Distr.
GENERAL
E/ESCWA/AGR/1992/9/Rev.1
3 November 1992
ORIGINAL: ENGLISH

United Nations Economic
and Social Commission
for Western Asia (ESCWA)

United Nations Environment
Programme Regional Office
for West Asia (UNEP/ROWA)

THE NATIONAL PLAN OF ACTION TO COMBAT DESERTIFICATION IN BAHRAIN

November 1992

93-0068

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1 Bahraini dinar (BD) = $US 2.645

1 $US = BD 0.378

ACKNOWLEDGEMENT

The United Nations Environment Programme (UNEP) Regional Office for West Asia (ROWA) and the Economic and Social Commission for Western Asia (ESCWA) acknowledges the valuable cooperation and assistance received from the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD). Also, the cooperation and assistance received from the following ministries, government authorities and private organizations during the course of the preparation of the National Plan of Action to Combat Desertification (NPACD) in Bahrain are highly appreciated.

- Ministry of Commerce and Agriculture (MOCA) -- Secretariat of Agriculture

  Agricultural Projects Directorate
  Water Resources Bureau
  Agricultural Research Directorate

- Arabian Gulf University, Bahrain (AGU)

  College of Applied Sciences
  Desert Sciences and Arid Lands Post-Graduate Programme

- Ministry of Health

  Environment Protection Council

- Ministry of Works, Power and Water

  Roads and Sewerage Directorate
  Water Supply Directorate

The personal efforts offered by Dr. Nabil Rofail of the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) in developing this plan and its priority programmes and projects, and also the personal efforts of Dr. Walid Zubari of Arabian Gulf University (AGU) in updating the information on water resources and uses in Bahrain and in preparing the coloured diagrams for this plan are gratefully acknowledged.

Professor Dr. Nabil Alaa El-Din of the Arabian Gulf University (AGU) has done a commendable job in updating information, editing and finalizing this plan. This personal contribution by him is highly appreciated.

Executive Summary

A team of consultants and national experts was commissioned by The United Nations Environment Programme (UNEP) -- Regional Office for West Asia (ROWA) to prepare a National Plan of Action to Combat Desertification (NPACD) for the State of Bahrain. The preparation of a National Plan of Action to Combat Desertification (NPACD) was delayed because of the Gulf conflict.

After a thorough study of the inventory and potential resources of the State of Bahrain, the socio-economic setting, the status of desertification in Bahrain, as well as the review of past and current efforts to combat desertification in the country the report arrives at a number of conclusions.

The State of Bahrain comprises an archipelago of 36 islands located at the mid-point of the Arabian Gulf in relatively shallow waters. The islands are located midway between Saudi Arabia to the west (56 kilometres [km]) and Qatar to the east (27 km) and Iran straight across the width of the Gulf (235 km). The islands are situated at a latitude between 25° and 27° north and longitude between 45° and 51° east of Greenwich. The largest island, Bahrain, with the capital town Manama, represents 85 per cent of the total area of the State, which comprises 692.5 square kilometres (sq km).

The general topography of the islands is flat. The islands rise almost imperceptibly from the shallow waters of the Gulf. Bahrain Island is formed from an anticlinal dome of sedimentary limestone rocks with a displaced centre forming a long shallow saucer called the central depression, some 10 km long by 2.5 km wide. This is encircled by inward-facing scarps up to about 20 metres (m) high formed from the remaining rock strata (rim rock). Outwardly the back slope shelves gently down from the rim rock to the coastal region. All that remains of the summit of the dome is a ridge of hills in the central depression, of which Jabal Dukhan (135 m above sealevel) is its highest point.

Bahrain has a desert climate which is characterized by high temperatures, erratic -- often scanty -- rainfall and high humidity levels due to the surrounding Arabian Gulf water. Temperature averages vary from 17°C in winter to 35°C in summer. The rainy season extends from November to April. The annual rainfall, averaging only 74 millimetres (mm), is sufficient only to support the most drought-resistant desert vegetation, while evapotranspiration can peak to over 10 mm a day in July. The air humidity in Bahrain has a mean annual relative humidity of 67.2 per cent, indicating high humidity throughout the year. The prevailing winds are in the path of north-westerlies known as Shamal winds which temper Bahrain's high temperatures. The clima-diagram of Bahrain shows no humid period prevailing during the whole year. The soils are almost dry all the year except for a few days after rainfall.

The soils of Bahrain Island were formed under arid conditions. Apart from a narrow fertile strip of land in the north, Bahrain has little soil which could be considered as agriculturally useful. The soil textures are mainly sandy with low organic matter content (0.05-1.5 per cent), deficient in macro- and micro-nutrients, moderate to high salinity (4-12 mmhos) in irrigated lands and very low water-holding capacity (available water 2-6 per cent). Most of the soils contain high amounts of calcium carbonate (15-30 per cent) and moderate amounts of gypsum.

In areas along the coastal strip, calcareous impermeable layers at a depth of one to three metres have caused localized waterlogging, increased salinization and abandoned agriculture.

Bahrain's water supply is drawn from two main sources: groundwater and desalinated sea water. Groundwater is provided by the Eocene aquifers extending beneath the sea from Saudi Arabia, with west-to-east regional hydraulic gradients which implies recharge on the outcrop area of the aquifer system in Saudi Arabia.

In Bahrain there are principally two aqifers, "A" and "B", both in Dammam Formation (Lower and Middle Eocene). Aquifer "A" developed in the dolomitic limestone of the Alat member and possesses limited water-yielding properties (250 m^2/day transmissivity and 0.0005 storage coefficient) and salinity ranging between 2,500-4,500 mg/L.sals. Lower aquifer "B" is developed in the Khobar member and represents the principal reservoir, providing more than 70 per cent of groundwater abstracted in Bahrain for agricultural, domestic and industrial uses. Its transmissivity (10,000 m^2/day) is higher than that of the "A" zone and the storage coefficient is about 0.00005 dimensionless). The salinity of this aquifer ranges between 2,000 and 4,000 mg/L.

A third less important aquifer, "C", developed in the Rus (Lower Eocene) and Umm Er-Radhuma (Upper Paleocene) formations, contains high-salinity waters (10,000 mg/L) and is used mainly for industrial purposes and reverse osmosis desalination plants.

There are now about 2,000 water abstraction points, of which 800 are boreholes and the rest large-diameter dug wells. The present annual abstraction of groundwater is in the order of 191 Mm^3 (153,9 and 29 Mm^3 from Dammam, Neogen, Rus and Umm Er-Radhuma aquifers respectively). The increased abstraction of groundwater has led to the decrease of the piezometric head in Bahrain by 4-5 metres, permitting upward intrusion of saline water from aquifer "C" into the "B" aquifer and rendering some central coastal regions unproductive.

In 1987, the abstraction of groundwater was, by user's sector, 98 Mm^3 for agriculture (30 Mm^3, 41 Mm^3 and 28 Mm^3 for dates, vegetables and alfalfa and private gardens, respectively, 41 Mm^3 for municipalities, 14 Mm^3 for industry, 22 Mm^3 for desalination plants and 15 Mm^3, for land and offshore springs as natural discharge.

Treated sewage effluent (TSE) represents a valuable resource, providing presently 22 Mm^3/y and an ultimate supply of around 60 Mm^3/y. The quality of TSE is improving and can now be considered good for agricultural purposes. Chemical and hygienic properties are within international standards. The present use of TSE is still limited to about 5,000 Mm^3/day for irrigation purposes and the rest (70,000-75,000 Mm^3/day) is discharged into the sea.

The agricultural land in 1989 was about 4,048 hectares (ha), representing only 5.9 per cent of the total area of the country. The cultivated area decreased from 3,793 ha in 1966 to 1,750 ha in 1989. During the oil boom, urban development at the expense of better agricultural land led to a remarkable decrease of cultivated areas.

The population of Bahrain increased from about 90,000 inhabitants in 1941 to about 516,000 in 1991 (medium projection). The employed labour force increased from 52,300 in 1965 to 177,500 in 1991, out of which 41.8 per cent and 37.5 per cent were Bahrainis, respectively. Employment in the agricultural sector declined from 12.4 per cent of the total labour force in 1971 to 5.3 per cent in 1981, coinciding with the decrease of cultivated areas. Recent figures show increased employment in this sector, which stood at about 7,000 in 1991.

The contribution of agriculture and fisheries to the Gross Domestic Product (GDP) was limited to only 1.6-1.8 per cent until 1986 and increased to reach 2.5 per cent in 1991; it is expected to rise to 2.3 per cent in the year 2001.

The last four decades in Bahrain have witnessed a large increase in population (3 per cent annually) and hence a decrease of per caput cultivated area, from 0.026 ha in 1953 to only 0.006 ha in 1989. Increased prices of agricultural products caused farmers to increase irrigation to improve land productivity. As flood irrigation of sandy soils is the common practice in Bahrain, high water consumption (44,000-111,000 m^3/ha/year) with low water productivity (3,865-6,500 m^3/ton dry alfalfa and 2,126 m^3/ton fresh tomatoes) has led -- along with the increased domestic demands -- to drastic increases of water abstraction from Dammam aquifer, from 63 Mm^3/y in 1952 to about 180 Mm^3/year in 1989. This exceeds the recharge from mainland Saudi Arabia (about 90 Mm^3/y). Water is being taken from the aquifer storage, thus decreasing the aquifer's potentiometric surface and leading to: (a) ceasing flow of land and offshore fresh-water springs, (b) contamination of the aquifer water by sea-water encroachment and by the upward invasion from the underlying saline goundwater zones. This process has reached alarming levels as more than half of the original aquifer water volume has been polluted. Irrigation water became increasingly saline and farmers tend to use more water to combat the increasing salinity. Important areas for agriculture were abandoned due to salinization of the soil, which is due to misuse of saline irrigation water and the lack of drainage systems.

Through deliberate negligence by some owners of agricultural land, Bahrain has lost 2,000 ha of good agricultural land to residential, industrial and public use since 1976.

Agricultural development is hampered by other socio-economic factors, i.e., fragmentation of holdings, lack of appropriate mechanization, the absence of fair relationships between landlords and tenants, domination of foreign labour with resulting discontinuity and the unwillingness of young Bahrainis to work in agriculture.

The Government of Bahrain, realizing the magnitude of desertification problems, has carried out several activities to help reduce water consumption, reclaim agricultural land and improve land productivity. Legislative action was taken to protect water and agricultural lands. Research activities were carried out by the Ministry of Commerce and Agriculture (MOCA) to evaluate the

magnitude of problems related to increased groundwater abstraction, salinization of soils, improved irrigation methods and water distribution and use efficiencies. The Ministry of Commerce and Agriculture (MOCA) has executed several plans (1981-1990) in the agriculture sector aimed at preserving water and land, expanding cultivated areas and improving land productivity. The Ministry of Housing prepared and adopted a National Land Use Plan 2001, identifying the present and projected needs up to the year 2001.

Considering the magnitude of the desertification problems identified, action to combat desertification is urgently required before the cost of rehabilitation rises beyond reason, or before the opportunity to act is lost forever. Desertification is not a problem susceptible to quick solutions, but it is already urgent in Bahrain. It calls for continuous assessment and long-term planning and management at all levels. The management of natural resources is a critical component of the strategy for physical, social and economic development. The adoption of improved policies for managing natural resources is essential to the ecosystem if its productivity is to be restored and developed.

A mathematical model to cover the total developed area in Bahrain is proposed, taking into consideration its calibration using the periodical data accumulating in the Directorate of Water Resources of the Ministry of Commerce and Agriculture (MOCA). The model involves simulation of the main aquifers and salt-water intrusion.

A systems analysis approach is proposed for defining the National Plan of Action to Combat Desertification (NPACD), to arrive at optimal solutions and to gradually construct an integrated development plan for desertification control. The approach should simultaneously cover most pending requirements, should not have detrimental effects on either natural resources or the environment, and should be economically advantageous.

A long-term strategy for desertification control (1992-2010) is suggested. Long- and short-term programmes are considered. Among the long-term programmes, the following are to be considered:

(a) Continuous evaluation of desertification and improvement of water and land management including updating the land-use map and the preparation of desertification maps;

(b) Public participation programme;

(c) Corrective anti-desertification measures programme which includes:

(i) Sound planning, development and management of water resources;

(ii) Soil and water conservation in irrigated areas;

(iii) Prevention and control of waterlogging and salinization;

(iv) Maintenance and protection of existing vegetation;

(v) Monitoring climatic, hydrogeological and ecological conditions of land, water, plants and animals in areas affected by desertification.

The National Plan of Action to Combat Desertification (NPACD) of Bahrain stresses the following field actions:

(a) Land management measures

(i) The establishment of a land database management system for continuous data storage, retrieval, dissemination and processing;

(ii) The use of the proper water duty for each crop;

(iii) The application of effective soil conservation measures for cultivation;

(iv) The application of a proper crop rotation system whereby land remains protected under a crop cover;

(v) The avoidance of pollution, especially in areas irrigated by treated sewage effluent (TSE);

(vi) The replenishment of soil fertility by periodic applications of organic and chemical fertilizers;

(vii) The use of proper remedial measures to combat plant diseases;

(viii) The improvement of physical properties of soil.

(b) Water management measures

(i) The establishment of a water database management system for continuous storage, retrieval, dissemination and assessment;

(ii) The construction of leaching slot trenches and infiltration basins in suitable areas to enhance groundwater quality and to improve groundwater storage;

(iii) The development of the groundwater quality network to help in the study of salt-water intrusion;

(iv) The application of water-saving irrigation methods such as sprinklers and/or drip irrigation;

(v) The avoidance of over-irrigation which may lead to waterlogging and soil salinization;

(vi) The avoidance of contamination of groundwater;

(vii) Limiting well digging and controlling the tapping of groundwater;

(viii) The construction of artificial groundwater recharge systems by infiltrating treated sewage effluent (TSE).

(c) Manpower and strengthening of science and technology

This programme deals with training and research in order to strengthen the scientific and technological capabilities required for the success of anti-desertification programmes.

(d) International action and cooperation

This programme includes regional projects needed to control desertification, with the suggestion that maximum use of the Consultative Group on Desertification Control (DESCON) be made.

The priority programmes and projects for a short-term (1992-1994) plan are suggested.

The suggested establishment of a national machinery for desertification control would include:

(i) The formation of a national desertification control commission (NDCC) under the chairmanship of the Minister of Commerce and Agriculture (MOCA), with members of the concerned ministries and institutions in Bahrain and;

(ii) The establishment of a general directorate for desertification control coordination (GDDCC). The structure, responsibilities and functions of NDCC and GDDCC are described.

The framework of the projects suggested in the short-term priority programmes (1992-1994), including title, objectives, executing agents, cost, duration, background and activities was made for the following projects:

(i) Evaluation of desertification and improvement of water resources and land management

a. Establishment of data-bank system;
b. Development of groundwater networks;
c. Construction of mathematical model;
d. Improved irrigated agriculture;
e. Artificial recharge to groundwater formations with treated sewage effluent (TSE).

(ii) Assessment and monitoring of desertification

Monitoring of desertification;

(iii) Public participation programme

Public awareness and participation;

(iv) Socio-economic programme

Environmental education for youth;

(v) Manpower and strengthening sciences and technology

Regional research, training and communications programme on desertification control in the ESCWA region (phase I).

It is also suggested that the national machinery entrusted with desertification control give priority to the establishment of a small group who would dedicate their efforts towards desertification control plans, including the preparation of the suggested projects in the format required by the donor organizations.

The suggested long-term programme includes a project to ensure against risk and effects of drought. This project is recommended for priority action in view of the high probability that a drought may soon affect the country. In preparing proposals for this project, reference should be made to Recommendation No. 17 of the United Nations Conference on Desertification (UNCOD) plan wherein a series of 13 steps are described.

It is suggested that the Ministry of Commerce and Agriculture (MOCA) be responsible for follow-up and may be appointed as a caretaker to look after desertification matters, especially:

(a) Pursuing the matter of securing the approval of the Government for the draft National Plan of Action to Combat Desertification (NPACD);

(b) Pursuing the establishment of the institutional machinery National Desertification Control Commission (NDCC) and the General Directorate for Desertification Control Coordination (GDDCC);

(c) Identification of project proposals and selected areas where United Nations Environment Programme (UNEP)/Economic and Social Commission for Western Asia (ESCWA)/Food and Agriculture Organization of the United Nations (FAO) assistance is required in order to address them accordingly.

INTRODUCTION

The islands of Bahrain are located approximately at the mid-point of the Arabian Gulf in relatively shallow waters and encompass 36 islands. Saudi Arabia lies 56 kilometres (km) to the west (and south), connected since 1986 by a causeway; Qatar is 27 km to the east; and Iran is 235 km straight across the width of the Gulf. The dimensions of the main island, Bahrain, are 50 km north-south and 16 km east-west. The total land area, including a number of small islands, is about 700 km^2.

Land reclaimed in shallow water-table areas has drastically altered the face of Bahrain. Reclamation mainly began in the 1950s. The total reclaimed areas increased the country's land mass by about 3,000 hectares. Furthermore, additional areas and/or man-made islands have been contemplated to cope with ever-increasing demand by all sectors of development.

The oil in Bahrain was first discovered in the southern part of the Arabian Gulf in 1931. Now the oil reserves are nearly exhausted, although still sufficient for local consumption, and natural gas is plentiful for power generation. The anticipated decline in oil revenues triggered a guided shift in the economic base, which has been largely completed. A large oil refinery built in 1934 is supplied through pipelines from Saudi Arabia. Other major industrial operations include an aluminium smelter, shipyards, an iron-pellet plant, a petrochemical plant, and other heavy industrial activities.

In terms of physical development, heavy industry is placed in a relatively compact district in the eastern part of the island, with almost all of the old as well as new urban development concentrated in the north-east corner. The jamming of most urban activities into a corner has resulted inescapably in overloads and congestion, which even massive and expensive public works improvements have not solved entirely or satisfactorily. The Government's programme of locating its new settlements and towns on dispersed sites is a response to this problem.

Bahrain has a much more "Western" attitude towards social behaviour and entertainment than the other countries around it. Bahrain has become a strong centre for communciation, financial transactions, trade, and entertainment. Every international bank has a branch there, as does almost every hotel chain.

A peculiar hydrological feature of Bahrain is the presence of aquifers originating in Saudi Arabia that generate springs in the northern third of the main island. This water is truly a gift of nature that allowed Bahrain to be at one time a lush agricultural land. Development has always been attracted to these areas, as compared to the barren southern part of the country. The groundwater supply, not surprisingly, is becoming exhausted, and unless current practices are drastically reformed, a real problem faces the island in a decade or so.

All the operations as well as future projects in Bahrain highlight the need for an in-depth comprehensive study of the nation's environment, to properly control the growth and development of the country and at the same time maintain adequate environmental safeguards against unnecessary destruction of the natural resources.

I. INVENTORY AND POTENTIAL OF NATURAL RESOURCES

A. Areas and sites

The State of Bahrain comprises an archipelago of 36 low-lying islands (table 1) located in the Arabian Gulf, about midway between Saudi Arabia on the west and Qatar to the east. The islands are situated at a latitude between 25° and 27° north and a longitude between 45° and 51° east of Greenwich. The largest island is Bahrain, where the capital Manama is situated. It represents 85 per cent of the total area of the State. Tables 2 and 3 and figure I illustrate the area according to the major islands and regions.

Table 1. The islands of Bahrain

1.	Qassar Khusayfah
2.	Qassar Jurdi
3.	Jazirat as-Sayah
4.	Al Muharraq
5.	Halat as-Sultah
6.	Halat an-Na'im
7.	Qassat Al-Qulaya
8.	Qassar Abu Shahin
9.	Jazirat Umm ash-Shajar
10.	Jazirat al-'Azl
11.	Juzayyirah
12.	Jazirat an-Nabih Saleh
13.	Jaradah
14.	Sitrah
15.	Al-Muhammadiyah
16.	Jiddah
17.	Al Baynah as-Saghirah
18.	Umm an-Na'san
19.	Al Bahrain
20.	Jazirat as-Shaikh
21.	Umm Jalid
22.	Jazirat Mashtan
23.	Al Mu'tarid
24.	Rabad ash-Sharqiyah
25.	Jazirat Ajirah
26.	Halat Nun
27.	Rabad al-Gharbiyah
28.	Al Hul
29.	Jazirat Hawar
30.	Juzur al-Hajiyat
31.	Suwad ash-Shamaliyah
32.	Umm Haswarah
33.	Juzur al-Wakur
34.	Suwad al-Janubiyah
35.	Juzur Bu Sadad
36.	Janan

Table 2. Bahrain State area by island

Island	Area	
	Square kilometres	Square miles
Bahrain	586.59	226.48
Muharraq	20.83	8.04
Nabih Saleh	0.74	0.29
Sitrah	14.26	5.51
Qassar Al-Qulaya	0.09	0.03
Umm Sabban	0.14	0.05
Jiddah	0.33	0.13
Umm Na'san	18.93	7.13
Hawar	50.61	19.54
Total	692.52	267.38

Table 3. Bahrain State area by region

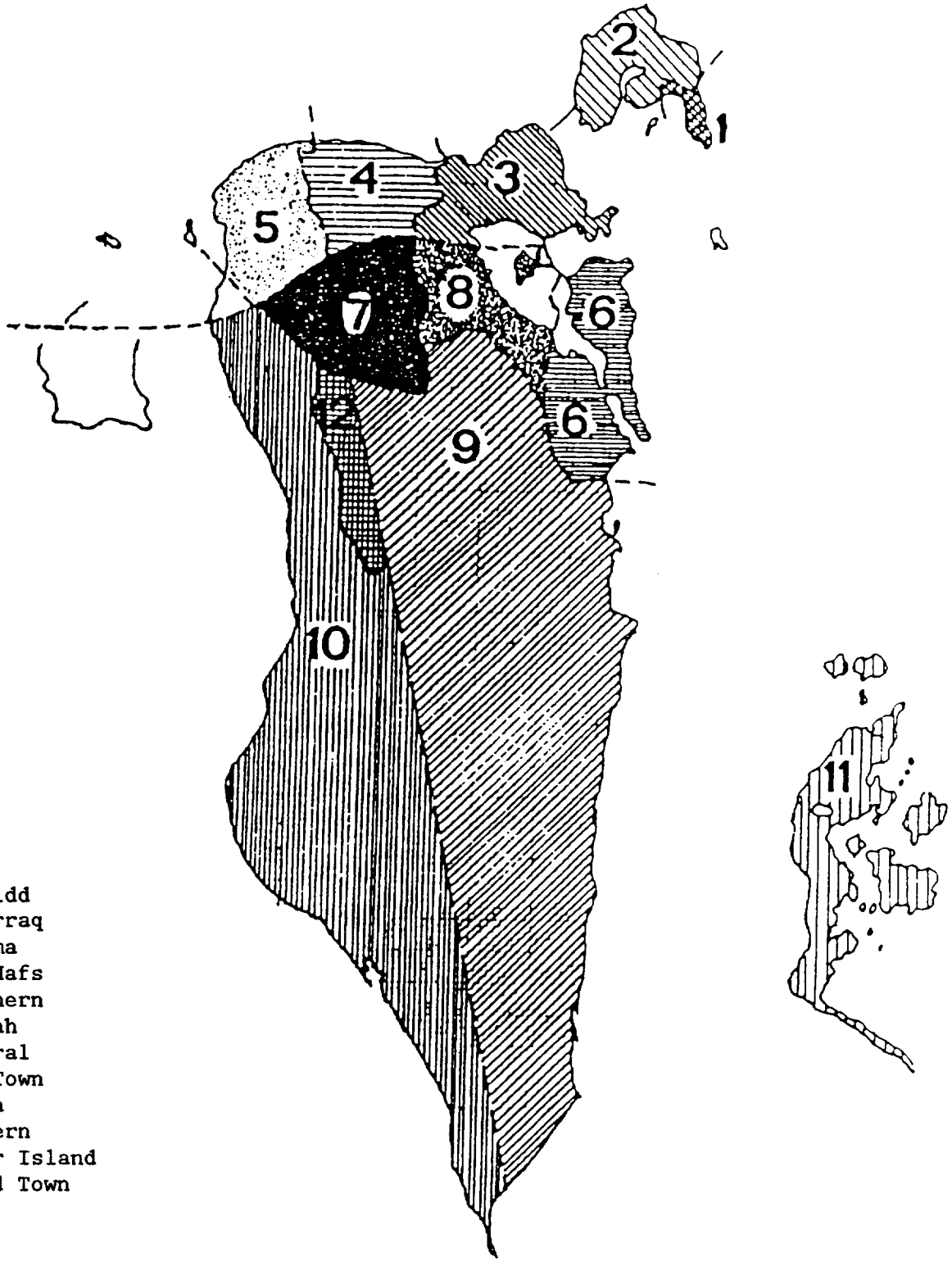
Region	Area	
	Square kilometres	Square miles
Hidd	5.60	2.16
Muharraq	15.23	5.88
Manama	25.68	9.92
Jid Hafs	21.58	8.33
Northern	36.84	14.22
Sitrah	28.62	11.05
Central	35.20	13.59
Isa Town	12.36	4.77
Rifaa	291.64	112.60
Western	156.04	60.25
Howar Island	50.61	19.54
Hamad Town	13.12	5.07
Total	692.52	267.38

Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

B. Topography

The islands are flat, rising almost imperceptibly from the shallow waters of the Gulf. Bahrain Island is formed from an anticlinal dome of sedimentary limestone rocks. Much of its centre has been displaced, however, creating a

Figure I. Bahrain State area by region



(1) Al-Hidd
(2) Muharraq
(3) Manama
(4) Jid Hafs
(5) Northern
(6) Sitrah
(7) Central
(8) Isa Town
(9) Riffa
(10) Western
(11) Howar Island
(12) Hamad Town

long shallow saucer; the central depression is some 10 km long and 2.5 km wide. This is encircled by inward-facing scarps up to about 20 metres high formed from the remaining rock strata and called the "rim rock". Outwardly, the back slope shelves gently down from the rim rock to the coastal region. All that remains of the summit of the dome is a ridge of hills in the central depression, of which Jabal Dukhan, rising to a height of 134 m above sea level, is its highest point (figure II).

Harsh sunlight and sand-laden winds -- and, to a lesser extent, water -- weather the rocks so that the hillsides and backslopes are composed of crumbling rock pavement, boulders and small screes. These are interwoven with wadis and gullies through which are washed and deposited the finer products of erosion, sand sediment particles and stone fragments. There are many flint stones among the pieces of chert and limestone. This detritus fans onto the central depression and coastal region, respectively, forming flat or slightly undulating plains of consolidated stony or gravelly sand and sediment. "Aeolian" sands in the form of thin sheet, hummocks or very small dunes cover quite extensive areas of the plains. Salt flats, sabkha, occupy much of coast and low-lying southern central depression. The island is bordered by a narrow strip of marine sand.

From the geological point of view, Bahrain is dominated by a dome of predominantly carbonate sediments of Cretaceous to Tertiary age. The Tertiary rocks are overlain by younger flat-bedded rocks of Pleistocene and Recent ages. The sequence of different geological formations encountered in Bahrain is illustrated in a geological map (figure III) and given in table 4.

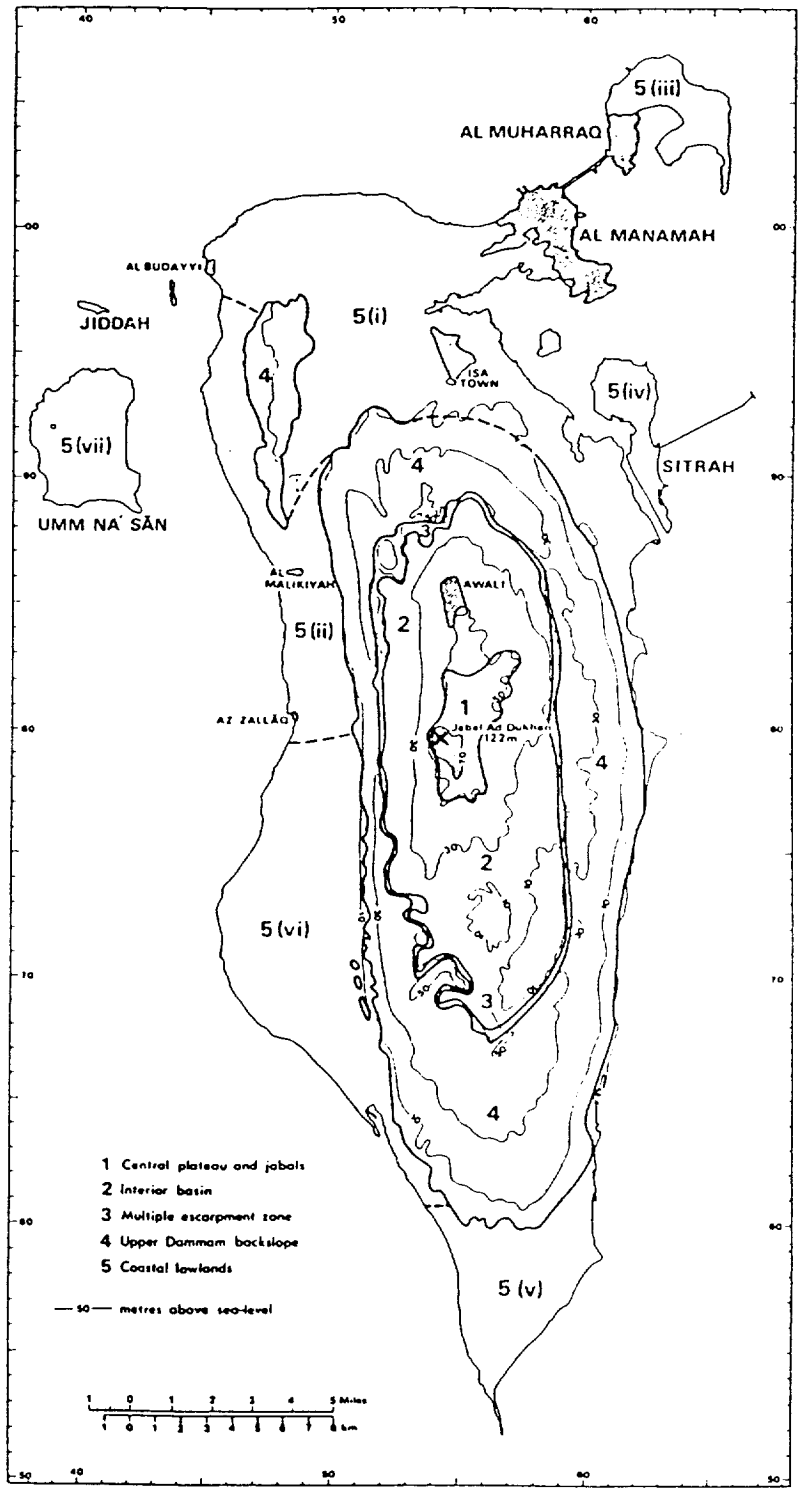
The Bahrain dome is elongate, about 30 x 10 km, and with slight asymmetry; beds are dipping more steeply along the west side. In the central area, rocks of the Dammam Formation were eroded, exposing a core of almost horizontally bedded rocks of the Rus Formation. The erosional edge of the Dammam Formation is now an inward-facing scarp of the Khobar member and constitutes a major topographic feature. Outward from the scarp, the younger rocks of the Dammam Formation, the Alat member and rocks of Miocene-Oligocene age, overlie the Khobar member.

C. Climate

Bahrain and its surroundings are classified as lying within an extremely arid environment. The climate is characterized by high temperatures, erratic, often scanty, rainfall, and high humidity levels due to the surrounding Arabian Gulf water. The year may be divided into two main climatic periods, with summer from June to September and winter from December to March. These periods are separated by two transitional ones: April-May and October-November, respectively.

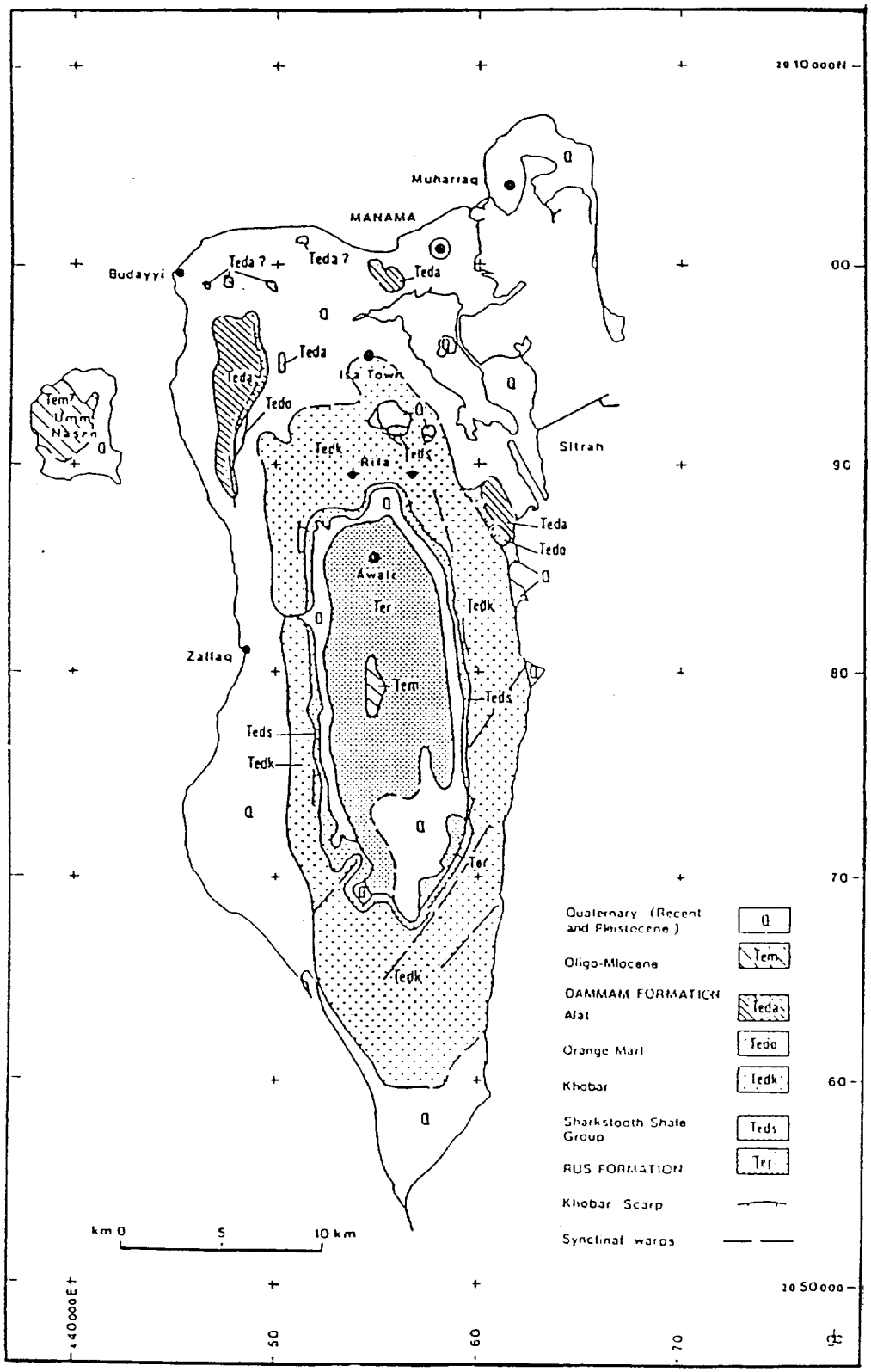
The period from December to March is coolest, with north or north-easterly winds with little rain.

Figure II. Relief and physiographical sub-divisions of Bahrain



Source: Geology, Geomorphology and Pedology of Bahrain, edited by D. Brundsen, J.C. Doornkamp and D.K.C. Jones on behalf of the members of Bahrain Surface Materials Resources Survey, published by Geo Abstracts Ltd., University of East Anglia (Norwich, U.K., 1980), p. 8.

Figure III. Geological map of Bahrain



Source: Groundwater Development Consultants (GDC), "Groundwater resources, Bahrain assignment", vol. III, Umm Er-Radhuma Study, technical report prepared for the State of Bahrain (1980).

Table 4. Geological sequence in Bahrain

Age	Formation	Member	Zone	Thickness (Metres)	Lithology
Recent	Surface deposits	-	-	-	Aeolinite, bioclastic limestone, beachrock
Pleistocene	Ras Al Aqr	-	-	5-10	Sand and sabkha deposits
Miocene	Jabal Cap	-	-	33	Dolomitic limestone, algal coral breccia, claystone, marl
	Dammam	Alat	Alat limestone	15-25	Fossiliferous dolomotic limestone
			Orange marl	9-15	Orange-brown dolomitic marl
		Khobar	Khobar dolomite	30-39	Dolomitic limestone, dolarenyte, foraminiferal;
			Khobar marl		basally with marl
L. Eocene		Alveolina limestone	-	10	Friable brown dolarenyte
		Shark's tooth shale	-	8-20	Shale with silty dolomitic limestone
	Rus	-	-	60-150	Chalky dolomitic limestone, shale, anhydrite, gypsum
Paleocene	Umm Er-Rhaduma	-	-	200-350	Dolomitic limestone, calcarenite, bituminous

Source: W.K. Zubari, "A numerical three-dimensional flow model for the Dammam aquifer system, Bahrain and Eastern Saudi Arabia", Master of Science thesis, Ohio University (Athens, Ohio, USA, 1987).

Temperatures rise sharply from March and reach a peak in August, although a cool north wind sometimes brings relief in June. This is known as the Barah. The remainder of the year is dominated by the Shamal, a moist north-easterly wind or the hot sand-bearing Qaws from the south. These summer months are hot and humid, but the weather cools down quickly in October when the autumn season starts. Temperatures vary from 17°C in winter to 35°C in summer. Annual rainfall averages 74 mm, falls in the winter period from November to April and is sufficient only to support the most drought-resistant desert vegetation. Evapotranspiration can peak to over 10 mm a day in July, which poses severe stresses on cultivated crops during the summer period. North-westerly maritime winds and relatively cool nights mitigate to a certain extent the otherwise agriculturally hostile climate.

The average number of days per annum with measurable rain of one mm or more is 15.5 days, with the highest being four days in March. Thunderstorms occur on average nine days per annum, with March having the highest average at 2.3 days. The average number of days per annum that visibility is reduced to 1,000 m or less by fog is 6.4 days and by thick dust haze 5.5 days. The highest monthly frequency of fog occurs in January (1.5 days), while the highest frequency of thick dust haze occurs in July (1.5 days on average).

1. Air temperature

Bahrain has a hot desert climate, with mild winters and very hot summers. The mean monthly temperature, the mean daily maxima, and mean daily minima for the forty-year period 1945-1985 are illustrated in table 5. Long-term records are also included in the table and show that the highest temperature ever recorded was 46.7°C (in May 1972), while the lowest ever recorded was 2.8°C (in January 1964). The lowest temperatures recorded are those of January with a mean of 17.3°C. Therefore, there is never a danger of frost. The temperatures increase steadily, with a rapid increase in May. Maximum temperatures are reached in July or August (33.9 and 34.2°C, respectively). The mean daily minimum in August is higher than the mean daily maximum in the winter and early spring months. The recent records for mean daily maxima and minima of air temperatures during the period 1985-1989 are given in table 6.

2. Rainfall

The records of annual precipitation in Bahrain during the period 1903-1990 as illustrated in figure IV show that the amounts of precipitation in Bahrain vary considerably from year to year and may become extremely scant. Averages range from 234 mm, in the period October 1975 to May 1986, to as low as 15 mm in 1972/1973. An examination of the data of annual rainfall in Bahrain also reveals that the number of growing seasons with rainfall below 50 mm represents 37.5 per cent of the total numbers of years of records. That is also true for those with rainfall between 50 and 100 mm, while those with rainfall above 100 mm represent 25 per cent. Annual rainfall of more than 200 mm is exceptional.

Table 5. Air temperature, average values for the period 1945-1985

Month	Mean daily maximum	Mean daily minimum	Mean monthly	Highest recorded	Lowest recorded
January	19.9	14.6	17.3	31.7	2.8
February	20.9	15.1	18.0	34.7	7.2
March	24.5	17.9	21.2	38.0	7.8
April	29.1	21.6	25.4	41.7	13.5
May	33.4	26.1	29.8	46.7	18.7
June	35.9	28.9	32.4	45.7	22.7
July	37.4	30.4	33.9	45.0	25.3
August	37.7	30.7	34.2	45.0	26.1
September	36.1	28.8	32.5	42.8	24.4
October	32.5	25.5	29.0	40.8	18.8
November	27.5	21.5	24.5	35.0	13.5
December	22.1	16.6	19.4	29.4	6.4

Source: Civil Aviation Directorate (State of Bahrain).

Rainfall in Bahrain is confined to the eight months extending from October to May (table 7). July and August show no rain, June and September show negligible amounts of less than 0.05 mm but more than zero, and are considered virtually rainless months. Showers in October and May, however, are usually of low efficiency. This is attributed to the high evaporative power of the atmosphere and dry soil during these months.

Records of rainfall (table 7) show that the rainiest month is March, with 24.0 mm on the average. The average monthly rainfall is 15.6 in February and 11.9 mm in December, while the lowest rainy month is October (0.3 mm on the average).

The longest drought on record in Bahrain ended with a thunderstorm on 27 February 1984 after 319 rainless days.

An important characteristic of rainfall in Bahrain, as in other arid areas, is its irregularity and variability in both time and space; hence it is extremely unpredictable. The temporal fluctuations of rainfall are evident from the data incorporated in table 7 showing the monthly and annual rainfall for a period of 10 years (1980-1989). Thus, while the average annual rainfall is 73.8 mm, this figure fluctuates between 28.9 mm in 1981 and 197.3 mm in 1982. Not only is irregularity evident from year to year, but also there is wide variation between corresponding months of the different years.

3. Climatic aridity

The clima-diagram for Bahrain (figure V) shows that the precipitation curve underlines the temperature curve throughout the year. The area lies within the sub-tropical dry zone at the desert, and no humid period prevails during the whole year. As a consequence of the severe climatic aridity, the soil moisture supply to plants is meager. The uppermost soil layers are dry all the year except for a few days after rainfall.

Table 6. Monthly mean daily maximum and minimum temperatures for the period 1985-1989, °C

Year	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Mean of daily maxima												
1985	20.0	21.2	22.8	29.7	33.3	35.0	34.5	36.5	33.1	28.5	28.5	22.8
1986	19.5	21.4	25.4	29.7	36.0	37.0	38.0	38.5	34.8	28.5	21.5	24.1
1987	21.0	23.5	24.8	30.6	33.8	35.5	38.4	38.6	35.1	32.5	26.0	24.1
1988	19.4	21.0	31.6	29.7	34.4	37.5	38.3	39.0	37.4	34.4	27.9	23.0
1989	17.9	19.2	25.0	29.6	35.0	36.0	39.0	39.3	36.5	33.3	21.6	29.1
Mean of daily minima												
1985	14.4	12.5	15.7	20.9	25.2	26.5	29.0	29.4	27.7	23.3	20.6	15.0
1986	11.4	13.2	15.7	20.2	28.0	29.0	28.0	30.0	26.5	24.5	19.0	12.2
1987	12.3	14.5	17.1	20.7	24.5	28.3	27.8	29.0	24.8	22.2	19.6	14.5
1988	13.2	15.0	19.3	21.8	26.2	28.6	30.3	30.5	29.0	25.8	20.3	16.5
1989	11.1	12.2	17.0	20.8	25.8	28.1	30.4	30.6	28.3	25.0	15.8	22.4

Source: Annual Statistical Report, Ministry of Commerce and Agriculture (MOCA) (State of Bahrain, 1989).

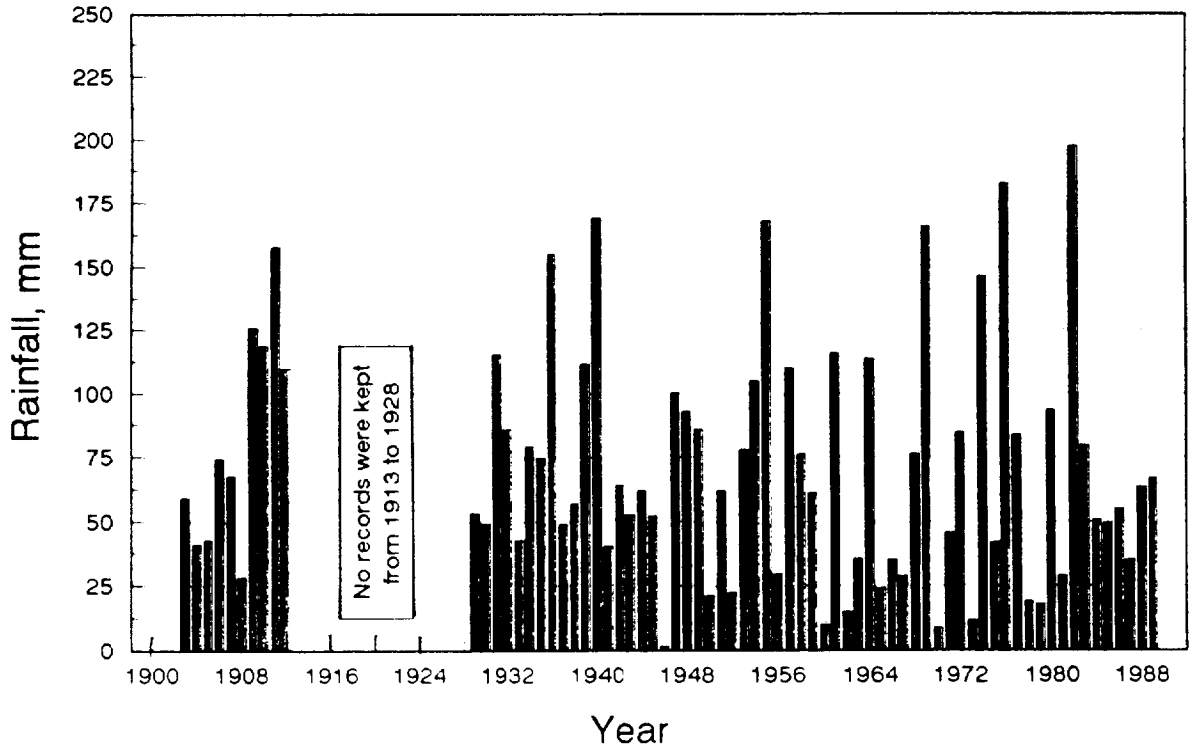
Table 7. Rainfall in Bahrain, 1981-1989
(Millimetres)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1980	31.2	57.4	2.0	-	-	-	-	-	-	-	-	3.2	93.8
1981	19.1	1.3	5.2	Tr	3.3	-	-	-	-	-	Tr	Tr	28.9
1982	4.4	41.3	71.9	3.9	Tr	-	-	-	-	3.0	58.8	14.0	197.3
1983	19.2	1.1	55.8	3.7	Tr	-	-	-	-	-	-	Tr	79.8
1984	Tr	10.5	29.9	Tr	Tr	-	-	-	-	-	0.8	9.4	50.6
1985	10.5	Tr	1.1	Tr	5.1	-	-	-	-	-	-	32.6	49.3
1986	9.2	2.7	8.4	10.6	Tr	Tr	-	-	Tr	-	Tr	24.2	55.1
1987	0.7	33.6	-	-	-	-	-	-	-	-	-	0.8	35.1
1988	14.7	1.8	2.3	-	-	-	-	-	-	-	3.0	0.6	63.3
1989	Tr	0.3	30.1	2.7	-	-	-	-	-	-	Tr	33.9	66.9
Mean	10.9	15.6	24.0	2.3	0.8	-	-	-	-	0.3	6.3	11.9	73.8

Source: Civil Aviation Directorate (State of Bahrain).

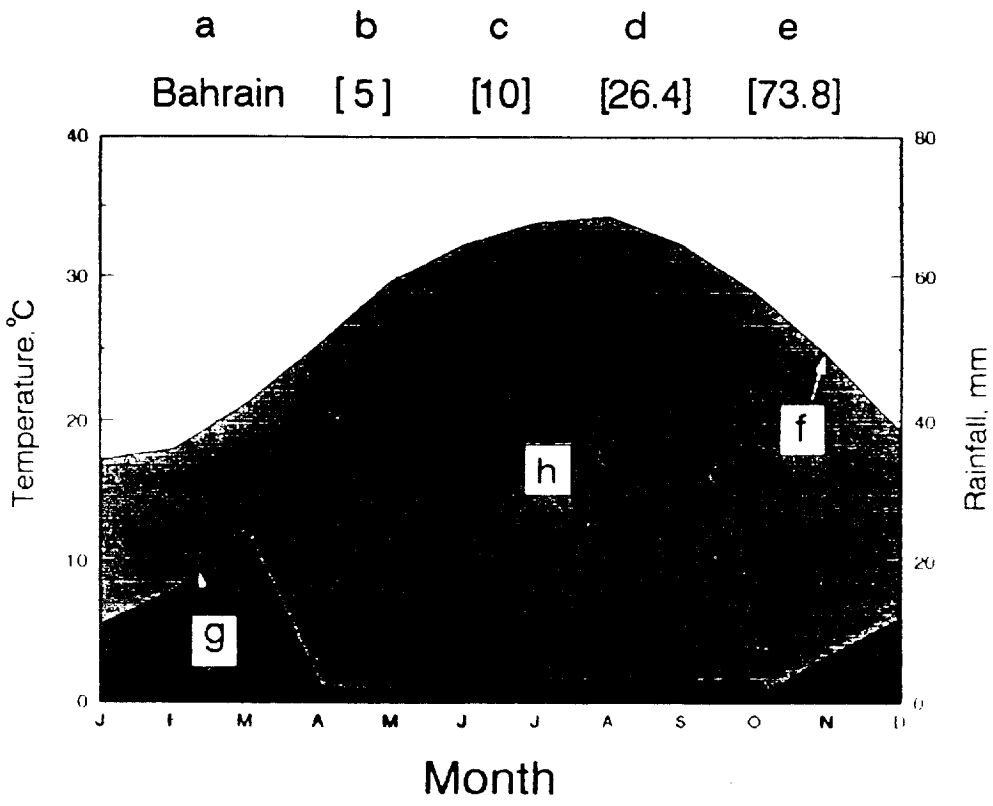
0 < Tr = Trace < 0.05 mm

Figure IV. Annual precipitation in Bahrain during the period 1903-1990



Source: Prepared according to data of the Civil Aviation Directorate (State of Bahrain).

Figure V. Clima-diagram of Bahrain



a. Place of metereological station
b. Elevation above sea level (m)
c. Number of years of observation
d. Mean annual temperature(°C)
e. Mean annual rainfall (mm)
f. Temperature curve (mean monthly)
g. Rainfall curve (mean monthly)
h. Drought season

4. Relative humidity

Night-time relative humidity in the region of 90 - 100 per cent is not uncommon. Long-term records in Bahrain indicate that the mean daily maxima for February and October were 88 per cent and 89 per cent respectively, and the mean daily minima for those months were 56 per cent and 46 per cent respectively. August shows a mean daily maximum of 84 per cent and minimum of 44 per cent.

Table 8 shows the monthly relative humidity (mean of maxima and minima) for the period 1983-1985. The mean annual relative humidity of 67.2 per cent indicates high humidity throughout the year. The mean monthly relative humidity is above 70 per cent in the winter months. A gradual decrease occurs in March and April, till a minimum of 58.5 per cent is reached in June. An abrupt increase in the monthly relative humidity is observed in August, reaching 66.5 per cent. This has been attributed to the influence of the northern limit of the intertropical convergence zone, or monsoon front, lying at this time (end of July) along the eastern Arabian coast and into the Indian sub-continent, and extending into the Arabian Gulf, bringing no rainfall, but doldrums-type weather and a high humidity value (over 90 per cent) during the night.

5. Wind

Bahrain lies in the path of north-westerlies known as Shamal winds, which blow most of the year and, though persistent, rarely become unpleasant. Light to moderate breezes are normal, with winds sometimes reaching strong gale force during winter. The highest gust speed recorded in recent years was 51 knots. There are occasional dust storms and at times, during summer, an extremely oppressive wind from the south-east, but Bahrain's high temperatures are mainly tempered by the prevailing winds.

D. Land resources

1. Soils of Bahrain

Apart from a narrow fertile strip of land in the north, Bahrain is low-lying, rocky and bare, consisting of limestone rocks covered with varying depths of sand, which is too poor to support vegetation apart from a few tough desert plants. There is little soil in Bahrain which could be described as good from an agricultural point of view. The soil texture is mainly sandy, with traces of organic matter (0.05-1.5 per cent) and deficit in major nutrients and trace elements. Electrical conductivities (EC) in irrigated soils lie within the range of 4-12 mmhos. Non-irrigated sites have a higher range of EC. The dominant cation is sodium, which exceeds sulphate, the dominant anion. The calcium carbonate in most soils ranges from 15-30 per cent. Most of the soils contain moderate amounts of gypsum, mainly in the upper 75 cm of the soil profile. The water-holding capacity is very low and the available moisture is about 2-6 per cent. Infiltration rates are generally high, up to more than 120 mm/hr.

In areas along the coastal strip, calcareous impermeable layers are found at varying depths of 1, 2, and 3 metres and these have caused localized

Table 8. Average relative humidity by month during the period 1983-1989
(Mean maximum, mean minimum and mean of maxima and minima)

Year	Month												
	January	February	March	April	May	June	July	August	September	October	November	December	Annual Average
1984	91	89	85	74	75	73	80	75	87	84	85	86	82.1
1985	88	83	83	84	76	75	77	87	86	84	86	87	83.0
1986	92	89	85	86	79	78	82	85	86	87	86	87	85.2
1987	87	87	80	75	76	70	79	77	83	82	87	82	80.4
1988	86	87	83	78	69	72	77	80	81	82	82	84	80.1
Average minimum													
1984	56	56	49	39	37	40	41	44	43	43	53	75	48.0
1985	58	45	49	42	41	40	43	42	43	48	56	57	47.0
1986	56	57	47	47	36	40	36	48	41	42	51	57	46.5
1987	57	50	46	36	31	33	34	42	40	43	54	54	43.3
1988	55	60	49	41	36	33	39	39	44	43	49	54	45.2
Mean of maxima and minima													
1983	71	72	67	66	65	62	56	59	66	72	73	74	66.9
1984	81	73	67	82	82	61	56	56	57	68	73	74	69.2
1985	75	73	68	66	69	68	68	64	65	72	68	87	70.3
1986	72	74	70	72	72	65	67	66	74	70	77	77	71.3
1987	73	74	65	62	58	52	53	62	70	78	75	81	66.9
1988	71	67	64	64	60	59	51	53	61	73	74	71	64.0
1989	61	72	63	61	59	62	55	52	60	64	66	64	61.7
Mean years	72.0	72.3	66.3	67.6	66.5	61.3	58.0	58.9	64.7	71.0	72.3	75.4	67.2

Source: Civil Aviation Directorate (State of Bahrain).

waterlogging and impeded leaching. In many areas of the recently abandoned agriculture, salinity levels have built up to a level where cultivation is not possible without extensive leaching.

2. Agricultural lands

The quality and availability of both soils and water have led to the concentration of agricultural activities on a relatively narrow strip of arable land around the north-western coast of Bahrain Island, with isolated pockets in the north central areas and along the east coast (figure VI).

Historical findings reveal that agriculture in Bahrain was very prosperous during earlier days. Cultivated areas fluctuated between 15,300 ha around the year 2000 B.C. and 4,600 ha around the year 650 B.C. In recent years the cultivated area decreased gradually, while population continued rising rapidly. The per caput cultivated area (table 9) therefore decreased from 0.036 ha in 1924 to about 0.006 ha in 1989 and thus escalated the problem of self-sufficiency in food products.

The decrease in cultivated areas during the last two to four decades has been attributed to several factors which will be discussed later. The dominant factor, however, seems to be urbanization at the cost of agricultural lands. Figures 7 and 8 show the changes in land use in the years 1977 and 1988 as compared to 1956 (figure VI). The changes in land use in Bahrain were also reported by Hunting (1979). The report classified Bahrain land areas according to their capability for agriculture in the year 1976 (table 10). Recent estimates for land capabilities for agriculture (1988) were compared with those of Hunting report.

Table 9. Development of agricultural lands in Bahrain during the period 1924-1989

Year	Agricultural land (ha)			Population (Thousands)	Per caput cultivated area (ha)	Relative figures
	Unused	Cultivated	Total			
1924	-	2 385	-	66.0	0.036	100
1953	-	3 224	-	124.0	0.026	72.2
1966	2 049	3 793	5 842	187.8	0.020	55.6
1971	3 950	2 220	6 170	216.1	0.010	27.8
1979	-	1 750	-	330.0	0.005	13.9
1985	909.4	2 909.5	3 818.9	424.7	0.007	19.4
1987	901.9	2 940.5	3 848.4	457.6	0.006	16.7
1989	1 041.4	3 006.5	4 047.9	488.6	0.006	16.7

Source: Annual Statistical Reports (1966-1991), Ministry of Commerce and Agriculture (MOCA) (State of Bahrain).

It can be seen from tables 10 and 11 as well as figures VI, VII and VIII that urban development has taken place mainly at the expense of the better agricultural land, where economic farming would be possible. If this trend is allowed to continue, viable agriculture will not be possible even if investment is made.

Table 10. Land capability for agriculture (1979)

Class	Hectares	Percentage
1. Good	1 055	1.78
2. Moderate	613	1.03
3. Moderate, liable to salinization	4 740	7.98
4. Moderately low, salt-tolerant crops only	6 918	11.65
5. Low	17 940	30.20
6. Unsuitable	22 473	37.83
7. Urban and industrial	5 663	9.53
Total	59 398	100.00

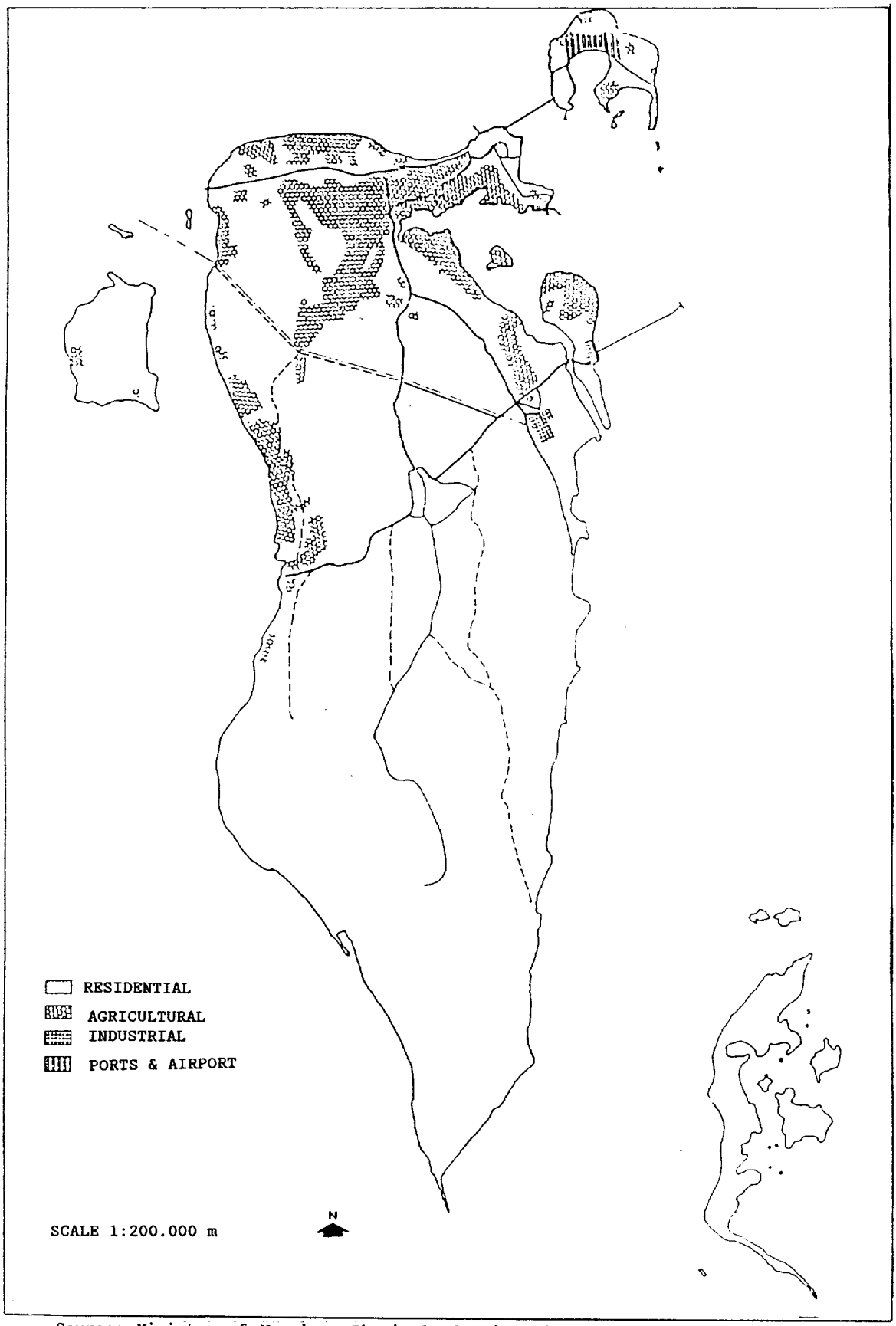
Source: "Land utilization in Bahrain 1966 and 1977", February 1979, Hunting Technical Services Limited.

Table 11. Land capability for agriculture, recent estimates (1988)

Class	Hectares	Percentage	Change since 1976	Percentage
1. Good	1 055	1.77	0	0
2. Moderate	350	0.64	-263	42.92
3. Moderate, liable to salinization	3 100	5.21	-1 640	34.60
4. Moderately low, salt-tolerant crops only	6 250	10.51	-668	9.66
5. Low	17 540	29.52	-400	2.23
6. Unsuitable	22 473	37.82	0	0
7. Urban and industrial	8,634	14.53	+2 971	52.46
Total	59 402	100.00		

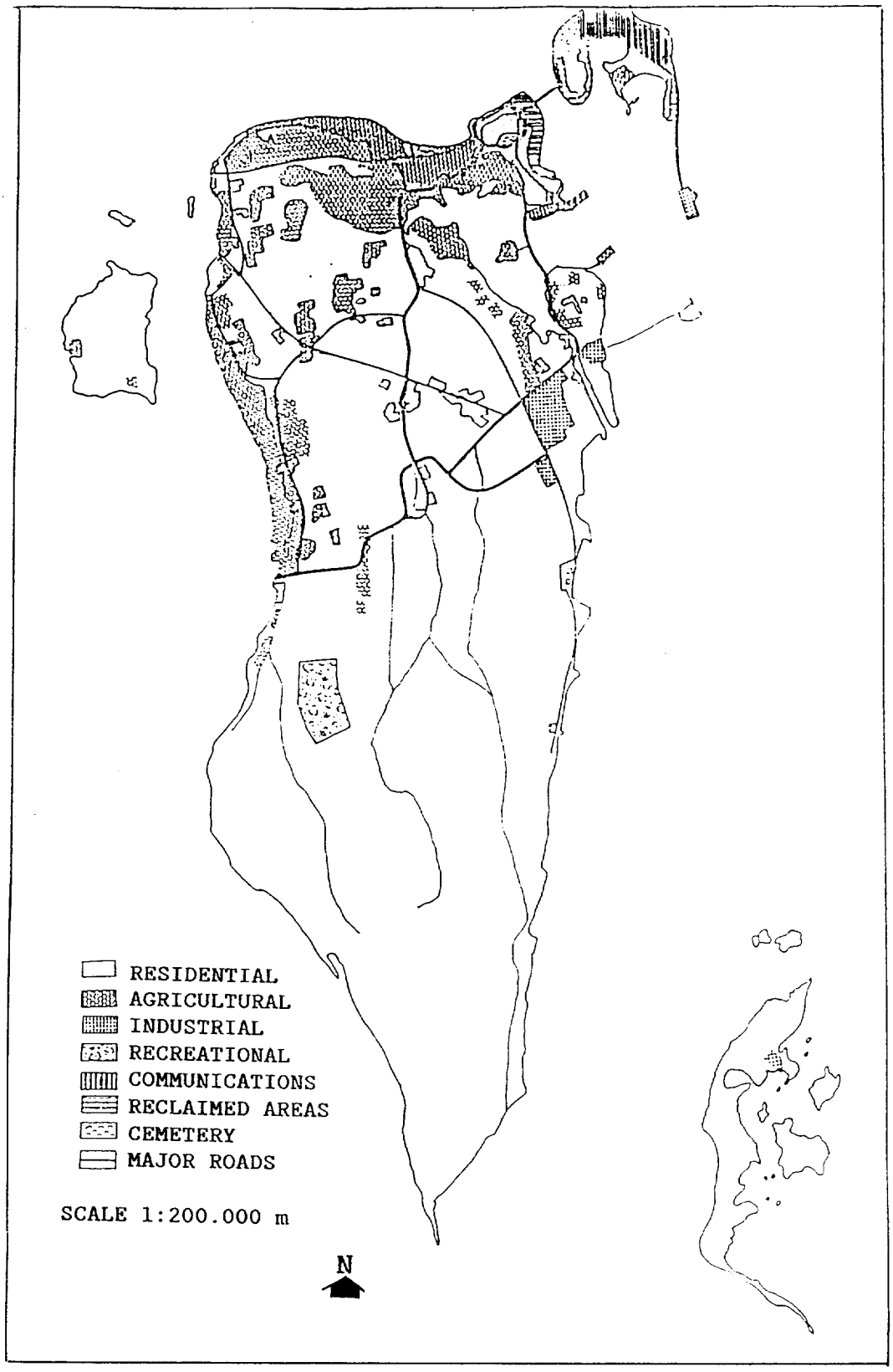
Source: Ministry of Housing, Physical Planning Directorate, National Land Use Plan 2001, vol. III, (1988), p.44.

Figure VI. Land use in Bahrain (1956)



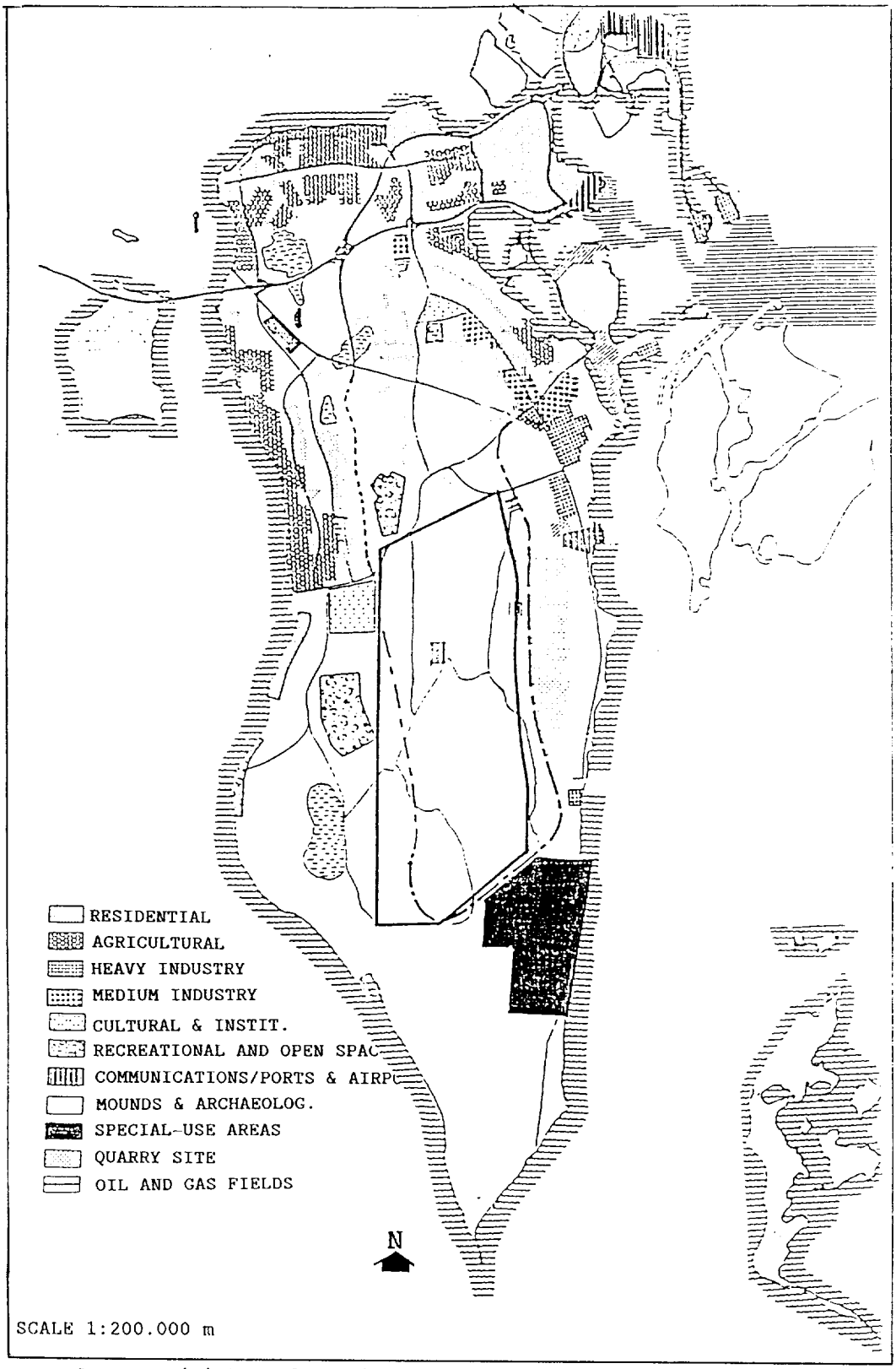
Source: Ministry of Housing, Physical Planning Directorate National Land Use Plan 2001, vol. III, (1988), p. 44.

Figure VII. Land use in Bahrain (1977)



Source: Ministry of Housing, Physical Planning Directorate, National Land Use Plan 2001, vol. III, (1988), p. 44a.

Figure VIII. Land use in Bahrain (1988)



Source: Ministry of Housing, Physical Planning Directorate, National Land Use Plan 2001, vol. III, (1988), p. 45.

Category 1 (1,055 ha) soil, which should be ideal for agricultural and horticultural use, is unfortunately situated in areas where water is not available (figure IX). It is fragmented to such an extent that its immediate development is neither practical nor economical. This leaves category 2 (350 ha) or category 3 (3,100 ha) types of soils for immediate agricultural use. In fact, these are the areas where farming is already concentrated, and therefore, this is not a question of acquisition but of preservation.

As the extent of category 4 (6,250 ha), land is fairly limited, it also requires some degree of protection. Categories 2 and 3 can only be preserved adequately if their usage is preserved exclusively for agriculture. Part of category 4 could be used for urban development only where it is essential to allow the building of houses or amenities and where there is no lower-category soil in the vicinity.

As cultivable land is an irreplaceable national asset which cannot be created or regained easily once built upon, it was proposed that, even if all such land cannot and will not be used today for crops, it could still be preserved and kept in reserve. Therefore, lands falling in category 1 through 4 and 4D would be designated for exclusive agricultural use. Selected parts of category 5 could be preserved if they have a reasonable chance of being productively farmed in some form. The rest of category 5 land and all land in category 6 could be made freely available for urban and industrial development, as these do not have specific requirements for soil quality.

Studies show that for a period of 13 years (between 1956 and 1969) very little change took place in agricultural areas. In the early 1970s and beyond, sporadic residential compounds as well as direct encroachment caused by the horizontal expansion of existing settlements resulted in the decrease of agricultural land from 6,460 hectares in 1956 to about 4,070 hectares in 1988, reducing its ratio to total land area from 9.6 per cent to 5.9 per cent (tables 12 and 13).

Table 12. Changes in agricultural land use during the period 1956-1988 and proposed growth in usage in 2001

Year	Area (Hectares)	Projected use, 2001
1956	6 460	5 720
1963	6 460	
1969	6 460	
1982	3 748	
1988	4 070	

E. Water resources

Bahrain's water supply is drawn from two main sources: groundwater and sea water which is desalinated for domestic supply. Bahrain is fed by the Eocene aquifers, which provide the groundwater from a part of the regionally extensive system which extends beneath the sea from Saudi Arabia. The regional hydraulic gradient is from west to east, which implies recharge on the outcrop area of the aquifer system in Saudi Arabia.

Table 13. Changes in agricultural land use during the period 1956-1988 (as a per cent of total area of Bahrain)

Year	Percentage	Projected use, 2001
1956	9.6	8.2
1963	9.6	
1969	9.6	
1982	5.5	
1988	5.9	

Source: National Land Use Plan 2001, Part III, 1988.

1. Groundwater resources

The aquifer system occurs beneath confining beds in the coastal zone of the Hasa region of Saudi Arabia. The aquifers and the confining layers extend beneath the sea to Bahrain. Immediately to the east of Bahrain, the aquifer system outcrops below sea level and sea-water intrusion can occur. Bahrain acts as a major natural discharge area for these aquifers.

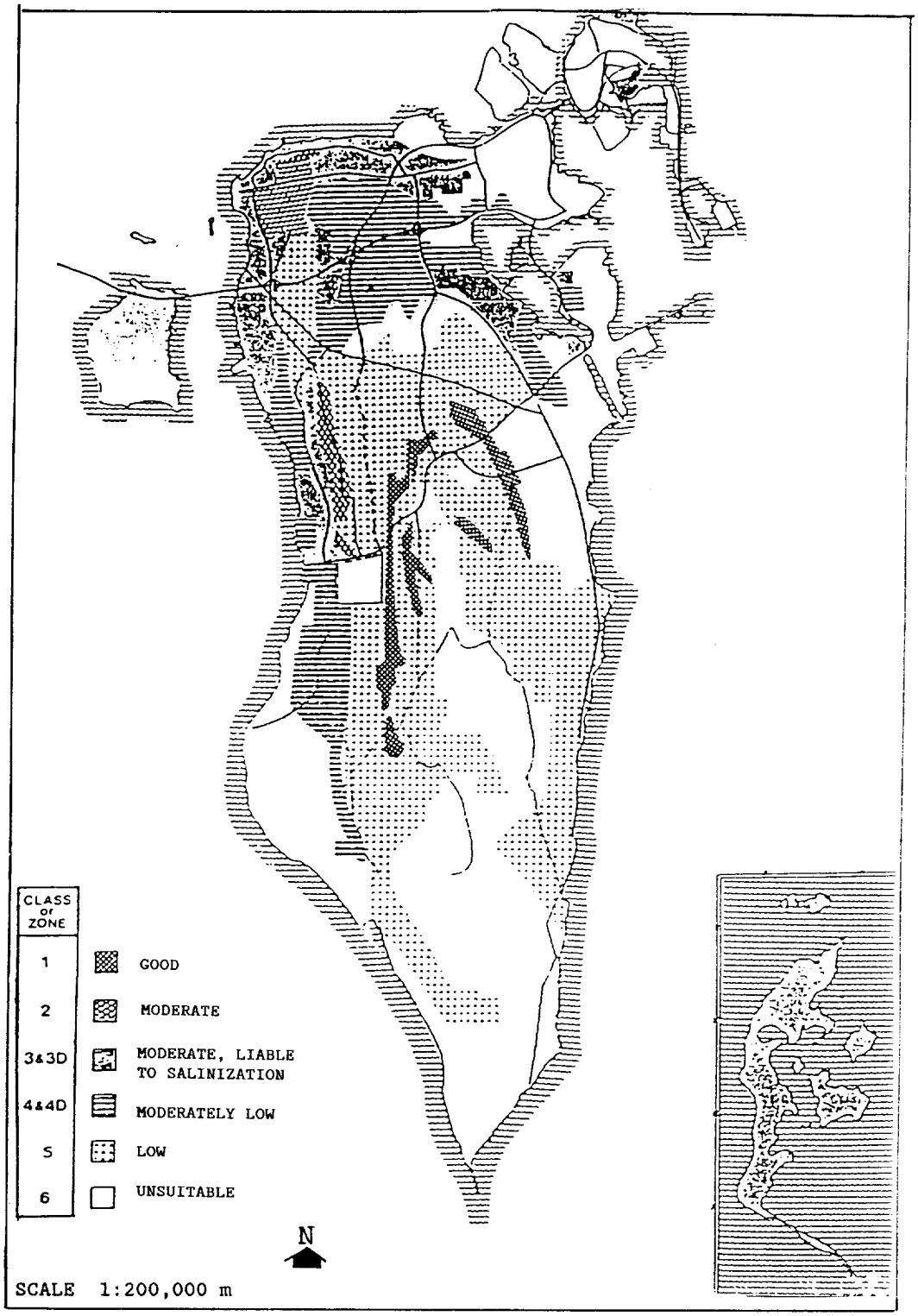
In Bahrain, there are principally two aquifers, termed "A" and "B" (figure X) both belong to the Dammam Formation (of the Lower and Middle Eoceneage) and are thus termed collectively the Dammam Aquifer System, (table 14). The upper aquifer "A" is developed in the dolomitic limestones of the Alat member and the basal sandy limestone unit of the Neogene Formation (Lower Miocene). This zone possesses limited water-yielding properties; its transmissivity averages about 350 square metres per day (m^2/day). The average storage coefficient of the zone is about 0.0005 (dimensionless). The total dissolved solids in its water range between 2,500 and 4,500 milligramme per litre (mg/1). Presently, the aquifer water has deteriorated beyond usability for domestic purposes and is utilized mainly for small-scale agricultural purposes by the local inhabitants.1/

The lower aquifer, "B", is developed in the Khobar Member (highly fractured dolomitic limestone) of the Dammam Formation. The "B" aquifer is the principle groundwater reservoir in Bahrain, providing more than 70 per cent of the total groundwater requirements in the State (agricultural, domestic, and industrial). The unit is characterized by high transmissivity, averaging about 10,000 m^2/d, and a relatively low total of dissolved solids, ranging between 2,000 and 4,000 mg/1. The "B" zone storage coefficient averages about 0.00005 (dimensionless).

The two aquifers "A" and "B" are separated by the basal marl of the Alat Member (Orange Marl Aquitard). The entire Dammam aquifer system is bounded on the top by the thick clay stones of the Neogene Formation and on the base by the Shark's Tooth Shale Member of the Dammam Formation, as shown in figure X.

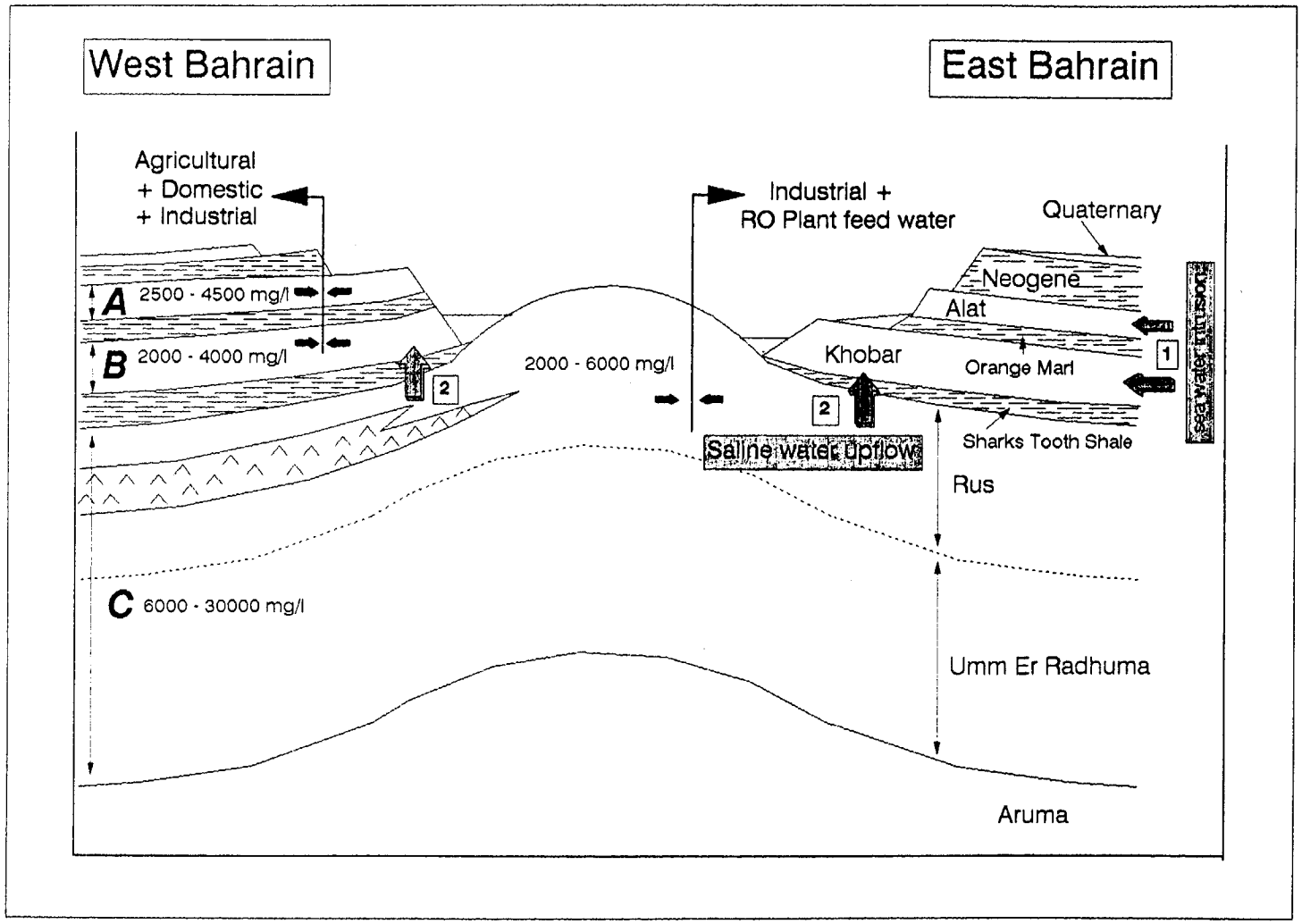
1/ A.R. Mussayab, "Water supply in Bahrain", Al-Muhandis (Journal of Bahrain Society of Engineers), (June 1984).

Figure IX. Land capability for agriculture



Source: Ministry of Housing, Physical Planning Directorate, National Land Use Plan 2001, vol. III, (1988), p. 150.

Figure X. Schematic hydrogeological cross-section showing Bahrain aquifers



Source: W. Zubari, Numerical groundwater flow modeling; example application. Al-Muhandis, (Journal of Bahrain Society of Engineers) No. 18, (1991).

At the crest of the Bahrain anticline, the Dammam aquifers are absent due to erosion, hence exposing the Rus Formation. As the aquifers dip away from the axial crest of Bahrain structure, they show a thickening of about 60 metres for the "A" aquifer and about 55 metres for the "B" aquifer in an outward direction from the anticlinal axis.

Table 14. Characteristics of the main aquifers in Bahrain

Aquifer	Name	Thickness (Metres)	Transmissivity (m^2/day)	Storage coefficient (Dimensionless)	Permeability (M/day)	Quality Salts (Mg/L)
A	Alat	up to 80	350	0.0005	2-6	2,500-4,500
B	Khobar	40-55	10,000	0.00005	15-1200	2,000-4,000
C	Umm Er-Radhuma	350-400	3,000	-	-	-

A third aquifer, termed "C", is developed in the Rus (Lower Eocene) and Umm Er-Radhuma (Upper Palaeocene) formation rocks, and has good hydraulic properties (transmissivity averages about 3,000 m^2/d), but unlike the situation in Saudi Arabia, contains high-salinity water. Typical salinities of the "C" aquifer are about 10,000 mg/l. At the core of the Bahrain anticline (figure X), Rus formation is exposed.

Produced water from the "C" zone is used mainly for industrial purposes and also as the raw feed-water for a 10 Mm^3/y reverse osmosis desalination plant.

A lesser salinity water, ranging between 2,000 and 6,000 mg/l, is present in the form of floating lenses above the more saline, deeper water. This fresher water is the result of direct downward infiltration of rainfall.

Table 15 illustrates typical chemical compositions of groundwater drawn from the "B" and "C" aquifers, in addition to the average drinking water in Bahrain.

The surface aquifer, known as the Neogene, is a shallow, alluvial, unconfined aquifer adjacent to the coast. Its source of water is vertical leakage from deeper aquifers, spring flows, rainfall recharge and agricultural drainage water.

Figure XI illustrates the salinity contours for the Khobar aquifer in Bahrain for the year 1989,[1/] and shows that salinity increases rapidly to the south and east. Salt-water intrusion from the sea is almost certainly

1/ S. Al-Junaid, "Groundwater situation in Bahrain, 1979-1989", Master of Science thesis, Arabian Gulf University, (Bahrain, 1990).

occurring in the vicinity of Sitra Island,[2/] due to the decrease in the piezometric level of the aquifer locally in the island and in Bahrain in general. Elsewhere in Bahrain Island, the deterioration in quality of "B" aquifer is a result of saline flow from the underlying "C" aquifer under head differentials created by the excessive pumping of "B" aquifer. A third source of salinity is the irrigation return flows seeping to the shallow aquifers in areas where they are exposed at the surface and under water-table conditions. The return flows are concentrated in the upper zone of the aquifers affected and cause marked deterioration in the water quality, in particularly shallow hand-dug wells.

The piezometric head in Bahrain has also declined as a result of increased groundwater abstraction from wells. It is estimated that a decrease of 4 to 5 metres has taken place since 1925, permitting saline water intrusion into the aquifer and rendering some central and coastal regions unproductive water-wise due to water quality deterioration. The piezometric heads are highest north-west of the island and gradually decrease to the south-east (figure XII). This gradient reflects the groundwater flow, which is in a south-easterly direction.

Table 15. Chemical composition of groundwater in Bahrain (1985)
(Mg/L)

Chemical composition	Aquifers			Drinking water
	A	B	C	
PH	7.47	7.52	7.00	7.58
Total dissolved solids (TDS)	3 027	3 942	9 130	736
Sodium	734	874	1 890	161
Potassium	68	94	81	9
Calcium	254	298	440	64
Magnesium	52	107	598	23
Chloride	243	1 527	3 700	284
Sulphate	558	845	2 196	125
Bicarbonate	183	256	180	62

Source: The United Nations Environment Programme (UNEP), State of the Environment: Bahrain, Regional Office for West Asia (ROWA), (1985).

2/ E.P.W. Wright, "Groundwater resources of Bahrain Islands", Ministry of Commerce and Agriculture (MOCA) (State of Bahrain, 1967).

Since mechanized well drilling and pumping started in 1925, there has been a progressive decrease in spring water; in certain areas (particularly the east coast), aquifers have become polluted with a consequent abandonment of land. There are now about 2,000 water-abstraction points, of which 800 are boreholes and the rest large-diameter dug wells.

2. Groundwater utilization

Groundwater use is restricted to the northern part of the island where water salinity is least. In broad estimates groundwater abstraction/discharge can be divided into the following groups:

- Agriculture
- Gardens, private, etc.
- Municipal
- Industrial
- Desalination plants
- Land and offshore springs

Table 16 indicates groundwater utilization by the previous groups. This table shows that estimated current agriculture usage is 71 Mm^3/y.

A further 28 Mm^3/y is used for gardens, private land and landscaping.

3. Treated sewage effluent (TSE)

The shortage and the poor quality of groundwater in Bahrain has prompted the Government to consider the use of effluent water in agriculture, after suitable treatment. The only natural source of water supply is groundwater, estimated to have a yield of around 180 Mm^3/y in 1989[3/]. This source of supply is not sufficient to meet the various demands, and its quality places some limitation on its use. Groundwater supplies are being supplemented with desalinated fresh water, which is primarily used for domestic water supplies. Treated effluent hence presents a valuable resource, providing an initial supply of 25 Mm^3/y in 1990 and an ultimate supply of around 60 Mm^3/y by 2010.

The most practical utilization of treated sewage effluent (TSE) in Bahrain is in agriculture, as irrigation water. The reasons for this are:

(a) Agriculture is one of the major users of water in Bahrain, as successful cultivation is nearly entirely dependent on irrigation;

(b) Agricultural production must increase to provide food security for the growing population and to help trade balances;

(c) Available groundwater for irrigation is of poor quality, severely restricting the level of agricultural production.

3/ Al-Junaid, op. cit.

Table 16. Groundwater utilization by sector, 1987
(Mm^3/y)

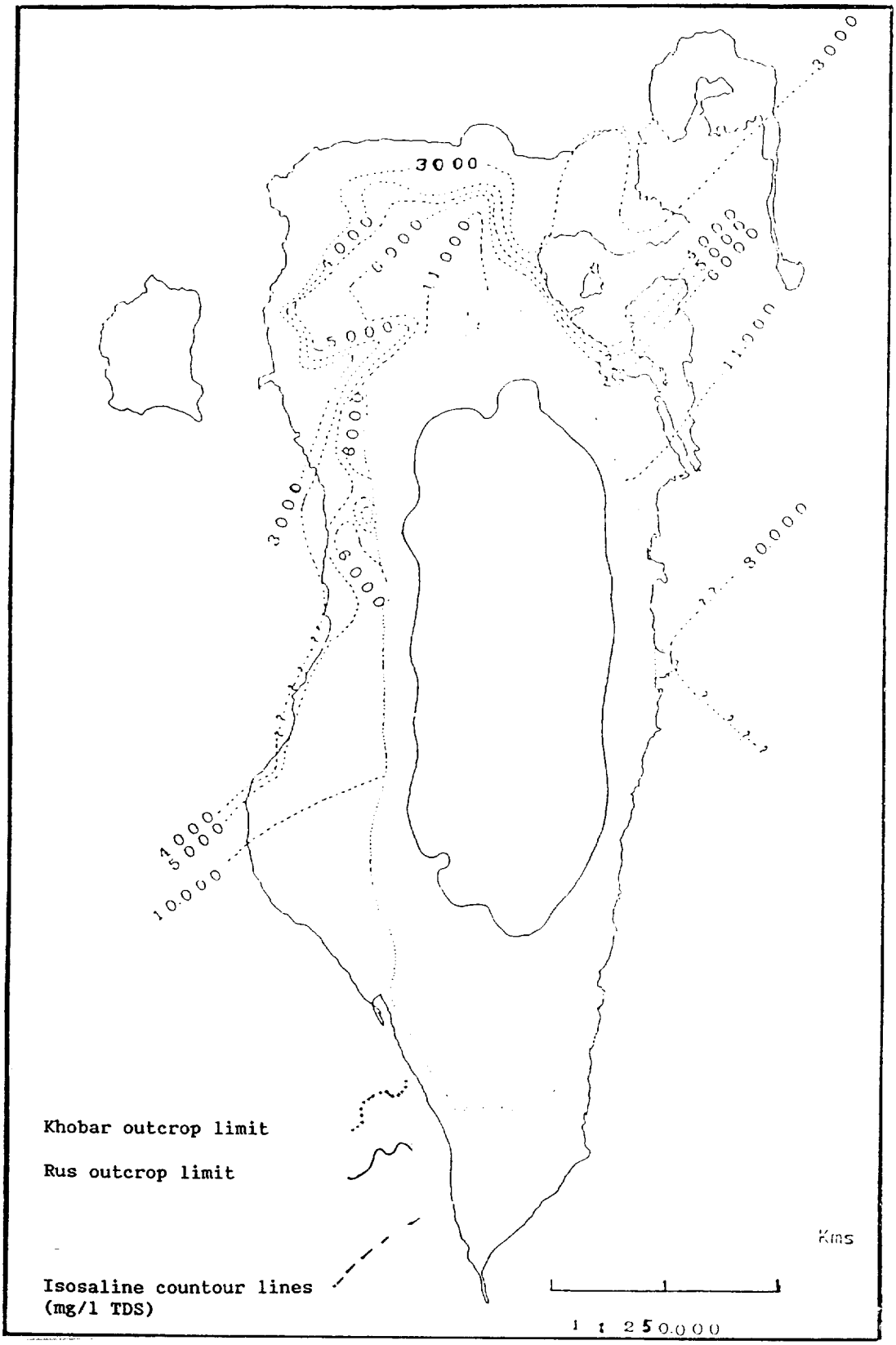
Sector use	Aquifer source			Quantity	
	Dammam	Neogene	RUS-UER	Subtotal	Total
Agriculture:					
(a) Dates	21	9		30	71
(b) Vegetables and alfalfa	41			41	
Gardens, private, etc.	28			28	
Municipal	41			41	
Industrial	7		7	14	120
Desalination plants	-		22	22	
Land and offshore springs	15			15	
Total	153	9	29		191

Quantities of TSE

The waste-water flow to the Tubli Water Pollution Control Centre (TWPCC) at present is around 65,000 m^3/day, of which about 22.500 m^3/d originates from house connections, 17,000 m^3/d from septic tank discharges, 20,000 m^3/d from groundwater infiltration and 6,000 m^3/d from dewatering. A gradual increase in the flow is expected in the future, primarily as a result of new house connections and the connection of new areas such as Muharraq and Hamad Town.

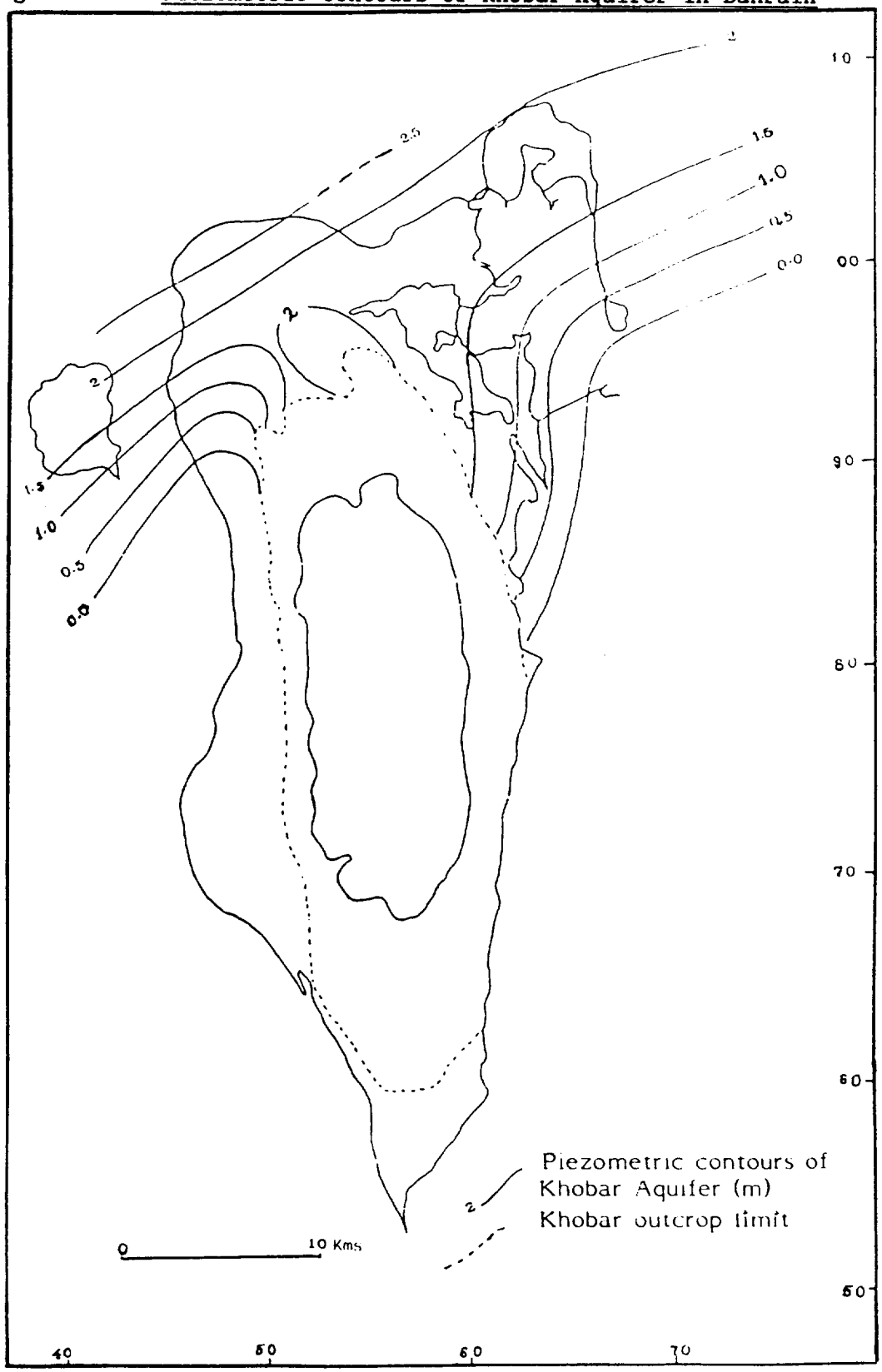
For the year 1995, it is estimated that the average daily flow will be around 95,000 m^3/day and in the year 2010 around 166,000 m^3/day (table 17). Presently commitments could be made for the utilization of around 55,000 m^3/day of treated effluent corresponding to the capacity of the existing Tubli works.

Figure XI. Isosaline contours of Khobar Aquifer in Bahrain



Source: S. Al-Junaid, "Groundwater situation in Bahrain, 1979-1989", Master of Science thesis, Arabian Gulf University, (Bahrain, 1990).

Figure XII. Piezometric contours of Khobar Aquifer in Bahrain



Source: S. Al-Junaid, "Groundwater situation in Bahrain 1979-1989", Master of Science thesis, Arabian Gulf University, (Bahrain, 1990).

Table 17. Proposed TSE quantities, by use
(m^3/day)

Description	Initial 1985 a/	1990	1995	2010
Landscaping	9 000	12 000	16 000	28 000
Agriculture	31 000	43 000	54 000	100 000
Industrial	5 000	8 000	17 000	22 000
Groundwater recharge b/	6 000	6 000	8 000	16 000
Total	51 000	69 000	95 000	166 000

a/ Proposed but not implemented.

b/ Quantities for groundwater recharge would be appreciably higher than those indicated in this table if the effluent in excess of agricultural requirements during the cold season is utilized for recharging.

Until recently, only a small quantity (5,000-6,000 m^3/day) of the treated wastewater is being used for irrigation in Bahrain.4/ The remaining quantities (70,000-75,000 m^3/day) are at present being discharged into the sea.

Quality of treated wastewater

The Tubli wastewater 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 various harmful ions. The projected quality of treated effluent is illustrated in table 18.

4/ Al-Junaid, op. cit.

Table 18. Projected quality of Tubli effluent water
(Values in mg/l)

Year	TDS mg/l	TDS (mmhos/cm)	Na^+	CI^-	SO_4
1983	5 000	(7.0 mmhos/cm)	1 170	2 250	750
1985	4 400	(6.2 mmhos/cm)	880	1 600	880
1990	3 200	(4.5 mmhos/cm)	640	1 150	640
1995	2 750	(3.9 mmhos/cm)	550	1 000	550
2000	2 200	(3.1 mmhos/cm)	440	800	440

The table indicates that with the decrease in salinity, the concentration of harmful ions such as Na^+, C^- and SO_4 will also decrease. In 1983, the ratios of concentration of these ions to TDS concentration were 0.23, 0.45 and 0.15 for Na^+ Cl^- and SO_4, respectively. These ratios were affected to some extent by the infiltration of highly saline water and would definitely change once such infiltration is reduced or eliminated, and would approach the ratios found in aquifer water and potable water supplies. Accordingly, the expected ratios in the year 2000 would be 0.20, 0.36 and 0.20 for Na^+, C^- and SO_4, respectively.

The quality of the treated wastewater generated at the Tubli plant could be considered as rather good from other non-agricultural points of view. Chemical and hygienic properties of treated sewage effluent (TSE) of Tubli plant are given in table 19.

4. Water quality for irrigation

The quality of irrigation water dictates its suitability for various uses. Its suitability is determined by its potential to cause soil salinization problems and/or ionic toxicity; these may in turn call for special management practices for water use. Evaluation at the farm level needs to be carried out in connection with any specific use to determine the potential hazard to crop production under existing management capability.

The Food and Agriculture Organization of the United Nations (FAO) has established guidelines for use in evaluating and interpreting water quality for irrigation; these are shown in table 20.

Comparison of the predicted Tubli water quality for the year 2000 (table 18) and the FAO guideline (table 20) could lead to the conclusion that the quality of the effluent will be slightly worse than the "severe problem" category, especially for NA^+ and Cl^-. Therefore, when irrigating with the Tubli effluent (especially for fruit trees) actual field tests have to be carried out.

Table 19. Quality of treated sewage effluent (TSE) of Bahrain[a/] as compared with TSE of Florida and the United Nations limits (Schaefer, 1984)

	Bahrain	Florida	United Nations limits
Parameter	mg/l	mg/l	mg/l
Biological oxygen demand (BOD)	1.2	2.0	10.0
Chemical oxygen demand (COD)	33	-	40.0
Salinity	2 833	-	-
pH value	7.6	-	7.0
turbidity	0.014	0.05	-
Total suspended Solids (TSS)	10.0	1.0	10.0
NH_4	0.302	-	-
Total number of bacteria (cells/100 ml)	0.25		100.0

a/ Extracted from the Yearly Report (1988) of the Tubli Water Pollution Control Centre (State of Bahrain).

5. Crop tolerance to salinity

Table 21 indicates the yield reduction expected for certain crops due to salinity of irrigation water under surface irrigation conditions. The table includes selected crops that can tolerate a certain minimum salinity at 0 per cent yield reduction. The crop tolerances, however, are not fixed values. These tolerances also depend on irrigation and water management practices as well as the stage of growth, root stock of root trees and varieties. Table 22 also shows different salt-resistant species of landscape and forest trees, shrubs and grasses.

6. Water requirements

The water requirements for each crop depend mainly on climate, growth stage and crop species itself. In Bahrain most of the vegetables are grown during the cool season; fruit trees, landscape trees, grasses and turf need to be irrigated all year round.

Table 20. Guidelines for interpreting water quality for irrigation

Irrigation problem	Degree of problem		
	No problem	Increasing problem	Severe problem
Salinity EC_w (mg/1)[a/]	500	500-2 000	2 000
Permeability EC_w (mg/1)[b/]	320	320-1 280	1 280
Adjusted SAR [c/]			
Montmorillonite	6	6-9	9
Illite-vermiculite	8	8-16	16
Kaolinite-sesquioxide	16	16-24	24
Specific ion effect[d/]			
Sodium mg/1[e/]	70	70-20	210
Chloride mg/1[e/]	140	140-350	350
Boron mg/1	0.75	0.75-2	2
Miscellaneous effects[f/]			
No^3-N (or) NH_4-N mg/1	5	5-30	30
HCO_3mg/1 (sprinkling)	90	90-520	520
PH	Normal range 6.5-8.4		

Source: Food and Agriculture Organization of the United Nations (FAO) Irrigation and Drainage Paper No. 29, "Water quality for agriculture" (Rome, 1985).

a/ Salinity affects crop water availability.

b/ Permeability affects infiltration rate into soil.

c/ SAR (sodium absorption ratio) = $\frac{NA}{\frac{Ca + Mg}{2}}$

d/ Specific ion effect affects sensitive crops.

e/ Most tree crops and woody ornamentals are sensitive to sodium and chloride in excess of 70 ppm and 100 ppm respectively. The use of sprinkle irrigation results in excessive leaf absorption and crop damage.

f/ Affects susceptible crops.

Na, Ca and Mg are in meg/1.

Table 21. Crop tolerance to salinity

Crop	Percentage yield reduction 0%		10%		25%		50%	
	EC[a/] e	EC[b/] w	EC[a/] e	EC[b/] w	EC[a/] e	EC[b/] w	EC[a/] e	EC[b/] w
Field crops								
Barley	8.0	5.3	10	6.7	13	8.7	18	12
Sugarbeet	7.0	4.7	8.7	5.8	11	7.5	15	10
Wheat	6.0	4.0	7.4	4.9	9.5	6.4	13	8.7
Cotton	7.7	5.1	9.6	6.4	13	8.4	17	12
Sorghum	4.0	2.7	5.1	3.4	7.2	4.8	11	7.2
Safflower	5.3	3.5	6.2	4.1	7.6	5.0	9.9	6.6
Fruit trees								
Date palm	4.0	2.7	6.8	4.5	10.9	7.3	17.9	12
Fig,olive, Pomegranate	2.7	1.8	3.8	2.6	5.5	3.7	8.4	5.6
Grapefruit	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3
Orange	1.7	1.1	2.3	1.6	3.2	2.2	4.8	3.2
Lemon	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2
Grapes	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5
Vegetables								
Tomato	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0
Melon	2.2	1.5	3.6	2.4	5.7	3.8	9.1	6.1
Cabbage	1.8	1.2	2.8	1.9	4.4	2.9	7	4.6
Pepper	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4
Lettuce	1.3	0.9	2.1	1.4	3.2	2.1	5.2	3.4
Onion	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9
Carrot	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.1
Potato	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9
Forage crops								
Tall wheatgrass	7.5	5	9.9	6.6	13.3	9.0	19.4	13
Wheatgrass	7.5	5	9.0	6.0	11.0	7.4	15.0	9.8
Bermuda grass	6.9	4.6	8.5	5.7	10.8	7.2	14.7	9.8
Barley (hay)	6.0	4.0	7.4	4.9	9.3	6.3	13.0	8.7
Ryegrass	5.6	3.7	6.9	4.6	8.9	5.9	12.2	8.1
Sudan grass	2.8	1.9	5.1	3.4	8.6	5.7	14.4	9.6
Alfalfa	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9
Berseem clover	1.5	1.0	3.2	2.1	5.9	3.9	10.3	6.8

a/ EC_e is electrical conductivity of the saturation extract of the soil in mmhos/cm.

b/ EC_w is electrical conductivity of the irrigation water in mmhos/cm at 25°C. This assumes a 15-20 per cent leaching fraction and an average salinity taken by the crop about three times that of the irrigation water applied.

Table 22. Salt-resistant landscape and forest trees, shrubs and grasses

Trees:

1. Acacia arabica
2. Acacia decurren mollis
3. Casuarina cunninghamiana
4. Casuarina equisetifolia
5. Ceratonia siliqua
6. Cordia alyssinica
7. Eucalyptus globulus
8. Eucalyptus longifolia
9. Ficus religiosa
10. Melia azedarach
11. Phoenix dactylifera
12. Pistacia atlantica
13. Prosopis juliflora (can be used as animal feed)
14. Schinus maple
15. Sesbania grandiflora
16. Tamarix sp.
17. Terminalia catappa

Shrubs:

1. Dodonea viscosa
2. Lawsonia inermis
3. Myrtus communis
4. Nerium oleander
5. Puncia granatum florepleno
6. Sesbania agyptiaca
7. Yucca filamentasa
8. Yucca gloriosa

Climbers and creepers:

1. Asparagus sprengeri
2. Clerodendron
3. Ipomoea pes-caprae
4. Jasminum species
5. Thunbergia alata

Tuberous and herbaceous plants:

1. Agave americana
2. Agave sisalana
3. Sanservieria trifasciata

Herbs:

1. Anethium gravelous
2. Citrullus colocynthis
3. Herniaria hemcistemou
4. Plantago ovata
5. Robbairea prostrata
6. Utrica urens

Grasses:

1. Aegilops kotschyi
2. Arisida sp.
3. Cenohurus ciliaris
4. Cymbopogon schoenauthus
5. Tynodon dactylon
6. Eragrostis binnata
7. Pispalum vaginatum
8. Festuca arundinacca
9. Stenotaphrum secun-datum

Table 23 summarizes the net monthly water requirements for some of the crops to be grown at the different sites.

The water requirements values in table 23 would be reduced by around 20 per cent for crops and forages should a piped distribution system be utilized.

The crop water requirements indicated in table 23 are for the initial stage of effluent use. The requirements would gradually be reduced as the quality of water improved. Also, with the improvement of water quality, other forms of irrigation, such as spray irrigation, could be used, which would further reduce water needs.

The landscape water requirement is minimal after establishment; the gross water requirement is as follows:

Tree, large:	238	L/tree/day
Tree, small:	230	L/tree/day
Shrubs:	80	L/tree/day
Grass:	20	$L/m^2/day$

7. Irrigation regions and zones

The evaluation of water requirements for irrigation and future productivity potential necessarily involves a procedure for zoning. Zonal definitions are determined on the basis of existing soil, land capability and water quality resources characteristics.

Features such as bore inventory areas, natural and geographical, and treated sewage effluent (TSE) project proposals are all taken into account in deciding on the most appropriate boundaries for the irrigation zones.

Three main irrigation regions can be defined: (a) northern coast; (b) western coast, and (c) central/east coast.

These can be further divided into 13 zones and 20 sub-zones as shown in table 24.

These zones and sub-zones are used for determining priority areas of development for the water management strategies and the treated sewage effluent (TSE) project. They can also be used for the administration of agricultural policies and organization of the extension services to farmers. Figures IX and X show the location of the regions and zones.

These zones and sub-zones are used for determining priority areas of development for the water management strategies and the treated sewage effluent (TSE) project. They can also be used for the administration of agricultural policies and organization of the extension services to farmers. Figures IX and X show the location of the regions and zones.

Northern coastal irrigation region

This region comprises two zones, the first from Budaiya to Jid Hafs, North of the Manama-Budaiya highway, and characterized by a high level of

water use and significant urbanization. The second zone includes other minor irrigation areas to the coast such as Muharraq and Manama.

Table 23. Water requirements for field crops and fruit trees in Bahrain, by month

(m^3/hectare)

	Field crops				Fruit trees	
Month	Alfalfa[a/]	Rhodes grass[a/]	Ryegrass[b/]	Barley[c/]	Dates	Mango
January	1 865	980	1 220	1 280	600	390
February	2 240	1 435	1 435	1 650	760	765
March	3 760	2 690	2 380	3 110	1 400	1 760
April	4 700	2 955	3 130	-	2 000	2 585
May	6 050	3 780	-	-	2 465	3 710
June	6 700	4 200	-	-	2 655	4 285
July	6 840	4 335	-	-	3 115	4 165
August	6 650	4 210	-	-	3 625	3 775
September	5 380	3 430	-	-	3 290	2 710
October	4 290	2 690	-	2 870	2 510	1 820
November	2 740	1 715	1 830	2 130	1 400	880
December	2 100	1 280	1 465	1 710	850	520
Total	53 315	3 370	11 460	12 570	24 670	27 365

Source: N.G. Dastane and M. Ayub, "Revitalizing Bahraini farming with improved water management and higher crop density, "Food and Agriculture Organization of the United Nations (FAO) Document No. TF/REM/MUL/22, Ministry of Commerce and Agriculture (MOCA) (State of Bahrain, 1982).

a/ Planting in October.
b/ Planting in November.
c/ Planting in October for first crop, and in January, second crop for hay.

Western coastal irrigation region

This includes the coastal strip extending from Budaiya south to beyond Zallaq. This region comprises four zones, and is bounded by the coast and the escarpment and poor soils to the east.

Central irrigation region

This includes all areas where groundwater is not a feasible source of supply for irrigation. There are 7 zones and 14 sub-zones.

The only feasible water resource for the Central Irrigation Region is treated sewage effluent (TSE) from the Tubli plant. Preliminary studies have shown a favourable balance between land potentially suitable for agriculture and water required to irrigate that land.

Table 24. List of agricultural regions and irrigation zones

Agricultural region	Zone	Irrigation areas Sub-zone	Total area (ha)	Net area a/ (ha)
North coast	A	North coast	472	
	B	East coast b/	224	
West coast	C	Bani Jamrah	586	
	D	Hamalah	600	
	E	West coast	982	
	F	Al Zallaq	153	
Subtotal	Coastal			3 017
Central irrigation (TSE)	G 1	North Burham Green Belt	200	125
	2	South Adari	205	130
	H 1	North Buquwwah	200	150
	2	South Buquwwah	225	170
	J 1	Shakhurah	325	245
	2	Maqabah	70	55
	3	Sar	125	95
	K 1	Nabi Saleh	65	50
	2	Sanad	165	125
	L 1	Hawarat Ali	223	170
	M 1	Salmabad	195	145
	2	Ali	354	265
	N 1	Highway	284	215
	2	Buri	113	85
Subtotal	Central		2 750	2 025

a/ In zones A-F, this is actual based on known data; in the treated sewage effluent (TSE) region, the areas available are estimated at 75 per cent of total surface area.

b/ Includes Muharraq, Manama, etc.

These zones and sub-zones are used for determining priority areas of development for the water management strategies and the treated sewage effluent (TSE) project. They can also be used for the administration of agricultural policies and organization of the extension services to farmers. Figures IX and X show the location of the regions and zones.

II. SOCIO-ECONOMIC SETTING

A. Population

Population records in Bahrain are well established since the first national census conducted in January 1941. Since then, five other censuses were conducted, namely in 1950, 1959, 1965, 1971 and 1981. The Government of Bahrain was planning to carry out the seventh national census in 1990. Necessary steps were taken, but the census was delayed because of the Gulf War.

1. Population changes, 1941-1981

According to the census of 1941, the population of Bahrain was around 90,000 inhabitants (table 25). The Bahraini proportion of the total was 82.3 per cent. The population increased with an annual growth rate of 2.31-8.55 per cent during the period 1941-1981. The Bahraini proportion of the total population remained stable at around 82 per cent until 1971. The Bahraini proportion has decreased since 1981 to only 68.7 per cent, indicating a significant increase in the expatriate population over the decade 1971-1981.

The average annual growth rates for the Bahrain population is of interest. There was a conspicuous rise in the early years due to improvements in health care, but since 1971 there has been a decline in the growth rate. The data imply a declining trend, since fertility levels are likely to decrease with increased female education and participation in the labour force.

Non-Bahrainis have displayed a growth pattern consistent with the growth of the Bahraini economy and emphasizing the reality that most non-Bahrainis are supplying labour to the national economy. From table 25, it is clear that their numbers in the period 1971-1981 rose from 37,885 to 112,378. The growth is even more marked in examination of the intercensal annual growth rates. The non-Bahraini population is predominantly male. In 1971, males accounted for 70.06 per cent of total expatriates and 75.52 per cent in 1981. The male proportion of the Bahraini population remained static at around 50.3 per cent in the same period.

2. Components of changes in the Bahraini population

(a) The crude birth rate for Bahrainis declined from 44.0 in the period 1965-1971 to 37.6 for 1971-1976 and reduced further to 30.0 in 1976-1981 (crude birth rate is the number for births per annum per thousand population);

(b) The total fertility rate for Bahrainis, measured as the average number of children born per female, is declining. It was estimated to be 6.6 during 1965-1971, 5.6 for the period 1971-1976 and 4.8 for 1976-1981;

(c) Data on mortality is not as comprehensive as that on fertility. However, mortality has declined since 1941. The crude death rate for Bahrainis was 10.1 per thousand population per annum in 1965-1971, 8.2 in 1971-1976 and 6.3 in 1976-1981.

Apparent birth rates are declining faster than death rates, indicating that Bahrain is moving towards the end of a transitional phase, although it may take many years to reach a new level of stability.

Table 25. Census of the State of Bahrain

Year	Bahrainis	Non-Bahrainis	Total	Bahrainis (percentage)	Annual growth rate (Percentage) Bahrainis	Non-Bahrainis	Total
1941	74 040	15 930	89 970	82.29	--	--	--
1950	91 179	18 471	109 650	83.15	2.31	1.64	2.19
1959	118 734	24 401	143 135	82.95	2.91	3.07	2.94
1965	143 814	38 389	182 203	78.93	3.38	8.18	4.28
1971	178 193	37 885	216 078	82.47	3.55	-0.22	2.82
1981	238 420	112 378	350 798	68.65	2.95	11.46	4.95

Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

3. Population distribution

Reliable information is required in order to decide what facilities are to be planned, to be able to reserve land for their physical accommodation at the present time and in the future.

The Central Statistics Organization (CSO) has published population forecasts to the year 2001 (table 26 and figures XIII, XIV and XV). Population distribution by administrative area is also essential for the preparation and detailed plans for human settlements. Tables 27 and 28 illustrate population projection by administrative areas for 1981 and 1988, respectively. Most of the population lives in Muharraq and Manama. However, the share of the total population for these two towns is decreasing. Their shares of population were 17.7 per cent and 34.8 per cent in 1981, dropping to 15.75 per cent and 29.32 per cent in 1988. Hidd, Jid Hafs, Northern Region, Sitra and Western Region maintained their share of population in the period 1981-1988. Central Region, Riffa, Isa Town and Madinat Hammad areas are maintaining the increase in their share of population.

B. Employment and labour force

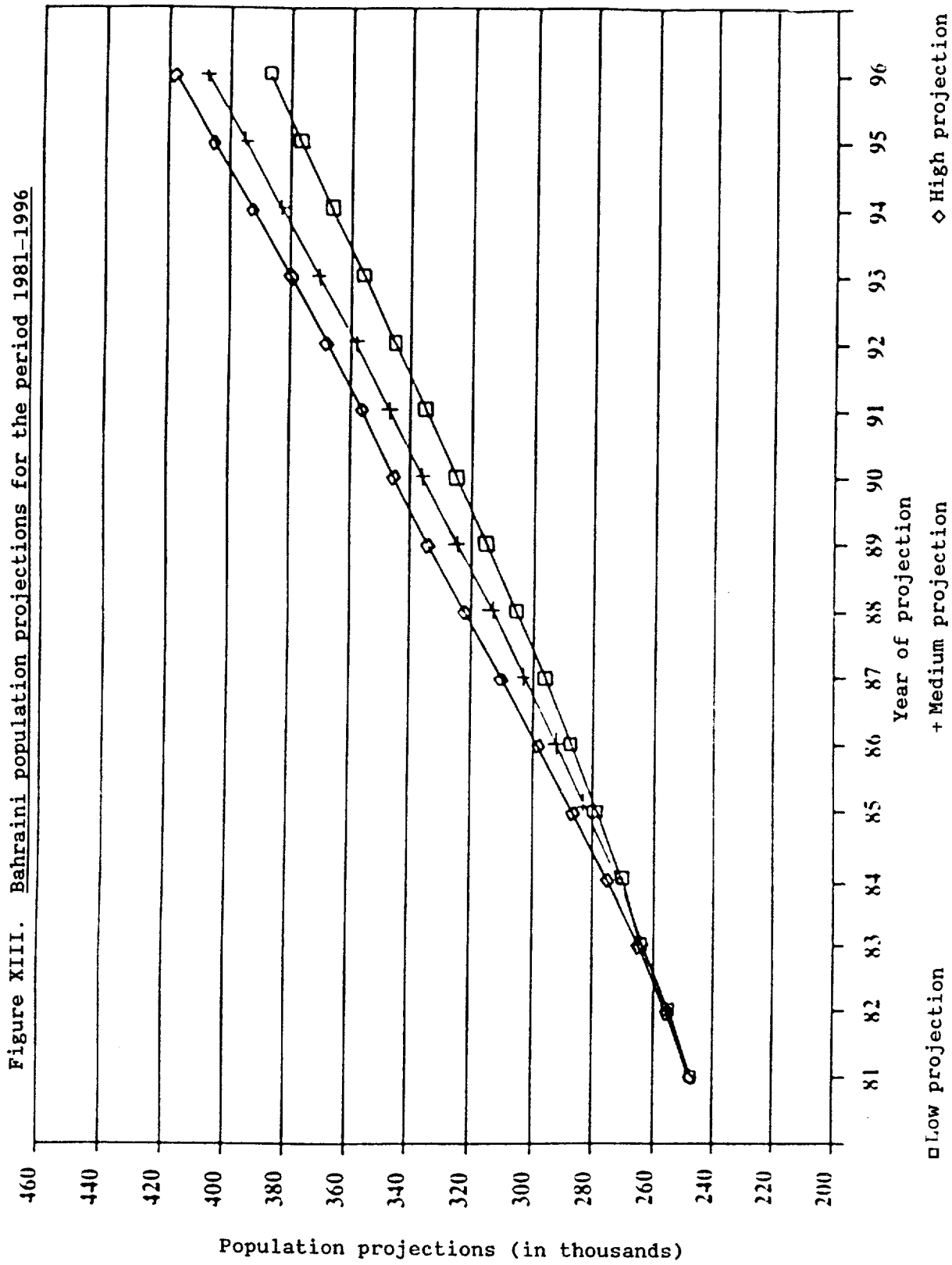
The labour force in Bahrain has grown rapidly over the last years (1965-1991). The employed labour force increased from 53,274 in 1965 to 177,459 in 1991 (table 29). The participation rates in the labour force have, however, differed according to nationality and sex. The participation of Bahraini males was on the order of 40 per cent, ranging from 41.8 per cent in 1965 to 37.5 per cent in 1991. Bahraini females on the contrary participated at the much lower rate of 1.4 per cent in 1965. The percentage of Bahraini female participation increased steadily, to reach 10.2 in 1991, and is projected to reach 11.6 per cent in 2001. The overall participation of Bahrainis in the labour force remains within the range of 21.3-24.7 per cent of their population. Non-Bahrainis contributed to the labour force at higher rates, 57.4 per cent in 1965. This rate increased to reach a maximum of 72.5 per cent in 1981 and decreased thereafter, reaching 55.7 per cent in 1991. Further decrease to 34.7 per cent in the year 2001 is projected.

Table 26. Projection for Bahrain population classified by sex, nationality and year of projection

Year	Population (thousands) Bahraini Males	Bahraini Females	Bahraini Total	Non-Bahraini Males	Non-Bahraini Females	Non-Bahraini Total	Total population Males	Total population Females	Total population Total
(A) Low projection									
1971	89.8	88.4	178.2	26.5	11.3	37.8	116.2	99.8	216.0
1981	124.5	123.0	247.5	84.6	27.4	112.0	209.1	150.4	359.5
1991	168.2	166.8	335.0	117.8	45.1	162.9	286.0	211.9	497.9
2001	218.9	217.5	436.4	130.9	56.7	187.6	349.8	274.2	624.0
(B) Medium projection									
1971	89.8	88.4	178.2	26.5	11.3	37.8	116.3	99.8	216.1
1981	124.5	123.0	247.5	84.6	27.4	112.0	209.1	150.4	359.5
1991	174.2	172.8	347.0	122.7	46.7	169.4	296.9	219.5	516.4
2001	234.8	233.7	468.2	139.2	59.7	198.9	374.1	293.4	667.5
(C) High projection									
1971	89.8	88.4	178.2	26.5	11.3	37.8	116.3	99.8	216.1
1981	124.5	123.0	247.5	84.6	27.4	112.0	209.1	150.4	359.5
1991	178.7	177.7	356.4	133.7	50.2	183.9	312.4	227.9	540.3
2001	240.2	239.9	480.1	155.9	65.8	221.7	396.1	305.7	701.8

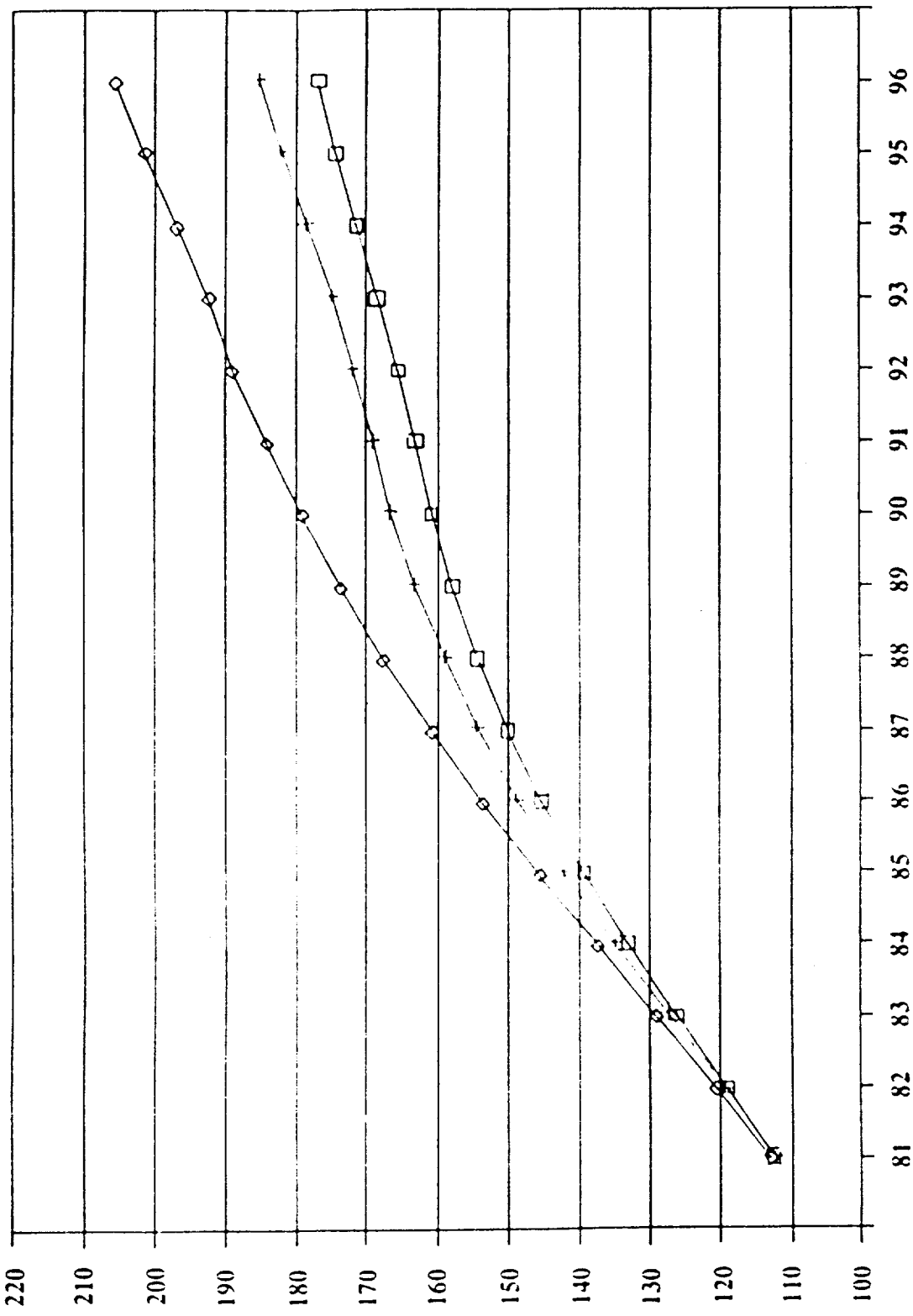
Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

Figure XIII. Bahraini population projections for the period 1981-1996



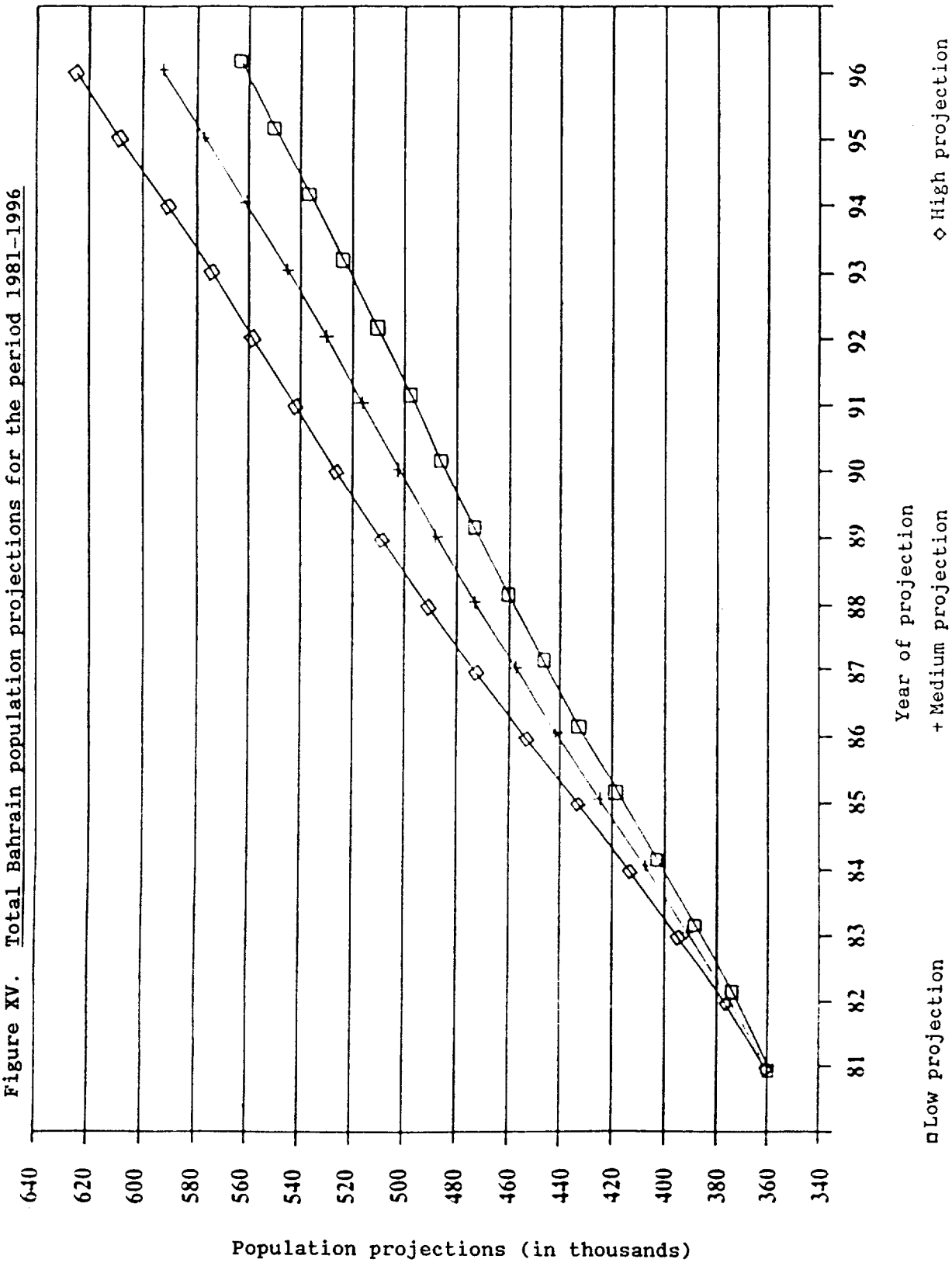
Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

Figure XIV. Non-Bahraini population projections for the period 1981-1996



Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

Figure XV. Total Bahrain population projections for the period 1981-1996



Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

Table 27. Population distribution by administrative area according to the 1981 census

Region	Bahrainis	Percentage	Percentage of total	Non-Bahrainis	Percentage	Percentage of total	Total	Percentage
Hidd	5 535	2.3	1.6	1 576	1.4	0.4	7 111	2.0
Muharraq	47 827	20.1	13.6	14 026	12.5	4.1	61 853	17.7
Manama	58 108	24.4	16.6	63 878	56.9	18.2	121 986	34.8
Jid Hafs	29 747	12.5	8.5	3 946	3.5	1.1	33 693	9.6
Northern	16 716	7.0	4.8	5 401	4.8	1.5	22 117	6.3
Sitra	19 472	8.2	5.6	3 521	3.1	1.0	22 993	6.6
Central	12 903	5.4	3.7	3 873	3.4	1.1	16 776	4.8
Isa Town	19 957	8.4	5.7	1 318	1.2	0.4	21 275	6.1
Riffa	14 898	6.3	4.2	13 252	11.8	3.8	28 150	8.0
Western	12 945	5.4	3.7	1 558	1.4	0.4	14 503	4.1
Hawar Island	7	0.0	0.0	14	0.0	0.0	21	0.0
Total	238 115	100.0	68.0	112 363	100.0	32.0	350 478	100.0

Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

Employment in agriculture

Employment in the agricultural sector, which includes agriculture, animal husbandry and fishery represented only a minor part of the total labour force in Bahrain (table 30). The numbers of agricultural labourers have steadily declined, from 4,464 in 1959 and to 3,990 and 3,700 in 1971 and 1981, respectively. The share of agricultural labour in the total labour force has also declined, from 12.4 per cent in 1971 to 5.3 per cent in 1981. This decline coincided with the shrinking of agricultural areas. The Ministry of Commerce and Agriculture has embarked on an ambitious programme of expanding agricultural land, encouraging private farmers to modernize their farming and irrigation methods. This development has helped to reverse the declining trends in employment in this sector. Employment in the agricultural sector rose to 5,460 and 5,986 in the years 1984 and 1991, respectively. It is also expected that the numbers will reach 6,370 and 6,440 in the years 1996 and 2001, respectively.

Table 28. Projected population distribution by administrative area for the year 1988

Region	Bahrainis	Percentage	Non-Bahrainis	Percentage	Total	Percentage
Hidd	6 956	1.47	2 472	0.52	9 428	1.99
Muharraq	53 454	11.30	21 057	4.45	74 511	15.75
Manama	58 225	12.30	80 551	17.02	138 776	29.32
Jid Hafs	37 846	8.00	7 116	1.50	44 962	9.50
Northern	22 009	4.65	8 328	1.76	30 337	6.41
Sitra	24 659	5.21	6 303	1.33	30 962	6.54
Central	21 346	4.51	6 653	1.40	27 999	5.91
Isa Town	31 870	6.73	3 628	0.77	35 498	7.50
Riffa	26 737	5.65	19 713	4.16	46 450	9.81
Western	17 985	3.80	2 812	0.60	20 797	4.40
Hamad Town	12 670	2.68	905	0.19	13 575	2.87
Third New Town	--	--	--	--	--	--
Total	313 758	66.30	159 538	33.70	473 296	100.00

Source: Special Project Team, Central Statistics Organisation (CSO) (State of Bahrain, October 1989).

Table 29. Changes in employment structure, 1965/2001

	1965[a/]		1971[a/]		1981[a/]		1991[b/]		2001[b/]	
	Number	Share (%)	Number	Share (%)	Number	Share (%)	Number	Share (%)	Number	Share (%)
(A) Labour force										
Bahraini:										
Male	30 236		36 102		51 949		65 395		81 525	
Female	995		1 848		9 250		17 701		27 212	
Total	31 231	58.6	37 950	62.9	61 199	43.0	83 096	46.8	108 737	61.3
Non-Bahraini:										
Male	21 015		20 950		74 230		86 248		62 810	
Female	1 028		1 401		6 955		8 155		5 910	
Total	22 043	41.4	22 351	37.1	81 185	57.0	94 363	53.2	68 720	38.7
Grand total	53 274	100	60 301	100	142 384	100	177 459	100	177 457	100
(B) Percentage labour to population[c/]										
Bahraini:										
Male		41.8		40.2		41.7		37.5		34.7
Female		1.4		2.1		7.5		10.2		11.6
Total		21.7		21.3		24.7		23.9		23.2
Non-Bahraini:										
Male		-		79.1		87.7		70.3		45.1
Female		-		12.4		25.4		17.5		9.9
Total		57.4		59.1		72.5		55.7		34.7
Grand total		29.2		27.9		39.6		34.4		26.6

Source: Statistical Abstract 1988, Central Statistics Organisation (CSO) (State of Bahrain, 1989).

a/ Actual census.
b/ Projections made by CSO.
c/ Calculations based on medium projection for the population.

Table 30. Labour force of Bahrain by economic activity and nationality according to the 1971 and 1981 censuses[a/]

Economic Activity	1971[b/]				1981[c/]			
	Bahraini	Non-Bahraini	Total	Percentage	Bahraini	Non-Bahraini	Total	Percentage
Agriculture and fishery	2 995 75.1	995 24.9	3 990 100.0	12.4	2 439 65.7	1 272 34.3	3 709 100.0	5.3
Mining, quarrying and manfacturing	5 614 66.3	2 850 33.7	8 464 100.0	26.2	7 461 46.2	8 704 53.8	16 165 100.0	22.9
Electricity, gas and water	1 480 86.8	225 13.2	1 705 100.0	5.3	1 855 65.0	999 35.0	2 854 100.0	4.0
Construction	5 639 54.2	4 765 45.8	10 404 100.0	32.2	3 903 13.3	25 358 86.7	29 261 100.0	41.5
Wholesale, retail trade, restaurants and hotels	4 851 63.0	2 855 37.0	7 706 100.0	23.9	5 836 31.5	12 671 68.5	18 507 100.0	26.3
Grand total	20 579 63.8	11 690 36.2	32 269 100.0	100.0	21 494 30.14	49 004 69.9	70 493 100.0	100.0

Source: Calculated from Statistical Abstract 1988, Central Statistics Organisation (CSO) (State of Bahrain, 1989).

a/ Persons seeking work for the first time were excluded.
b/ 14 years old and over.
c/ 15 years old and over.

C. Economic activities

Bahrain has experienced several changes vis-a-vis economic activities. Agriculture, fishery and pearl catching were the major economic activities in early days. With the discovery of oil in 1931 and the commercial exploitation of oil in 1934, the national economy of Bahrain started to depend mainly on this commodity. The refinery industry was then established, based on oil supply through pipelines from Saudi Arabia. The impact of oil on the economy of the country has, until recently, been considerable. Now the oil reserves are nearly exhausted, although still sufficient for local consumption, and natural gas is plentiful for power generation.

The anticipated decline in oil revenues in Bahrain triggered a guided shift in economic activities. Significant industrialization and improvement of business ventures were achieved. Major industrial operations include one of the biggest aluminium smelters in the world, shipyards, an iron-pellet plant, a petrochemical plant and other heavy industry activities. Bahrain has also become a strong centre for communications, financial transactions, trade and entertainment. The Western attitude of Bahrain has made the island an attraction point for weekend tourism. Every international bank has a branch here, as does almost every hotel chain. The centuries-old tradition of Bahrainis as far-ranging traders has been instrumental in fostering all these activities.

The relative importance of the different economic activities is made clear through calculating the share of those activities in the gross domestic product (GDP). The distribution of GDP by sector and the per cent share of sectors to GDP are presented in table 31. The contribution of agriculture and fishery was limited to only 1.6-1.8 per cent of GDP until the year 1986. The share of agriculture and fishery increased, to reach 2.0 per cent in 1991, and is expected to rise to approach 2.3 per cent of GDP in the year 2001. During the same period (1975-1991), the share of oil in the national economy decreased from 25.5 per cent in 1975 to 11.1 per cent in 1991 and is expected to remain so until 2001. Transport and communications have witnessed a large increase, from 6.2 per cent in 1975 to 14.0 per cent in 1991.

Agriculture and fishery were among the economic activities showing positive actual growth during the period 1981-1982 (table 32). The highest growth percentage (22.4) per cent was recorded in 1981.

D. Agricultural production

The agricultural land in Bahrain amounted to 4,047.9 hectares in 1989, out of which 3,006.5 ha were actually cultivated. This limited land area is mainly used for growing date palms, alfalfa and vegetables. Some animal production activities based on local agricultural products, i.e., milk production, or based on imported feed, i.e., poultry and table-eggs production, are also carried out.

1. Date cultivation

Dates occupy a unique position within the culture of Bahrain. Their historical, religious, aesthetic and social importance are comparable to their economic value to the community as a whole. The decline in date cultivation and the recent rapid dying of many plants on the island is of concern to the whole population.

Table 31. Gross domestic product (GDP) by sector or origin (millions of 1977 BD) and percentage share of each sector

	1975		1977		1981		1986		1991		1996		2001	
	Millions of BDs	Percentage	Millions of BDs	Percentage	Millions of BDs	Percentage	Millions of BDs	Percentage	Millions of BDs	Percentage	Millions of BDs	Percentage	Millions of BDs	Percentage
Agriculture and fishing	9.9	1.7	12.3	1.6	15.7	1.7	19.2	1.8	23.6	2.0	28.8	2.2	32.9	2.3
Mining and quarrying	144.9	25.5	194.0	25.0	155.2	16.8	136.5	13.1	130.4	11.1	149.0	11.4	160.6	11.4
Manufacturing	123.1	21.7	86.1	11.1	126.2	13.7	122.1	11.7	159.9	13.6	184.6	14.0	201.1	14.2
Electricity and water	1.2	0.2	3.2	0.4	7.5	0.8	14.2	1.4	15.9	1.4	21.6	1.6	27.7	2.0
Construction	41.1	7.2	81.4	10.5	110.7	12.0	145.7	14.0	139.0	11.8	121.0	9.2	102.4	7.3
Transportation and communications	35.1	6.2	65.1	8.4	88.0	9.5	137.9	13.2	165.2	14.0	194.0	14.6	214.1	15.2
Trade, hotel and restaurants	76.3	13.4	122.0	15.7	113.0	12.3	127.8	12.3	164.6	14.0	191.0	14.5	214.1	15.2
Services	33.2	5.8	23.1	3.0	33.7	3.7	41.7	4.0	44.2	3.2	-	-	-	-
Banking and insurance	12.7	2.2	60.9	7.8	93.2	10.1	103.6	9.9	94.1	8.0	95.0	7.2	95.0	6.7
Real estate	43.9	7.7	48.3	6.2	77.4	8.4	65.9	6.3	80.2	6.8	97.6	7.4	118.7	8.4
Government	46.8	8.2	80.8	10.4	101.0	11.0	127.2	12.2	159.1	13.5	232.6	17.7	244.9	17.4
GDP	568.2	100.0	777.2	100.0	921.8	100.0	1 041.8	100.0	1 176.2	100.0	1 315.2	100.0	1 411.5	100.0

Source: Based on information from National Land Use Plan 2001, vol.III, Ministry of Housing (State of Bahrain, 1988).

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Table 32. Actual economic growth by type of economic activity (1981-1987)
(Percentage)

Type of economic activity	Year						
	1981	1982	1983	1984	1985	1986	1987
Agriculture and fishery	22.4	6.7	(5.0)	(3.8)	(2.0)	0.5	9.5
Mining and Quarrying	(21.8)	(10.2)	3.7	13.7	7.4	(8.9)	(10.3)
Quarrying	(6.2)	113.3	15.6	(10.8)	(9.1)	(10.0)	(11.1)
Manufacturing	32.6	(12.4)	(7.6)	7.2	(8.1)	46.3	(0.3)
Electricity and water	1.2	6.5	22.3	11.4	5.7	(9.7)	(2.1)
Building and construction	4.1	3.4	17.6	15.1	(19.7)	(13.8)	(4.2)
Transport and communications	8.4	17.8	8.3	13.3	(4.1)	(14.4)	0.8
Trade, hotels and restaurants							
Trade	(12.9)	39.8	(11.1)	(27.8)	(13.7)	(12.0)	3.8
Hotels	(1.7)	1.7	(12.4)	(14.2)	(9.9)	26.4	23.3
Restaurants	8.1	25.0	30.0	6.2	--	(5.8)	9.2
Services	7.3	0.7	6.7	10.1	9.2	(3.9)	13.3
Banking and Insurance							
Local banks	(8.6)	64.6	(1.0)	(3.0)	12.5	31.9	(4.4)
Offshore banking units	40.6	54.4	(11.8)	(7.9)	(4.1)	31.0	(24.9)
Insurance	30.8	30.2	(6.3)	(8.7)	(48.2)	(33.3)	(27.6)
Real estate	15.9	4.6	3.4	5.9	(10.6)	(1.0)	(8.9)
Public Administration	10.4	11.4	1.4	10.9	6.6	0.2	2.4
Input service change	(35.5)	(92.5)	(34.2)	9.4	(15.5)	3.3	19.4
GROSS DOMESTIC PRODUCT	0.5	4.8	(4.2)	6.5	(5.3)	3.3	(2.5)

Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

Note: Figures between brackets are negative values.

From over 3,000 hectares of productive, properly tended dates about 20 years ago, there remain only an estimated 983 ha of productive dates (1986/1987 agricultural census), with the remainder in various stages of degradation.

The decline of productive date palms in many areas of Bahrain is not caused directly by the increased salinity of the water used for their irrigation but by the progressive build-up of salt in the root zone due to ineffective leaching. With effective drainage and correct irrigation methods, many of the original date groves recently abandoned could be rehabilitated. If this is undertaken with water of high salinity, drip irrigation to the root zone which allows leaching downwards and away from the palms is essential. Table 33 shows the number of date palms by municipality.

Table 33. Number of date palms by municipality

Municipality	Number of date palms				
	Pollen palms	Bearing	All other palms	Total	Percentage
Muharraq	1 415	18 383	4 053	23 851	6.87
Manama	2 181	29 850	4 182	36 213	10.43
Jid Hafs	4 795	44 495	6 295	55 585	16.01
Northern	3 282	45 018	24 642	72 942	21.01
Central	1 103	20 831	18 928	40 862	11.77
Sitra	389	3 781	4 898	9 068	2.61
Western	2 842	67 517	38 329	108 688	31.30
Total	16 007	229 875	101 327	347 209	100.00
Percentage	4.61	66.21	29.18	100.00	100.00

Source: Agricultural Directorate, Results of the 1980 Agricultural Census, (February 1980).

Note: Date palms in abandoned areas number about 446,500 of which 336,741 are bearing palms and 109,759 are not bearing.

2. Alfalfa

The 1987/1988 census indicated that about 37 per cent of all horticulture (defined as all crops other than dates and fruit trees) is devoted to the cultivation of alfalfa, used primarily as green fodder. Though some farmers devote most of their land to alfalfa, it is common to find it grown as part of a crop mixture. Unlike vegetables, alfalfa provides a year-round income. Many farmers use the fodder directly to feed their own cattle, sheep and goats. However, there is an active market for fodder to feed horses, cattle and imported livestock awaiting slaughter. Alfalfa is the major and an important crop both as a cash crop and for the feeding of animals by the farmers themselves.

The average green yields of 311.9 hectares cultivated alfalfa in 1989 were estimated at 75 tons green weight per ha (table 39). Due to its ability to tolerate a high degree of water salinity (even up to 6,000 ppm), alfalfa represents a valuable crop for Bahrain.

Table 34. Alfalfa area and estimated production

Year	1984	1985	1986	1987	1988	1989
Description						
Area (ha)	303.9	306.9	311.0	311.8	312.1	311.9
Production (t/ha)	71.6	72.5	74.4	74.7	74.8	74.8

Source: Annual Statistical Report, Ministry of Commerce and Agriculture (MOCA), State of Bahrain.

Alfalfa is the most water-demanding crop cultivated in Bahrain and the present small basin flood irrigation system commonly practiced leads to extensive water wastage.

It has been estimated that the present water-consumption rate of 66,000 m^3/ha/yr is approximately double the water actually needed to cultivate this crop. Some other reports indicate that the common irrigation regime of alfalfa is every second or third day.1/ during the period October-March and every day during the period April-September. The average amount of water applied by flood irrigation each time is in the order of 70 mm (700 m^3/hectare), totalling 179,340 m^3/ha. Diekmann (1981) reported more realistic figures for irrigation of alfalfa based on lower frequency of irrigation, i.e., every three to seven days during winter and every two to four days during the summer season, totalling about 66.000 m^3 water/ha. However, when considering the water losses in irrigation canals (40 per cent according to Dastane and Ayub2/ and the wasted areas for boundaries around the basins (20 per cent), the amount of water to grow alfalfa becomes very high, being about 111,000 m^3/ha/year.

1/ S.R. Nagmoush, "Soil reclamation and improvement report", regional project for land and water use in the Near East and North Africa, Food and Agriculture Organization of the United Nations (FAO) document No. TF/REM/508 (MUL) NECP Terminal (Doha, Qatar, 1981).

2/ N.G. Dastane and M. Ayub, "Water management for crop production in the State of Bahrain: review and suggestions", regional project on land and water use in the Near East, Food and Agriculture Organization of the United Nations (FAO) document, Bahraini Ministry of Commerce and Agriculture (MOCA) (State of Bahrain, 1979).

The productivity of alfalfa (table 34) remained during the last years within the range of 74.8 ton/ha of green material. Average dry-matter content in alfalfa in Bahrain was found to be 22.83 per cent (18.26-30.89 per cent).3/ The actual water amounts needed for production of alfalfa dry biomass range between 3,865 and 6,500 m^3/ton. These figures are very high when compared with the productivity of alfalfa in some neighbouring countries.

3. Vegetables

Field measurements were undertaken by the Ministry of Commerce and Agriculture (Agriculture Affairs), to determine the area cultivated with vegetables during the agricultural years 1987/88 and 1988/89. The study showed that the total area under vegetable cultivation slightly increased during the last three years (table 35). The major changes, however, were in the reduction of traditionally cultivated areas in the years 1987/88 and 1988/89, reaching 98.2 per cent and 88.2 per cent respectively of the original area reached for 1986/87. The area under protected agriculture, on the contrary, increased by 19.4 per cent and 118.5 per cent, respectively, in the same years. The areas under drip irrigation showed a slight increase of 2.5 per cent in 1987/88 over the year 1986/87 and higher increase of 21.1 per cent in the year 1988/89.

Over 35 different vegetables are grown, but there is a strong seasonality of supply, with 86 per cent of production during winter and early spring. Gluts of local produce, particularly tomatoes, the main crop, are common during spring.

Table 35. Indices for 1986/1987, 1987/1988 and 1988/1989 growing seasons

Type of comparison	Results			Index (Base = 100)		
	1986/87	1987/88	1988/89	1986/87	1987/88	1988/89
1. Area under vegetables (ha)	834.7	835.4	851.3	100	100.08	102.0
(a) Traditional agriculture	520.6	511.4	459.2	100	98.23	88.2
(b) Protected agriculture	11.9	14.2	26.0	100	119.44	218.5
(c) Drip irrigation	302.2	309.7	366.1	100	102.48	121.1
2. The estimated production of all vegetables (tons)	10 406	10 410	10 138	100	100.04	97.4

Source: Annual Statistical Report, 1988 and 1989, Ministry of Commerce and Agriculture (MOCA) (State of Bahrain).

3/ J. Diekmann, "Untersuchungen zum Futterbau in der bahrainischen Landwirtschaft", Ph.D. thesis, College of Agriculture, University of Bonn (Germany, January, 1981).

Present water consumption on vegetable cultivation is estimated at about 20 mcm/yr, which represents an average rate of 44,000 m^3/ha/crop, which is well over twice the amount of water needed for this cultivation. Table 36 illustrates the index values of the total area under vegetable cultivation during the period from the agricultural years 1974/1975 to 1987/1989.

Table 36. Total area under vegetable cultivation during the period 1974/1975 to 1987/1988

Agricultural year	Area (ha)	Index
1974/1975	374.67	100.00
1977/1978	428.93	114.48
1980/1981	575.39	153.57
1983/1984	555.66	148.31
1986/1987	834.72	222.79
1987/1988	835.36	222.96
1988/1989	851.27	227.21

Source: Annual Statistical Report, 1988 and 1989, Ministry of Commerce and Agriculture (MOCA) (State of Bahrain).

Average tomato production in Bahrain in the last two census years 1987/1988 and 1988/1989 was 18.9 and 20.7 ton/ha, respectively. The cost of water to produce tomatoes therefore slightly increased during the last three years. The major changes, however, were in the reduction of traditionally cultivated areas in the years 1987/1988 and 1988/1989, reaching 98.2 per cent and 88.2 per cent respectively, of the original area recorded for 1986/1987. The area of protected agriculture, on the contrary, increased by 19.4 per cent and 118.5 per cent in the same years, respectively. The areas under drip irrigation showed a slight increase of 2.5 per cent in 1987/1988 over the year 1986/1987 and a higher increase of 21.1 per cent in the year 1988/1989.

4. Dairy production

Milk and its by-products are considered essential elements of meals in Bahrain. It is estimated that total consumption of milk and dairy products amount to 30,000 tons per annum, of which only 5,000 tons are locally produced (16.7 per cent). Freshly produced milk represents 25 per cent of total demand for liquid milk. The average per capita consumption of milk is 75 kg per annum, which is considered low when compared to the international average of 120 kg. This figure is even higher in the developed countries -- 300 kg per capita per annum.

Bahrain's livestock statistics show that there are almost 8,500 cattle, of which 3,000 are lactating cows. Dairy cows in Bahrain produce 1,000 kg of milk/cow/year on average. This amount is too little even though cattle have adjusted to local production. A total of 1,500 imported cattle of good breed produce between 2,500-3,500 kg of milk per annum each.

There are five factories for dairy products, of which three are for fresh milk production and the other two for dried (skimmed) milk production. Operating at full capacity, these factories are able to cover most of local demand. The quantity of milk produced was estimated at 19,650 tons. All these products were locally consumed.

5. Poultry production

Local poultry production has developed in the past 10 years, and the yield of meat and eggs has increased. It now occupies first place in investment in the agricultural field. The production of poultry meat has increased five-fold since 1975. Egg production has increased four-fold since 1975. Tables 37 and 38 show poultry meat and eggs locally produced and imported from 1975-1989. Local production of poultry meat is limited to about 25 per cent self-sufficient, while egg production in some years reached 93 per cent self-sufficiency.

6. Livestock production

Livestock plays a vital and integrated role in crop and vegetable production in Bahrain. In addition to its being an essential food supply to humans, it contributes to maintaining and reclaiming agricultural land by supplying organic manure.

The livestock sector in Bahrain consists of cattle, sheep and goats. According to statistics, there are 8,500 head of cattle; local and imported sheep amount to 6,500; goats 14,500; camels 1,000; and poultry are estimated to be 448,000. Most animals (livestock) are kept in or near houses and only a few are kept on farms.

Table 37. Poultry production, 1975-1989

Year	Poultry, ton/year			Self-sufficiency
	Locally produced	Imported	Total	Percentage
1975	731	1 994	2 725	26.8
1976	1 176	4 385	5 561	21.2
1983	1 449	7 437	8 886	16.3
1984	1 856	8 247	10 103	18.4
1985	2 910	10 313	13 223	22.0
1986	2 644	11 567	14 211	18.6
1987	3 250	9 992	13 342	24.6
1988	3 445	9 998	13 443	25.6
1989	3 419	..	..	..

Sources: For years 1975-1976: Ministry of Finance and National Economy (1976) Strategic Options Committee Report, Volume III; for years 1983-1988 Statistical Abstract (1989), Central Statistics Organisation, State of Bahrain; for the year 1989: Annual Statistical Report (1989) Ministry of Commerce and Agriculture (MOCA) (State of Bahrain).

Note: Two dots (..) indicate that data are not available.

The Government is responsible for importing and providing the livestock for the population. The private sector's role is negligible. The main imports come from Australia (sheep) and Africa (cattle).

A yearly plan is set to import approximately 300,000 sheep and 10,000 cattle in conjunction with other GCC countries. The import meets up to 90 per cent of the red-meat demand in Bahrain.

Locally produced red meat (table 39) constitutes not more than 8 per cent of the total demand and mostly comes from sheep and goats and a small amount of cattle.

The restraints in meat production in Bahrain can be summarized as follows:

(a) Shortages in fodders, especially green fodders;
(b) The decline in local livestock production;
(c) Limited agricultural land and irrigation water;
(d) Harsh climate;
(e) Insufficient experience of livestock breeders.

The agricultural improvement plan incorporates many programmes and projects that aim to increase red-meat production. This will be achieved through the improvement of local livestock production and increasing livestock size through the expansion of green-fodder production by using treated sewage effluent (TSE). In 1991, it is expected that local red-meat production will reach 1,000 tons or 12 per cent of local demand and in the year 2000 will reach 1,500 tons or 16 per cent of demand.

Table 38. Egg production 1975-1989

Year	Eggs, million/year			Self sufficiency
	Locally produced	Imported	Total	Percentage
1975	17.8	35.6	53.4	33.3
1976	20.0	39.4	59.4	33.7
1984	67.0	17.1	84.1	79.6
1985	70.2	12.0	82.2	85.4
1986	90.4	6.9	97.3	92.9
1987	78.7	19.0	97.7	80.5
1988	58.5	39.3	97.8	59.8
1989	55.5	..	..	..

Sources: For years 1975-1976: Ministry of Finance and National Economy, Strategic Options Committee Report, vol. II; for years 1984-1988: Statistical Abstract (1988), Central Statistics Organisation (CSO), State of Bahrain (1989); for the year 1989: Annual Statistical Report (1989), Ministry of Commerce and Agriculture (MOCA) (State of Bahrain).

Note: Two dots (..) indicate that data are not available.

Table 39. Local meat production, 1980-1984

Year	Local production (tons)
1980	640
1981	682
1982	690
1983	710
1984	750

7. Fish production

Bahrain has been known since ancient times for its fishery and pearl harvesting activities. Fish and fish products are among the very few commodities in which Bahrain has reasonable self-sufficiency. Table 40 indicates that the percentage of self sufficiency in fish and fish products remained stable at around 70 per cent throughout the last decade, in spite of the large increase of the population of Bahrain from 359,500 in 1981 to 473,300 in 1988 (a nearly 32 per cent increase in seven years).

Table 40. Fish locally caught and imported, 1981-1988
(Tons)

Year	Local	Imported	Total	Self-sufficiency Percentage
1981	5 747	1 786	7 533	76.3
1982	5 594	1 932	7 526	74.3
1983	4 812	3 154	7 966	60.4
1984	5 599	3 021	8 620	65.0
1985	7 773	2 929	10 692	72.6
1986	8 057	2 932	10 989	73.3
1987	7 842	3 568	11 410	68.7
1988	6 737	3 079	9 816	68.6

Source: Statistical Abstract 1989, Central Statistics Organisation (CSO) (State of Bahrain).

III. THE STATUS OF DESERTIFICATION IN BAHRAIN

Desertification is the man-made degradation of land so that it loses its capacity to provide economic returns from cultivation or grazing. In other terms, desertification leads to an increase of the deserted area and a decrease in fertile, productive land.

The process has recently been recognized internationally as a world-wide problem, with the holding of the United Nations Conference on Desertification, in Nairobi, Kenya in 1977. Accordingly, desertification commonly appears as the deterioration of land, water and other natural resources under ecological stress. Deterioration implies that activities in an area have been unsuitable, either in degree or in kind. Such activities may have been pursued because of lack of environmental knowledge or experience, because alternatives were lacking, or in an attempt to maximize short-term gain at the expense of long-term productivity. Education, social and economic advancement and the adjustment of population growth to the development of resources are the key elements responsible for initiation of desertification or successfully combating it.

While water, soil and other material and biological resources are often the limiting physical factors, social, political and other human systems for making decisions and implementing plans, and the inadequate availability of financial resources, may constitute the major constraints to development, prevention of desertification and rehabilitation of desertified lands.

In Bahrain, desertification can be attributed mainly to several factors:

(a) Adjustment of population growth to the development of resources;
(b) Social and economic advancement;
(c) Water and soil quality.

Until recent decades, Bahrain was known as the "green spot of the Gulf". The remains of palm trees and signs of irrigation systems in the northern and north-eastern areas of Bahrain prove that this was a green area in the midst of desert.

The last four decades in Bahrain have witnessed a large increase in population and hence a sharp decrease of the per caput cultivated areas, from 0.026 ha in 1953 to only 0.006 ha in 1989 (table 9). This has escalated the problem of self-sufficiency in food products. Increased prices of agricultural products, which occurred due to scarcity, called on the farmers to increase consumption of irrigation water in order to improve land productivity. With both the rapid increase in population and prosperity, farming expanded and borehole pumping increased.

Prior to 1925, the Bahrain population depended entirely on the numerous land and offshore naturally flowing fresh-water springs fed by the Dammam aquifer. The estimated natural flow from these springs was about 93 million cubic metres per year (mm^3/y). The aquifer's pre-1925 condition was conceptualized by many studies to constitute a steady-state condition, and the estimated level of discharge from the aquifer to be close to the safe yield for the Dammam aquifer.

The transient conditions of the aquifer started when mechanized well-drilling and pumping of the groundwater was introduced in the early 1930s, along with the discovery of oil at Bahrain. Since then, due to the rapid growth of the population of the islands (about 3 per cent annually), agricultural and domestic demands increased tremendously, and were met mainly by well development in the Dammam aquifer; aquifer withdrawal increased substantially, from about 63 mm^3/y in 1952 to about 180 mm^3/y in 1989 (figure XVI). Due to this the aquifer has been experiencing a sharp and continuous decline in its potentiometric levels, indicating that the aquifer's total discharged volume at Bahrain Islands is exceeding its recharge from mainland Saudi Arabia and that water is being taken from the aquifer storage. As a result of this decline in the aquifer's potentiometric surface, a significant reduction in spring flow has occurred. At present, most springs have ceased to flow, and, more dangerously, aquifer water is being contaminated by: (a) sea-water encroachment; and (b) the upward invasion from the underlying saline water zones (figure X). These processes have already reached alarming levels at Bahrain Islands, where more than half of the original aquifer fresh-water volume has been polluted. The water supply for irrigating agricultural lands has become increasingly more saline. To combat this salinity, farmers have resorted to using more and more water, thus exacerbating the situation. Important areas have therefore been abandoned because of their salinization. The major water resources are in a precarious balance as a result of continuous and prolonged over-abstraction of the Dammam aquifer system, mainly in the northern and western coastal regions. The over-abstraction of groundwater is posing a crisis for agriculture in Bahrain, due to the loss in piezometric head of up to 5.5 metres,[1/] leading to saline intrusion from the sea and vertically from the underlying salty Umm Er-Radhuma aquifer. This has already led to considerable loss of agricultural land in the central area. If the current rates of abstraction continue, most of the remaining agricultural areas will become unsuitable for vegetable production; a general decline in the productivity of many date groves will occur as well.

The loss of agricultural land was slow and gradual in the 1950s but was very radical and fast in the following decades, giving rise to a decrease in agricultural area from 5,063 ha in 1966 to 4,020 ha in 1988.

The causes of desertification by degradation of agricultural land in Bahrain are summarized below.

A. Physical causes

1. The non-availability of suitable water for irrigation caused a gradual degradation of agricultural land. In the early 1980s less than a quarter of the original farm land had access to irrigation water with salinity of less than 2000 ppm. Agriculture has gradually retreated to the northern and western coastal strip, leaving abandoned and partly abandoned fields in the southern and eastern zones.

2. Water consumption per hectare is among the practices leading to desertification consumption for agricultural purposes now exceeds that used in the past, when almost double the amount of land was being cultivated. The overuse of irrigation water and the absence of drainage systems are responsible

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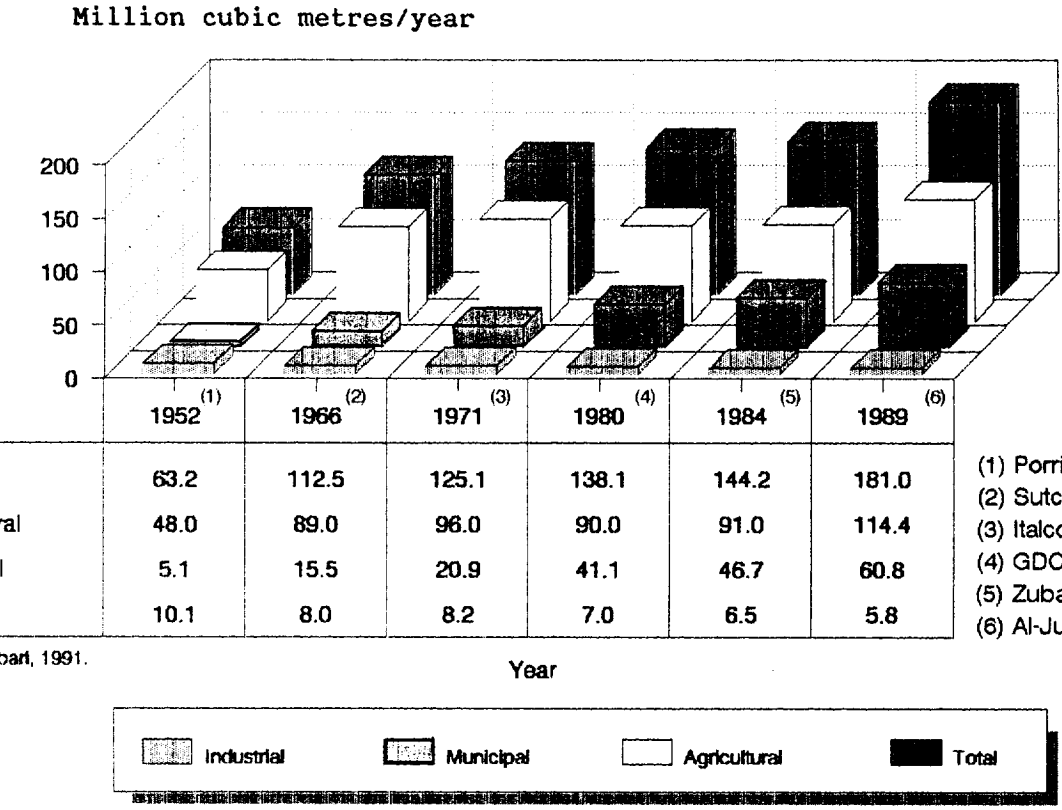
1/ Al-Junaid, op. cit.

Figure XVI. Groundwater extraction in Bahrain by sector during the period 1952-1989



	1952 (1)	1966 (2)	1971 (3)	1980 (4)	1984 (5)	1989 (6)
Total	63.2	112.5	125.1	138.1	144.2	181.0
Agricultural	48.0	89.0	96.0	90.0	91.0	114.4
Municipal	5.1	15.5	20.9	41.1	46.7	60.8
Industrial	10.1	8.0	8.2	7.0	6.5	5.8

(1) Porritt, 1952
(2) Sutcliff, 1966
(3) Italconsult, 1971
(4) GDC, 1980
(5) Zubari, 1987
(6) Al-Junaid, 1990

Source: Zubari, 1991.

Source: W. Zubari, "Numerical groundwater flow modeling: example application", Al-Muhandis (Journal of Bahrain Society of Engineers), No. 18 (1991).

for the accumulation of salts in the soil. Waterlogging is also present due to over-irrigation. Important areas have been abandoned because of salinization. Therefore, there is a serious problem due to the overuse of finite water resources, which puts all agriculture on the island of Bahrain in jeopardy.

3. Reclamation activities along the shoreline have adversely affected the quality of some good agricultural areas, thus bringing about an evolution in the ecosystem.

B. Socio-economic factors

1. Deliberate negligence by some owners of agricultural land has resulted in their abandonment and conversion to industrial and commercial sites.

2. Land speculation, is a problem especially in areas adjacent to main urban centres.

3. Land devoted to active agricultural production has been subjected to encroachment by other uses (i.e., encroachment on agricultural areas by urban sprawl has eaten up more than 740 ha from Manama's greenbelt, and about 2,000, ha of agricultural land has given way to residential, industrial and public uses since 1976).

The dangers of giving up good agricultural land to real estate are apparent. The anticipated significant and rapid profits have led to an increase in prices, which has made it too expensive to keep agricultural land for all time. This has resulted in the destruction of agricultural land and palm trees.

4. Fragmentation of agricultural holdings, the use of basin irrigation and the sporadic, unorganized cultivation of date palms has hindered the mechanization of agriculture.

5. Agricultural activities (farming) are carried out mainly through tenants, who face many problems, e.g.:

(a) Dealing with several landlords for small areas;

(b) Absence of fair rent and security that could encourage tenants to improve their production (written contracts are not common);

(c) Most agricultural labourers are foreigners (45 per cent), old (average age, 48 years) and illiterate.

6. The unwillingness of young Bahrainis to work in agriculture is due to its low prestige, hard working conditions, and long daily working hours with little reward. The availability of other, easier jobs with better conditions and a more promising future does not encourage careers in agriculture.

The natural consequence has been the deterioration of agricultural land and the decline in its share in the country's economy. The predominant feeling is that the continuation of this situation will lead to the complete atrophy of agriculture and that the destruction of the remaining green areas as a valuable resource and the gradual transfer to semi-desert will take place by the turn of the century unless certain measures have been considered and implemented.

IV. REVIEW OF EFFORTS TO COMBAT DESERTIFICATION IN BAHRAIN

Recognizing the desertification problems in Bahrain, the Government has started several projects and carried out several activities to help in reducing water consumption and reclaiming agricultural lands. The actions taken by government institutions have so far concentrated on water and land resources.

A. Efforts to conserve groundwater in Bahrain

Faced with the problem of increased withdrawal of groundwater in Bahrain and problems related to this (i.e., increased salinity of water), the water authorities in the State of Bahrain have made the following efforts to conserve groundwater, namely:

1. Issuance of several Amiri decrees to regulate drilling for water and water use, i.e. Water Law 2 of 1971 (Annex I) and Amiri Decree No. 12/1980 (Annex II).

2. Installing borehole flow meters. This was initiated at the end of 1982 and completed at the end of 1984, and included about 1,600 boreholes (the total number of boreholes is 2,000). The purpose of this metering programme is to have control over the abstraction rates.

3. The construction of desalination plants. Two desalination plants were constructed to substitute for some of the domestic abstraction volumes from the aquifer. The first plant, commissioned in 1976, uses a multi-stage flash (MSF) technology with an output of 36.8 mm^3/y and is fed by sea water. The second plant, commissioned in early 1984, utilizes the new technology of reverse osmosis (RO), with an output of 14 mm^3/y, and uses brackish groundwater from the lower Rus Umm Er-Radhuma aquifer. A third reverse osmosis (RO) plant with an output of 10 mm^3/y is due for commissioning in 1991, using sea water.

4. An Amiri decree (No. 12/1980) for preventing the production of water from the Dammam aquifers for two years. The decree went into effect in 1981, and was extended for another two years, from 1983-1985. The decree was not extended after that.

5. An Amiri decree (No. 7/1982) for the formation of the Higher Council of Water Resources.

6. The construction of a sewage treatment plant. Presently about 5.9 mm^3/y tertiary treated water is used for agriculture (about 15 per cent of total production).

7. The initiation of a major water-loss detection programme in 1985 by the Ministry of Works, Power and Water. This programme has reduced the water supply network loss from about 30 per cent to about 12 per cent (early 1991).

8. The formation of the permanent committee for water research with representatives from the Ministry of Commerce and Agriculture (MOCA), the Ministry of Works, Power, and Water, the Bahrain Centre for Research and Studies (BCRS), and the Arabian Gulf University (AGU).

9. Training and education:

(a) Presently, there are 10 Bahraini hydrogeologists (two with a Ph.D., one with a M.Sc. and seven with a B.Sc.);

(b) The Arabian Gulf University offers a M. Sc. degree in hydrogeology under the Postgraduate Programme for Desert and Arid Zones Sciences. In addition, the University is in the process of offering a specialized hydrogeological workshop entitled "Microcomputer use in groundwater hydrology", to be offered in the 1991/1992 academic year.

10. Research development:

(a) A comprehensive hydrogeological study on the groundwater resources of Bahrain, including a computer flow model;[1/] the numerical study covered the period from 1925 to 1979. The major recommendation of the 1979/80 study is that in order to preserve the aquifer from total contamination by saline waters, the total abstraction rate should be gradually reduced to 90 mm^3/y by the year 2000, and the increase in demand volumes should be met by constructing major desalination plants. As can be seen from the 1989 level of production, this 1980 recommendation could not be implemented due to financial problems;

(b) The initiation of a national research project, "Strategy for development and use of water in Bahrain". The study started in October 1990, and is sponsored by the Bahrain Centre for Research and Studies (BCRS), the Ministry of Works, Power and Water, and the Ministry of Commerce and Agriculture (MOCA), with technical assistance from the Arabian Gulf University (AGU). The project objective is to build a master plan for optimum water use in Bahrain;

(c) A proposed seminar on desertification, organized by the Arabian Gulf University (AGU) in cooperation with the Secretary-General of the Gulf Cooperation Council, the Islamic Development Bank and the United Nations Environment Programme (UNEP), to be held at AGU-Bahrain in February 1992;

(d) An artificial recharge study on the storage of fresh water in saline aquifers in Bahrain.[2/] The study tested the temporary storage of treated sewage water in the Umm Er-Radhuma aquifer and its feasibility, particularly in its upper parts, where salinity is relatively lower. The study included the best practices for such storage procedures;

1/ Groundwater Development Consultants (GDC), Groundwater resources, Bahrain assignment, vol. 3, Umm Er-Radhuma Study. Technical report prepared for the State of Bahrain, (1980).

2/ E. Lori, "Injection of treated sewage effluent into saline aquifers of Bahrain", Ph.D. thesis, University College, University of London (London, 1988).

(e) A numerical hydrological study for the Dammam aquifer system in Bahrain and eastern Saudi Arabia.[3/] The main conclusion of the numerical study is that the aquifer condition, in terms of quality and quantity, is reversible if production of water in Bahrain is reduced, and the aquifer usefulness can be prolonged if the abstraction rates from the aquifer are reduced or at least maintained at their 1984 levels of 144 mm^3/y. The study indicated that the Bahrain production is responsible for about 85 per cent of the lowering of the potentiometric heads at Bahrain, while Saudi Arabia is responsible for the rest;

(f) A study on saline Khobar Model.[4/] The study objective was to evaluate the Rus Umm Er-Radhuma (C) brackish aquifer as an alternative feed-water source to sea water for a proposed reverse-osmosis desalination programme for municipal water supply. Several models were constructed to provide detailed assessment of aquifers (C) and (B). The study recommended that the overall (B) aquifer production be reduced to 90 mm^3/y and that cuts be concentrated in the areas where the threat of salinity is most immediate. The models forecasts that if this recommendation is implemented, the saline interface will retreat to approximately its 1955 position by the year 2000. Furthermore, upward leakage in the central areas will decline markedly by the year 2000 due to reduced abstraction from the (B) aquifer and increased abstraction from the lower (C) aquifer;

(g) A study for evaluating the water resources in Bahrain from 1979 to 1989.[5/] The major conclusion of the study was that salinity had increased in all areas of Bahrain due to the increase in water abstraction in the past decade. The major recommendation emphasized the use of the non-traditional waters to alleviate the aquifer stresses;

(h) Mass media and awareness. Media campaigning was started in 1984 by the Water Supply Directorate and aimed at rationalizing water use at the steady-state level.

B. Efforts to improve land capabilities in Bahrain

The Ministry of Commerce and Agriculture (MOCA) in Bahrain is the only organization in charge of development of agriculture in the country. Bahrain University and the Bahrain Centre for Research and Studies contributed to the matter through organizing information about water resources. A survey of agricultural lands and productivity of actually cultivated lands, as well as research activities to improve agriculture production, was undertaken by the Agricultural Affairs Department of the Ministry of Commerce and Agriculture. Studies and projects aiming at improving irrigation methods, fertilization, cultivation methods and crop yields have been carried out in the last two

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3/ W. Zubari, "Numerical groundwater flow modeling: example application", Al-Muhandis (Journal of Bahrain Society of Engineers), No. 18, (1991).

4/ Groundwater Development Consultants (GDC), "Reverse Osmosis Desalination Project 25/18", technical report prepared for the Bahraini Ministry of Works, Power and Water (State of Bahrain, 1983).

5/ Al-Junaid, op. cit.

decades. Most of these activities were carried out by experts and local staff, with the collaboration of United Nations organizations, i.e., United Nations Development Programme (UNDP), Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP), as well as the Federal Republic of Germany (GTZ) and China. Major studies to improve land capabilities in Bahrain are listed below:

1970 Irrigation with Polythene. Dept. Agric. Bahrain (Ayub, M.).

1970 Vegetable variety, planting date and fertilizer trials. Rep. Dept. Agric. Bahrain (Badawi).

1971 Water and agricultural studies in Bahrain. Final Report, vol. I (Italian consultant, Rome).

1973 Survey of agricultural land in Bahrain. Dept. Agric. Bahrain (ERCON, England).

1973 Strengthening of the department of agriculture services in Bahrain, vol. II. Dept. Agric. Bahrain (ERCON, England).

1974 Irrigation and drainage in Bahrain. Mimeographed report. Dept. Agric. Bahrain (M. Ayub).

1974 Irrigation trials on winter vegetables. First Rep. UNDP/FAO/BAH/71/50/ (C. Peterson and M. Ayub).

1974 Trickle feed irrigation system. Dept. Agric. Bahrain (C. Peterson and M. Ayub).

1975 Improved irrigation practices in Bahrain. Dept. Agric. Bahrain (A. Al-Hasan, M. Ayub and M.A. Ashkar).

1975 Feasibility study on the reuse of sewage effluent for agricultural purposes. Report to the State of Bahrain (X. P. McGowan and Associates Pty. Ltd. Australia).

1976 Irrigation methods and practices in Bahrain. Final report. UNDP/FAO/BAH/74/005 (C. Peterson).

1976 Drainage in Bahrain. Final Report. UNDP/FAO/BAH/74/005 (W. Brinkhorst).

1976 Farm mechanization. Final report. UNDP/FAO/BAH/74/016.

1977 Results of research and demonstration programme of vegetable crops. UNDP/FAO/BAH/74/016 (S.A. Baha-Eldin and A.A. Mansour).

1978 Bahrain agricultural potential study. Report. 1 -- Survey and Sector Review. State of Bahrain (Hunting Technical Services).

1978 Mitteilungen zur Beurtielung der Boeden von 10 Luzernebaubetriebe in Bahrain. University of Bonn, Germany (unpublished).

1979 Water management for crop production in the State of Bahrain, review and suggestions. Rep. FAO to Dept. Agric. Bahrain (N.G. Dastane and M. Ayub).

1979 Progress of drainage work in Bahrain. General report. Dept. Agric. Bahrain (M. Ayub).

1979 Sprinkler irrigation trial on forage crops in Bahrain. GTZ (Germany). Rep. Dept. Agric. Bahrain (Diekmann).

1979 Groundwater abstraction and irrigation in Bahrain. Inst. Geological Sciences, London and Agric. Directorate, Min. Commerce and Agric. Bahrain (E.P. Wright and M. Ayub).

1981 Soil reclamation and improvement report. FAO regional project for land and water use in the Near East and North Africa. A study about Bahrain and Qatar (TF/REM/508 (MUL) NECP, terminal report (S.R. Nagmoush).

1981 Untersuchungen zum Futterbau in der bahrainischen Landwirtschaft. "Experiments on cultivation of fodder crops in Bahraini agriculture". Ph.D. thesis, University of Bonn, Germany (J. Diekmann).

1982 Revitalizing Bahraini farming with improved water management and higher crop density. FAO/TF/REM/Mul Field Document 22 (N.G. Dastane and M. Ayub).

1988 National land use plan 2001. Min. Housing. Physical Planning (Bahrain) and United Nations Commission for Human Settlements (UNCHS) (HABITAT), Nairobi.

1988/1989 Youth participation in environmental preservation. A UNDP and GOYS of Bahrain programme to encourage youth to plant drought-resistant trees in Bahrain as a measure to combat desertification.

1989 Reuse of treated wastewater and sludge for agriculture in Bahrain. Report FAO/AGLS to Min. Commerce and Agric. Bahrain (A. Arar).

1989 Treated effluent utilization, Phase II. ACE-Bahrain, Min. Commerce and Agric. and Min. Works, Power and Water.

V. NATIONAL PLAN OF ACTION TO COMBAT DESERTIFICATION

A. The magnitude of the desertification problem

The great demographic growth and the continuous expansion of economic construction since the early 1970s have led to an increase in the demand for water to serve the needs of urban, agricultural, and other developing sector. This has led to a widening of the gap between demand and available water resources. Indications of water deficiencies appeared on the horizon; total water consumption from the El-Dammam formation, which was 113 mm^3 in the year 1966,[1/] increased to almost 180 mm^3 in 1989.[2/] As for the Rus Umm Er-Radhuma formation, a 2 mm^3 consumption in 1966 became 32.5 mm^3 in 1989. The continuous increase in the rate of exploiting groundwater is liable to lead to a great fall in the water level of the Dammam formation. It is estimated that it has fallen by about 4-5 metres since the year 1924. Moreover, discharge rates from natural springs decelerated at an increasing rate during the past 50 years. This has led to the extinction of some of the springs, and to an overall diminishing of the proportion of irrigation waters acquired from springs. Discharge in the year 1924 was 0.57 mm^3. It was only 8.1 mm^3 in 1979.[3/] Salinity of spring waters also increased to a great extent. Pumping from groundwater also led to a deterioration in water quality due to upward leakage at the north central part of the Khobar layer and to sea-water encroachement at the eastern and southern parts. It is estimated that the saline interface between sea water and groundwater advances at the rate of 75-130 metres per year.[4/]

The trend in land-use patterns underwent immense changes in type, intensity and spatial occupation of use. Especially since 1970, agricultural areas have been encroached upon by other uses, particularly in the northern and central areas. The competition for land during the period of economic take-off has caused drastic changes in land use. Once highly productive agricultural land (particularly date-palm groves) gave way to other profitable usages, i.e., residential divisions, industries, public buildings, and the like.[5/] Furthermore, the increasing salinity of groundwater has also caused a decline in agricultural land-use, and farms which were formerly cultivatable have ceased to be so. Accordingly, agricultural land-use has steadily declined, from 6,460 ha in 1956 to 3,748 ha in 1982. In recent years, due to

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1/ J.W. Sutcliff, "Groundwater extraction of Bahrain Island and Coastal Hasa" (State of Bahrain, 1967).

2/ Bureau for Water Resources (BWR), "Assessment of water resources in Bahrain", Bahraini Ministry of Commerce and Agriculture (MOCA) (in Arabic) (State of Bahrain, 1990).

3/ Groundwater Development Consultants (GDC), Groundwater resources, Bahrain assignment, vol. III, Umm Er-Radhuma Study, technical report prepared for the State of Bahrain, (1980).

4/ Ibid.

5/ Bahrain, Ministry of Commerce and Agriculture (MOCA), Annual Statistical Report, 1989.

intensive efforts of the Ministry of Commerce and Agriculture (MOCA), the agricultural areas slightly increased, from 3,748 ha in 1982 to 4,020 ha in 1988. Nevertheless, the overall situation in Bahrain is characterized by the appearance and steady advance of desertification.

1. National Plans

Various plans adopted by the State of Bahrain have paid particular attention to topics that are directly or indirectly related to controlling and reversing desertification phenomena. They aim at combating the continuous deterioration in the agricultural sector and at improving Bahrain's agricultural map.

Plan of the agricultural sector for 1981-1986

The main aim of this plan was to preserve the most important natural resource required for agriculture, namely water. It aimed at conserving the current agricultural regions and at adding additional areas not used at that time for such activities. Agricultural productivity should also be enhanced (crop and animal production, including poultry). Thus, the plan aimed at: increasing the agricultural area by about 10-25 per cent according to the type of crop; conserving up to 30 per cent of water requirements for agriculture; and improving the productivity of agricultural labour by 15 per cent. The plan projected a 40-50 per cent increase in agricultural output.6/

This plan gave particular attention to a scheme for subsidies and economic aid, to improve the conditions of the farmers. Their living standard was to improve noticeably. This scheme included various items: machinery and tools to encourage their intensive use and to diminish the dependence on an unavailable work force, subsidies for specific crops to permit the Bahraini farmer to acquire experience in products considered to be important for Bahrain, e.g. potatoes, onions, etc.

Financial incentives were included for:

(a) The introduction of modern irrigation techniques that conserve water;

(b) Drainage schemes for stopping saline intrusion and enhancing productivity;

(c) Productivity schemes that encourage the use of modern methods, such as vertical methods of planting within controlled environments in plastic domes;

(d) The planting of date-palm trees, because of their particular historical connection to Bahrain's society, in addition to their economic, health, and aesthetic properties;

(e) The marketing and distribution of products;

6/ Bahrain, Ministry of Commerce and Agriculture (MOCA), National Plan for Development of the Agricultural Sector, 1981-1986, (1980).

(f) Making credit available at advantageous terms, especially to encourage small farmers to expand their agricultural activities.

It is apparent that the provisions in the plan for supporting agriculture were comprehensive.

The plan included 14 projects, of which 8 were for crop production, 3 for animal production, and 3 for poultry. The budget appropriated for these schemes was approximately 42 million Bahraini dinars, to cover all projects and programmes during the plan years; 40 per cent of this amount was for crop production, and the rest was divided almost equally between animal and poultry production.

This reflects the support and attention given by the Bahraini Government to the agricultural sector, which depends basically on projects and programmes that conserve water, enrich the soil, and improve productivity -- thus combating desertification or the encroachment of fallow, low-quality lands.

With the implementation of this plan, the active agricultural area increased from 2,637 ha in 1983 to 2,947 ha in 1987 (the 1987 Agricultural Census). However, the rates of water consumption for agricultural purposes also increased during the same period, estimated at 117.2 mm^3 in 1987. The water was pumped from the Neogene and the Dammam formation (Directorate of Water Resources, Ministry of Commerce and Agriculture), i.e., an increase of about 9 mm^3 per year.

National Land Use Plan 2001

In the year 1988, the Ministry of Housing (MOH), Physical Planning Directorate (PPD), adopted the National Land Use Plan 2001. This plan depicted the current status and predicted the needs and requirements up to the year 2001.7/,8/

The National Land Use Plan 2001 detected some deterioration of agricultural land. Many crops are now imported, in contrast to past practices. Local agriculture meets only 6 per cent of the country's demand for food.

The National Land Use Plan 2001 defined the following goals:

(a) Reserve and systematically develop all lands that have agricultural potential, classes 1-4, into 5;

(b) Utilize and/or reserve class 2 and 3 lands, develop others only under reasonable cost effectiveness;

7/ Bahrain, Ministry of Housing, Physical Planning Directorate and United Nations Commission for Human Settlements (UNCHS). National Land Use Plan 2001, (1989).

8/ Sutcliff, op. cit.

(c) Develop only those combinations of land that can compete in international markets;

(d) Restore and reserve existing agricultural lands along the northern and western coasts;

(e) Develop all lands that have agricultural potential (classes 2, 4 and 4D);

(f) Increase the area under cultivation from 3,500 ha to 5,500 ha;

(g) It is important from a social standpoint to invest in agriculture in Bahrain. Expansion of agricultural land, given the limited water resources available, can only be achieved by using improved irrigation techniques and agricultural methods.

Within the agricultural sector, which is assigned top priority in the plan, the current policy has embarked on an ambitious programme of expanding agricultural land and encouraging private farmers to modernize their farming and irrigation methods. Thus, the policy may be taken as an indication of an indirect attack against the spread of desertification.

Plan of the Ministry of Commerce and Agriculture, 1990

The current plan of the Ministry of Commerce and Agriculture (MOCA) aims, within the agricultural sector, at the following:

(a) Design and monitor the construction of new irrigation networks, with emphasis on modern techniques. Maintain and improve existing networks;

(b) Improve lands by using treated sewage effluent (TSE) at the Adhari, Hawrat Ali, Tubli and the central municipal regions;

(c) Construct new discharge network to connect the principal and secondary drainage canals, including all accessory engineering and hydrogeologic works;

(d) The Farmer Services Directorate will continue to give support and advice and to make available all materials required by farmers for production purposes. They will thus be helped and encouraged to adopt efficient methods; the Department extends veterinary protection, and pest control services and financial aid, encourages greenhouse agriculture, and disseminates agricultural information.

The overall implications of desertification for Bahrain, and for its agricultural resources potential in particular, are distressing. Crop yields are declining, the good topsoil is being continuously removed from agricultural lands by erosion, soils and groundwater in many localities are becoming salinized, and underground aquifers are being depleted. The projection of desertification trends into the future augurs the worst.

It can also be considered (or even expected) that the continuation of the current situation will lead to the complete atrophy of the agricultural sector,

the destruction of the remaining green areas as a food resource, and a gradual transfer to semi-desert by the turn of the century unless certain (rather drastic) measures are considered and implemented.9/

Desertification control as such, therefore, does not figure among these priorities. However, environmental issues or concerns permeate through all projects. By this is meant that the environmental dimension constitutes a parameter in formulating and evaluating the feasibility of development projects.

2. Constraints

Different activities carried out in Bahrain have considered the current situation in detail and have discovered the following factors affecting agricultural development:10/

Physical constraints

(a) Climate. A very short winter and high temperatures are limiting factors to good growth of some crops, as they restrict the crop season. Winter protection and summer shading are advantageous to improved farming. High humidity encourages many fungal diseases and particularly affects soft ripening dates;

(b) Water

(i) Groundwater quality is generally saline, causing a reduction in plant growth efficiency and yields;

(ii) Higher volumes of water are required for continuous leaching than in less saline conditions; therefore, good drainage conditions are a prerequisite for improved farming. Moreover, pollution problems may appear from using inadequately treated water in irrigation;

(c) Land and soil. Agriculture development is concentrated on the north and north-west coasts, as prescribed by soil, and water quality and availability. In the past, springs located at the contact of the limestone uplands (Dammam back slope) and the coastal fringe deposits were used for irrigation on the coastal lowland soils. These fairly large continuous areas of flat, easily filled, permeable soils are served by groundwater of moderate quality, and this zone has been intensively cultivated over long periods;

(d) Bacteriological and virological quality of treated sewage effluent. Although the infiltration plan meets the most stringent international standards, certain problems can be encountered with parasites, which should be overcome by careful operation of the plan and by increasing the ozone dosage

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9/ Bahrain, Ministry of Commerce and Agriculture (MOCA), Annual Statistical Report, (1988).

10/ Sutcliff, op. cit.

if deemed necessary.[11/] Also, because of the possibility of the presence of eggs of Helminthes (Nematodes and Ascaris), even after nine months of drying sewage sludge, the use of dried sludge as a soil conditioner should be restricted to locations not accessible to human contacts. Moreover, the total dissolved solids (TDS) concentration in the treated sewage effluent (TSE) varies at present between 2,600 and 3,000 ppm, sometimes reaching 4,000 ppm;

(e) Crop suitability. Many crops are not compatible with the physical environment because of climatic and/or water quality limitations.

Human constraints

Nearly all farming is labour intensive, approximately half of all farm labour being expended on applying water to the land. The majority of full-time farm labour is expatriate, (35 per cent of the total labour force), mainly of Pakistani and Indian origin. Farm labourers are poorly motivated and generally unskilled. Work output levels are very low.

Approximately half of the farmers do not own their farms and thus are disinclined to make investments of a permanent nature.

The market for locally grown agricultural products

Given the high cost of crop production in Bahrain and the consequent difficulty in achieving profitability, the only major crops that are grown are vegetables, fruits and alfalfa. A market exists for fruits but, for mainly technical reasons, commercial fruits can be expected to be confined mostly to the modern sector in the future. The prospects for expanding alfalfa output from the traditional sector are limited. Thus, vegetables are the most promising crops.

B. Policy of the plan of action

Action to combat desertification is urgently required, before the costs of rehabilitation rise beyond practical possibility, or before the opportunity to act is lost forever. Desertification is not a problem susceptible to quick solutions, but it is already urgent in Bahrain. It calls for continuous assessment and long-term planning and management at all levels. The management of natural resources is a critical component of the strategy for physical, social and economic development. The adoption of improved policies for the management of natural resources is essential to the ecosystem if its productivity is to be restored and developed.

1. Management of natural resources

The management of natural resources encompasses both water and land resources, with socio-economic aspects considered to be of primary importance. Water resources include both types of water: traditional sources (groundwater), and non-traditional (desalinated, treated sewage effluent (TSE),

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11/ Bahrain, Ministry of Works, Power and Water, "Report on the status of waters in Bahrain" (in Arabic), (1988).

and water drained from irrigated lands). It can be clearly formulated that the national strategy on desertification control puts special emphasis on protecting the groundwater from both over-exploitation and from deterioration in quality. Thus, proper groundwater management is of primary concern, whereby traditional as well as non-traditional water resources are carefully considered and developed.

In harmony with the fact that the agricultural sector is the major consumer of the various water resources, the strategy includes provisions for conserving and restoring agricultural lands. Land management is an essential element in the policy of the Plan of Action. Moreover, socio-economic aspects include the impact of the process of desertification on man -- his welfare and his institutions. The prevailing social behaviour and economic system are considered to be the primary causes of desertification. These aspects cover numerous interrelated items: population, human and environmental health, food, human settlements, education, socio-cultural patterns, man as a land user, production and productivity, marketing, inflation, etc.

2. Objectives of the Ministry of Commerce and Agriculture

The objectives of the Ministry of Commerce and Agriculture (MOCA) have to be carefully considered. These objectives strive towards rational exploitation and use of water resources, protecting groundwater from both depletion and quality deterioration, expanding agricultural land, encouraging private farmers to modernize their farming and irrigation methods through the provision of equipment, improved seeds, loans, technical guidance to increase land production with reasonable water consumption, and subsidized farm equipment and services.

The increased demand for water has led to intensive exploitation of groundwater resources. As mentioned above, present groundwater abstraction is estimated at around 150 mm^3 per year, while the safe yield is estimated at around 90 mm^3 per year. This intensive abstraction has produced adverse effects, such as groundwater depletion, deterioration in groundwater quality, and the drying up of natural springs as a result of decreased piezometric head.

However, development of an aquifer depends on its potentialities, especially its inherent limitations. Local shortages of water may develop because of failure to plan for rational development and to implement strict management in accordance with the safe yield of an aquifer.

The maintenance of groundwater quality at acceptable levels is one of the major requirements for the successful management of an aquifer. It is recommended to apply mathematical modeling techniques for groundwater management. Different mathematical models have been developed for Bahrain, but their models covered one area or one aquifer for the steady or the unsteady state.

3. Mathematical model to cover developed area in Bahrain

It is proposed to apply a mathematical model that covers the total developed area in Bahrain where the following items have to be studied:

(a) Simulation of the main aquifers, Neogene, Dammam, and Umm Er-Radhuma formations, and the hydraulic connection in between;

(b) Simulation of the salt-water intrusion, whether from the sea or from the deep-seated formations (Umm Er-Radhuma formation);

(c) Formulation of the partial differential equation for the unsteady state, including the effect of water quality.

Generally, introducing the stratified flow equation with dispersion complicates the solution of the parabolic partial differential equations, but different alogorithms, such as the alternating direction algorithm (ADI), can be applied. The model has to be calibrated with periodical data, which are available at the Directorate of Water Resources, Ministry of Commerce and Agriculture (MOCA). The calibration of the hydraulic parameters of the aquifer (transmissivity, storage coefficient, leakage factor, etc.) has to be carried out for each cell or polygon. This can be done by matching the values of the water levels computed by the model to those values measured in the field. The groundwater development plan will be determined by running the model after calibration, according to the prevailing hydrogeological boundary conditions.

The main components of the development plans usually include recommendations to determine upper limits to the rate and duration of pumping from each cell (polygon). The total amount of water to be abstracted from each aquifer is kept within the safe yield of the aquifer and without the deterioration of water quality. Thus, traditional water resources are reliably assessed, a required prerequisite for proper management. As for non-traditional water resources -- desalinated waters, treated sewage effluent (TSE), drained irrigation waters -- they can be (relatively) easily and more accurately assessed, thanks to the extensive measurements recorded by the competent authorities in Bahrain.

The problem of assessing water requirements is critical for Bahrain. Evaluating water needs depends mainly on the actual consumption and their projection for future developments. The current water consumption for agricultural, municipal, industrial, and landscaping uses can be assessed relatively easily, since there already exists periodical records for actual consumption. Such assessments are essential to forecasting water demands on the basis of needs which can effectively be met. Several factors are involved, such as the rate of population increase, economic factors, social conditions and technological operations. The National Land Use Plan 2001 can be considered as the basis for preparing a time plan for the different water needs.

Upon having detailed data (both quantitative and qualitative) on available water resources and also on water demands, the complex problem of planning for and monitoring water distribution and consumption may then be tackled.

Locations where traditional or non-traditional waters are available do not necessarily correspond to or agree with locations where waters are required for consumption. Both qualitative and quantitative discrepancies occur. The problems are further complicated and obscured by having, in the

case of groundwater, several possibilities for alternative development schemes which are all compatible with the safe-yield requirements of the groundwater reservoirs, as determined from computations of the mathematical model. moreover, there are also several alternatives for crops and irrigation methods for each soil unit, function of texture, salinity, water level, probability of contamination, etc. The proper (feasible) solution has to also consider socio-economic aspects. Within the context of Bahrain, all previously considered elements are interrelated. They confront the State of Bahrain with a real conundrum -- one that could lead to seriously harmful repercussions.

4. Systems analysis designs proposed for defining the Plan of Action for Desertification Control

Systems analysis designs are proposed for defining the Plan of Action for Desertification Control (figure XVII). Concepts from the domain of systems analysis are called for in order to arrive at optimal solutions. First of all, all the various constraints should be defined. Then the objective functions are formulated and suitable slack variables are chosen. The resulting system of equations will include physical factors as well as socio-economic aspects. The constraints should take into account economic concerns and should state policies and preferences for desertification control.12/

Relations between the plan-elements and the imposed constraints may be symbolically stated as:13/

$$\sum c(i) * Q(i) = \text{Min/Max}$$

$$\text{Subject to } 1(i) \leq c(i) \leq u(i)$$

$$i = 1,2, \ldots, n$$

Where:

Q(i) are the plan variables or possible alternatives (sources of water, quality, crop output, irrigation method, etc.,).

c(i) are the plan constraints (costs, benefits, desirability, etc.,).

1(i) and u(i) are lower and upper limits, respectively, for c(i).

Some of the constraints may include contradictory nuances; e.g., as a result of studying the mathematical model, it may be found that water levels at a given location should not exceed a certain level (drainage constraints), while water levels at another location should not fall below another certain level (region of intensive pumping, with constraints due to possible upward

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12/ Bahrain, Water Supply Directorate, "Future demand and resources development, 1981-2001", technical report, (1981).

13/ Bahrain, Ministry of Housing, Physical Planning Directorate and United Nations Commission for Human Settlements (UNCHS). National Land Use Plan 2001, (1989).

leakage from saline Umm Er-Radhuma water formations). A similar situation may appear for pumping rates. The conditions may be stated as follows:

For groundwater levels:

$$(\min h(j) \leq h(j) \leq (\max h(j) \; ; \quad j = 1, 2, \ldots, n$$

For pumping rates:

$$(\min Q(j) \leq Q(j) \leq (\max Q(j) \; ; \quad j = 1, 2, \ldots, n$$

All the various constraints, even those imposed due to physical or socio-economic requirements, may be similarly formulated.

Analytical optimization models, techniques, and algorithms include the use of some rather advanced mathematical topics: calculus, Lagrangian multipliers, theory of convex variables, linear programming, generalized matrix inversion, and control theory. These disciplines are both descriptive and prescriptive, in that they usually incorporate quantitative relationships in order to describe interactions among variables of the system, and they display an analytical structure that promotes the convergence towards an optimal solution.

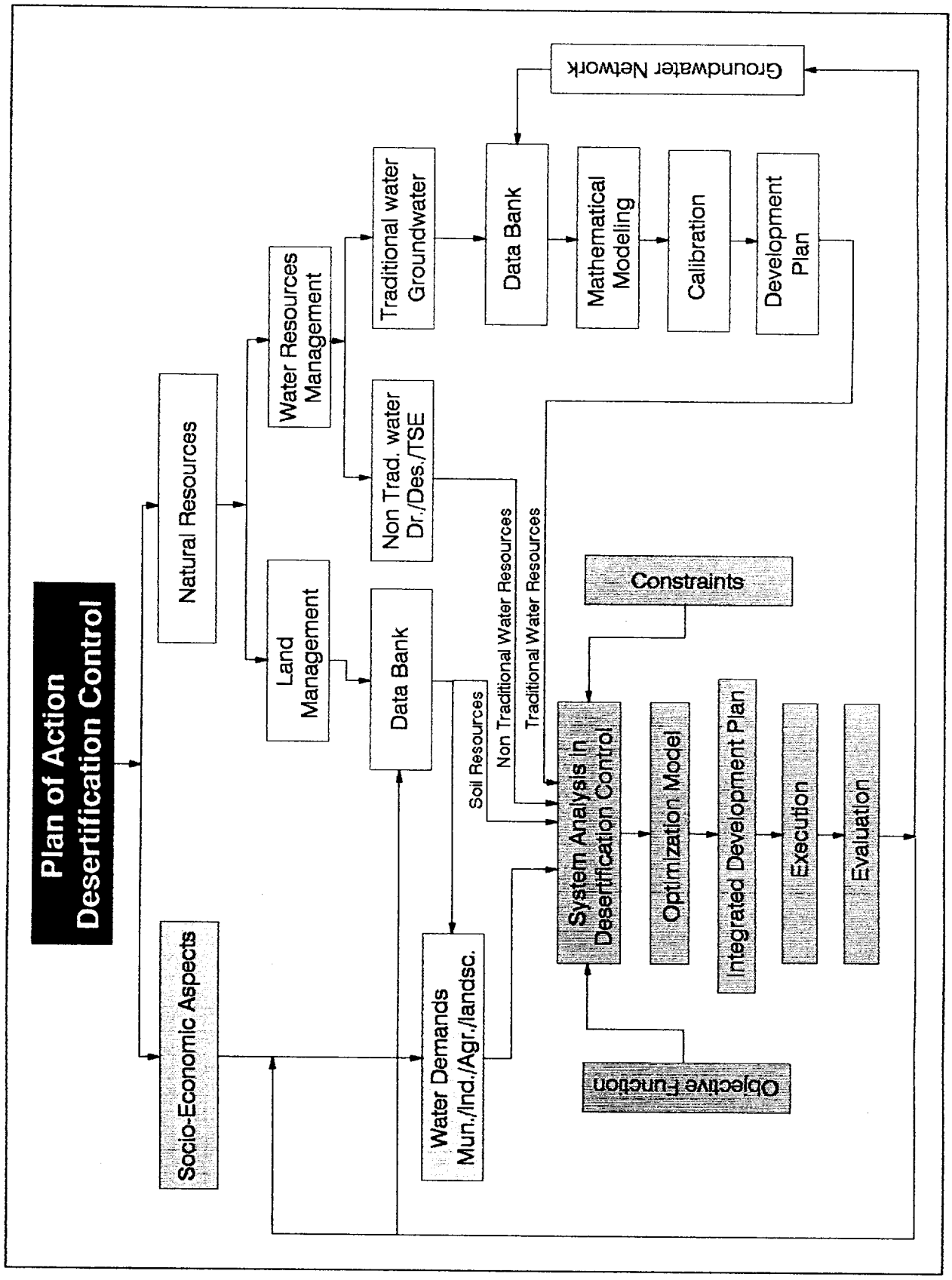
It is thus possible to gradually construct an integrated development plan for desertification control, one that simultaneously covers most pending requirements, does not have detrimental effects on either natural resources or the environment, and is economically advantageous.

The plan includes, for the development regions, detailed integrated programmes that cover all components. These programmes specify water source, exploitation regimen, pumping quantities, crop patterns and types, irrigation and drainage methods; municipal, landscaping, and industrial requirements are also covered. Furthermore, the appropriate technology to be applied is an important factor in promoting the efficiency of the plan of action. Suggestions for specific technological methods are related to the human element -- the degree to which experts and workers are prepared to assimilate and accept new technologies.

The possibility of development and coordination between traditional and new methods should, therefore, be carefully investigated. The proposed (possibly hybrid) technologies should, first of all, be tested; these would include schemes for land reclamation, water duty for different crops, irrigation with treated sewage effluent (TSE), artificial groundwater recharge with TSE, etc.

Moreover, an estimate of available personnel at the various levels of experience should be given, as well as the recommendations for the proposed method for securing the required personnel and practical suggestions for training and upgrading the available labour force. It should also be kept in mind that water and land legislation are considered to be the principle methods for ensuring the actual implementation of and strict adherence to the plan. Finally, a financial budgetary estimate should be given. It is very important that the plan clearly and convincingly state the expected results of applying its recommendations, as well as the projected effects on the desertification phenomena in Bahrain.

Figure XVII. Schematic design for systems analysis proposed for the Plan of Action for Desertification Control in Bahrain



It is strongly recommended that, after adopting the plan, a yearly review of the situation be undertaken. The actual results, which will be monitored during the year, should be compared with the plan's projected estimates. Coincidence cannot be exact since the plan deals with random variables with unknown distribution parameters or even functions. Therefore, a monitoring network should be developed. A data bank should be continuously updated with all newly collected data. After a suitable lapse of time (e.g., once a year), the model should be recalibrated. The newly calculated values are then re-input to the optimization model. All objective function equations and constraints should be reviewed. Any problems with human efficiency or suitability of the governing legislation may be remedied. Thus a continuously improving plan of action will be developed.

The Plan of Action to Combat Desertification (PACD) is not static, but rather dynamic. It should be conceived of as a time series that is dependent, at any given point in time, on the actually prevailing conditions. It will perforce be periodically revised and modified. The final aim should always be kept in mind: contain and combat desertification and improve production and the productive environment. An increase in the average per capita income in Bahrain will thus be attained.

C. A long-term strategy for desertification control (1992-2010)

1. National Goals

The ultimate goal of socio-economic development plans has always been the welfare of man. This can be described in terms of an estimated rate of economic growth which consequently would have the effect of raising per capita income at a certain percentage per annum. Within this overall target of fast economic growth, there are several specific goals relating to the following:[14/]

(a) Improvement of social and economic conditions;

(b) Achievement of a high percentage of literacy;

(c) Expansion of basic social amenities (health, housing).

In its endeavour to realize national goals, the State of Bahrain has adopted systematic planning. The agricultural sector in the National Land Use Plan 2001 was assigned the highest priority, although expected agriculture contribution to the national economy for the year 2001 represents 2.3 per cent of the total national economy.

The threat which desertification poses to the world and to the countries of the Mediterranean region and Middle East was shown in a meeting in February

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14/ United Nations Environment Programme (UNEP) and United Nations Economic and Social Commission for Western Asia (UN ESCWA), "National Plan of Action to Combat Desertification in the Yemen Arab Republic" (E/ESCWA/AGR/88/2) (1988).

1977 in Algarve, Portugal, and again in United Nations Conference on Desertification (UNCOD) in September 1977 in Nairobi. For the State of Bahrain, the need to formulate a national plan to combat desertification was agreed upon, and the United Nations Environment Programme (UNEP) assistance in this matter was requested. Perhaps it is worth recalling paragraph 7 of the United Nations Plan of Action to Combat Desertification (PACD) which states that "action to combat desertification is required urgently before the costs of rehabilitation rise beyond practical possibility or before the opportunity to act is lost forever".

The immediate goal of Plan of Action to Combat Desertification (PACD) (adopted in 1977) was to prevent and arrest the advance of desertification and, where possible, to reclaim desertified land for productive use. Paragraph 9 states that "the goal is to implement the Plan of Action by the year 2000".

It is logical to suggest that this draft plan should have a short-term horizon for the years 1992-1994 and a long-term horizon for the year 2010. The first will coincide with the date fixed by the United Nations Environment Programme (UNEP) Governing Council (GC) for a second assessment of progress made in the world-wide implementation of the United Nations Conference on Desertification (UNCOD) plan.

The long-term date of 2010 was fixed by UNEP GC and endorsed by the United Nations General Assembly for stopping desertification in the world. Obviously, this can also be considered the date to be set as a target for arresting desertification in the State of Bahrain.

2. Aims of the strategy

The principal target is to stop desertification by the year 2010. Within this overall target, the following specific aims are included:

(a) To ensure that desertification, once stopped, will not be allowed to recur;

(b) To effect a change in man so that he recognizes the desertification problem as endangering the requirements of food production and, consequently, of all the subsequent components of food security and self-sufficiency;

(c) To ensure that desertification control is seen as the basis for increased plant and animal productivity, a better environment, and a better quality of life;

(d) To ensure that desertification control is understood to be the cornerstone of the development process, and that the essential elements of its strategy are vital components of any comprehensive (integrated) rural development endeavour.

3. Basic assumptions

(a) The proposed long-term and short-term programmes and projects will be subject to frequent revisions and changes, in view of the dynamic nature of the phenomenon;

(b) Future social and economic development will produce a change in man that is bound to improve his perception of the desertification problem;

(c) The validity of the desertification control project should not be judged solely by the standard methods of economic and financial feasibility. Some of the parameters important to this issue cannot be measured by such yardsticks;

(d) Fighting desertification is a long-term undertaking; therefore, the political will and priority assigned to it by the Government should be maintained at the same level throughout the long term.

4. Elements of the strategy: a long-term programme (1992-2010)

Plan of Action to Combat Desertification (PACD) was formulated bearing in mind the world's fundamental social and economic goals and aims. It also embodies a long-term strategy for the realization of these goals in a manner that has taken into account almost every possible situation in the desertification problem. Its 28 recommendations are presented in 4 major divisions and some 11 sub-divisions, each of which is related to, yet fairly independent of, the others. Nevertheless, one of the basic principles in the plan states that "ideally all recommendations in the plan have to be implemented if desertification is to be brought to an end". But the choice of priorities and suitable action to be taken was left to the individual Governments to decide upon. The important part, however, is that continuous reference has to be made to the plan, of the United Nations Conference on Desertification (UNCOD) for guidance. In the case of Bahrain, the following programmes are proposed:

(a) Evaluation of desertification and improvement of water and land management

This programme comprises activities relating to the assessment and monitoring of desertification. These two activities, by their very nature, are continuous. They should be actively pursued from the present to the end of the long-term programme in 2010. The activities will also continue after that date in order to detect any recurrence. The programme will determine which parts of the country are affected and which parts are vulnerable.

The programme should also cover improved land management in affected areas and in those threatened. This work involves a broad range of social, economic, institutional, legislative and technical measures. It should deal with specific situations on the basis of accurate and, as far as possible, full information. The commencement however, should not await the preparation of complete files for every locality. Reference to procedures relating to assessment and land use are found in the texts of recommendations 1 and 2 of the UNCOD plan.

The following actions are suggested under this programme:

(i) Updating the land-use map;

(ii) Preparation of a desertification map using the provisional methodology for the assessment and mapping of desertification.[15/]

(b) Public participation programme

The prevention and combating of desertification cannot succeed without the direct involvement of the public. Recommendation No. 3 of the plan gives examples of some of the types of activities involved. A programme should be formulated to increase public awareness of the insidious degradation that is taking place, and people should be increasingly involved in discussions about problems, project ideas and project preparation and execution.

The Bahrainis are keen television viewers. The wide coverage of the State television and extensive distribution of sets in the country makes the use of this medium an important information and extension-service tool for the control of desertification.

(c) Corrective anti-desertification measures programme

This section received much attention in the United Nations Conference on Desertification (UNCOD) plan. Of the 22 recommendations directed towards national and regional action, seven (Nos. 5-11) dealt with corrective anti-desertification measures. These covered:

(i) Sound planning, development, and management of water resources as part of the measures to combat desertification;

(ii) Soil and water conservation to fight desertification in the irrigated areas;

(iii) The prevention and control of waterlogging and salinization;

(iv) The maintenance and protection of existing vegetation and vegetation in denuded areas so as to promote soil conservation;

(v) The development of systems for monitoring climatic, hydrogeological, pedological, and the ecological conditions of land, water, plants or animals in areas affected or likely to be affected by desertification.

In the UNCOD plan, this section was the longest and most detailed because this was the kind of action required in the field to correct existing damage and to prevent further damage. This, in effect, is what people can see and feel, and what they reap economic benefits from. Notwithstanding the above, the general assessment revealed that very little field action was undertaken during the first Five Year Plan (1982-1986).16/

For these reasons, the strategy in this programme will stress the following field action:

15/ Food and Agriculture Organization of the United Nations (FAO), "Survey and evaluation of available data on shared water resources of the Gulf States and the Arabian peninsula", (1979).

16/ Sutcliff, op. cit.

(i) Land management measures

a. The establishment of a land database management system for continuous data storage, retrieval, dissemination and processing;

b. The use of the proper water duty for each crop;

c. The application of effective soil conservation measures for cultivation;

d. The application of a proper crop rotation system whereby land remains protected under a crop cover;

e. The avoidance of pollution, especially in areas irrigated by treated sewage effluent (TSE);

f. The replenishment of soil fertility by periodic applications of organic and chemical fertilizers;

g. The use of proper remedial measures to combat plant diseases;

h. The improvement of the soil's physical properties.

(ii) Water management measures

a. The concentration of a water database management system for continuous storage, retrieval, dissemination and assessment;

b. The construction of leaching slot trenches and infiltration basins in suitable areas to enhance groundwater quality and to improve groundwater storage;

c. The development of the groundwater quality network to help in the study of water intrusion phenomena;

d. The application of water-saving irrigation methods such as sprinklers and/or drip irrigation;

e. The avoidance of over-irrigation, which may lead to waterlogging and soil salinization;

f. The avoidance of contamination of groundwater;

g. Limiting well-digging and controlling the tapping of groundwater;

h. The construction of artificial groundwater recharge systems by infiltrating TSE.

Under this programme of corrective anti-desertification measures, several sub-programmes and projects are to be included.

(iii) Manpower and the strengthening of science and technology

This programme deals with training and research in order to strengthen the scientific and technological capabilities required for the success of anti-desertification programmes. Three recommendations in the United Nations Conference on Desertification (UNCOD) plan deal with this objective. They stressed the need for strengthening national capabilities, with emphasis being placed on planning and management and the need for research on alternative or unconventional energy sources. Both training and research should be suitably linked to the needs of development and to solving the problems and constraints faced by inhabitants, particularly those related to the need of plants for water.

Presently, the manpower engaged in planned desertification control is relatively weak. Persons with adequate training and with knowledge of the desertification situation in the country are extremely few in number and, indeed, not completely available because of their current responsibilities.

The planning, formulation and implementation of projects called for in this plan will require professionals and technicians. To prepare and adequately train these numbers is a colossal undertaking that needs to be tackled immediately.

(iv) International action and cooperation

This programme will include regional projects needed to control desertification in areas where national or individual efforts are insufficient. Since the financial resources to combat desertification have remained a constraint for the State of Bahrain, this programme should undertake to search for possibilities of financing the campaign from bilateral and multilateral donors. Maximum use of the Consultative Group on Desertification Control (DESCON) should be made in order to provide financing for the plan.

5. Remarks

These three major groups of projects are summed up under programmes that are seemingly independent but which, as mentioned above, are interdependent and which complement one other.

The priority programmes and projects for the short-term (1992-1994) that are detailed in chapter VII constitute a selection of those derived from the long-term programme.

In concluding this section, it should be emphasized that all desertification control work, whether this is part of long-term strategy or included in the priority action for the short-term, actually forms a part of the national, social and economic development plan.

VI. MEASURES AND INSTITUTIONAL FRAMEWORK

A. Current set-up

Several institutions in Bahrain are related in some aspects to the issue of desertification in the country. The diversity of these institutions will certainly help in carrying out the National Plan of Action to Combat Desertification (NPACD). Organization and integration of efforts is, however, a prerequisite for success. The following institutions are involved:

1. Ministry of Commerce and Agriculture

The Ministry of Commerce and Agriculture, through its Secretariat of Agriculture, is very much involved in the activities related to the NPACD. The Secretariat of Agriculture with its Directorates of Projects, Farmer Services, Agricultural Research, and Water Resources is currently in charge of agricultural planning, development and trade in the country. The Secretariat of Agriculture is well established and has professional and technical staff capable of carrying out the present job and those of the NPACD as well. Some professional support and training of local staff is, however, needed. More details about such support is dealt with later in this report.

2. Ministry of Works, Power and Water

The Ministry of Works, Power and Water is also involved in the NPACD, as it is in charge of: groundwater studies, drilling and evaluation; water desalination plants; and treated sewage effluent (TSE) plants. The Ministry, through its General Directorates of Water Supply and of Roads and Sewerage, has qualified professionals and technicians.

3. Ministry of Housing

The Ministry of Housing through its General Directorate for Physical Planning is responsible for land use, establishment of new towns and, hence, planning for water needs.

4. Environment Protection Agency

The Environment Protection Agency (EPA) was established in 1980. The EPA is headed by the Minister of Health, and technical representatives of concerned ministries are members of the Agency. The Directorate of Environmental Health (DEH) at the Ministry of Health is the implementing arm of the EPA.

5. Arabian Gulf University, Bahrain

The Arabian Gulf University (AGU), through its Post-Graduate Programme for Desert Sciences and Arid Lands (DSAL) in the College of Applied Sciences established in 1983, has offered since 1986 post-graduate studies, both academic and applied, leading to a diploma/M.Sc., and a programme of community services and training. The activities aim at preparing specialists and experts

in various fields of desert sciences by providing them with modern information and experience in one of the following areas:

(a) Environment and desert community studies;
(b) Desert resources studies;
(c) Desert agriculture;
(d) Desert engineering and physical development;
(e) Water resources engineering and management;
(f) Meteorology and climatology;
(g) Alternative energy;
(h) Integrated socio-economic and engineering and management.

Established by Gulf Cooperation Council (GCC) countries, Arabian Gulf University (AGU) acts as a scientific and academic focal point for several activities in the region.

6. Bahrain Centre for Studies and Research

The Bahrain Centre for Studies and Research (BCSR), established in 1981, is overseen by its Board of Trustees chaired by His Excellency Shaikh Hamad Bin Isa Al Khalifa, the Crown Prince.

BCSR, through both the Scientific Research Department and the Economic and Social Research Department, is capable of coordinating scientific efforts at the national level to solve national problems. The Centre carried out and coordinated, among other activities, several research activities dealing with groundwater and agriculture in Bahrain.

B. National machinery for desertification control

1. Structure of the national machinery

The control of desertification is the concern of several disciplines and professions. To name just a few, water scientists, soil specialists, geographers, economists, ecologists, agriculturalists, sociologists, veterinarians, scientists, climatologists and demographers are involved. Therefore, no single profession or discipline can claim overall responsibility for this complex field. It is necessary to make this statement in order to dispel any presumptuous views on the placement of the desertification control unit.

Recommendation No. 21 of the United Nations Conference on Desertification (UNCOD) plan calls for the establishment of coordinated national machinery to combat desertification and drought. It further expresses a desire that the machinery be in the form of a national desertification commission at the highest level of Government, composed of high-ranking representatives of the appropriate ministries, agencies and institutes, together with community leaders and non-governmental organizations (NGOs).

The recommendation gives advice on the task of coordinating and consolidating activities, as well as the need for administrative and scientific support for the national body.

National desertification control commission

It is recommended that a national desertification control commission (NDCC) be established (by Prime Minister's decree) under the chairmanship of the Minister of Commerce and Agriculture (MOCA), with the following members:

(a) Assistant Deputy Minister of Commerce and Agriculture in charge of the Desertification Control Unit and Secretary of the Commission;

(b) Assistant Deputy Minister of Housing;

(c) Assistant Deputy Minister of Information;

(d) Director-General of Physical Planning Directorate, Ministry of Housing;

(e) Director of Water Resources, Ministry of Commerce and Agriculture (MOCA);

(f) Director of Agriculture Projects, Ministry of Commerce and Agriculture (MOCA);

(g) Director of Agriculture Research Station, Ministry of Commerce and Agriculture (MOCA);

(h) Representative of Environment Protection Agency (EPA);

(i) Representative of the University of Bahrain;

(j) Representative of Desert Sciences and Arid Lands Post-Graduate Programme, Arabian Gulf University (AGU);

(k) Representative of Bahrain Centre for Studies and Research (BCSR).

General directorate for desertification control coordination

It is recommended that a general directorate (under a Director or preferably a higher-ranking professional), be established in the Ministry of Commerce and Agriculture (MOCA). This directorate should be supported by a suitable number of professionals and technicians.

The Ministry of Commerce and Agriculture (MOCA) has been chosen for the placement of this unit in order to ensure its ability to function. Experience in other countries has shown that the location of this coordination unit is vital to its success; it works better when placed in a ministry that has "teeth" rather than when located in a particular place for purposes of prestige. The lessons learned from the previous general assessment are that more action in the field is required in order to combat desertification, and placing the unit in the Ministry of Commerce and Agriculture (MOCA) gives it a better chance of success.1/

1/ Sutcliff, op. cit.

The director-general would be designated secretary of the national desertification control commission. The number of staff required would be determined in accordance with the amount of administrative and technical support required for the functioning of the commission and for whatever executive activities the unit becomes responsible for.

2. Responsibilities of the national machinery

The responsibilities of the national desertification control commission might include the following:

(a) Analysis, evaluation and dissemination of existing information on desertification;

(b) Preparation of a national plan of action to combat desertification that would coordinate all national activities;

(c) Arrangement of the financing for the implementation of the national plan of action through national institutions;

(d) Monitoring the progress of measures to combat desertification and recommending necessary changes to the national plan of action;

(e) Participation in international and regional programmes and maintaining liaison with regional and international organizations on the problems of desertification.

Functions of the general directorate for desertification control coordination

(a) To service NDCC as its technical and administrative arm;

(b) To coordinate and consolidate activities related to desertification;

(c) To undertake the following:

(i) Execution alone or in cooperation with national, regional, or international bodies, of desertification control projects of a multi-disciplinary nature;

(ii) Maintaining an up-to-date inventory of all programmes and projects as well as present and planned activities, in order to identify the gaps related to finance or the technical omissions;

(iii) Preparation of preliminary surveys and studies for the formulation of programmes and projects for the implementation of the national plan;

(iv) Monitoring the implementation of the national plan and preparing an evaluation of its effectiveness;

(v) Recording the results of the monitoring of human conditions in areas prone to desertification, including demographic and social indicators;

(vi) Maintaining liaison with regional and international organizations the United Nations Environment Programme (UNEP) Regional Office, Desertification Control Programme Activity Centre (DC/PAC), the Global Environmental Monitoring System (GEMS), Economic and Social Commission for Western Asia (ESCWA), etc.) in order to receive and update knowledge on the international situation;

(vii) Preparing and publishing a quarterly newsletter on programmes, desertification processes and progress made in the implementation of the National Plan.

C. Implementation of the recommended set-up

Proposals and assistance from UNEP/ESCWA/FAO could be requested in order to formulate details and provide advice on implementation, staffing and financial requirements.

VII. SHORT-TERM PRIORITY PROGRAMMES AND PROJECTS 1992-1994

A. General

Priority programmes and projects for the short term that cover the period 1992-1994 form part of the programmes proposed for the long term (1992-2010). An attempt will be made to follow the same titles and sequence or presentation as in chapter V. This has the benefit of enabling those responsible for action to see how this small part can relate to the whole (presented in chapter V). It will also facilitate additions in the future so that in each area, progress can be measured and gaps identified.

The priority project under each of the programmes identified in chapter V will be presented in a brief form and is considered to be clear. There seems to be little point in working out a project proposal or a recommendation in any great detail if it is not going to be accepted. It will thus save time, effort and funds to work out the details at a later date, only for those proposals that are accepted by the Government.

B. Evaluation of desertification and improvement of water resources and land management

Project No. 1

Project: Establishment of data bank system.

Objectives: Constructing an integrated database system to collect all data and store and disseminate processed data and information which could be utilized for the appraisal, planning and management of water and land resources.

Execution: National desertification control commission (NDCC) with complete cooperation of:

(a) Directorate of Water Resources, Ministry of Commerce and Agriculture (MOCA);

(b) Agricultural Research Centre, Ministry of Commerce and Agriculture (MOCA);

(c) Directorate of Agricultural Projects, Ministry of Commerce and Agriculture (MOCA);

(d) Arid Lands and Desert Sciences Programme, College of Applied Sciences, Arabian Gulf University (AGU).

Cost: $US 1,500,000.

Duration: Two years.

Background: Water and soil data have great value and should be used in the numerous aspects of the plan of action. The value of these data not only depends on the use to which they are put but also the

context in which they are used. They will ensure a significant impact on the decisions that are made. Therefore, the data have to be collected and presented in a logical manner so that they can be used to make projections and studies on which to base policy decisions. Furthermore, there is a continuous need to keep the data current, consistent, and adequate for the object of the appropriate management of natural resources. It is worthwile to mention here that the Water Resources Directorate possesses a good filing system for water resources data storage. This will help in the establishment of the water resources database system.

Activity: Two integrated database systems must be established, one for water resources and the other for land resources.

Remarks: (a) Technical assistance needed;
(b) Computer facilities need to be enhanced;
(c) Training required.

Project No. 2

Project: Development of groundwater networks.

Objectives: Upgrading the observation programme, especially for monitoring groundwater quality at different depths.

Location: Covers the whole country.

Execution: National desertification control commission with complete cooperation of:

(a) Directorate of Water Resources, Ministry of Commerce and Agriculture (MOCA);

(b) Desert Sciences and Arid Lands Programme, College of Applied Sciences, Arabian Gulf University (AGU).

Cost: $US 800,000.

Duration: 18 months.

Background: Approximately 70 sites are regularly monitored by the Directorate of Water Resources. More than 60 of them are equipped with automatic recorders; the rest are measured manually each month. Water samples from irrigation boreholes are collected according to the following schedule: every three months from Khobar formations, every six months from Alat formations, and once a year from Umm Er-Radhuma formation. A complete routine analysis of these samples is carried out. Discharge quantities from the wells are recorded monthly by gauge meters. All these periodical data are stored in computer files and published in tabular or graphic forms. The network can be further developed to monitor the water quality in the different formations at different depths; this will help in the study of water-intrusion phenomena.

Activity: Geophysical investigations needed, drilling some observation wells in selected area, executing monitoring programme.

Remarks: (a) Technical assistance needed;

(b) Supporting the instruments and equipment (well logger, samplers etc);

(c) Training.

Project No. 3

Project: Construction of mathematical model.

Objectives: A good simulation of the groundwater reservoirs in Bahrain, in order to first assess the current state and study the water balance, and then to propose development plans that are compatible with the safe yield of the aquifers.

Location: Covers the whole country.

Execution: National desertification control commission with complete cooperation of:

(a) Directorate of Water Resources, Ministry of Commerce and Agriculture;

(b) Desert Sciences and Arid Lands Programme, College of Applied Sciences, Arabian Gulf University;

(c) Bahrain Centre for Studies and Research (BCSR).

Cost: $US 1,000,000.

Duration: Two years.

Background: A mathematical model is the practical tool to correctly manage groundwater development. Different models have already been established for some local aquifers in Bahrain. The construction of a mathematical model that simulates an integrated view of all the aquifers is badly needed. This model should include provisions for considering the prevailing boundary conditions, especially the hydraulic connections between the different formations and the phenomenon of salt-water intrusion.

Activity: (a) Preparation of the conceptual model;

(b) Formation of the flow equations for unsteady state (partial differential parabolic equations;

(c) Calibration of the model with the available field data;

(d) Defining a groundwater development plan.

Remarks: (a) Technical assistance needed;
(b) Computer facilities need to be enhanced;
(c) Training needed.

Project No. 4

Pilot project: Improved irrigated agriculture.

Objectives: Establish the prerequisites for a sound integrated land- and water-use policy, with the objective of optimum net returns per unit of water under the prevailing ecological conditions.

Location: Selected areas to be investigated.

Execution: National desertification control commission with complete cooperation of:

(a) Agricultural Research Centre, Ministry of Commerce and Agriculture (MOCA);

(b) Directorate of Agricultural Projects, Ministry of Commerce and Agriculture (MOCA);

(c) Desert Sciences and Arid Lands Programme, College of Applied Sciences, Arabian Gulf University (AGU).

Cost: $US 1,000,000.

Duration: Three years.

Background: As noted, there is a degradation of agricultural lands. The causes can be attributed to different factors: crop selected and rotation, water and soil management etc. A study of schemes to improve irrigated farming should be carried out. Therefore, there is a need for testing, appraising and evaluating different methods of irrigation and water distribution networks, and different types of drainage under the prevailing conditions. Crop tolerance to salinity and biomass productivity of water can also be experimented with under irrigation and water management practices.

Project No. 5

Pilot project: Artificial recharge to groundwater formations, using treated sewage effluent (TSE).

Objectives: Test the efficiency of applying different methods of infiltration to recharge groundwater, which will enhance groundwater quality and improve groundwater storage.

Location: In north A'ali area or any other candidate area (to be investigated).

Execution: National desertification control commission with complete cooperation of:

(a) Directorate of Water Resources, Ministry of Commerce and Agriculture (MOCA);

(b) Desert Sciences and Arid Lands Programme, College of Applied Sciences, Arabian Gulf University (AGU);

(c) Biological Sciences Department, College of Science, Bahrain University;

(d) Ministry of Health;

(e) Ministry of Housing and Public Works.

Cost: $US 750,000.

Duration: Two years.

Background: The current intensive and uncontrolled exploitation of groundwater results in the depletion of aquifers, drying of springs and wells, and in a general and pernicious deterioration in water quality. Therefore, it is recommended that the practicability of developing groundwater reservoirs via artificial recharge with treated waters should be considered, aiming at improving the reservoirs both several alternative methods for groundwater quantitatively and qualitatively. However, since there are several alternative methods for groundwater recharge, it is recommended to start with a pilot project in order to evaluate the results thereof and to plan for additional future developments.

Activity: Two types of artificial recharge may be tested: leaching slot trench and infiltration basin. A complete observation network has to be implemented. A thorough study of the effects (quality and quantity) of the infiltrated treated sewage effluent (TSE) to the groundwater has to be investigated.

Remarks: (a) Technical assistance needed;
(b) Supporting the available equipment;
(c) Training needed.

C. Assessment and monitoring of desertification

Project No. 6

Project: Monitoring of desertification.

Activity: Organizing and establishing the machinery. This is a continuing activity. The machinery to perform it is that which is addressed in this project. It will be partly included in the desertification control unit (to be established) and partly in other departments or ministries.

Duration: Continuous.

Execution: Multi-disciplinary: national, regional and United Nations agencies.

Cost: $US 300,000 yearly.

Remarks: The nature and components of the work in this project and in the preparation of land-use are complementary.

D. Public participation programme

Project No. 7

Project: Public awareness and participation.

Activity: Preparation of documentary material for extensive use in communications media, e.g., television, radio, press and public meetings, with the assistance of cooperatives and voluntary organizations. Preparation of five television films of about 10 minutes each. These films should cover different subjects important to the public, i.e., saving water in different uses, waterlogging in irrigated lands, increased production by applying practical methods in plantation and irrigation. Such ways of communicating to the public are effective in increasing public awareness and bringing about the desired change in their perceptions -- people learn quicker by example.

Duration: Continuous; first part, five films.

Execution: National expatriate, in collaboration with the ongoing research activities to improve irrigated agriculture.

Cost: About $US 50,000 for the first series of films.

E. Socio-economic programme

Project No. 8

Project: Environmental education for youth.

Activity: This is an urgent function so that the opportunity to influence the attitudes and perceptions of the young is ensured. Material on desertification processes and how these relate to the food security and stability of society should be prepared for inclusion in school curricula.

Duration: Continuous.

Start: Immediately.

Execution: Nationals in complete collaboration with Desert Sciences and Arid Lands Programme, College of Applied Sciences and the College of Education, Arabian Gulf University (AGU).

Cost: One million dollars for the first five years.

F. Manpower and strengthening science and technology

Project No. 9

Project: Regional Research, Training and Communications Programme on Desertification Control in the Economic and Social Commission for Western Asia (ESCWA) Region (Phase I) (a United Nations Environment Programme (UNEP) Project Document).

Duration: Five years.

Execution: Through national and regional institutions with the help of concerned international organizations and bodies [United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), the Centre for the Study of Arid Zones and Dry Lands (ACSAD), etc].

The integrated regional programme proposed for implementation under this project will consist of three major components: research, training and communications. It includes comprehensive coverage of all the issues concerning desertification control.

G. International action and cooperation programme

Preparation of national priorities for action and financing

The programme for desertification control includes many activities, and there is always an urgent need for deciding on priorities in order to allocate the available resources. This will also determine the order in which projects are submitted for external financing.

The national machinery entrusted with desertification control should give priority to the establishment of a small group, two to three persons, who would dedicate their efforts towards desertification control plans. The function of this group would also include the preparation of projects in the format required by the donor organizations. International assistance in this respect is readily available.

The long-term programme includes a suggestion for a project to insure against risk and effects of drought. This project is recommended for priority action in view of the high probability that a drought wave may soon affect the country. In preparing proposals for this project, reference should be made to Recommendation No. 17 of the United Nations Conference on Desertification (UNCOD) plan, wherein a series of 13 action steps are described.

VIII. CONCLUSION AND FOLLOW-UP

The draft National Plan for Desertification Control in the State of Bahrain, the subject of this report, gives the main outlines of two programmes, one for the long term (1992-2010) and the other for the short term (1992-1994). It describes in some detail the structure and functions of the institutional machinery so that action is not hampered by lack of clarity.

The project proposals in both programmes are only presented in a preliminary form. They should be elaborated only after the Government signifies its agreement with the proposals.

The follow-up action required is primarily the responsibility of the Government of Bahrain. However, a start is necessary on the part of the United Nations. This will begin with the delivery of this report to the Government, and of the expression of keen interest of both United Nations Environment Programme (UNEP) and Economic and Social Commission for Western Asia (ESCWA) and indeed, of other member organizations and bodies of the United Nations that are willing to assist the State of Bahrain in its endeavour to control desertification.

The Government of the State of Bahrain, particularly the Ministry of Commerce and Agriculture (MOCA), is expected to take subsequent steps to secure whatever assistance is required from the United Nations. In this respect, four steps seem to be essential.

1. The Ministry of Commerce and Agriculture (MOCA) appears to be the body most suited to assume responsibility for the follow up and may be appointed as a caretaker professional to look after desertification matters, as was suggested in Chapter VI.

2. The Ministry of Commerce and Agriculture (MOCA) should pursue the matter so that the approval of the Government for the draft plan is secured.

3. The Ministry of Commerce and Agriculture (MOCA) should pursue the establishment of the institutional machinery.

4. The caretaker, and any other staff recruited for the desertification control machinery, can embark immediately on the identification of project proposals and selected areas where UNEP/ESCWA/FAO assistance is required, in order to address them accordingly.

Having reached this stage, the matter is once again in the hands of the United Nations, and a lot then depends on the zeal and promptness with which the matter is treated. No doubt quick responses can be expected from these organizations, and in the last analysis, it will be the quality of the product of their missions that determines the success or failure of all these efforts to combat and contain desertification.

ANNEXES

Annex I

WATER LAW NO. 2 OF 1971, BAHRAIN

H.M. the Amir of Bahrain promulgated Law No. 2 of 1971 concerning regulation and supervision of water control on recommendations of the President of the Department of Development and Engineering Services. The original Arabic version is reproduced below, following this loose translation, to allow readers who do not know Arabic to grasp the substance of the law.

Article 1

Definitions Council: Bahrain Government's Water Council and its staff.

Well: Any well, hole, construction for water control, meant for extracting, uplifting, upward conveying, transporting and utilizing water for any purpose.

Well completion: Carrying out final preparation of plugging any part of a well away from extraction layer.

Well casing: Casing the inside walls to prevent water leakage to the permeable or disturbed layers.

Article 2

Written permission from the Council must be obtained before initiation of:

(a) Drilling new well/s or installing new pump on an existing well;

(b) Any change or alteration in size, depth or discharge of the well or its pump.

Article 3

All applications to the Council for works of Article 2 must include:

(a) Name and address of the applicant;

(b) Location or its change of pump installation of the well;

(c) Map of well location;

(d) Water quantity needed;

(e) Purpose of drilling;

(f) Date of application.

Article 4

The Water Council is the only legitimate organization to look into the works specified in Article 2.

Article 5

(a) The Water Council may or may not approve any application for drilling or may impose conditions or suggest alterations necessary;

(b) The Water Council may cancel any permission for drilling if it conflicts or possibly conflicts with the Government's public-water projects, without any compensation.

Article 6

The Water Council will respond by giving written permission or refusal to any application, along with conditions and alterations/or reasons for such actions.

Article 7

The Water Council will carry out all drilling or construction of new wells or changing or installing any pumps for water extraction.

Article 8

Water-well owners will be obliged to comply with all Water Council regulations.

Article 9

The well casing will be done according to the Water Council regulations.

Article 10

The Water Council will decide on well diameter, depth and pump horsepower for water extraction.

Article 11

The owners of old wells will notify in writing the list of their wells and locations within 30 days of the day of executing this law.

Article 12

The Water Council will register all wells in Bahrain and notify their owners.

Article 13

Through the municipalities and police, the Water Council will issue notices and warnings to all land owners whose wells are not registered according to Article 11, and will close or remove the pump.

Article 14

The municipalities and police will have the right to enter any premises or land to enforce necessary action, and the Water Council will not bear the cost of such action.

Article 15

The Water Council will inform the owner of the well by written notice at least 30 days before any shutting down or removal of the pump. In case no owner is identified, this notice will be published in the Official Gazette.

Article 16

The Water Council has the right to enter any land to test or measure or take water samples, or remove any instrument related to the well and owned by the Water Council for repairs.

Article 17

(a) The Water Council will install a water meter on any well temporarily or permanently;

(b) The owner of the well will be responsible for the protection and safety of the meter;

(c) The Water Council will bear all costs first of meter installations, maintenance and repairs and will carry these costs over to the well owner to be paid later by him.

Article 18

The Water Council will ask the owner to repair his well if it is necessary for any reason; the Water Council will shut down the well if the owner is late in doing so.

Article 19

The Water Council will notify the well owner in writing at least 30 days before shutting down the well as mentioned in Article 18.

Article 20

(a) The well owner will stop all unnecessary discharge within 30 days from the execution of this law;

(b) The Water Council will send a notice to the owner of a well which discharges with no use ordering him to close this well, after 30 days from the enforcement of this law.

Article 21

(a) The well owner can object to any decision of the Water Council in the proper court;

(b) This objection should be made within 30 days of the decision date of the Water Council;

(c) The decision of the Court will be final; otherwise the decision of the Water Council will be enforced until ruled out by the Government.

Article 22

Violations of this law:

(a) Anyone drilling a well in his land or any other land without the permission of the Water Council, or not following the conditions of the permission of the Water Council;

(b) Any destruction of any device of the Water Council, installed on the well for measurement or the like.

Article 23

(a) The violators in Article 22 will pay not more than BD 100 or will be jailed up to six months or will be punished by both (the fine and jail);

(b) The violators of Article 22b. will pay BD 10 and be obliged to pay for all costs and repairs of destruction or be jailed up to one month.

Article 24

This law will be enforced one month after its publication in the Official Gazette. All concerned parties should see to its enforcement (heads of municipalities, agriculture, development and engineering services departments).

Signed: Isa Bin Salman Al Khalifa
Amir of the State of Bahrain

Issued at Rifaa Palace on 16 Dhul Que'da 1390 Hijra corresponding to 13 January 1971

مرسوم بقانون رقم [٢] لسنة ١٩٧١
بشان مراقبة وتنظيم التحكم في المياه

نحن عيسى بن سلمان الخليفة حاكم البحرين وتوابعها.
بعد الاطلاع على المادة [٦] من المرسوم رقم [١] لسنة ١٩٧٠.
وبناء على عرض رئيس دائرة التنمية و الخدمات الهندسية.
وبعد موافقة مجلس الدولة
رسمنا بالقانون التالي:

المادة -١ -

يقصد بالعبارات و الالفاظ التالية لأغراض هذا القانون المعاني المبينة ازاءها ما لم تدل القرينة على خلافها.

المجلس: مجلس الماء التابع لحكومة البحرين. او من يفوضه المجلس من الموظفين.

البئر: اية بئر او ثقب او بناء لتنظيم الماء وتحويله. او اية وسيلة لاستخراج الماء او رفعه او دفعه او اية طريقة للحصول على الماء ورفعه ونقله و استعماله من اجل غاية من الغايات.

اكمال البئر: القيام بالتجهيزات النهائية للبئر بما في ذلك سد وطمر اي جزء من البئر يكون فيها هذا الجزء ابعد من المنطقة التي يستخرج منها الماء.

تغليف البئر: القيام بتغطيس جدران البئر من الداخل لمنع تسرب المياه من البئر الى اية منطقة مسامية او من اي تشقق في الطبقات التي يمر فيها البئر.

المادة - ٢ -

يجب الحصول مسبقا على اذن خطي من قبل المجلس قبل الشروع في العمليات التالية:

ا - حفر بئر او اثار جديدة. او تركيب جهاز جديد في بئر موجودة.

ب - اجراء تغيير في بئر موجودة او في جهاز موجود. بحيث يؤدي هذا التغيير الى توسيع محيط البئر او عمقها. او يزيد القوة المستخدمة لسحب المياه.

المادة - ٣ -

يجب ان تشمل جميع الطلبات التي تقدم للمجلس للقيام بالعمليات المذكورة في المادة الثانية البيانات التالية:

ا - اسم وعنوان مقدم الطلب.
ب - موقع البئر المراد اقامتها او التغيير فيها او تركيب الجهاز عليها.

ج - خارطة مرفقة بالطلب تبين موقع البئر.
د - كمية المياه المراد استخراجها من البئر.
هـ - الغرض من حفر البئر.
و - تاريخ تقديم الطلب.

المادة - ٤ -

للمجلس دون غيره صلاحية النظر في الطلبات للقيام بالعمليات المذكورة في المادة الثانية من هذا القانون.

المادة - ٥ -

أ - بعد النظر في طلب الاذن، يجوز للمجلس ان يعطي او يرفض الاذن بالحفر الذي قد يكون مطلقا او مقيدا بشروط او تعديلات يراها المجلس واجبة الاتباع.

ب - للمجلس في اي وقت ان يلغي الاذن بالحفر اذا رأى ان اجراء ات الحفر تتعارض او من الممكن ان تتعارض مع مشروعات المياه الحكومية او الاهلية، وذلك دون تعويض عن عمليات اجريت أو مصروفات انفقت خلال فترة الاذن.

المادة - ٦ -

يقوم المجلس باتلاغ مقدم الطلب كتابة في حالة الاذن بالحفر، او في حالة رفض او طلب ادخال تعديلات او رفضه بعض التعديلات مع ابداء الاسباب.

المادة - ٧ -

يختص المجلس بالقيام بجميع عمليات حفر و انشاء الابار الجديدة او تعميقها او وضع جهاز لاستخراج المياه او سحبها الى سطح الارض.

المادة - ٨ -

يضع المجلس الانظمة و اللوائح التي تنظم عمليات الحفر و التغليف و الاشراف عليها وعلى اصحاب الابار الالتزام بهذه الانظمة و اللوائح.

المادة - ٩ -

يجب تغليف البئر حسب تعليمات المجلس.

المادة -١٠-

يحدد المجلس محيط البئر وعمقها وكذلك القوة المستعملة لسحب المياه منها.

المادة -١١-

على جميع اصحاب الابار القائمة و التي تحت الحفر تقديم بيان كتابي للمجلس عن كل بئر وموقعها خلال فترة لا تتجاوز ثلاثين يوميا من تاريخ نفاذ هذا القانون.

المادة -١٢-

يقوم المجلس بتسجيل جميع الابار الموجودة في البحرين وتواريخها و اشعار اصحاب الابار بهذا التسجيل.

المادة -١٣-

للمجلس - بواسطة البلديات او الشرطة - ان يصدر التنبيهات و الاخطارات الى اصحاب الاراضي التي توجد فيها ابار غير مسجلة او التي لم يتم تسجيلها خلال الفترة المحددة في المادة العاشرة عشرة. وذلك بسد وطمر البئر او فك جهازها.

المادة - ١٤ -

تخول البلديات او الشرطة رخصة الدخول الى الارض او العقار و القيام بجميع العمليات الضرورية لتنفيذها. ويسترد المجلس جميع تكاليف هذه العمليات.

المادة - ١٥ -

يجب على المجلس ان ينشر كتابة صاحب البئر بوجوب سد وطمر البئر وذلك قبل القيام بسدها وطمرها او فك الجهاز الموضوع بثلاثين يوما على الاقل. وفي حالة صعوبة التعرف على صاحب البئر يجب ان ينشر هذا الاشعار في الجريدة الرسمية قبل البدء في سد وطمر البئر بثلاثين يوما.

المادة - ١٦ -

للمجلس صلاحية دخول اية ارض للقيام بالفحوص و القياسات او اخذ عينات من الماء. كما يجوز له رفع اية اداة لها علاقة بالبئر ونقلها لاصلاحها شريطة ان تكون الاداة مملوكة للمجلس.

المادة - ١٧ -

ا - على المجلس ان يضع جهاز التدفق او غيره من اجهزة القياس على كل بئر بصورة مؤقتة او مستديمة.

ب - على صاحب البئر القيام بالاجراءات او الترتيبات اللازمة للمحافظة على اجهزة القياس من الاضرار المتعمدة او العرضية.

ج - يتحمل المجلس تكاليف نقل وتركيب وتصليح وصيانة اجهزة القياس التي توضع على الابار الموجودة او التي هي في دور الحفر ويرجع بهذه التكاليف على صاحب البئر.

المادة - ١٨ -

يجوز للمجلس اذا رأى ان الضرورة تستدعي القيام باصلاح اية بئر لاي سبب من الاسباب ان يطلب من صاحب البئر اصلاحها بالصورة التي يراها. وفي حالة التباطؤ في القيام بذلك يقوم المجلس بسد وطمر البئر.

المادة - ١٩ -

يجب على المجلس قبل القيام بسد وطمر البئر بمقتضى المادة الثامنة عشر ان يشعر كتابة صاحب البئر بثلاثين يوما على الاقل.

المادة - ٢٠ -

ا - يجب على كل صاحب بئر ان يمنع تدفق المياه هدرا خلال ثلاثين يوما من تاريخ سريان مفعول هذا القانون.

ب - للمجلس ان يرسل اشعارا لصاحب البئر التي تذهب مياهها هدرا بعزمه على سد وطمر البئر وذلك بعد مضي ثلاثين يوما من تاريخ سريان مفعول هذا القانون.

المادة - ٢١ -

ا - لكل صاحب بئر ان يعارض في قرار المجلس لدى المحكمة المختصة.

ب - يجب ان ترفع المعارضة خلال ثلاثين يوما من تاريخ صدور قرار المجلس.

ج - يكون حكم المحكمة نهائيا بالنسبة للمعارضة ويظل قرار المجلس ساري المفعول حتى الفصل في المعارضه.

المادة - ٢٢ -

يرتكب مخالفة بمقتضى احكام هذا القانون:

ا - كل من شرع فى حفر بئر في ارضه او فى اية ارض اخرى بدون رخصة من المجلس او حفر بئرا خلافا للشروط و التعليمات التى اذن بها المجلس.

ب - كل من شرع في اتلاف او اتلف اى جهاز يضعه المجلس على اية بئر لعملية القياس او غيرها.

المادة - ٢٣ -

ا - يعاقب مرتكب المخالفة بمقتضى المادة الثانية و العشرين فقرة" [ا] بغرامة لا تتجاوز مائة دينار او الحبس لمدة لا تتجاوز ستة اشهر او العقوبتين معا.

ب - يعاقب مرتكب المخالفة بمقتضى المادة الثانية و العشرين فقرة [ب] بغرامة قدرها عشرة دنانير مع الزامه بتكاليف القيام باصلاح ما اتلف او الحبس لمدة لا تتعاوز شهرا و احدا.

المادة - ٢٤ -

يعتبر هذا القانون ساري المفعول بعد شهر و احد من تاريخ نشره في الجريدة الرسمية وعلى رئيس دائرة البلديات و الزراعة ورئيس دائرة التنمية و الخدمات الهندسية كل فى اختصاصه. تنفيذ هذا القانون.

صدر بقصر الرفاع
بتاريخ ١٦ ذو القعدة ١٣٩٠هـ
الموافق ١٣ يناير ١٩٧١م

Annex II

AMIRI DECREE NO. 12/1980 GOVERNING THE USE OF UNDERGROUND WATER

We, Isa Bin Salman Al Khalifa, Amir of the State of Bahrain, after referring to the Constitution, to Amiri Order No. 4/1975, to Proclamation No. 48/1351 issued on 19th, Dhul Que'da, 1351 Hijra corresponding to 25 March 1933 with respect to drilling water wells, and to Amiri Decree No. 2/1971 with respect to supervision and regulation of water control, and upon the submission of the Minister of Commerce and Agriculture, and after the approval of the Council of Ministers, hereby decree:

Article 1

In the application of the provisions of this Law, the following expressions shall have the meanings hereby assigned to them, respectively:

(a) "Well" means any well, hole or construction kept for the supply of water or diversion thereof, or any means for the supply of water from which it may be drilled or pumped. It also means any device for obtaining water, drilling or pumping thereof to be used for agricultural, industrial or recreational purposes;

(b) "Completion of the well" means undertaking the final fitting of the well including the walling with stone or tubbing of any part of the well, if the said part is separate from the area wherefrom water is obtained;

(c) "Well casing" means the tubular lining of a drilled well to prevent water from leaking out of the said well to any porous area or from any cleft in the underground layers through which the well is bored;

(d) "Umm El-Radhuma layer" means the layer wherein underground water is maintained and which follows Al-Aalat layer and Al-Khobar layer.

Article 2

No new well may be drilled nor any alteration or modification may be made to any existing well or to any device attached thereto resulting in the enhancement of the well's diameter or depth, or resulting in raising the capacity of drawing water therefrom except after obtaining a permit from the Minister of Commerce and Agriculture.

Article 3

The Regulations which shall be issued for implementing this Law shall determine the areas wherein wells may be drilled as well as the locations wherein wells may not be drilled, whether such wells are used for agricultural, industrial or recreational purposes.

However, in case of wells used for industrial and recreational purposes, water may be drilled from Umm El-Radhuma only. In this event, the owner of the well shall be required to install the necessary devices which may render the drilled water fit for consumption.

Article 4

Applications for permits shall be submitted to the Directorate of Water Resources at the Ministry of Commerce and Agriculture (MOCA) on the prescribed form to which shall be attached such drawings, statements and documents which shall be specified by the Regulations for implementing this Law.

Article 5

Fees shall be charged for the issue of the permit, and annual fees shall be imposed in respect of each well. The said fees shall be determined by an order to be issued by the Minister of Commerce and Agriculture after obtaining the consent of the Council of Ministers.

Article 6

After approval has been given to grant the permit, the Directorate of Water Resources shall undertake all operations pertinent to the drilling and construction of the well until it is fit for use. The said office shall also undertake the walling and tubbing of the well in the instances provided for in the Law at the owner's expense and in the manner outlined in the Regulations for implementing this Law.

In certain cases, the Minister of Commerce and Agriculture may authorize the owner to carry out the aforesaid works under the supervision and control of the Directorate of Water Resources.

Article 7

No permits may be granted to wells maintained for agricultural purposes unless the area of land which shall benefit from the water thereof shall not be less than the minimum areas which shall be specified by means of an order to be issued by the Minister of Commerce and Agriculture after the approval of the Council of Ministers.

Article 8

If the area of land is below the minimum requirement, the Minister of Commerce and Agriculture may, by virtue of an order to be issued thereby, suggest to landowners in the neighbourhood that they participate in the drilling of one well whose costs shall be divided amongst them in proportion to the area of land held by each.

Article 9

The Directorate of Water Resources may, after or before the permit is granted, introduce the modifications which shall be deemed necessary to be made. The Office may serve notice to the owner of the well at any time revoking the permit if it is found that drilling operations are or may become inconsistent with groundwater conditions.

The owner of the well shall not have the right to claim any compensation for any expenses which he may have incurred in the course of drilling works or

otherwise, even if such works have been effected before receiving notice of the revocation of the permit.

Article 10

The Directorate of Water Resources shall install in each well, whether constructed before or after the coming into operation of this Law, the necessary devices for gauging the flow of water or for the computation of water drawn therefrom or any other systems which are deemed necessary for monitoring the use of water. The owner of the well shall meet all the costs of installation, maintenance and repair of such devices. He shall be required to take all the necessary steps and measures needed for protection of the aforesaid devices against deliberate or occasional damages.

Article 11

The Directorate of Water Resources shall determine, in collaboration with the Directorate of Agriculture, the amount of water required from each well used for irrigation purposes for cultivating the land. If more than the authorized quantity of water is drawn from the well, the excess shall be charged for at the rates to be laid down by the Regulations.

Article 12

A notification shall be given to the Minister of Commerce and Agriculture upon undertaking any of the following acts:

(a) Process of blasting of the seabed;

(b) Dredging and reclamation works in the sea;

(c) Any town planning or the erection of major projects which mainly rely upon the use of groundwater on site.

In the above-mentioned cases, a reasonable notification period shall be given before the commencement of works. The Minister may order the cessation of such works if it is established that groundwater in the area is inadequate, or if such works damage the water supply in any manner whatsoever.

Article 13

The Directorate of Water Resources shall have the right to issue directives and instructions which are deemed necessary for protecting the well and preventing any waste of the water thereof. If the owner of the well fails to carry out the repairs during the period specified thereto, the Minister of Commerce and Agriculture may issue orders for effecting such works or the walling or tubbing of the well at the expense of the owner.

All costs which have been defrayed by the Directorate in the aforesaid instances shall be collected by administrative means.

Article 14

Without prejudice to the rules set down in respect of public health, proprietors of pools used exclusively for swimming shall be required to

install water-purifying and -cleaning devices on a permanent basis, provided that the approval of the Directorate of Water Resources is obtained before the installation of the said devices. Pools and water springs located on farms and which are used for agricultural purposes shall be exempted from the above.

Article 15

All proprietors of existing wells or those under construction shall serve the required notification in respect thereof in accordance with the form prescribed in the Regulations for implementing this Law within 30 days from the date of the coming into force of this Law.

Article 16

Any works subject to a permit in accordance with this Law but effected without the said permit or in contravention of the directives and instructions issued by the Directorate of Water Resources may be suspended or removed by administrative means without prejudice to imposing any other penalty.

Article 17

An appeal tribunal shall be formed by an order to be issued by the Minister of Commerce and Agriculture to investigate any appeals made by the persons concerned against any decision taken by the Directorate of Water Resources for the enactment of this Law. Such appeals shall be made within 30 days from the date of the knowledge of the person concerned of the decision against which he is appealing.

Article 18

The person concerned may appeal against the decisions issued by the Minister of Commerce and Agriculture and the decisions adopted by the appeal tribunal provided for in the foregoing Article within 30 days from the date of his knowledge of the decision against which he is appealing.

The appeal shall be made by means of a petition to be submitted to the High Court in the usual manner.

However, reference of the matter to the Court shall not result in stay of execution of the decision required to be revoked. Meanwhile, the Court may order stay of execution if a requisition to this effect is made in the petition and if the Court considers that the results of such execution become impossible to alter. In this case, the Court shall issue its judgement as soon as possible.

Article 19

The Directorate of Water Resources staff, who are designated by an order to be issued by the Minister of Commerce and Agriculture, shall have the right of access to any place wherein licensed or unlicensed wells are located to put this Law into effect. They shall have the power to apprehend any breach in contravention of the provisions of this Law and to issue statements in respect thereof.

Article 20

Without prejudice to the right of the Directorate to issue decisions for suspension of works or walling or tubbing of wells, anyone who contravenes the provisions of this Law or the Regulations which are issued for implementation thereof shall be punished with a fine which shall not be less than 200 Bahraini dinars (BD) and not more than BD 500 and imprisonment for a period of no more than six months or either penalty.

Attempting to commit any of the contraventions mentioned in the foregoing paragraph shall be punishable with a fine not exceeding BD 200.

Article 21

The above-mentioned Proclamation No. 48/1351 and Amiri Decree No. 2/1971 shall be revoked and any provisions which are inconsistent with this Law shall be repealed.

Article 22

The Minister of Commerce and Agriculture shall issue the Regulations for implementing this Law within three months from the date of its publication. He shall also issue the orders required for putting it into effect.

Article 23

The Ministers, each in his respective capacity, shall implement this Law, which shall come into effect after three months from the date of its publication in the Official Gazette.

Signed: Isa Bin Salman Al Khalifa
Amir of the State of Bahrain

Issued at Rifaa Palace on 16 Jumada Al Thaniya 1400 Hijra corresponding to 1 May 1980

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