed the potential for agricultural production under improved practices and especially with regard to water conservation. Consequently, a third phase project, known as 'Water Resources and Agricultural Development' was initiated in July 1977 with the continued assistance of a team of FAO experts but now under a Funds-in-Trust agreement with the Food and Agriculture Organization of the United Nations.

1.2 DESCRIPTION OF THE PROJECT

The objective of the project was to assist the Government in initiating the implementation of proposals and recommendations arising from the UNDP/FAO assisted project - Integrated Water and Land Use - for an 18-month period by which time it was expected that suitably qualified government staff would have taken over the implementation of these programmes. Specifically, the project was to :-

- (a) Continue the operation of the hydrometeorological, hydrological and groundwater data collection survey; assemble, analyse and store all data in a computerised retrieval system; introduce the regular publication of all data on an annual basis, provide data on regular basis to all government agencies and prepare to hand over all water resources data collection to Government at the appropriate time.
- (b) Continue to provide advisory services on water resources questions to all Government agencies and technically assist the Water Department in the monitoring of water resources and remote sensing investigations to be undertaken by consultants. To collaborate with consultants to the Water Department in the formulation of a groundwater model.

^{1/} See FAO. Integrated Water and Land Use. Report on Project findings and recommendations, Rome, 1978 AG : DP/QAT/73/007, Technical Report.

- (c) To examine, monitor and assist in specific water resources development proposals for agricultural development at farm level or for specific agricultural development projects, including recharge enhancement works.
- (d) To initiate an agricultural extension programme to disseminate information and assist private farmers in the raising of production through the appropriate improved technical agricultural and irrigation methods.
- (e) Continue to expand investigations into crop water requirements and new methods of irrigation (drip irrigation, shade irrigation).
- (f) Continue horticultural experimental work and expand this to production trials at farm level, if possible. Continue cooled greenhouse and controlled environment vegetable trials with the view to expanding these systems.
- (g) Continue soil management studies over a wider range of soils.
- (h) Assist in the establishment of a pilot farm on sandy soils in Abu Samra area of southern Qatar to investigate the possibilities of using moderately saline water for irrigation for the production of fodder and vegetable crops.
- (i) Undertake further investigations into cost/price relationships at farm level, a marketing survey and assist the Department of Agriculture in consolidating their statistics section, including training.
- (j) Assist the Department of Agriculture in the establishment, organisation and management of farm machinery hire centres.
- (k) Undertake a detailed evaluation programme of the full agricultural potential of Qatar, taking into account all technical constraints of water, soil climate and crop suitability. This analyses will be undertaken by consultants employing specialised techniques who will be appointed by the Ministry of Industry and Agriculture, based on basic data provided by the project.

Owing to delays in the recruitment of government staff intended to take over the duties of the FAO experts the term of project was extended, with a reduced team of experts, to April 1980. In December 1979 government requested a further extension of the project until 30 April 1981. Early in 1981, the Council-of-Ministers issued a comprehensive directive concerning the future of water resources and agricultural research in Qatar whereby provision was made for the establishment of a new government department to succeed and continue the work of the project. While it was never the intention that the project would play an institution-building role, the organization built-up over the years has evolved into an organization capable of continuing the work of the project.

The total cost of the three successive FAO-executed projects was \$ 2,717,489 of which UNDP contributed a total of \$ 511,026 to the first two projects.

1.3 PROJECT IMPLEMENTATION

The objective of this third phase project was to intensify investigations in certain areas and to initiate the implementation of proposals and recommendations arising from the former project. With the accumulated experience of some 6 years of prior investigations, this project was able to make significant strides towards concluding major unresolved problems as well as initiating new phases of work, particularly in the agronomy, soil management and extension fields.

In the hydrogeological sector a renewed, but closely supervised, drilling programme was carried out and 12 further exploratory wells were drilled. Geophysical logging of wells was undertaken and these data, together with those obtained from chemical and isotope analysis enabled the project to modify the previously held concept of a floating freshwater lens to a more complex, two-layered aquifer system in which all previous anomalies and unexplained features may now be reconciled. Based on these additional data a computerized mathematical model was devised and is now available for the testing of future aquifer behaviour under simulated or assumed future operating rules.

Irrigation investigations were expanded and concentrated on reducing water losses and improving irrigation efficiency. These investigations have included drip irrigation, different levels of water application, reducing conveyance losses and the introduction of sprinkler irrigation on an experimental basis. Soil management investigations were intensified and over 30 separate experiments involving physical, mechanical and chemical methods designed to improve the management and productivity of both heavy calcareous and sterile dune sands, were undertaken. Definitive conclusions and recommendations for their improved management have been made and this work is being continued.

In south-western Qatar the project established an experimental station in the dune sands of the Wadi el Araig region. At this station two seasons of agronomic experimental work on a wide range of field and fodder crops were completed and work is continuing. Agronomic screening nurseries were established in conjunction with ICARDA and other international research organizations where the performance of well over 100 entries of wheat, barley, sorghums and millets have been evaluated. The results of three years pilot work have been both impressive and encouraging and the Project has assisted the Ministry in framing terms of reference for further detailed investigations.

Horticultural investigations were expanded at the Rawdat el Faras experimental farm to production trials of known and tested varieties under improved management, the evaluation of methods designed to extend the growing season, by wind breaks, shading, misting systems and cooled greenhouses. This work led to the decision to expand experimental work in cooled greenhouses and in 1979 the project established a new experimental station at Al Otoriyah in central Qatar where 12 additional cooled greenhouses were erected. Other activities covered the economic analysis of vegetable production, and continued involvement in water resources and agricultural planning, the preparation of preliminary engineering designs and an investment feasibility study for the agricultural utilization of sewage effluent and other irrigation and drainage schemes.

In 1978 the project purchased a HP 9830 B computer with extended mass memory with the objective of creating a computerized water resources and agricultural data bank. By 1980 this objective had been achieved with a large volume of data archived in a computerized retrieval system with a full range of program packages. The computer facilities have also proved to be of the greatest value in developing the groundwater model and the solution of optimizing problems by linear programming and in the development of the master plan.

In 1978 a significant step was taken in the initiation of an agricultural extension programme. This programme, with a few co-operating farmers in the first instance, was designed to familiarize them with the results of experiments and trials conducted by the project and to assist in adopting them to increase agricultural production and net income. The FAO expert was withdrawn after 12 months and the programme taken over by the Department of Agriculture but owing to staff shortages much of the impetus has been lost. Similarly, the training of counterpart staff, implicit in the project objective, suffered from a lack of suitable candidates for further training.

A major objective of project operations was the preparation of an evaluation of the full agricultural potential of Qatar, taking into account all technical constraints of water, soil, climate and crop suitability. During the course of the project, however, it became clear that such an analysis could not be undertaken in isolation and that a systems approach was required. It was therefore decided to undertake the preparation of a master water resources and agricultural development plan by systems analysis with the assistance of specialised consultants in this field. As a first stage FAO appointed a consultant in systems analysis in May 1979 to determine the nature and extent of available data, subsequent to which specialised consultants in the field of systems analysis were invited to submit proposals. Owing to a series of delays final selection and the appointment of a consultant was not finalised until late 1980 and the study only commenced in January 1981 in the closing stages of the Project.

Five technical reports have been reproduced locally by the Project. These reports cover Agronomy (No.1), Soil Management (No.2), Horticulture and Extension (No.3), Irrigation Practices (No.4) and Water Resources (No.5). In addition, 56 technical notes, 9 technical papers and studies and 5 project proposals were published (See Appendix II) together with a summary technical report (Project Findings and Recommendations) and which was submitted to the Government of Qatar in September 1981.

1.4 RELATED ACTIVITIES

In 1978, two experts of the FAO Regional Land and Water Project (REM/508/MUL) were outposted to Qatar and were integrated into the project team to work on soil reclamation and irrigation practices. In 1980 the FAO Regional Marketing Information Project (REM/503/MUL) moved its headquarters from Cairo to Doha and was accommodated within the project building complex where it was assisted administratively and in computing facilities for the processing of marketing data.

In 1978, at the request of the Secretariat of the Congress of Ministers of Agriculture in the Gulf States and the Arabian Peninsula, FAO undertook a detailed survey and evaluation of available data on the groundwater resources of the entire region. This survey was undertaken by a team of consultants under the aegis of the FAO Regional Land and Water Project (REM/508/MUL) and all groundwater and other relevant data from Qatar were provided by the Project for this study. Project staff also collaborated in the final drafting of the report which was issued in four volumes in 1979.

During late 1979/early 1980 Shell Gas International Ltd. undertook a wide-ranging study of future energy and water demands for Qatar in connexion with the proposed development of the North Dome off-shore gasfield on behalf of the Qatar General Petroleum Corporation. With the possibility that large quantities of distilled sea water could be made available for agriculture as an integral part of any future development, the Project became closely identified with these proposals and provided much of the water resources, agricultural data and possible development options for consideration. In June 1980, Shell Gas International Ltd. decided to prepare a separate agricultural

proposal and engaged Messrs Hunting Technical Services of the United Kingdom to undertake the work over a period of two months. The team of consultants worked with the project staff in all fields and, with the prior approval of the Government, were provided with all available data.

CONCLUSIONS

2.1 LAND AND WATER RESOURCES AND UTILIZATION

Qatar has, over the past decade, enjoyed unprecedented economic growth which in large part has resulted merely from transforming oil into financial assets. However, in attempting to diversify the economy to attain some measure of self-sufficiency, particularly in food production, the country is faced with meagre and declining soil and water resources set in adverse climatic environment.

The total arable soils in the country cover some 29,600 ha of which 3,200 ha are at present under irrigation and some 800 ha has already been abandoned as a result of excessive water use and inefficient irrigation. Water is being extracted from the main northern aquifer system at nearly twice the rate of replenishment and the quality is deteriorating at a rate of 5 per cent per annum caused by sea water intrusion and upward diffusion of deeper saline water. To meet increased domestic and commercial demands for water, the fresh groundwater source has been supplemented by distilled sea water since 1964, growing in volume to provide almost 42% of total water consumption in the country by 1980. Total water use in Qatar in 1980 amounted to $125.4 \text{ Mm}^3 \text{ yr}^{-1}$ (million cubic meters per annum) of which:-

- $76.2 \text{ Mm}^3 \text{ yr}^{-1}$ is composed of fresh (500-2500 mg/l) groundwater of which 13.8 Mm^3 is returned to the upper aquifer as irrigation return.
- $3.3 \text{ Mm}^3 \text{ yr}^{-1}$ of brackish groundwater (3500-10,000 mg/l) is abstracted for agricultural use on sandy soils in SW Qatar and in the Doha area for blending with distilled sea water.
- $44.0 \text{ Mm}^3 \text{ yr}^{-1}$ of distilled sea water is supplied for exclusive domestic and commercial use of which approximately $14 \text{ Mm}^3 \text{ yr}^{-1}$ is lost in distribution and is recharging an aquifer under Doha where it is being polluted by leakage from sewers and overflow from septic tanks. Of the $28 \text{ Mm}^3 \text{ yr}^{-1}$ consumed directly approximately

35% or 8.4 Mm^3 is utilized in garden watering of which 20% (1.7 Mm^3) is also being returned to the aquifer.

- $1.6 \text{ Mm}^3 \text{ yr}^{-1}$ of treated effluent water is being used for the irrigation of municipal trees and parks.

The real (economic) cost of water in Qatar in 1980 has been determined to be as follows:

- QR $6.00/\text{m}^3$ for distilled sea water at existing distillation plants near Doha and QR $5.30/\text{m}^3$ for the proposed new plant at Ras Laffan with gas at world market price. If gas is considered as a free gift the costs are reduced to QR 4.15 and QR 4.25 per cubic meter respectively.
- QR $0.85/\text{m}^3$ for treated sewage effluent delivered to a site in Central Qatar.
- QR $0.25/\text{m}^3$ for groundwater abstracted by pumped well on a farm.

Conveyance costs, incorporating all capital, operators, maintenance and fuel costs (at the full economic cost) are estimated to range from 0.014 to $0.047 \text{ QR}/\text{m}^3/\text{km}$ depending upon the size of conveyor.

An important component of project investigations was the development of a computer-based mathematical model of the main northern aquifer system, which is the major source of fresh groundwater. This model has clearly shown the groundwater situation to be in a more precarious state than hitherto realised. Whereas it had always been assumed that the system behaved as a simple input/output aquifer where in some years recharge might just possibly exceed abstraction, this assumption is no longer tenable because of the geological control at the base of the upper aquifer inhibiting the downward flow of recharge to the higher yielding lower aquifer. Thus, while the upper aquifer is in approximate balance between recharge, (including irrigation return), outflow, transfer to the lower aquifer and limited abstraction the lower aquifer exhibits a progressively increasing deficit and where the freshwater reserve is being irreversibly displaced laterally by saline water.

In the eastern sector of the northern groundwater province there has been a progressive deterioration in water quality over the past decade and which may be directly related to an advancing saline front in this area. At the estimated rate of 1 km yr^{-1} many farms of this region will face increasing and serious salinity problems with the next decade. The fact that water levels have not declined substantially in recent years has unfortunately induced some complacency among land owners of this area. This is a paradox as there is no relationship between increasing salinity and declining water table.

In summary, the mathematical model of the somewhat complex aquifer systems shows:

- The total annual abstraction from northern Qatar in 1978/79 was 26.7 Mm^3 from the upper (Rus) aquifer and 25.1 Mm^3 from the lower (Umm er Radhuma) aquifer.
- The deficiency in both aquifers amounted to $26 \text{ Mm}^3 \text{ yr}^{-1}$ in 1978/79.
- At present abstraction rates the advance of the salt water interface is estimated to be at a rate of 1 km/yr^{-1} .
- At present abstraction rates the aquifers will be depleted in 20 years.

Of the greatest importance are the conclusions that

- One third of fresh groundwater abstraction amounting to $24 \text{ Mm}^3 \text{ yr}^{-1}$ is being utilized for the irrigation of trees, landscape areas, non-productive date palms and limited non-marketed production on amenity farms. This is equivalent to the safe yield of the aquifer which is being overdrawn by more than twice the rate of recharge.
- One third of all domestic water produced by the desalination plants is being lost by leakage in distribution and is recharging the formations under Doha where it is being polluted by sewage discharges.

Although the irrigated area represents only 11% of the arable land, soil and water management on existing farms is poor, with indicated irrigation efficiencies ranging from 35 to 60%. This low efficiency results from poor land levelling and layout, incorrect land preparation and a high irrigation frequency arising from a general lack of understanding of the optimum use of poor quality water on soils with a high calcium carbonate content. Careful land levelling is rare and irrigation layout is by small basins or furrows. Land preparation is normally performed by mould-board ploughing, resulting in large clod formation. This is followed by repeated disc harrowing, forming a hard crust on the surface which inhibits infiltration and seed emergence. With a poor quality irrigation water, of a total dissolved solids ranging from 1,000 to 2,000 mg/l with a high salinity hazard and low to medium sodium (alkali) hazard, there is usually a rapid build up of salts in the surface layers leading to reduction in yield and eventual abandonment.

2.2 AGRICULTURAL PRODUCTION

In 1980 there were 573 registered farms in Qatar of which 377 were in operation. Of these only 228 farms can however, be said to be productive. The remaining 149 farms may be regarded as amenity farms which serve as country estates for a number of leading citizens and do not participate in the production of crops for the market.

Total agricultural production in 1980 amounted to 30,000 tons. In terms of economic value, vegetable production is clearly the foremost agricultural enterprise accounting for 70% of the total value but only 40% of total production. At current (1981) prices the total national agricultural crop production is estimated to be QR 39 million and the value of produce actually sold as QR 19 million. This may be accounted for by production from 70 vegetable/fodder farms on average size of 18 ha using observed production factors. Thus, the average vegetable type farm realises a gross sales revenue of QR 273,000. The costs of production, including subsidised supplies such as seeds, herbicides, insecticides but excluding the cost of pumping water, would amount to QR 200,000 approximately. The value of government subsidy is estimated to be QR 22,500 and the net revenue of typical vegetable farm is therefore estimated to be QR 67,500 per annum which, after deduction of

pumping costs would be of the order of QR 35,000.

On the other hand considering the value of the total state production, either sold or otherwise disposed of, as QR 39,381,000 from 228 farms, the gross return per farm would be QR 173,700 and gross costs

(excluding pumping and subsidy value) would be QR 159,300. The net overall value of crop production per operating farm would therefore appear to be QR 11,000. To this should be added the value of mutton produced at QR 12,900 less the value of the crops consumed at QR 17,880, leaving an average net loss per farm of QR 15,500. It is concluded that the return to active farms would, with a few exceptions, lie between QR 67,000 and QR-60,000 depending on the amount of produce distributed traditionally instead of marketed.

The average tenant vegetable farmer probably earns an annual profit of about QR 67,000 but needs to meet annual working expenses of some QR 145,000 and living costs estimated to be QR 45,000 and his average return may amount to 12%. This highlights the hand-to-mouth situation endured by most tenant farmers in Qatar where then would probably only have available 3½ months supply of working capital whereas the majority of vegetable crops give a first yield only after 3-4 months. Elsewhere farm operating capital is usually provided through credit arrangements by co-operatives, land banks or by government itself under certain circumstances. In Qatar none of these sources are open to tenant farmers who are immigrant workers and what small amount of credit they may obtain is usually from friends, relatives or dealers in agricultural supplies as a form of deferred payment and, in rare cases, from vegetable wholesalers. Although landlords have access to credit from commercial banks very little of this is invested in the land either in the form of providing or renewing farm infrastructure or as loans to tenant farmers. The opportunity cost of investment in the urban sector is so very much lower under prevailing conditions that landlords very rarely invest in their farms leased to tenants.

On owner-operated farms, usually through a manager, which are predominantly of the orchard/forage type, it cannot be assumed that the intention is to derive profit from farming. In most cases the

landowner has an alternate source of income and which may be of the order of ten to twenty times that which could be generated by farming. To the landowner, a farm is considered as a country estate which furnishes him and his family with a fresh supply of produce and congenial alternative to life in Doha. The value of QR 60,000 must therefore represent the amenity value of the farm which cannot provide a return on capital running to several hundred thousands of riyals per farm.

In summary, it is concluded that

- Agricultural production in Qatar cannot be said to be an entirely viable commercial enterprise under present circumstances. An exception to this generalised statement are the small number of tenant farmers (less than one-fifth of all farmers) engaged upon exclusive vegetable farming in northern Qatar and who derive a small profit of about 12% of gross costs.
- Crop production is hampered by a number of serious constraints. Present levels of production per unit of water are low and on-farm investment and the provision of supplies are both sub-optimal. This stems from the non-commercial approach to farming decisions by many land-owners, insecurity of tenure by tenant farmers, the lower opportunity cost of investment in the rapidly developing urban sector, chronic labour shortages coupled with the low standard of farming skill by immigrant farm labour and poor land and water management.
- Agricultural production in Qatar may be greatly increased, by as much as 100%, on existing farms through a package of technical improvements whose value may be enhanced if the major constraints of land tenure and credit could be resolved in keeping with national policy.

3. WATER RESOURCES AND AGRICULTURAL DEVELOPMENT

3.1 INTRODUCTION

With large accumulated capital reserves and committed to an energetic development programme, one aim of which is to attain self-reliance in foodstuffs, the Government of Qatar is understandably anxious to undertake a considerable horizontal expansion of agriculture. However, the work of the project has clearly identified the circumscribed natural resource environment of Qatar and the many limitations and constraints militating against such an agricultural policy. The major limitation is the lack of an adequate water resource to sustain such an expansion and another is the adverse climate which imposes a severe constraint to diversified arable crop production on the limited area of arable soils.

In 1979 total food consumption amounted to 163,758 tons of which 20,525 or 13% was supplied from domestic sources, the bulk of which being fresh vegetables during the period January - May. By a simple projection based on estimates of future population the total food requirement by 2000 has been estimated to be 380,000 tons. Whilst in theory nearly all of this food requirement could be grown, in many instances the crops grown either do not produce in concert with demand or would not be fully acceptable as a replacement for imports. The degree to which the country could become self-sufficient in the potentially replaceable crops has therefore been re-assessed as follows:

Target replaceable food demands for Qatar
(tonnes and degrees of self-sufficiency (per cent)¹

Crop	1980		1990		2000	
	t	%	t	%	t	%
Milk	1400	4	4200	7	5600	7
Beef	—	—	180	11	240	11
Sheepmeat	400	6	3400	38	4500	38
Cereals	400	1	17000	29	23000	29
Dates	1600	52	2700	58	3700	58
Winter vegetables	8200	42	14000	47	18000	47
Summer vegetables	3600	68	6000	75	8100	75
Fruit	1400	9	2700	11	3700	11
Off-season cucumber	—	—	490	100	650	100

¹ The degree of self-sufficiency is the percentage of Qatar's total requirement which could practicably be produced in Qatar.

² Values shown for 1980 are actual production figures.

To achieve even this modest degree of food self-sufficiency large quantities of water would be required. By 2000 the total domestic/commercial and industrial demand for water will amount to approximately $105 \text{ Mm}^3 \text{ yr}^{-1}$. To meet agricultural demand an additional $240 \text{ Mm}^3 \text{ yr}^{-1}$ may be required and the overall total water demand may therefore amount to $245 \text{ Mm}^3 \text{ yr}^{-1}$ if such an agricultural policy were to be pursued.

The overall safe yield of the aquifer is $33 \text{ Mm}^3 \text{ yr}^{-1}$ and it is estimated that by the year 2000 $36.5 \text{ Mm}^3 \text{ yr}^{-1}$ of treated sewage effluent would be available for agricultural use, a quantity marginally greater than groundwater resources. Thus, the water resource potential of Qatar would be of the order of $70 \text{ Mm}^3 \text{ yr}^{-1}$ in the year 2000 and would only meet 23% of the projected demand by that time.

While the high cost of distilled sea water ($\approx \text{QR}5.50/\text{m}^3$ or QR 25/1000 galls) may, under present circumstances, be acceptable for agricultural use, it would be imprudent to base the entire future agricultural development of Qatar on a water resource, of which 77% would be distilled sea water. Distillation and power plants are vulnerable to accidental failure and an interruption of supply for a period as brief as two weeks could bring about complete crop failure.

Notwithstanding these overwhelming arguments against a major expansion of agriculture based on a very large element of distilled sea water, the project prepared, at the request of Government, a number of specific proposals for agricultural development based on the optimised conjunctive use of groundwater, sewage effluent water and distilled sea water and/or saline groundwater^{1/}. However, whilst these proposals may appear to be straight-forward in technical concept and design, they raise a number of complex issues and more importantly do not analyse the complicated technical, economic and social inter-relationships of each

^{1/}

- (a) An Agricultural Development Plan for Qatar,
FAO Project Proposal No. 3, 1980.
- (b) The Re-Use of Treated Sewage Water for Agricultural Development in the Al-Ashara Area,
FAO Project Proposal No. 2, 1979
- (c) The Re-Use of Treated Sewage Water for Agricultural Development in the Rakayih - Wadi Jalal Area
FAO Project Technical Note No. 14, 1980
- (d) Water Resources and Agricultural Development of S.W. Qatar
Report to H.H. The Emir, 1980.

part of the problem to every other part as well as the inter-relationship to each other, among objectives and the means by which they may be achieved. The optimal apportionment of the different sources of water and their relative inter-relationship to each other for different uses may conveniently be considered by systems analysis. Properly applied a systems approach to planning not only provides those responsible for planning with a realistic optimized solution to the overall problem but should also indicate what the consequences would be by the adoption or otherwise of certain policies and alternatives.

At mid-stage in project operations therefore it was decided that a specialised systems analysis approach to planning was essential if the full benefit of the project were to be realised. This was adopted and approved by Government and led to the appointment of specialist consultants - Messrs Halcrow-Balfour Ltd. of London - to undertake the analysis in collaboration with the project in its closing stages. The consultants report ^{1/} was submitted in September 1981.

3.2 THE WATER RESOURCES AND AGRICULTURAL DEVELOPMENT PLANNING BY SYSTEMS ANALYSIS

The major factors in formulating a master plan are water, land and labour. In a planning context these must be considered together with food demands, the suitability of different crops to different areas, the compilation of cropping calendars and the practical limitations on implementing new works and initiating unfamiliar procedures. Strong inter-relationships between these factors are readily apparent, and make the process of reaching a viable solution a tedious and time-consuming exercise by manual methods. For every realistic solution, there are many more that may ultimately prove to be impractical at a later stage of investigation. Moreover, the chances of locating a solution that satisfies a predetermined criterion of what constitutes a 'best' plan are remote unless the problem is cast in an appropriate mathematical

^{1/} A Master Water Resources and Agricultural Development Plan, 2000
for Ministry of Industry and Agriculture
by Halcrow-Balfour Ltd., 1981

framework. The translation of the planning problem into a form which can be examined using the computer involves the application through a group of techniques known as systems analysis.

A prerequisite to the application of such a systems model is the choice of a suitable objective function. Since a financial analysis of potential farm operations clearly showed that substantial capital subsidies would be required in most cases, application of conventional cost-benefit analyses was impracticable. The model was therefore designed to allocate the available water resources so that sufficient food would be produced for the inhabitants of Qatar, either by domestic agriculture or by means of imports, at the minimum economic cost under any assumed policy. The planning period over which the model was run began in 1980 (the base year) and ended in the year 2000 by which time it is estimated that the population will have reached 430,000.

As the resources of Qatar are not uniformly distributed the model was based upon a suitable division of the country into 6 separate characteristic regions of differing potential and a data bank of all relevant information compiled. These covered land resources, water resources, food requirements and farm data from which an allocation model involving about 50 variables and 40 constraints was constructed. This allocation model was run to search for a set of values for the variables which enabled all the constraints to be satisfied in a feasible solution.

The systems analysis model was programmed to handle a wide range of combinations of initial assumptions on population, potable water demands, treated sewage effluent, desalinated water, land, groundwater, gas and electricity and discount rates.

The model was intended to find the most economical method of attaining the required levels of production of particular crops so that Qatar could become less dependent on imports. Although many different combinations of options are possible, there are relatively few basic alternatives. Eight alternative options were tested followed by a further four sensitivity analyses to test the effects of major changes in the basic assumptions likely to be affected.

3.3 RESULTS OF THE ANALYSIS

Table 3.1 summarises the expected agricultural production, water and land requirements and the economic cost of each of the eight possible development options examined. Option 1 assumes that all agriculture will cease by 1985 and was made in order to test the economic cost, although essentially this is a control against which the other options may be evaluated. The seven other options 2 to 8 show an overlapping progression starting with the economic solution (2) based upon groundwater alone and thereafter supplementing this economic source with moderate-cost treated sewage effluent (upon which certain constraints in its utilization have been set) and increasing volumes of distilled water being brought in to finally achieve self-sufficiency in replaceable food demands (Option 6). The remaining two additional options are variations on the self-sufficiency option no. 6.

The following are the salient conclusions arising from the analysis:

- Winter and summer vegetables irrigated by groundwater are the only crops that may be economically grown in Qatar: all other crops are cheaper to import. The total economic cost of meeting this policy would amount to QR 186 million in the year 2000, some 20 per cent less than the cost in the same year if everything were to be imported. This suggests that there is real benefit to Qatar from growing vegetables.
- It was demonstrated (Option 3) that with treated sewage effluent transferred to central Qatar as planned at present, the maximum amount of milk and beef could be produced. Such an enterprise would not however require the entire expected quantity of effluent by 2000 and it would be necessary to develop sub-economic sheep farming in the same area.
- The first five options clearly established that cereal and sheep-rearing enterprises are highly uneconomic because of the heavy water demand and high farm costs for relatively low output. By including these two enterprises not only do the water costs increase dramatically by having to utilize high cost distilled

TABLE 3.1

SUMMARY OF POSSIBLE ALTERNATIVE AGRICULTURAL AND
WATER RESOURCES DEVELOPMENT OPTIONS
BY SYSTEMS ANALYSIS

Parameter	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
<u>Local produce (tonnes)</u>								
Milk	-	-	5600	5600	5600	5600	5600	-
Beef	-	-	240	240	240	240	240	-
Mutton	-	150	660	750	2400	4500	300	-
Cereals	-	-	-	18000	23000	23000	-	23000
Dates	-	-	-	-	3300	3700	3700	-
Winter vegetables	-	18000	18000	18000	18000	18000	18000	-
Summer vegetables	-	8100	8100	8100	8100	8100	8100	-
Fruit	-	-	-	-	1700	3700	3700	-
Cucumbers	-	-	-	-	-	650	650	-
<u>Water used (MCM)</u>								
Groundwater	-	19	19	21	29	29	23	24
Treated Sewage Effluent	-	-	35	35	35	35	11	20
Desalinated Water	-	-	-	50	142	242	35	23
Total	-	19	54	106	206	306	69	67
<u>Economic Costs (QR millions)</u>								
Farm costs	-	40	80	160	250	360	90	95
Water costs	-	5	35	350	940	1580	230	165
Imports	230	140	115	95	50	-	90	215
Total	230	185	230	605	1240	1940	410	475
Area formed (ha)	-	1900	2900	9100	13800	17600	4800	7700

water but also because farming costs alone still outweigh the value of production.

- Once the use of distilled sea water becomes necessary, the production costs of any crop rise dramatically. (See Fig 1) This also has the effect of highlighting the diseconomies inherent in developing agriculture in Qatar beyond the present water resource limits. For instance, the total economic cost of Option 3 based on groundwater and treated sewage effluent is QR 230 million whereas by introducing even a modest quantity of distilled water (35 MCM in Option 7) causes the water costs to increase by a factor of 6.5 from QR 35 million to QR 230 million and the overall costs to QR 410 million. In this particular case the benefits which accrue amount to an additional 8000 tonnes of dates, fruit and cucumber for an additional cost of QR 180 million per year. When cereals and sheep rearing are included in the Option (Option 6) the costs rise at an accelerated rate and the total cost rises to QR 1940 million, ten times greater than the economic optimum (Option 2).
- In Option 7 cereals and sheep-rearing were excluded for the reasons given above and because of this not all the available treated sewage effluent would therefore be required at the proposed development site in central Qatar. A cheaper overall solution could, however, be realised if some of this water were to be made available in northern Qatar. In an alternate option (12) it was shown that if the unused balance of treated sewage water was not restricted to central Qatar and allocated to the main farming areas of northern Qatar, the demand for distilled seawater was reduced by 27 MCM in 2000 with a saving of QR 140 million, per year. This conclusion draws attention to the high value of treated sewage effluent in comparison with other sources of water in future agricultural development. (This alternate, however economically attractive, is unlikely to be realised in view of Governments prevailing policy of not allowing the use of treated sewage effluent in the main populated farming districts of northern Qatar).

- The sensitivity test showed that variations in either the interest rate or, the population estimates, or whether or not gas was regarded as a free good did not affect significantly the preferred order of crops and their economic viability. In one parameter, however, the results were significantly affected by changing the estimated population for the year 2000 to a "conjunctural" one of 253,000 in the same year. This had the effect of reducing the economic cost of meeting the country's food demands and the annual costs are only 50 percent greater than at present. The "conjunctural" population estimate was taken at 60 percent of the assumed estimate, illustrating that the marginal cost of feeding an additional inhabitant under these policies is greater than the average cost. This results, once again, from the high cost of desalinated water being required to produce his fruit and vegetables if abstraction of groundwater is to be maintained at the safe yield of the aquifer. The total cost of water for both agricultural and domestic demand by 2000, even in this case, would be QR 325 yr⁻¹.

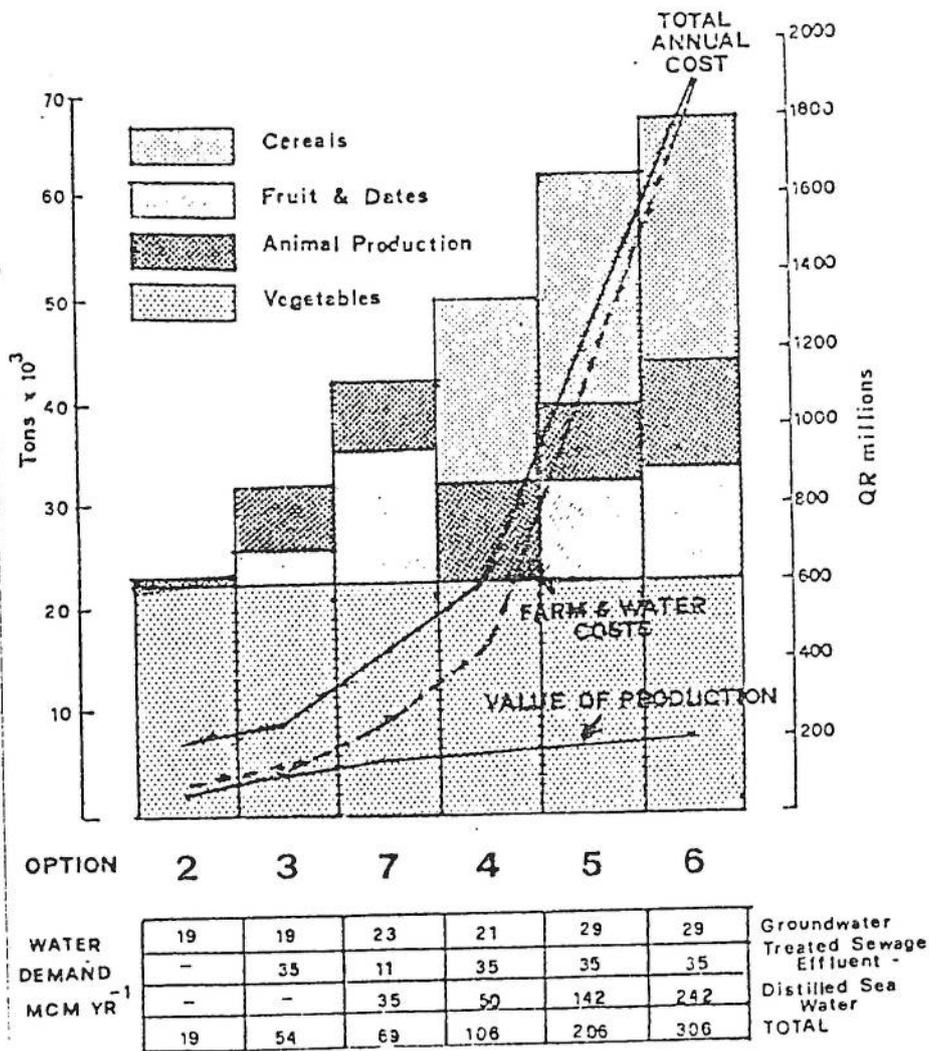


FIG 1: Summary of Possible Options in Increasing Order of Water Demand

3.4 POLICY OPTIONS

The eight options examined fall into two distinct groups. The first group composed of Options 2 and 3 have in effect maximised production with respect to available water resources at minimal cost and in accordance with all constraints and variables. Options 4, 5, and 6 on the other hand are the result of progressively supplementing the total water requirement with increasing amounts of distilled water to achieve full self-sufficiency in replaceable food demand by the year 2000 (Option 6). These latter options may be regarded as maximising production with regard to the location, distribution and extent of arable land with the water constraint partially relaxed. The remaining two Options, 7 and 8, are variations on Option 6 where in Option 7 highly uneconomic enterprises (cereals and sheep rearing) were excluded from the maximised solution and in Option 8 cereals precluded the economic production of all other crops.

After consideration of the allocation model results, the Consultants (Halcrow-Balfour Ltd) identified four basic policies, the choice essentially depending upon the level of agriculture desired by Government. The four policies are:

- I : concentrate on growing the economic crops of vegetables to the exclusion of all other non-economic crops, based on Option 2.
- II : as in Policy I, but using all available treated sewage effluent in central Qatar as planned and growing the appropriate traditional crops, based on Option 3.
- III : increasing production by the provision of distilled sea water to enable Qatar to raise its levels of production to the maximum practicable in all crops except cereals and mutton, based on Option 7.
- IV : as Policy III, but based on Option 6 including cereals and mutton to achieve the highest degree of self-sufficiency to the full extent of available arable land resources.

In framing a development plan based on any one of the foregoing four policy options it is clear that there are only two apparent choices: These are Policy II and IV and correspond in principle to the development options previously recommended for Governments consideration by FAO in 1977; a 'vertical' and a 'horizontal' expansion in agriculture. The crux of the matter was then seen to be a choice between whether or not high cost distilled water should be used for agriculture. Considered in a systems context, however, the choice is not as clear-cut as this earlier recommendation nor the various policy options shown in Table 3.1 might suggest

3.4.1 Maximum Expansion of Agriculture

The horizontal expansion option, as represented by Policy Option IV, has maximised production to available land and productive resources, with the limited water resource augmented to a considerable degree by distilled sea water. To meet the set targets, including cereals and mutton, the demand for land and water rise dramatically, while a total of nearly 4,000 agricultural workers would be required by the year 2000. Approximately $80 \text{ Mm}^3 \text{ yr}^{-1}$ of expensive distilled water would be required by 1990, rising to $240 \text{ Mm}^3 \text{ yr}^{-1}$ by the year 2000.

The expected value of agricultural production in 2000 is estimated at QR 204 million, a three fold increase over present levels of production. However, as Fig 1 shows, the escalation of costs is phenomenal, rising to an annual cost of QR 1940 by the year 2000, equivalent to about 12 percent of estimated 1980 GNP at 1980 prices while the value of agricultural production would be equal to 1.3 percent. This indicates a negative cost/benefit ratio of approximately 10. The diminishing returns from agricultural development based on high cost distilled water are particularly evident when it is recalled that this investment will only fulfill about 20% of Qatar's estimated food need by the year 2000. The agricultural sector at this level of output and costs would be obtaining a disproportionately large share of GNP in relation to its contribution.

In addition to these overwhelming economic arguments against the use of large amounts of distilled sea water for agriculture, as pointed out earlier, it would be imprudent to base 80% of the country's agricultural economy upon a source of irrigation water which is vulnerable to interruption from a variety of causes.

3.4.2 A Limited Expansion of Agriculture

Policy OPTION II represents the possible maximum production based on the safe yield of the groundwater aquifer and the expected volume of treated sewage effluent by the year 2000. In addition to economic vegetable targets being achieved those of beef and milk are also met. In this solution a constraint was set whereby all treated sewage water was to be utilized and confined to the central regions of Qatar. This has had the effect of introducing uneconomic sheep-rearing in this area to be set against the cost of dumping it if it were not used.

This policy would double the value of agricultural production realised in 1980 at similar prices and the annual cost would be QR 40 million higher in the year 2000 compared to the economic optimum. Total annual costs in the year 2000 for all elements including the remaining imports required is less than 2 percent of estimated GNP in 1980 prices and the total value of agricultural production would be less than 1 percent.

This solution is an optimum one whereby costs are minimised and although it represents only a small proportion of Qatar's total expected food imports, it provides the basis for a practical agricultural development plan within reasonable limits of subsidy and the country's capacity. However, by subjecting the whole question of agricultural and water resources development to a systems analysis study whereby the various inter-relationships of each part of the problem to every other part as well as the relationship to each other are examined, it is clear that this solution would not provide for an acceptable development strategy.

Under such a policy the use of treated sewage water being constrained to central Qatar, will have the effect of developing this area preferentially to the detriment of higher value vegetable and orchard enterprises in northern Qatar where farms would have to close in order to redress the present abstraction/recharge imbalance. This would bring about a radical alteration to existing farming patterns and is one which would not find favour with present landowners in northern Qatar. But in any event, even if the present high rates of abstraction are maintained and not brought back into equilibrium with average recharge, increasing

groundwater salinity will force the abandonment of almost all present vegetable farming in northern Qatar within 20 years. This would effectively bring about a shift away from economic vegetable production to increasingly uneconomic fodder production based on treated sewage water and increasingly saline water.

To preserve the preferred pattern of improving existing vegetable/orchard farms in northern Qatar, concentrate animal production on treated sewage effluent in central Qatar and reduce the abstraction of groundwater to the safe yield, any future strategy must therefore be based on providing a limited additional source of water in northern Qatar. This can be provided by either the unused balance of treated sewage effluent or distilled sea water. As there would be a serious social objections to the utilization of the former for vegetable production recourse would have to be made to distilled sea water. With this strategy in mind Policy III (based on Option 7) was developed by the Consultants as the most suitable alternative policy and upon which viable agricultural and water resources development plan could be based.

Under this Policy only $11 \text{ Mm}^3 \text{ yr}^{-1}$ of the $35 \text{ Mm}^3 \text{ yr}^{-1}$ of treated sewage effluent would be required for milk and beef production, uneconomic sheep-rearing having been specifically excluded. Additionally, $35 \text{ Mm}^3 \text{ yr}^{-1}$ of distilled water would be required in north-eastern Qatar to replace reduced groundwater abstraction which would be necessary to return the aquifer to equilibrium.

Under this policy total annual costs, including the balance of imports rises to QR 410 million; slightly less than double the equivalent costs under Policy II, and as pointed out earlier, water costs are increased by 75%. The incremental value of production for this very large increase in cost is QR 18 million worth of dates, fruit and cucumber representing only 15% of the total value of production. The additional cost should not, however, be compared with increased production for this represents in reality the cost of stabilizing the northern groundwater aquifer. The QR 200 million additional water costs may also be regarded as an annual subsidy cost to farmers in northern Qatar who would expect to be supplied from an alternate source as compensation for reduced groundwater abstractions.

As pointed out in Sec 3.3, if all unused treated sewage effluent were permitted to be introduced into northern Qatar and substituted for high cost distilled water, the annual cost saving would amount to QR 140 million. This potential saving of up to 70% in cost should stimulate consideration of the possibility of strictly controlled usage in the area despite present objections based on principle only.

As an alternate solution, not considered in the Master Plan, is the possibility of the artificial recharge of the unused balance of treated sewage water if direct usage is rejected. Detailed knowledge of the aquifer systems of Qatar suggest that such a solution would be feasible but the percentage recovery remains uncertain without further investigation.

3.5 A PROPOSED AGRICULTURAL AND WATER RESOURCES DEVELOPMENT PLAN

3.5.1 Introduction

The proposed agricultural development plan proposal assumes that the Government of Qatar will first select their required level of agricultural activity and that the development of water resources will then be organised to satisfy the overall water demands of the country. In accordance with this approach, the proposed Agricultural Development Plan is presented first followed by an associated Water Resources Development Plan designed to meet these needs. The proposed Agricultural Development Plan is a practical interpretation of Policy III and fully discussed in the foregoing section. This Policy involves raising the levels of agricultural production of all suitable crops except cereals and mutton to the level at which the greatest practicable amount of imports have been replaced. The production of both cereals and mutton a large scale requires very large quantities of desalinated water at considerable cost, and even if this water cost is ignored, these foodstuffs can only be produced in Qatar at several times the imported cost. Table 3.2 summarised expected production, water requirement, costs and value of the plan.

3.5.2 The Agricultural Development Plan

3.5.2.1 Traditional Mixed Farming Development

This sector would continue to provide the bulk of local vegetables, fruit and dates as well as some mutton. Using the three farm types, vegetable, vegetable/orchard/forage and orchard/forage (See Sec. 2.2.2.4) with average areas of 18, 19 and 10 ha respectively, about 250 productive farms would be required. These farms should be encouraged to adopt new techniques and to invest in new equipment to save water, and to increase yields and cropping intensity.

The increase in the area of fruit would need to be relatively greater than the growth in the area of vegetables and could be established on land currently fallowed. Fruit production could be increased from existing trees and new plantations, but prices are low and the high cost of labour discourages production by landowners who are not greatly interested in producing for the market. Financial incentives, access to credit and increased security of tenure should be used to encourage fruit production from tenanted farmers, although some direct Government investment would also be necessary in view of the delay between planning and full production (at least 5 years).

The proposed expansion in vegetables and fruit cannot be achieved using groundwater only as availability is limited. Vegetable and fruit farms using water saving and improved production technologies should be developed in northern Qatar as close as possible to the proposed desalination plant at Ras Laffan, so minimising the cost of the reticulation system. About 30 MCM in the year 2000 for the production of vegetables, fruit and dates.

The quality, grading and packaging of domestically produced vegetables and fruit particularly tomatoes would need to be improved for them to be competitive with imports. Care would be needed to avoid stimulating production at a rate faster than the market could absorb the extra food-stuff, which would lead to falling prices and ultimately defeat the objective of raising output.

Table 3.2

PROPOSED AGRICULTURAL AND WATER RESOURCES
DEVELOPMENT PLAN
(2000)

1. Production

Product	Replace- able imports (tons)	Local Pro- duction (tons)	Cul- tivated area (ha)	Labour (no)
Milk	5628	5628		
Beef	235	235	370	200
Mutton	3883	300		
Cereals	23034	-		
Dates	3650	3300		
Vegetables (W)	18270	18270	4401	1900
Vegetables (S)	8070	8070		
Fruit	3650	3700		
Cucumber	650	650	13	100
Total	67070	40,153	4784	2200

2. Water Requirements (MCM)

	Agriculture	Domestic
Groundwater	23.5	-
Treated Sewage Effluent	10.5	-
Distilled Water	35.2	105
Total	69.2	105

3. Cost (QR millions)

	Agriculture	Domestic
Farming Costs	92.2	-
Water Costs	229.5	618
Food Imports	89.5	-
Total	411.1	618

4. Value

Total value of production (QR million)	115.4
Total value of production (% of 1980 GNP)	0.7
Total % increase in value of agricultural production over 1980.	139

3.5.2.2 Milk and Beef Production

Assuming the Qatar Dairy Company continues to produce 1,450 tonnes of milk per year from 380 cows, approximately 1,430 cows would be required to produce 5,600 tonnes of milk by 2000. The Qatar Dairy Company is currently considering plans for increasing milk production which would need to be taken into account prior to embarking on the expansion of milk production. The Qatar Dairy Company has the infrastructure and dairy management expertise, and its production costs per unit of milk would probably be less than those of completely new ventures. Therefore, encouraging its expansion up to the levels required would be preferable.

Assuming all additional milk output is produced from new farms using treated sewage effluent in central Qatar, the milk production strategy could be as follows:-

- establish a 90 cow pilot farm ready for production in 1985;
- double up the above 90 cow unit to 180 in 1990 and develop one new 180 cow unit;
- develop two further 150 cow units in 1995; and
- develop two further 195 cow units in the year 2000.

At present, the Qatar Dairy Company feeds a high proportion of imported concentrates and the minimum of alfalfa because this is a cheaper policy than producing larger quantities of alfalfa. If the costs of supplying irrigation water were set too high, any new private dairy enterprise would do likewise and merely import cattle feed, thereby partially defeating the objective of increasing self-sufficiency.

3.5.2.3 Protected Agriculture

Off-season cucumber production from coolhouses located in central Qatar and using good quality groundwater should be developed from the existing 0.5 ha of Ministry of Industry and Agriculture and IDTC coolhouses so that in 1990 there would be 1.65 ha of coolhouses plus 1.65 ha of adjacent

outdoor vegetables. This development would rise to 6.5 ha of coolhouses and 6.5 ha of outdoor vegetables by the year 2000.

Each one hectare of coolhouses would produce 100 tonnes of off-season cucumber and could also supplement vegetable production during other periods.

3.5.2.4 Abu Samrah Sheep Farm

Domestic mutton production has been shown to be very uneconomic. However, as the Abu Samra sheep farm is a sunk cost, the Government should rehabilitate its drainage and irrigation systems and continue to utilise existing groundwater resources. The farm's original objective of producing improved breeding stock for distribution to the traditional sector should be the main aim.

3.5.3 THE WATER RESOURCES DEVELOPMENT PLAN

3.5.3.1 Annual Demands

Under the proposed Agricultural Plan, the demand for water for productive agriculture rises from 53 MCM in 1980 to about 69 MCM in the year 2000, which should be added to demands from other sectors. However, not all of the demands need to be considered directly in preparing an overall plan. Industrial and other consumers with their own desalination plants may be excluded. The specific requirements in Doha for landscaping (0.7 MCM IN 1980) may in future be met by the development of the freshwater dome building up under the city, (See Section 2.2.1 (a)). The remaining demands are for productive agriculture, amenity farms, central potable supplies and isolated domestic supplies not drawn from agricultural wells. These isolated supplies amount to about 0.8 MCM, and may be expected to continue at a similar level. The demands from each of the three remaining sectors rise from 124 MCM in 1980 to 196 MCM in the year 2000.

The most practical large source of desalination water in Qatar would be multistage flash distillation associated with waste heat from thermal power stations or industrial processes. The installations at Ras Abu Fontas and Ras Abu A boud could produce about 64 MCM at present at a load factor

of 75 percent. This capacity will rise to 88 MCM when the installation of four new units and ancillaries is completed in the next 2-3 years. No further extension to either plant is planned and future desalination facilities are proposed at Ras Laffan. The results obtained from this Study confirm that there are no cheaper or more reliable sources of water, and that any deficit in Qatar's supplies should be made good by increased capacity at Ras Laffan.

Under the suggested Water Resources Development Plan, the dependence of productive agriculture upon groundwater would be reduced in order to curtail the over-abstraction in the north to restore equilibrium with recharge. This would involve :

1. continuing abstraction at their present level until 1985; then
2. reducing the level of net abstraction progressively to 27 MCM/year in 1990; and
3. continuing thereafter at the lower abstraction rate.

Under this operating rule, the overall net abstraction rate for the next 30 years would be equivalent to the safe yield of 33 MCM.

The quantity of distilled sea water required would however, be considerably reduced if treated sewage water could either be made available in the north east of Qatar or if the quality constraints could be relaxed. Neither of these changes has been incorporated into the Water Resources Development Plan and so Ras Laffan would be called upon to produce about 29 MCM in 1990 rising to 45 MCM in the year 2000. Although in theory there would be some spare capacity at Ras Abu Aboud and Ras Abu Fontas in 1990, the construction of a special distribution system would not be practicable for such a short period, and all the agricultural demands have been assumed to be met from Ras Laffan.

3.5.3.2 Monthly Variations in Water Demand

The total annual water demand figures derived in the foregoing show a considerable variation in demand within the year. The importance of these variations depends upon the source of supply concerned.

Assuming that the groundwater reservoir will be properly monitored and good practice encouraged, groundwater abstractions could be regulated to reduce the peak demands on other sources, particularly desalination. Under the suggested Plan, distilled sea water for agriculture is proposed for irrigation in northern Qatar, close to the Ras Laffan site. The allocation model indicated which farm types should be located in which areas, and on combining these results with the overall monthly irrigation demands for each farm type, the monthly agricultural water requirements were obtained.

After subtracting the groundwater supply in a suitable temporal pattern, the agricultural demand for desalinated water was found to range from 1.7 to 2.7 MCM/month in 1990, and from 2.1 to 3.3 MCM/month in 2000. Combining agricultural demand with the potable demand the total pattern of demand for desalinated water is arrived at.

The conclusions of the analysis of annual and monthly water requirements are :

1. The installed desalination capacity at Ras Laffan will need to rise to 33 MCM by 1990 and 57 MCM by 2000, representing 4 units and 7 units respectively of the site currently installed at Ras Abu Fontas and proposed for Ras Laffan.
2. The land factors for Ras Laffan are adequately high yet retain sufficient margins to allow for maintenance; and
3. The demands for water are sufficiently well matched to the supply to avoid the need for very large storage reservoirs.

As a corollary to point (3) above, the earlier proposal that aquifer storage by injection should be provided to minimise fluctuations in demand is therefore seen to be unnecessary. Further investigation of this proposal has not therefore been pursued.

4. RECOMMENDATIONS

4.1 SUMMARY AND CONSIDERATIONS

Qatar is one of the countries making up a region which has a large food deficit. The present food gap is alarming; the region is the highest per capita food importer in the world which constitutes a grave problem with far-reaching implications. The long-term demand for food poses an unprecedented challenge to food production in the region and unless production efforts are intensified, dependence of imported food will probably reach an unsupportable limit and bring-about serious socio-economic problems. The Government of Qatar is keenly aware of this problem and has decreed that all future deliberations in future agricultural development should have as their objective the attainment of self-sufficiency in basic foodstuffs.

In the final chapter of this report a summary of the detailed systems analysis study undertaken by consultants to the project to provide a number of policy options has been given and a suggested development plan put forward. This systems analysis study has shown very clearly the limited choice of options open to the Government of Qatar in developing agriculture and complete self-sufficiency is not a practical policy. While four possible options are presented for consideration, the choice is apparently limited to one of two of these if the overall objective of some measure of food self-sufficiency is to be maintained, the crux of the matter being whether or not distilled sea water should be utilized in agriculture. Economically there is no justification for the use of this high cost water for agriculture but the systems analysis approach to the problem has shown that a modest proportion of this water needs to be employed to ensure a long-term balanced agricultural strategy and to correct over-exploitation of groundwater resources in the past.

The present analysis has shown that :

- By the year 2000 the population of Qatar will have reached 440,000 persons, food requirements will be 380,000 tons at an estimated cost of QR 450 million at an assumed rate of price inflation, and the potable water requirement would be $105 \text{ Mm}^3 \text{ yr}^{-1}$ at probable production costs of QR 650 million

- Food self-sufficiency is not a practical policy and taking into account the availability, distribution, size of arable land and climatic factors, (excluding water) the maximum amount of food capable of being produced in Qatar amounts to 67,500 or 20% of the total requirement by the year 2000.
- The groundwater reserves of Qatar are being over-exploited at an accelerating rate and by the end of the century project investigations have shown conclusively that groundwater will have been exhausted or reduced to an unusable quality.
- To produce the maximum amount of food possible (67,500 tons) would require a total of $306 \text{ km}^3 \text{ yr}^{-1}$ of water, 80% of which would need to be distilled sea water at an annual cost of QR 1580 million, to which other agricultural costs must be added bringing the total annual cost to QR 1940. The value of agricultural production in this case realised would be QR 204 million giving an negative cost/benefit ratio of 10.
- The very high water costs of achieving the maximum production possible results from cereal production which has a low yield and price and yet requires large areas of land and volumes of expensive water. Once distilled water is introduced into agricultural development, costs escalate rapidly and soon lead to diminishing returns.
- The systems analysis study has indicated a modest but sound strategy for development based on the safe yield of groundwater, treated sewage effluent and an equal amount of distilled sea water to make up for over-abstraction of the aquifer in the past. This plan would cost QR 410 annually and would meet all replaceable import targets except in sheep and cereals.

4.2 MAJOR RECOMMENDATIONS

4.2.1 During the course of the project a number of major recommendations were made to the Government of Qatar which in due course were either accepted in their entirety or incorporated within wider internal organizational matters prior to project termination.

- a) The first of these was a recommendation to continue the work of the project, which had been organized as a separate entity successfully integrating staff and equipment provided by both the Ministry of Industry and Agriculture and the Ministry of Electricity and Water. This resulted in a decision by the Council-of-Minister's to establish a new department - the Department of Agricultural and Water Research - within the Ministry of Industry and Agriculture to continue the work of the project immediately upon project termination on 1st May 1981.
- b) As a result of a number of audiences with His Highness The Emir of Qatar, Sheikh Khalifa bin Hamad Al-Thani, arising out of earlier memoranda on the continued and worsening groundwater deficit, an Amiri decree prohibiting the drilling of new wells throughout the country, except in cases of exploration and investigation, was promulgated.

4.2.2 In the final chapter of this report a summary of the detailed systems analysis study undertaken by consultants to the project to provide a number of policy options has been given and a suggested development plan put forward. This systems analysis study has shown very clearly the limited choice of options open to the Government of Qatar in developing agriculture and complete self-sufficiency is not a practical policy. While four possible policy options are presented for consideration, the choice is in reality limited to one of two of these if the overall objective of food self-reliance is to be pursued. Whilst it is for the Government of Qatar to decide which policy they wish to pursue, it is strongly recommended that urgent consideration

be given to the suggested plan outlined in the foregoing section and based on Policy Option III. This provides for raising the level of production of all suitable crops except cereals and sheeprearing to that which the greatest practicable amount of imports are replaced. By including both cereals and sheep-rearing the water requirement would be increased by a factor of 3.5 and the annual cost five-fold. Even if the additional high cost of water is ignored, these two items could still only be produced at several times their import cost.

4.2.3 It is prudent and a common feature of the policies of governments to ensure that sufficient foodstocks are held in the country to enable any unforeseen shortages or total failure of supply to be met. Project studies have indicated that there is no possibility of Qatar becoming self-sufficient in foodstuffs and indeed a relatively high proportion would still need to be imported. Given this situation it is recommended that Government consider and implement the provision of storage facilities to the following extent:-

Wheat	:	100,000 tons
Animal food-stuff (wheat, bran, and barley)	:	45,000 tons
Meat	:	10,000 tons (frozen)
Selected Fruit and Vegetables	:	30,000 tons (chilled)
Milk and Dairy Products	:	40,000 tons

In addition to these food storage facilities there would be a need to maintain adequate stockpiles of seed, fertilizers, herbicides, insecticides and farm machinery spare parts.

4.2.4 In drawing-up a development plan based on the systems analysis study it has been realised that the practical implementation of any one of the options presented would be difficult given the present agricultural situation in Qatar. The greatest problem does not lie with devising a suitable plan and strategy but in the creation

of the incentives necessary to motivate owners, managers, tenants and farm workers. In particular, it is recommended that steps be taken by Government to educate the farming community to :

- (a) develop an interest in serious, efficient agriculture among Qatari landowners.
- (b) create a general awareness of the need for water and land conservation.
- (c) to persuade landowners and farmers to adopt economic farm planning in accordance with market forces.
- (d) to persuade owners to adopt efficient irrigation methods and inculcate an awareness of the need to reduce the abstraction of groundwater.

4.2.5 Because of competing investment opportunities elsewhere in the economy private investment in agriculture needs to be subsidized to ensure that owners realise a rate of return of at least 15%. It is recommended that an agricultural subsidy scheme embracing the following be implemented :

- (a) a system of capital grants on initial investment;
- (b) input cost subsidies for private farmers and when appropriate;
- (c) Government funding for water distribution schemes.

4.2.6 Notwithstanding the recommendation made in 4.2.4, the difficulties inherent in mounting an agricultural education programme designed to raise the level of agricultural production is considered to be very great, and would take many years to fully implement. As an alternative course of action it is recommended that consideration be given to the proposition that all new farms be developed under the aegis of a national farming corporation. This would be a semi-autonomous organization with the necessary flexibility to undertake commercial agriculture. Provision should be made to allow for the purchase of existing leased farms as these become available with the

ultimate aim of consolidating all productive agriculture in Qatar under one organisation but at the same time allowing for a continuation of amenity farms under private ownership. This would resolve the present unsatisfactory situation of tenant farmers operating under a land tenure system with its inherent disadvantages. Such a course would also relieve the Ministry of Industry and Agriculture from direct management of various agricultural enterprises and allow it to undertake its proper function in legislation, planning and research. It should however, be stressed, this recommendation does not advocate the establishment of 'State Farms' but rather a profit-oriented commercial enterprise.

4.3 OTHER RECOMMENDATIONS

It is also recommended that :-

- 4.3.1 A feasibility study of the Wadi el Araig area be undertaken by consultants to determine the economic and technical feasibility of developing large areas of dune sand in that area based on poor quality groundwater. Terms of reference have been prepared by the Project.
- 4.3.2 A design study of the El-Ashara project area should be carried out by consultants within the immediate future. Terms of reference have been prepared by the project.
- 4.3.3 An investigation of the magnitude of leakage of desalinated water and the associated groundwater situation within the Doha city area be undertaken. This study should propose a practical system of reducing, recovering and treating leakage for beneficial use.
- 4.3.4 A countrywide investigation leading to the design and implementation of constructing simple water retaining and induced recharge structures at suitable locations be undertaken based on work already carried out by the Project.

- 4.3.5 The final development of the Abu Samrah sheep farm by the construction of an adequate irrigation and drainage system on the basis of a design prepared by the Project be undertaken.
- 4.3.6 A renewed exploratory drilling programme be initiated by the Department of Agricultural and Water Research. This programme should be designed to explore groundwater conditions in certain special areas and thereafter maintained as monitoring wells to check on changes in quality.
- 4.3.7 In the short and medium terms, as a paralld activity to longer-term planning and implementation, the Ministry of Industry and Agriculture should be strengthened to undertake a comprehensive agricultural extension programme not only to raise general cultivation practices and increase production but to improve irrigation efficiency and reduce the high rate of water extraction through remedial works, controls and adequate provision of financial assistance and subsidies. In particular; action should be taken to :-

- Construct artificial recharge works in combination with flood protection works wherever possible.
- Construct drainage systems with depressed farm areas to remove damaging excess rainwater.
- Improve the efficiency of pumps and engines through subsidized replacement programmes.
- Reduce water transmission losses through the provision of gated pipe for water distribution.
- Introduce more effective irrigation methods for border strip, proper scheduling, reducing frequency, soil preparation and leaching.
- Provide adequate windbreaks around the periphery of farms and within the farm area itself by the planting of sesbania which may also be cropped for animal feed and green manuring.

- Introduce optimized cropping programme designed to maximize income as presented by the Project by reoptimization procedures with different cropping and constraints by the computer facility provided by the Project.
- Continue investigations into soil amendment and management, particularly in south western Qatar.

A P P E N D I X IList of Senior Project Staff

<u>Name</u>	<u>Designation</u>		<u>Dates of Service</u>	
			<u>Starting Date</u>	<u>Concluding Date</u>
<u>FAO</u>				
J.G. Pike	Project Manager	<u>1/</u>	1 Jul. 77	30 Apr. 81
F.A. Ruwayha	Horticulturist/ Ext. Specialist	<u>2/</u>	1 Jul. 77	30 Apr. 81
R. Hognestad	Farm Machinery Expert		11 Feb. 78	11 Aug. 79
B.L. Eccleston	Hydrogeologist		13 Mar. 78	30 Apr. 81
M. Khalifa	Agromist		24 Mar. 78	8 Oct. 79
M. Ramzan	Soil Management Expert		1 Aug. 78	1 Feb. 80
M. Rogers	Computer Systems Spec.		3 Feb. 79	3 Feb. 80
J. Kirkham	Drilling Supt.		15 Jun. 79	15 Apr. 81
E. McGregor (Mrs)	Administrative Asst.	<u>3/</u>	1 Aug. 77	30 Apr. 81
<u>Government</u>				
M. Farah	Co-Manager		1 Jul. 77	30 Apr. 81
I. Harhash	Head, Groundwater Section		1 Jul. 77	30 Apr. 81
M. Al-Faihani	Head, Water Resources Section ^{4/}		1 Jul. 77	30 Apr. 81
S. El-Sheikh	Head, Soils Section		1 Jul. 77	30 Apr. 81
O. Shahata Khalil	Agronomy Expert		1 Nov. 78	30 Apr. 81
A.S. Khunji	Horticulturist		1 Jul. 77	30 Apr. 81
M. Al-Mannai	Hydrometeorologist		1 Jul. 77	30 Apr. 81
M.A. Fauda	Asst. Hydrometeorologist		1 Jul. 77	30 Apr. 81
M. Yousseff	Computer Programmer		1 Sep. 78	30 Apr. 81
M. Hashim	Irrigation Engineer		1 Jul. 79	30 Apr. 81

1/ Arrived Qatar 9 September 1974

2/ Arrived Qatar 31 January 1974

3/ Arrived Qatar 17 November 1974

4/ Appointed Director of the Department of Agricultural and Water Research, to succeed the project with effect from 1st May 1981.

<u>Name</u>	<u>Designation</u>	<u>Dates of Service</u>	
		<u>Starting Date</u>	<u>Concluding Date</u>
<u>FAO Consultants</u>			
J. Lloyd	Hydrogeology	14 Dec. 77	21 Dec. 77
		28 Dec. 78	4 Jan. 79
		12 Dec. 79	22 Dec. 79
		11 Apr. 80	19 Apr. 80
		12 Dec. 80	19 Dec. 80
T.R.E. Chidley	Groundwater Modelling	14 Dec. 77	21 Dec. 77
		26 Jan. 79	31 Jan. 79
		26 Mar. 79	17 Apr. 79
		12 Dec. 79	22 Dec. 79
		11 Apr. 80	19 Apr. 80
		12 Dec. 80	19 Dec. 80
M. Rogers	Computer Systems	1 Aug. 78	5 Aug. 78
		9 Aug. 78	18 Aug. 78
		29 Nov. 78	13 Dec. 78
		3 Feb. 80	26 Mar. 80
D. Lueke	Systems Analyst	18 Apr. 79	5 May 79
D. McConnell	Production Economist	6 Nov. 79	17 Dec. 79
		9 Oct. 80	28 Nov. 80
C. Olympus	Greenhouse	27 Mar. 80	29 Mar. 80
J. Savva	Irrigation Expert	25 Feb. 80	4 Mar. 80
J. Pilgrim	Greenhouse	13 Mar. 78	19 Mar. 78

A P P E N D I X II

ABSTRACTS OF PROJECT TECHNICAL REPORTS

FAO Water Resources and Agricultural Development Project.

UTFN/QAT/OO3/QATAR. Technical Report No. 1. Agronomy

(based on the work of M.A. Khalifa and O.S. Khalil) Doha, Qatar, 1981

ABSTRACT

The evaluation of the present agricultural systems of Qatar together with investigations into the groundwater resources, trials and investigations designed to improve irrigation efficiency, cultivation practices, soil management, farm machinery, production economics and the preparation of master plan for future water resources and agricultural development was undertaken in a 4-year project executed by the Food and Agricultural Organization of the United Nations under a Funds-in-Trust agreement with the Government of Qatar and as a follow-on to an earlier 3-year UNDP/FAO project, Integrated Water and Land Use.

As part of this programme detailed agronomic investigations were initiated in 1978 at two representative experimental sites; on the heavy calcareous soils of northern Qatar and on the sterile dune sands irrigated by brackish groundwater in south-western Qatar. This report presents the results of the first year of experiments which have since been continued by the project based upon the recommendations made as a result of this first year's work.

Because of the short growing season, early maturing varieties of both wheat and barley were found to be well suited to local conditions. Best wheat yields were obtained from Chenab 70 sown in November and best barley yields were obtained from Beladi improved sown in late October. Projected production yields are estimated to be of the order of 3.5 - 4.0 t ha under improved standards of management.

The considerable potential for field and fodder crop production on the sterile sands irrigated by brackish groundwaters in south-western Qatar was demonstrated. Alfalfa, sorghum, millets, barley, wheat and pasture grasses all performed well. Yields of alfalfa were exceptionally high at an indicated field production level of 140 t ha which is higher than any reported yields from other countries in the region. Sorghum and millets were both introduced to Qatar for the first time as potential summer crops, both of which returned high experimental yields of 10 t ha grain and 70 t ha/cut of green fodder. A large number of new entries were tested in preliminary observation nurseries in a collaborative programme with ICRISAT and ICARDA.

FAO Water Resources and Agricultural Development Project,
UTFN/QAT/003/QATAR. Technical Report No. 2, Soil Management
(based on the work of M. Ramzan and S. El-Sheikh) Doha, Qatar, 1981

ABSTRACT

The evaluation of the present agricultural systems of Qatar together with investigation into the groundwater resources, trials and investigations designed to improve irrigation efficiency, cultivation practices, soil management, farm machinery, production economics and the preparation of a master plan for future water resources and agricultural development, was undertaken in a 4-year project executed by the Food and Agriculture Organization of the United Nations under a Funds-in-Trust agreement with the Government of Qatar and as a follow-on to an earlier 3-year UNDP/FAO Project, Integrated Water and Land Use.

As part of this programme detailed soil management investigations were initiated in 1978 to two representative experimental sites; on the heavy calcareous soils of northern Qatar and the sterile dune sands irrigated by brackish groundwater in south-western Qatar. This report presents the results of 35 detailed field experiments designed to investigate the chemical, physio-chemical, mechanical and cultivation methods of soil management and in particular to solve the problems associated with surface crusting of the heavier soils and increasing the water holding capacity and fertility of the aeolian sands.

This work clearly demonstrated practical methods of overcoming soil crusting, increasing infiltration, reducing salinity and increasing productivity through the application of chisel ploughing, pre-irrigation, the use of mulches, optimum application of chemical fertilizer, cereal straw, organic matter and re-cycled municipal garbage on the heavier soils. The agricultural potential of the sterile dune sands of south-western Qatar was demonstrated in a series of experiments to determine optimum amounts of fertilizer, organic matter, straw mulching and admixtures of clay soil designed to improve water holding capacity and increase fertility.

FAO Water Resources and Agricultural Development Project,
UTFN/QAT/003/QATAR. Technical Report No. 3. Horticulture
and Extension, (based on the work of F.A. Ruwayha,
I. AL-Badr, A.S. Khunji) Doha, Qatar, 1981

ABSTRACT

The evaluation of the present agricultural systems of Qatar together with investigations into the groundwater resources, trials and investigations designed to improve irrigation efficiency, cultivation practices, soil management, farm machinery, production economics and the preparation of a master plan for future water resources and agricultural development, was undertaken in a 4-year project executed by the Food and Agriculture Organization of the United Nations under a Funds-in-Trust agreement with the Government of Qatar and as a follow-on to an earlier 3-year UNDP/FAO Project, Integrated Water and Land Use.

Nearly 70% the total value of agricultural production in Qatar is made up of vegetables grown during the main winter season and horticultural investigations have occupied a central position in the project's agricultural programme continuing on the work initiated by the former FAO executed project in 1974 by the same authors.

A wide range of varieties of the sixteen types of vegetables grown in Qatar were evaluated under various replications of planting date, spacing, water application, fertilizer rate, susceptibility to disease and pests and other improved cultural practices. In addition, a further six new vegetables were introduced with good results.

The very considerable potential for the improvement of vegetable production over present levels of an average of 15 t/ha was demonstrated. These increase of up to 25 t/ha may be achieved through a package of relatively simple improved cultural practices with minimal investment. In an effort to extend the growing season into the hotter summer months investigations into the feasibility of protected horticulture and controlled environment was carried out. At the close of the project, after 4 years work, the economic and technical feasibility of introducing cooled greenhouses had not been established and it is unlikely to be in the prevailing climate of Qatar.

FAO. Water Resources and Agricultural Development Project
UTFN/QAT/OO3/QATAR. Technical Report No. 4. Irrigation
Practices. (based on the work of N.G. Dastane and
M.F. Al-Faihani). Doha, Qatar, 1981

ABSTRACT

The evaluation of the present agricultural systems of Qatar together with investigations into the groundwater resources, trials and investigations designed to improve irrigation efficiency, cultivation practices, soil management, farm machinery, production economics and the preparation of a master plan for future water resources and agricultural development, was undertaken in a 4-year project executed by the Food and Agriculture Organization of the United Nations under a Funds-in-Trust agreement with the Government of Qatar, as a follow-on to an earlier 3-year UNDP/FAO Project, Integrated Water and Land Use.

As part of this programme detailed investigations into irrigation practices were carried out at a number of sites. Work in 1975/76, as part of the previous FAO Project, high-lighted a low irrigation efficiency of about 35%, excessive applications of water at close intervals of between 2 and 4 days, lack of land levelling, rapid salinization of the upper soil and a low yield/water ratio.

During the renewed investigation phase commenced in 1978, with the collaboration of the FAO Regional Land and Water Use Project, it was demonstrated that water use efficiencies could be enhanced considerably by increasing plant density, inter-cropping and by the prolongation of irrigation interval, on different soil types by at least 1-2 days during summer and 2-4 days in winter without a reduction in yield. Tomato, which is the most widely grown crop in Qatar, offers exceptional opportunities for inter-cropping as well as water saving. Experimental work showed a ten-fold increase in total crop production per unit water when intercropped with other winter vegetables.

An economic evaluation of irrigation resulted in the conclusion that by the introduction of a package of improvements total water savings would amount to $15 \text{ Mm}^3 \text{ yr}^{-1}$ equivalent to 25% of net water use, with a 100% increase in yield.

FAO. Water Resources and Agricultural Development Project
UTFN/QAT/OO3/QATAR. Technical Report No. 5 Water Resources
and their Development (based on the work of B.L. Eccleston,
J.G. Pike and I. Harhash), Doha, Qatar 1981

ABSTRACT

The evaluation of the present agricultural systems of Qatar together with investigations into the groundwater resources, trials and investigations designed to improve irrigation efficiency, cultivation practices, soil management, farm machinery, production economics and the preparation of a master plan for future water resources and agricultural development, was undertaken in a 4-year project executed by the Food and Agriculture Organization of the United Nations under a Funds-in-Trust agreement with the Government of Qatar, as a follow-on to an earlier 3-year UNDP/FAO project, Integrated Water and Land Use.

The major source of usable groundwater in Qatar is derived from a body of meteoric water in the northern half of the country. Detailed investigations by the Project involving exploratory drilling, regular piezometric and salinity observations, a detailed analysis of the hydro-chemistry and environmental isotopes, field observations of rainfall, run-off and recharge have all confirmed the source of this quifer system to be from recent recharge over the northern part of the country amounting to some $27 \text{ Mm}^3\text{yr}^{-1}$. This resource is estimated to contain approximately 2500 Mm^3 of freshwater within two aquifer systems; an upper aquifer of the Rus Formation made up principally of chalky and marly limestones with a low transmissivity, storage and yield and a lower aquifer within the upper Umm er Radhuma composed of porous, fracture and karstified limestone of high transmissivity. Throughout the remainder of Qatar, except in the extreme south west, groundwater conditions are highly variable with generally poor yields and a higher salinity except in a few favourable localities. The differences in groundwater occurrence between the northern and southern provinces of the country are attributed to geological controls and the sub-surface erosion or original non deposition of gypsum within the Rus formation.

Total water use in Qatar amounts to $125 \text{ Mm}^3\text{yr}^{-1}$ of which $76.2 \text{ Mm}^3\text{yr}^{-1}$ is composed of fresh groundwater, the remainder of brackish groundwater or distilled sea water. The very large difference in groundwater abstraction and estimated recharge, now of the order of $26 \text{ Mm}^3\text{yr}^{-1}$ is depleting groundwater reserves at an ever increasing rate and it is destimated the life of groundwater reserves may be of the order of 20-30 years at present rates of abstraction.

The problems associated with this serious overdraft are examined and future development possibilities based on a systems analysis are advanced. These are based on the conjunctive use of groundwater, distilled sea water, reclaimed effluent water to meet domestic, industrial and agricultural needs, including a provision to meet self-sufficiency in food. This latter option involves a large element of distilled sea water derived from waste heat from natural gas liquefaction and linked to the development of the North Dome offshore gasfield.

APPENDIX III

LIST OF TECHNICAL DOCUMENTS, NOTES AND WORKING PAPERS

Water Resources and Agricultural Development Planning

An Agricultural Development Plan for Qatar 1980 - 2000 1980
Project Proposal No. 3
J.G. Pike

Economics

Farm Enterprises and Resources Used in Qatar 1976
Technical Note No. 39
A.K. Mitra

Analysis of Doha Wholesale Market for 21 Local 1979
Products for 1978
Technical Note No. 5 (New Series)
D.J. McConnell

A Proposed Agricultural Subsidy Scheme for Qatar 1980
Project Proposal No. 2
J.G. Pike

An Economic Evaluation of Improved Irrigation 1980
Efficiency in Qatar
Technical Note No. 13 (New Series)
D.J. McConnell

Electronic Data Processing

Basic Computer Considerations 1979
Aspects of Information Handling and the
Establishment of a Computerized Water Resource and
Agr. Data Bank
Technical Note No. 3 (New Series)
M.W. Rogers

Small Computers in Project Environments 1980
Technical Note No. 8 (New Series)
M.W. Rogers

Horticulture

Technical Report No. 3 based on the work of Abdullah	1973
Main Criteria for Selecting Vegetable Varieties Best Adaptable to Local Conditions Technical Note No. 1 F. Ruwayha and I. El-Badr	1974
Corn (Summer Planting) Technical Note No. 2 F. Ruwayha and I. El-Badr	1974
Cucumber (Summer Planting) Technical Note No. 3 F. Ruwayha and I. El-Badr	1974
Squash (Summer Planting), Variety and Dates of Planting Technical Note No. 4 F. Ruwayha and I. El-Badr	1974
Squash (Summer Planting), Fertilizer Trials Technical Note No. 5 F. Ruwayha and I. El-Badr	1974
Squash (Summer Planting), Ammonium Sulphate/ Urea Trial Technical Note No. 6 F. Ruwayha and I. El-Badr	1974
Squash (Summer Planting); Seed Production Trial Technical Note No. 7 F. Ruwayha and I. El-Badr	1974
Watermelon (Summer Planting) Variety Trial Technical Note No. 8 F. Ruwayha and I. El-Badr	1974
Cantaloupe (Summer Planting) Variety Trial Technical Note No. 9 F. Ruwayha and I. El-Badr	1974
Okra (Summer Planting) Variety Trial Technical Note No. 10 F. Ruwayha and I. El-Badr	1974
Okra (Summer Planting) Seed Production Trial Technical Note No. 11 F. Ruwayha and I. El-Badr	1974
Ethrel Application on Squash and Cucumber Technical Note No. 12 F. Ruwayha and I. El-Badr	1974

Technical Guidelines for Intensive Vegetable Production Technical Note No. 13 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Squash (Fall Planting) Seed Production Trial Technical Note No. 14 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Watermelon (Fall Planting) Variety and Dates of Planting Trial Technical Note No. 15 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Cantaloupe (Fall Planting) Variety and Dates of Planting Trial Technical Note No. 16 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Cucumber (Fall Planting) Variety and Dates of Planting Trial Technical Note No. 17 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Okra (Fall Planting) Variety Trial Technical Note No. 18 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Okra (Fall Planting) Seed Production Trial Technical Note No. 19 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Observational Trials on Vegetable Seed Samples Study Paper No. 1 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Factors Affecting Citrus Study Paper No. 2 F. Ruwayha, F. Abu Attayah and I. El-Badr	1974
Squash (Fall Planting) Variety and Dates of Planting Trial Technical Note No. 20 F. Ruwayha, F. Abu Attayah and I. El-Badr	1975
Tomato, Variety and Dates of Planting Trial Technical Note No. 21 F. Ruwayha, F. Abu Attayah and I. El-Badr	1975
Tomato, Application of Ammonium Sulphate vs Urea. Technical Note No. 22 F. Ruwayha, F. Abu Attayah and I. El-Badr	1975
Sweet Pepper, Variety Trial Technical Note No. 23 F. Ruwayha, F. Abu Attayah and I. El-Badr	1975

Application of Different Levles of Urea with Cantaloupe, Cucumber, Squash and Watermelon Technical Note No. 24 F. Ruwayha, F. Abu Attayah and I. El-Badr	1975
Spacing Trial with Cantaloupe, Cucumber Watermelon and Squash Crops Technical Note No. 25 F. Ruwayha, F. Abu Attayah and I. El-Badr	1975
Tomato Production by Trellis Technical Note No. 26 F. Ruwayha, F. Abu Attayah and I. El-Badr	1975
New Watermelon Varieties Variety and Dates of Planting Trial under Spring and Fall Conditions. Technical Note No. 27 F. Ruwayha	1975
New Cantaloupe Varieties Variety and Dates of Planting Trial under Spring and Fall conditions Technical Note No. 29 F. Ruwayha	1975
New Cucumber Varieties Variety and Dates of Planting Trial under Spring and Fall Conditions Technical Note No. 29 F. Ruwayha.	1975
Eggplant, (Summer Planting) Variety Trial Technical Note No. 31 F. Ruwayha	1975
Observational Trials on Vegetable Seed Samples Study Paper No. 3 F. Ruwayha, F. Abu-Attayah and I. El-Badr	1975
Observational Trials on Vegetable Seed Samples Study Paper No. 4 F. Ruwayha	1976
Preliminary Observations of Plant Behaviour under Local Greenhouse Conditions Study Paper No. 5 R. Ruwayha	1979
Eggplant (Summer Planting Fertilizer Trial Technical Note No. 32	1976
Hot Pepper (Fall Planting) Variety Trial Technical Note No. 33 F. Ruwayha	1976
Facts, Figures and Findings on Field Trials Technical Note No. 38 F. Ruwayha	1976

Local Factors that Affect Vegetable Quality Technical Note No. 40 F. Ruwayha	1976
Horticulture and Extension Project Technical Report No. 3 F. Ruwayha and I. El-Badr	1980
Cooled-Greenhouses in Qatar Technical Note No. 11 (New Series) F. Ruwayha	1980
<u>Hydrology and Water Resources</u>	
Rainfall and Recharge over Qatar Technical Note No. 24 J.G. Pike, I. Harhash and B.P. Gemmell	1975
Cost of Pumped Groundwater in Qatar Technical Note No. 30 A.K. Mitra	1975
Qatar Water Resources and Their Development Technical Note No. 34 D.H. Parker and J.G. Pike	1976
The Results of the 1975 Exploratory Drilling Programme and of the Rehabilitation of the Abu Samra Water Wells Technical Note No. 35 Hadi El Hag	1976
Artificial Recharge of Storm Water Run-off Technical Note No. 36 I. Harhash	1976
Cost of Lifting Pumped Groundwater on Private Farms Technical Note No. 37 A.K. Mitra	1976
Water Resources and Agriculture in Qatar Technical Note No. 42 J.G. Pike and A.K. Mitra	1976
Report on Al-Aurage Drilling Programme in the Artesian Aquifer Technical Note No. 44 I. Harhash	1977
Water Resources and Their Development Technical Report No. 1	1977
The Agroclimatology of Qatar Technical Note No. 1 (New Series) J.G. Pike	1978

- Correlations in the Qatar Raingauge Network 1979
 Technical Note No. 4 (New Series)
 M.W. Rogers
- Hydro-Meteorological Data Book 1972-1979 1980
 Technical Note No. 6 (New Series)
 M.W. Rogers and M.M. Youssef
- Rainfall-Runoff-Recharge Evaluation Qatar 1980
 1971/72 - 1978/79
 Technical Note No. 7 (New Series)
 I. Harhash
- The Hydrochemistry of the Groundwaters of Qatar 1981
 Technical Note No. 14 (New Series)
 J.W. Lloyd, B.L. Eccleston and J.G. Pike
- A Mathematical Model of the Northern Groundwater Aquifer 1981
 System of Qatar
 Technical Note No. 15 (New Series)
 T.R.E. Chidley
- Water Resources and Their Development 1981
 Technical Report No. 5
 B.L. Eccleston, J.G. Pike, and I. Harhash
- Soils/Agronomy
- Evaluation of the Analytical Procedures in the 1978
 Soil Laboratory, Comments & Recommendations
 Technical Note No. 2 (New Series)
 M. Ramzan
- Soil Management 1981
 Technical Report No. 2
 M. Ramzan and S. El-Sheikh
- Results of Research & Experiments on Field Crops 1981
 1979-1980
 Project Technical Report No. 6
 O.S. Khalil
- Agronomy 1981
 Technical Report No. 1
 M.A. Khalifa and O.S. Khalil
- Irrigation
- Investigation on Irrigation Requirements 1976
 Soil Salinity and Drainage in Qatar
 Technical Note No. 41
 C.R.K. Prashar
- Water Management and Irrigation Methods in Qatar 1977
 Technical Note No. 43
 C.R.K. Prashar

A Proposal for the Disposal of Doha Treated Sewage Effluent and its Re-use for Agriculture Project Proposal No.1 J.G. Pike	1980
Water Management Practices for Crop Production in the State of Qatar. Results of Investigations 1978-79 Technical NOTE No. 10 (New Series) N.G. Dastane, M. Al-Faihani, and A. M. Baidek	1980
Irrigation Practices Technical Report No. 4 N. Dastane and M.F. Al-Faihani	1981
 <u>Extension</u>	
Evaluating the Tractor Service (Extension Service) Field Report No. 1 F. Ruwayha	1977
Evaluating the Seed Distribution Service (Extension Service) Field Report No. 2 F. Ruwayha	1978
Evaluating the Pesticide Distribution Service (Extension Service) Field Report No. 3 F. Ruwayha	1978
Extension Services, The Cornerstone to Agricultural Development Field Report No. 4 F. Ruwayha	1978