Distr.
LIMITED
E/ESCWA/NR/1993/4
1 March 1993
ORIGINAL: ENGLISH

UNITED NATIONS

ECONOMIC AND SOCIAL COUNCIL

ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

Natural Resources Science and
Technology Division

Report on consultancy mission to the Ministry of Commerce and Agriculture of Bahrain State of Bahrain - Manama

(During the period from 14-25 December 1992)

"Integrated water Resources Management for Sustainable Agricultural Development in Bahrain"

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The views expressed in this report are those of the author and do not necessarily reflect those of the United Nations Economic and social Commission for Western Asia.

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A. CONTEXT

1. Description of the Water Sector in Bahrain

1.1 Traditional Water Supply Sources

Bahrain is characterized by an arid climate. The mean annual rainfall is about 72 mm/yr. Such rainfall rate has no significance for agriculture , and very limited effect on the groundwater supplies. No surface water rivers are found in Bahrain. Groundwater was traditionally the only source of water for all uses until the early 1970's. The groundwater resources are tapped by springs, dig-wells and drilled wells. The total annual sustainable yield for the groundwater does not exceed 100 million cubic meters (MCM). However, the total abstraction for different uses was 187 MCM in 1990. The quality of the groundwater is also poor, due to high salinity, and exceeds the recommended WHO standards for potable water (500 parts per million, ppm) and lies within the severe problem category for irrigation according to FAO guidelines. Groundwater overdraft has resulted in increased water salinity, reduction in the parametric head, and drying out of the springs on the main island. Groundwater in Bahrain occurs in three aquifers: The deep, Umm Er-Raduma, with salinity exceeding 8000, of the middle Khobar aquifer with salinity of 2000-5000 pmm, and the upper shallow aquifer, Alat, with salinity of about 2000 ppm.

Most of the present groundwater abstraction is from the Khobar aquifer, which is at the same time the most badly affected by the overdraft conditions. Recharge of all there aquifers is negligible in Bahrain. It takes place in Saudi Arabia and flows through confined aquifers beneath the sea. There is some vertical hydraulic connection between these aquifers, particularly between the middle and upper aquifers.

At the present, Bahrain's water is supplied from three sources: groundwater, desalinated water and treated sewage effluent (TSE). About 70 per cent of the total water supplies for all uses is obtained from the island's groundwater resources. The agricultural sector is the major groundwater consumer, using about 63 per cent of the total abstraction. About 34 per cent of the groundwater withdrawn is blended with desalinated water to provide a domestic supply within the recognized permissible quality limits. Treated sewage effluent provides an additional source for irrigation. However, it has not been utilized to its full capacity as will be discussed later.

Agricultural and domestic water supplies in Bahrain are drawn entirely from the Dammam (Khober and Alat) aquifers, whilst a limited industrial use is taken from the brackish groundwater of the Rus and Umm-Er-Radhuma waters. The Khobar aquifer is the only major source of relatively low salinity groundwater.The overall pattern of salinity in this aquifer increase towards the south and east. Even the best of the Dammam groundwater contains some 2500 to 3500 ppm of TDS, scarcely meeting international potable water quality standards. On standard irrigation quality criteria, all Dammam groundwater would be considered hazardous having high sodium adsorption ratios commonly in excess of 10 with excessive chloride levels. However, Khobar groundwater of up to TDS 4000 ppm is being successfully used to grow moderately salt tolerant crops. Apparently, the harmful effects of such hazardous water are some what ameliorated by the highly gypsiferous nature of the soil. Further, highly permeable sandy soils and the practice of over irrigation, prevents harmful salt build-up in the plant roof zone. The brackish and saline water of the Rus-Umm Er-Radhuma system is usable, except for such usable industrial purposes as plant cooling. However, even then it has problems as it is often highly corrosive.

1.2 Treated Sewage Effluent

The water shortages, the poor quality of groundwater, the overdraft conditions of the Khobar aquifer and the need to reduce groundwater abstractions, has prompted the Government to consider the use of treated sewage effluent as an additional source of water for agricultural purposes. Accordingly, Tubli sewage treatment works have been constructed in 1983 with an initial supply of 22 MCM/year. Presently, the Tubli treated outflow is around 42 MCM/year. Though re-cycling of waste water will expand in the future to produce an ultimate supply of around 70 MCM/year by 2010, only 22 per cent of the present treated outflow is being utilized, and the rest is disposed into the sea. Therefore, efforts are needed to promote the use of treated sewage effluent in the agricultural sector. The Tubli waste water treatment plant includes an extended aeration activated sludge process for secondary treatment, followed by dual media filtration and disinfection by chlorination or ozonation for tertiary treatment. The Tubli facilities were designed, constructed and are now operated with the objective of recycling both the treated effluent and the stabilized sewage sludge.

In considering treated effluent use for agriculture and landscaping, two aspects of its quality are to be examined, namely the overall salinity and the different harmful ions. The projected quantity and quality of treated effluent is illustrated in table 1.

Table 1: Quantity and Quality of TSE: 1985-1995

Year	Quantity MCM/YR.	Salinity PPM
1985	20	4000
1988	20	3200
1995	45	2500

It is expected that with the decrease in salinity, the concentration of harmful ions as Na, C1,and So4 will also decline.

The quality of the treated waste water generated at Tulbi plant could be considered as rather good from the point of view of other than non-agricultural uses. An interesting survey on the public acceptability of renovated water has been carried out by the staff of Arabian Gulf University and reported in **Environment International**, Vol. 18 (1992).

1.3 Desalination of Seawater and Brackish Groundwater

Desalination started in Bahrain in 1975 with a production capacity of about 8 MCM/year. The current production is around 73 MCM/year. This processed water for municipal water supply is then blended with lesser quality groundwater for distribution through the State. However, new desalination plants are required as soon as they can be constructed to keep pace with the rapidly increasing potable water demand and to minimize the need to draw water from the over drifted aquifers. About one fourth of the raw water comes from brackish water from Umm-Er-Raduma aquifer and the rest is derived from the sea.

Although this water source is totally used for municipal water supplies; however, it indirectly provides a most valuable water source for agricultural purposes by virtue of its Ultimate discharge into the sewerage network and treated in the sewage treatment plants. Unless additional desalination plants are provided to meet future municipal demand, the traditional groundwater sources will be heavily over-pumped in the future.

2. Host Country Strategy

The present water situation in Bahrain and the government strategy are characterized by the following:

- Already high consumption rate per capita, which has not been affected by the recent increase in the water supply tariff.

- Very high application rates for irrigation exceeding by far the irrigation requirement under the prevailing, crop, climatic, soil and water quality conditions. Rational exploitation and use of water is inevitable for all water use sectors.

- Depletion of the main groundwater source, the Khobar aquifer, mainly for irrigation purpose, resulting in increased water salinity. So far no effective legislation currently exists to control groundwater abstraction, although drilling new wells is prohibited, and groundwater extraction is being metered.

- Increasing reliance on desalinated water for municipal and industrial purposes. Both sea water and brackish groundwater provide the raw water source.

- Utilization of treated sewage effluent is presently limited by the capacity of the Tubli plant to produce tertiary treated water, which is only one fourth of the influence to the plant. The use of TSE water for irrigation would play an important role in the future to alleviate the pressure on the Khubar aquifer.

- There is a good potential for storing TSE water in the various aquifers by means of artificial recharge for different purposes among these:

    * To control sea water intrusion into the depleted aquifers.

    * To augment the yield of these aquifers.

    * For seasonal or long-term strategic storage.

    * To provide additional purification for the TSE water by the natural process of infiltration to the shallow aquifer.

The government recognizes that no simple solution exists to the water problem. However, proceeding with the above given options altogether and in an integrated manner would alleviate the problem.

3. Institutional Framework for the Sub-sector

The responsibility of the water resources and water supply in Bahrain is divided as follows:

(a) **Ministry of Commerce and Agriculture:**

- Water Resources Directorate, which is responsible for the drilling activities, groundwater monitoring, and planning and conservation of water.

- Project Directorate, which coordinates the distribution and planning of the programme for treated sewerage effluent for use in irrigation.

(b) **Ministry of Work, Power, and Water:**

- Water supply directorate, responsible for water production from groundwater and desalination plants, and for distribution for municipal and rural use.

- Roads and Sewerage Directorate, responsible for the installation, operation and maintenance of the sewerage network and treatment plants, and for the distribution of the TSE for the different agricultural areas.

(c) **The High Water Council:**

- Responsible for formulation of the water sector policy, protection and guiding development and coordinating between the Ministries concerned in the water sector. The council is headed by the Prime-Minister, with membership of the Ministries of Development, Industry, Health, Work-Power and Water and Commerce and Agriculture.

B. PROJECT JUSTIFICATION AND APPROACH

1. General

The main problem to be addressed by the proposed project is the ongoing loss of the traditional and main irrigation water source in Bahrain, the groundwater, by aquifer depletion and quality deterioration in terms of salinity buildup. This has resulted in insufficiency and inadequacy of the water supply for irrigation, and consequently threatening the overall agricultural development in Bahrain. Over-pumping of the groundwater aquifer is the prime reason for this ongoing depletion and deterioration. Reversing these adverse effects on groundwater is not a simple task, and it is a time consuming process. With complete control on groundwater extraction and limiting it to the original natural recharge rate, it will take years for aquifers to recover reasonable hydrogeological conditions in Bahrain.

Continued groundwater extraction at the present rate and pattern will lead to further depletion and deterioration of the groundwater resources, and ultimately will eliminate this water source as a traditional supply source for agriculture. Infiltration of the excess irrigation water in agricultural areas has le d to deterioration of the Shallow aquifer (Alat and Neogone). Presently, pumping from the Khobar aquifer is about twice the safe yield of this aquifer. Not mentioning the longer term effect of developing this aquifer in the head-water area, Saudi Arabia.

Realizing the seriousness of this problem, and its immediate threat to agricultural development in Bahrain, alternative water resources should be sought, and appropriate aquifer management should be implemented very soon. Alternative water resources in Bahrain are the following:

* Desalinated sea water and brackish groundwater.
* Treated sewage effluent.
* Drainage water from agricultural lands.

Desalinated water use, solely for irrigation is too costly. Presently, desalination plants in Bahrain supply about 20 MCM/yr. for municipal purposes after blending it with brackish groundwater. However, only a small portion of this supplied water is actually consumed in houses, and the remaining flows into the sewers and ultimately to the treatment plant at Tobli. About 78 per cent of the sewage influent receives secondary treatment and is discharged into the sea. The remaining 22 per cent is treated at the tertiary level and is used for agricultural production. Tertiary treatment at this plant includes ozonation (10 mg/L), chloruation and filtration. Presently 565 hectares (ha) are irrigated with various vegetable crops using tertiary treated sewage water (TSE). There are plans to irrigate additional 980 ha. in the future. However, this is not possible with the existing tertiary treatment facilities at Tobli plant, which has a maximum theoretical capacity of 34,000 m^3/day. However, due to the present operation schedule this capacity is limited to about 23,000 m^3/day.

Therefore, the second phase of the irrigation plan using TSE water can not be implemented without expanding the present Tobli plant or finding another method of treatment. The plant expansion, according to the officials in charge, for tertiary treatment is costly and may not be implemented until the year 2000.

In water-short areas, like Bahrain, where new water sources are scarce, and the cost of potable grade water is very high, it becomes more cost-effective to remove some of the waste materials and reuse the water for suitable applications such as irrigation. This will help reduce the demand for or augment available potable water sources. The state of Bahrain has already taken the first step in this aspect where about 15-20 per cent of the irrigated land uses TSE water. This initiative should be encouraged. However, new and less costly treatment methods should be sought.

Treatment of secondary or even primary sewage water using land application and artificial recharge techniques has proved technically and economically viable in different parts of the world. However, in water-short areas, the water treated this way constitutes a potential and valuable water source for appropriate uses requiring lower grade water ,and it should not be wasted without use.

It is a major objective of the proposed project to introduce artificial recharge technique as an inexpensive means for treating secondary or tertiary treated water in order to provide a new safe alternative water source for irrigation.

The second potential irrigation water source for the future is the drainage water, mostly from agricultural lands. The water table in Bahrain, particularly in the coastal areas and agricultural lands, is rather shallow, and it is wither the capillarity range. The low topographic relief over the island, excessive irrigation, and upward leakage from deep artisan aquifer are factors responsible for the high water table conditions. Among these factors infiltration of excess irrigation water is the most important and predominant in the agricultural areas. The resulting shallow water table aquifer drains naturally along the coast and in swamps, or thorough some existing recently constructed drains. It is also naturally discharging by evapo-transpiration and by evaporation under the effect of capillarity force. Successful agriculture under these conditions necessitates appropriate drainage. The drainage water salinity presently ranges from 3000 to 10,000 ppm. As return irrigation water is a major source of recharge to this shallow aquifer, the salinity of irrigation water would be reflected in the salinity of drainage water. With the increased use of TSE water, which is partly composed of desalinated water, and with the expected future increase in utilizing desalinated water for municipal use, the salinity of the drainage water is expected to decrease and would ultimately become better than any available groundwater for irrigation purposes. In addition, this water source will be gradually growing with the increased production and treatment of municipal sewage water.

Presently, 21 drains totalling 20 km in length have been constructed. The quantity of flow in these drains is not available. However, the drainage water production rate from a farm in Jesra area, 15 ha. area, provided with 3 km long main collector and a system of secondary collectors and field drains, was about 30 L/sec., i.e. about 2.0 L/sec. per hectare. Accordingly, a rough estimation of the total drainage water which can be produced from 1000 ha. would be about 2.0 m^3/sec. (about 60 million cubic meters per year, MCM/yr.). However, this is a relatively high value of drainage water to be generated from such area. The high production rate taken from the above mentioned farm could be attributed partly to that farm and partly to adjacent irrigated, high water table, areas. The purpose of this calculation is just to show the order of magnitude of drainage water which might be obtained from the shallow water-table aquifer. Testing the viability of using drainage water for irrigating appropriate crops is another objective for the proposed project.

As water resources problems and scarcity are common features, and bear large similarities in the Gulf States, the success of such integrated water resource project for sustainable agricultural development, will be of interest to all these countries. The transfer of the developed techniques and practices can then be an easy task, through appropriate training and participation of the local staff during the various phases of the project. Cooperation with the Ministry of Works, Power and Water and other research centres in Bahrain would be necessary and beneficial to the project.

2. Project Description

In the light of the above discussion and background information, the proposed project will consist of the following components:

(a) Artificial recharge facilities, consisting of infiltration Basins and distribution network with flow control facilities. Two parallel series of rectangular basins would be required for alternating operation and maintenance. A tentative total area for all basins would be five hectares which might need to be doubled based on the results of the detailed site investigation works.

(b) Water recovery system for the recharged water. This could be wells located along the centre line between the two series of basins, or a drainage system with the main collector along the down stream side of the recharge basins. The final selection of the type and size of the recovery system will be based on the results of field tests and investigations.

(c) The TSE water will be brought to the recharge site via a pipe line branching from the existing conveyors/ reservoirs of TSE. Therefore, proximity of the selected project site to these facilities is important to reduce cost.

(d) The recovered water will be used to irrigate an area, preferably close t the recharge site (area (1) Figure1). This area should be provided with appropriate drainage system which would serve two purposes: Lowering the water table and recovery of the drainage water for reuse on a second irrigation area down stream of the first area (area (2) Figure 1), which should also be provided with adequate drainage facilities. The drainage water from area (2) may be disposed into the sea.

The long term future situation of artificial rechange for the shallow aquifer using TSE water in Bahrain is expected to be as shown in figure2 .

C. DEVELOPMENT OBJECTIVES

The main development objectives of the proposed project is to achieve an integrated water resources development and efficient water use for sustainable agriculture in Bahrain. The water resources to be developed integratively and managed conjunctionly includes: The treated sewage water, the drainage water from irrigated areas, and the shallow groundwater aquifer in the northern part of Bahrain.

D. **IMMEDIATE OBJECTIVES**

1. Objective 1:

Upgrading and improving the utilization of TSE for unrestricted agriculture through artificial recharge.

Natural aquifer material and the soil profile have proved to have significant capability to purify infiltrating water from suspended solids, heavy metals and from bacteria. The level of purification which can be achieved this way is high enough to provide advanced purification for the infiltrating water at relatively very low cost as compared with the conventual type of treatment. The artificial recharge process, using infiltration basins, will change the identity of the TSE water and makes it physically and socially acceptable for direct use for unrestricted agriculture, thus providing an alternative and even better water source than the native groundwater, which has been salinized and overdeveloped. This technique has also proved technically and economically viable for treating secondary treated sewage effluent in many parts of the world. However, the present supply of the tertiary treated sewage water for irrigation is limited to the capacity of Tobli plant, which is presently over loaded, and the supply of such water is variable on daily and seasonal basis.

Aquifer recharge could help overcome this problem by providing short term storage in the aquifer. Another advantage of artificial recharge of TSE is the improvement of the salinity of the native groundwater. There is a trend of decreasing the salinity of the TSE with the increased supply from desalination plants.

1.1 Output 1:

Identification of potential and alternative sites for the proposed pilot project, and selection of the best site.

The prevailing hydrogeologic conditions are the key criteria for this identification process. Site conditions should allow for aquifer recharge through infiltration basins, short-term aquifer storage for the recharged water, favorable conditions for recovery of the recharged water by wells or drains, and for installation of a drainage network to recover drainage water from the agricultural land. Other important factors are land availability and soil suitability for agriculture. The availability of TSE water through the existing conveyance and storage facilities should also be taken into consideration to reduce the project cost. In addition the physical setting of the project site should represent the average conditions of the present agricultural areas in order that the project results could be transposed to other areas for project extension.

1.1.1 Activity 1

Review available literature on the hydrogeology of Bahrain including reports, maps, and borehole data.

1.1.2 Activity 2

Identify alternative potential sites for the proposed pilot project.

1.1.3 Activity 3

Select the best possible site in accordance with the given criteria.

1.1.4 Activity 4

Recommend and implement appropriate and detailed investigation programme for the selected site in order to assess the pre-project conditions and develop design criteria. The investigation programme should include but not necessarily be limited to the following:

(a) Topographic survey;
(b) Borehole drilling (6-8 bore holes);
(c) Conduct pumping tests on 2 boreholes;
(d) Excavation of test pits (about 6);
(e) Monitor groundwater levels and water quality;
(f) Conduct infiltration tests on small scale basins.
(g) Survey of existing drainage facilities, and monotor their flow rates and water quality.

1.1.5 Activity 5

Analyze the collected data and prepare the following maps for the project area:

(a) Topographic contour map;
(b) Water table contour map;
(c) Depth to water map;

(d) Depth to first impervious layer;
(e) Groundwater quality maps and graphs;
(f) Soil map.

1.2 Output 2

Design the various components of the recharge and recovery facilities.

1.2.1 **Activity 1**

Develop design criteria for the various components of the project. For objective No.1 the following design criteria or parameters are needed:

(a) Infiltration rates from basins;

(b) Possible pumping rates from wells;

(c) Groundwater recovery rate per linear meter of drains per meter penetration depth below the water table, should extraction of groundwater by machine drilled wells proves inefficient due to the limited aquifer thickness;

(d) Lag time and distance between the recharge basins and the recovery facilities. The recommended design criteria should be based on analysis of the data collected from the site investigation programme.

1.2.2 **Activity 2**

Prepare the final design for the recharge and recovery facilities, based on the design criteria obtained from output (1.2) and on the irrigation water requirements.

For the recharge basins :

- Location and attitude
- Size
- Water flow control structures, such as: pipes, canals, drops and rises, flow measuring devices.

For the recovery system :

- If wells: No. of wells, locations, depths, design, diameter and pump capacity, water collection system.

- If drains: Location, attitude, length, depth, location of sumps, pumping requirements.

1.2.3 Activity 3

Design the monitoring network required for evaluating the project performance including:

- Determine location and number of sites for monitoring groundwater levels and quality.

- Determine frequency of monitoring.

- Determine equipment and instruments required.

1.3 Output

Prepare documents for executing the project.

1.3.1 Activity 1

Prepare technical specifications including quantities of works and items.

1.3.2 Activity 2

Prepare the necessary drawings of the various project components.

1.3.3 Activity 3

Prepare cost estimates for the work.

1.4 Output 4

Construction of the artificial recharge and recovery components of the project.

1.4.1 Activity 1

Construct the infiltration/spreading basins and the associated flow control structures.

1.4.2 Activity 2

Construct the water recovery facilities (well and/or drains).

1.4.3 Activity 3

Construct and instrument the monitoring network.

1.5 Output 1.5

Project operation monitoring and assessment.

1.5.1 Activity 1

Start water spreading in the recharge basins.

1.5.2 Activity 2

Start pumping water from the recovery system.

1.5.3 Activity 3

Monitor inflow and outflow from the system, quantities and qualities.

1.5.4 Activity 4

Evaluate the project performance and propose possible improvements and modifications.

2. Immediate Objective 2

Management of agricultural land drainage and utilization of the drainage water for irrigating appropriate crops.

2.1 Output 1

Assesstment of the water logging problem and drainage conditions in the northern, north-central and north-western coasts of Bahrain, based on the available information.

2.1.1 Activity 1

Review available letriture and survey existing drainage network and its performance.

2.1.2 Activity 2

Prepare a general depth to water map.

2.1.3 Activity 3

Plot all existing drains on a map, and collect information on their design, lengths depths, flow rates of water, and water quality.

2.2 Output 2

Assesstment of the drainage conditions at the final selected site for the artificial recharge project and the associated agricultural area.

2.2.1 Activity 1

Analyze the data collected on the existing drainage system to come out with an estimation of the drainage characteristics of the different areas and different soil conditions.

2.2.2 Activity 2

Recommend and implement a detailed site investigation programme in order to assess the drainage characteristics and conditions in the project area, and to develop design criteria.

2.2.3 Activity 3

Analyze the collected data from 2.2.1 and 2.2.2 to determine design criteria and prepare the maps listed under item (1.1.5).

2.3 Output 3

Final design for the drainage and water recovery system in the areas to be irrigated.

2.3.1 Activity 1

Design the drainage system for areas (1) Figure (2) which will be irrigated from recovery of the recharged water and directly from the tertiary treated waste water supplied from Tubli plant.

2.3.2 Activity 2

Design the recovery system of the collected drainage water for later reuse in irrigation area (3) Figure (2).

2.3.3 Activity 3

Design the drainage system for area (3) figure (2).

2.3.4 Activity 4

Design an appropriate monitoring system for the rates of flow from various drains, for the groundwater levels in the irrigated fields, and for the water quality of the groundwater and drainage water.

2.4 Output 4

Tender documents for executing the drainage works.

2.4.1 Activity 1

prepare technical specifications, drawings, cost estimates and tender documents.

2.5 Output 5

Project construction, according to specifications.

2.5.1 Activity 1

Construct the drainage and recovery systems and the monitoring network.

2.6 Output 6

Project operation and assessment.

2.6.1 Activity 1

Start recovery and reuse of the drainage water for irrigation in area (3).

2.6.2 Activity 2

Monitor rate of application of irrigation water and recovery rate of the drainage water, (quantities and qualities).

2.6.3 Activity 3

Evaluate the project performance and propose possible improvements and modifications.

3. **Immediate Objective 3**

Evaluate the hydrogeological and economic feasibility of the overall project.

3.1 Output 1

Feasibility of artificial recharge.

3.1.1 Activity 1

Preparation of a final report on the hydrogeological and economic feasibility of artificial recharge of TSE water for later use for unrestricted agricultural under the prevailing physical conditions in Bahrain.

3.2 Output 2

Feasibility of reuse of drainage water for irrigation.

3.2.1 Activity 1

Include in the same report, the economic feasibility of reuse of drainage water for appropriate crops.

4. **Immediate Objective 4**

Introduce and familiarize local staff in the Water Resources Department artificial recharge techniques which are expected to have a significant role in the overall future water resources management schemes.

4.1 Output 1

A trained technical team in the various aspects and stages of development of artificial recharge projects.

4.1.1 Activity 1

Provide on job training of the local counterpart team through short course at the beginning of each phase of activities, field training and directed studies.

4.1.2 Activity 2

Arrange for and hold a workshop on artificial recharge at the end of the project and invite participants from neighboring countries.

E. INPUTS

1. Government (MOCA):

* **Personnel**

  - One hydrogeologist
  - One drainage engineer
  - Two hydrology technitions
  - Part time contribution from the computer section staff at the Water Resources Directorate.

* **Equipment and Services**

  - Drilling and pumping equipment of the drilling section to drill investigation and monitoring boreholes. .

  - Services of the geophysical logging unit.

  - Services of the drainage section mainly for the construction of the drainage system required.

  - Services of the computer section of the Water Resources Directorate.

  - Laboratory services for analyzing water and soil samples.

  - Access to existing water data base, information, reports and maps.

- Office facilities such as xerox, telephones, drafting, ... etc.
- Flow measuring equipment (weirs,flow meters).
- One field vehicle and one driver if necessary.

* **Project Area:**

About ten hectares land are needed for the artificial recharge and water recovery facilities. This land should be close to the areas to be irrigated and to the terminale of the TSE facilities.

* **Office Space:**

Office space and furniture for the local and expatriate staff .

1. United Nations Contribution

* **Personnel:**

- Senior Hydrogeologist, suitably qualified for the entire project period (two years). A job description is given in Appendix I.
- Short term consultants to be provided in accordance with the project needs. (Total of 8 man/months). Most of the assistance will be needed in the field of artificial recharge. It will also be needed for the drainage works.

* **Training:**

As artificial recharge is a new technique in the region, adequate training is needed for the national staff to be able to take over the project and to extend its capacity. Training is needed in the various fields and project stages. It could be done through short term training courses (2 weeks) at four months intervals or at the beginning of each task or major activity. The training course could be through lectures and field applications.

Continued on-the-job training will also be provided through out the project. The training themes will be hydrogeolgoy with emphasis on artificial recharge planning, design, construction of facilities, operation, maintenance, monitoring and evaluation. A study tour for the national serious hydrogeologist to similar projects will be extremely useful during the first quarter of the project period. A workshop on artificial recharge will be held for which candidadtes feom the neighbouring countries will be invited.

3. Cooperation with other local parties

* Cooperation and coordination with the Ministry of Work, Power and Water on technical issues.

* Cooperation with the Bahrain University on possible research projects will also be useful to the project.

F. **RISKS**

Treatment of sewage water through land application and artificial recharge has provided successful and technically and economically viable. The produced water will be safe for irrigation if sufficient flow path and lag time are provided for the recharged water before recovery.

The main source of risk would be the improper selection of the project site, particularly with regard to the infiltration rates from the spreading basins. However, such problem can be easily solved by increasing the area covered by the infiltration basins, and extending the water recovery system.

Appropriate maintenance of the infiltration basins can also enhance the infiltration rate and consequently reduce the area required.

G. **PRIOR OBLIGATIONS AND PRE-REQUISITES**

* The necessary counterpart staff should be assigned on full time bases, and put at the disposal of the resident expert.

* The services required from the MOCA should be made available as and when needed particularly for the well

drilling and testing activities as well as for the construction of the drainage and water recovery systems.

* Adequate office spaces and facilities should be provided at the beginning of the project.

H. PROJECT REVIEWS AND REPORTING

The project will be subject to tri-party review for evaluation of its performance by representatives from the Government, UNDP and the United Nations executing agency. Reviews will be needed at different stages throughout the project (Annex 1). During the operation of the project, and after submission of the final project report. The senior project officer of the United Nations executing agency shall prepare and submit to each review meeting a Project Performance Evaluation Report (PPER).

The following reports would also be required:

1. Inception report to be submitted two months after the commencement of the project (1st. progress report). The report should include the results of the literature review, field reconnaissance works, the identification and selection of the final project site, and a programme for the next phase investigations, particularly the site investigation programme.

2. Technical report on the results of the site investigation programmes.

3. Design report for the proposed artificial recharge and drainage systems and facilities.

4. Annual progress report (Brief).

5. Final report which should be in detail and to include:

   - All previous technical reports as annexes
   - Operation and maintenance manual.

I. BUDGETS

1. Project budget covering government contributions-in-kind.

Description	Time Allocation Man/Months	U.S. Dollars
a. Project Personnel:		
- Hydrogeologist	24	100,000
- Drainage Engineer	08	040,000
- Computer Specialist	04	020,000
- Hydrology technicians(2)	24	030,000
- Operator	24	030,000
Total		220,000

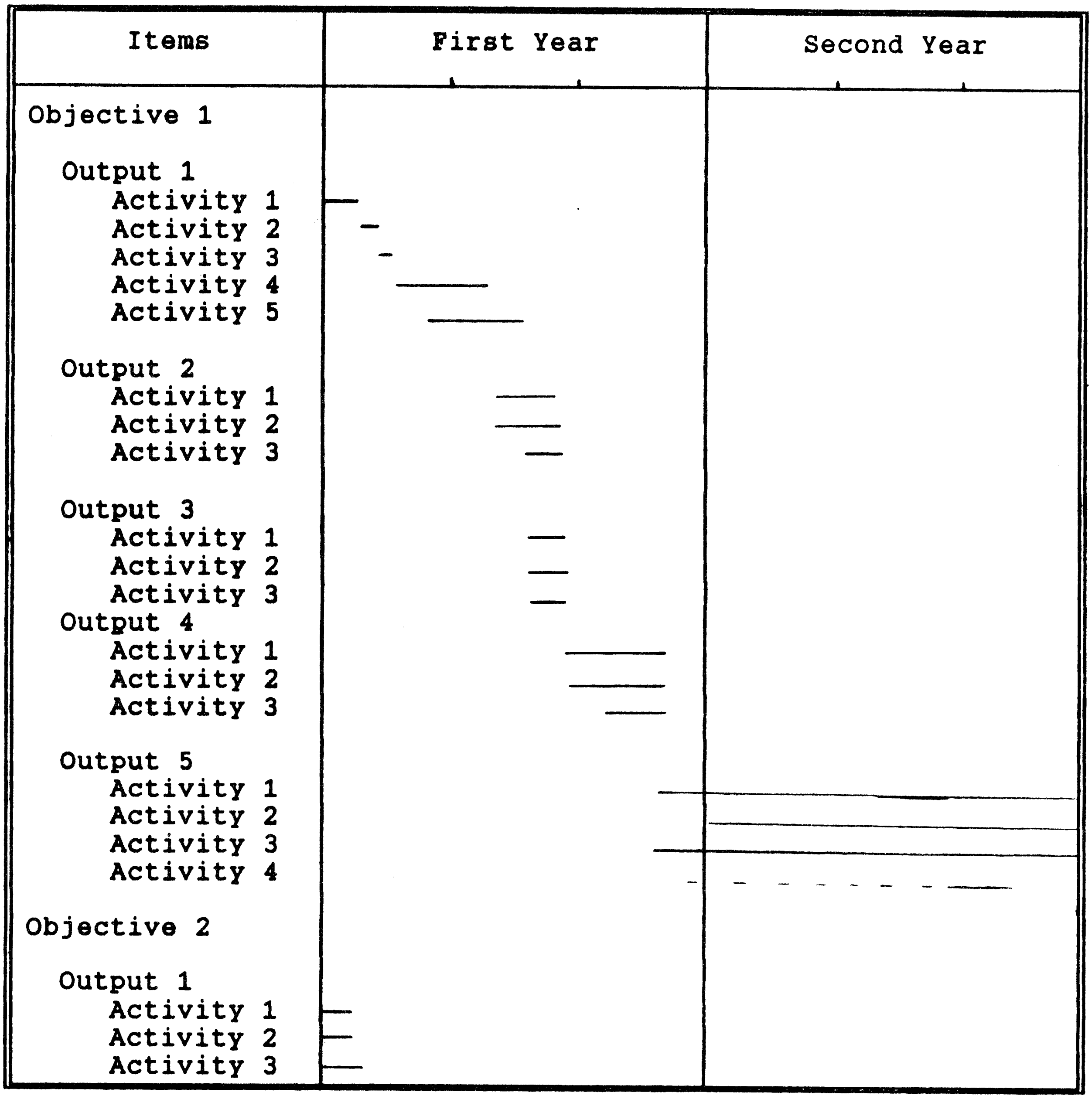
Description	Time Allocation Man/Months	U.S. Dollars
b. Equipment, material and services:		
- Field vehicle	24	20,000
- Logging equipment and crew	03	15,000
- Drilling rig and ancillaries	06	60,000
- Equipment for construction of drainage system	06	40,000
- Casing pipes for the drilled boreholes. Line pipes "8-12" for conveyance of TSE to the site.		15,000
- Low head high rates pumps for the water recovery system (8).		40,000
- Office Space and facilities for 24 months.		
<u>Sub-total</u>		<u>190,000</u>
<u>Total</u>		410,000
Contingency 10%		041,000
Grand total		<u>461,000</u>

2. Project budget covering United Nations Agency Contributions:

Description	Time Allocation Man/Months	U.S. Dollars
a. Project Personnel:		
* International Experts		
- Senior Hydrogeologist	24	300,000
- Consultant for drainage	4	080,000
- Consultant-Artificial Recharge.	5	100,000
Total		470,000
b. Training (out-of-country)		020,000
c. Equipment		005,000
- Water level records(2)		
- PH meter, E.C. meter, current flow meter,one each		005,000
d. Miscellaneous		005,000
Total		505,000
Contingency		050,000
Grand Total		555,000

Grand Total for the project about One million U.S. Dollars.

Appendix 1 Work Plan



APPENDIX 1 Continued

Items	First Year	Second Year
Output 2		
Activity 1		
Activity 2		
Activity 3		
Output 3		
Activity 1		
Activity 2		
Activity 3		
Activity 4		
Output 4		
Activity 1		
Output 5		
Activity 1		
Output 6		
Activity 1		
Activity 2		
Activity 3		
Objective 3		
Output 1		
Activity 1		
Output 2		
Activity 1		
Objective 4		
Output 1		
Activity 1		
Activity 2		

APPENDIX 2

JOB DESCRIPTION

Title:	Senior Hydrogeologist (Project Manager)
Duration:	2 years
Location:	Bahrain, Water Resources Directorate, Ministry of Commerce and Agriculture.
Duties:	The hydrogeologist will be responsible for planning, management and implementation of the overall project and during all phases. Short term consultants on specific tasks will be available to assist him. He will also be assisted by the local team of the staff. The consultants will advise on artificial recharge and drainage and will prepare the major part of the designs of these facilities in consultation and coordination with the project Manager. The local staff will assist him in the field activities and office work under his direct supervision. The project manager will conduct the preliminary reconnaissance study and literature review for site selection, prepare the site investigation programmes, supervise their implementation analyze and interpret the collected data in order to determine the design parameters, assist in the project design, supervise the construction works design the operation schedule, evaluate the results, and finally prepare the progress and technical reports as required. The project manager will also train the local staff on the various aspects of the project during all phases to a level which enables them to perform the duties assigned to them satisfactorily.

Qualifications:

* A minimum academic education of M.Sc. degree in Hydrogeology is required for this post. A Ph.D. degree holder is prefred.

* A minimum of 15 years experience is required in the field of hydrogeology.

* Experience in artificial recharge projects by spreading basins is a must.

* A proper experience in project management and report writing is required.

* Experience in the Middle East conditions is desirable.

Languages:

A good command of English is essential (both verbal and writing).

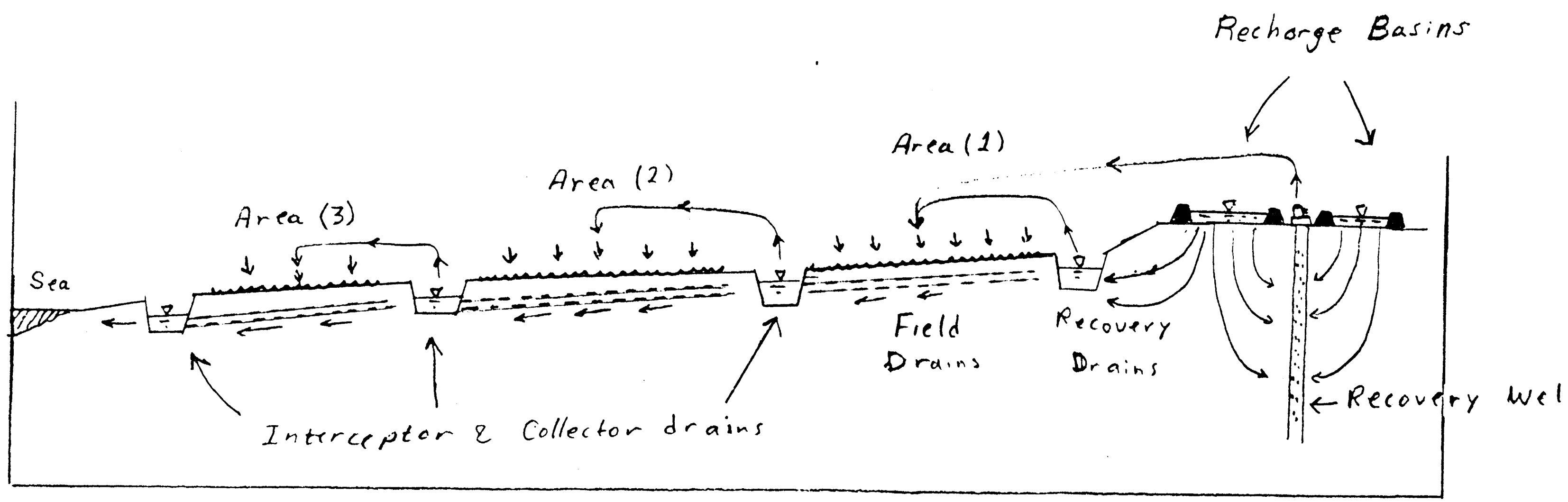


Figure 1 Recharge basins , recovery facilities for recharged and drainage water, and irrigated areas

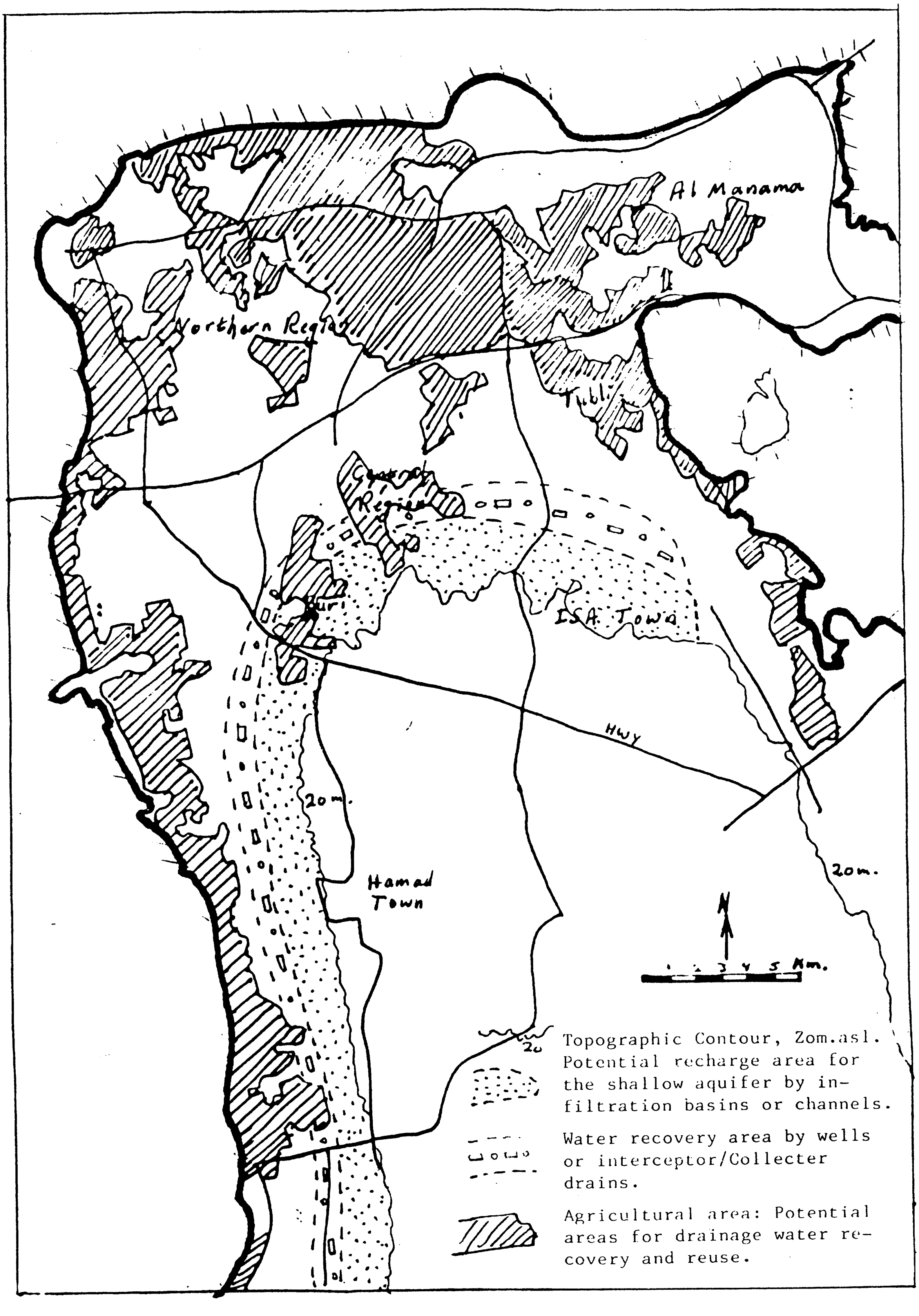


Figure 2 Potential Artificial Recharge Areas for the shallow Aquifer in Bahrain.