Kingdom of Bahrain
Ministry of Municipalities and Agriculture
Water Resources Directorate

Water Use and Management in Bahrain: An Overview

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Abstract
Bahrain is an arid country with acute water shortages problems. Rapidly increasing urbanisation, rapid population growth, extensive economic and social developments, and improved standards of living during the last four decades have substantially increased the demand for water, causing over-exploitation of the already scarce renewable groundwater resources well in excess of their safe yield. This has led to a significant decline in groundwater levels, a drastic storage depletion, and serious deterioration in groundwater quality. In response to this acute water situation, the government has embarked on a major water supply augmentation programme through the development of non-conventional water resources to provide additional water supplies for municipal and agricultural uses and to alleviate pressure on the available groundwater resources. The government is also adopting a number of demand-oriented measures and management policies to improve water use efficiency and encourage conservation. This country paper provides an overview of the water resources use and management in Bahrain, and briefly addresses the major water management problems facing the development of these resources. Water use forecasts for specified time-horizons are presented, and progress made towards the implementation of Integrated Water Resources Management (IWRM) tools is outlined. Options for improving water management policies are suggested.

Keywords: Water use, Water demand, Integrated Water Resources Management, Supply augmentation, Demand management.

Introduction
The Kingdom of Bahrain is an archipelago consisting of thirty three low-lying islands, situated in a shallow bay of the Arabian Gulf known as the Gulf of Salwa, approximately halfway between Saudi Arabia in the west and Qatar Peninsula in the east (Figure 1). It occupies an area of about 710.9 Km^2, with a population of 650,604 inhabitants (CSO, 2002). This gives a population density of about 916 inhabitants/Km^2, making it one of the most densely populated countries in the world.

The climate of Bahrain is typical of an arid and semi-arid zones, where the mean evaporation considerably exceeds rainfall. Rainfall is low, erratic and variable, and mainly occurs in the form of short duration rainstorms, with an annual average of about 78 mm. The daily average potential evaporation is 5.75 mm, giving an annual mean of about 2099 mm. The medium to long-term climatological means at Bahrain International Airport are given in Table 1.

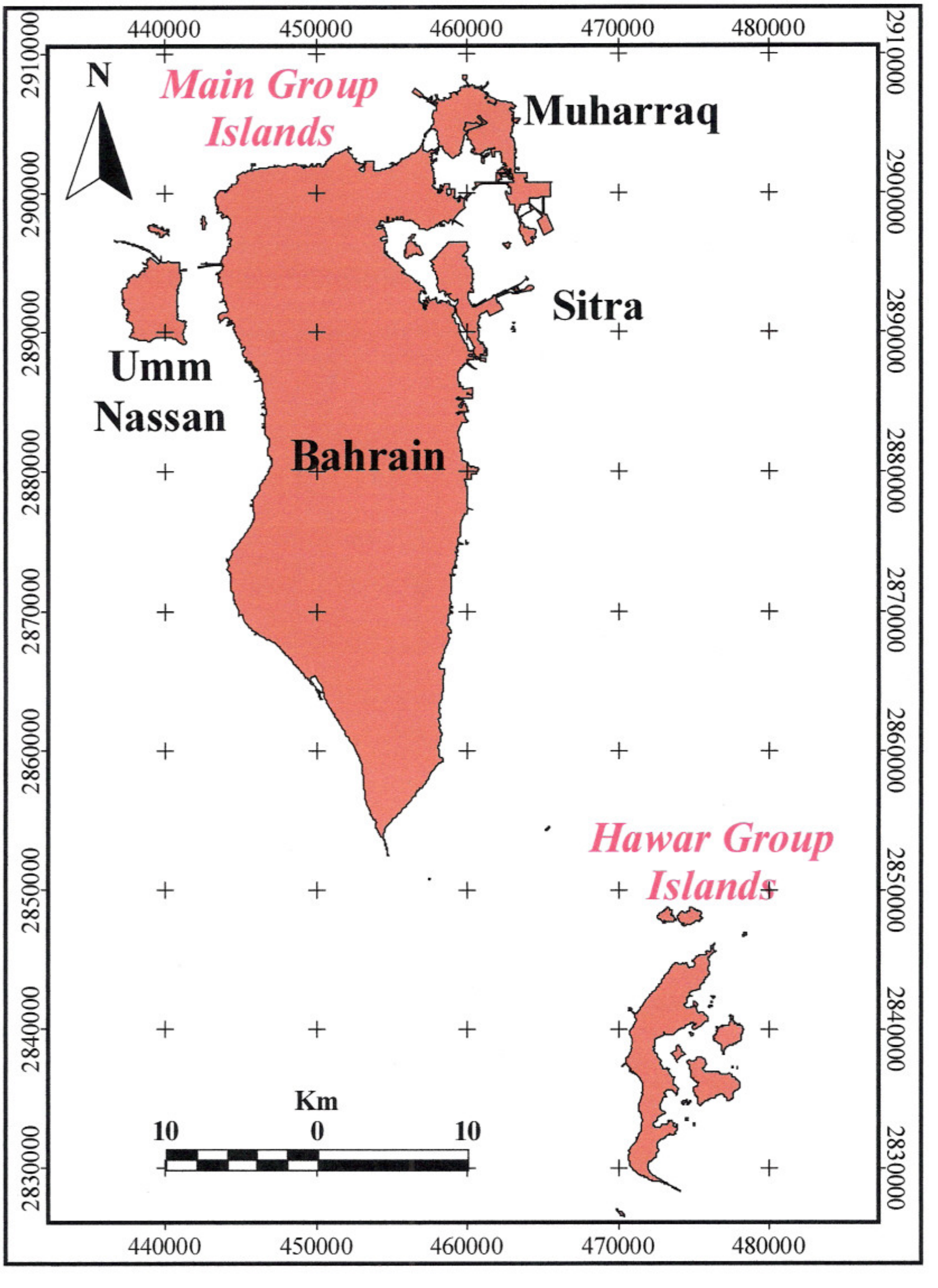

Figure 1 The Location of the Kingdom of Bahrain

Table 1 The medium to long-term climatological means at Bahrain International Airport

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean temperature (˚C)	17.2	18.0	21.2	25.3	30.0	32.6	34.1	34.2	32.5	29.3	24.5	19.3
Mean daily max. temp. (˚C)	20.0	21.2	24.7	29.2	34.1	36.4	37.9	38.0	36.5	33.1	27.8	22.3
Mean daily min. temp. (˚C)	14.1	14.9	17.8	21.5	26.0	28.8	30.4	30.5	28.6	25.5	21.2	16.2
Mean daily max. rel. hum. (%)	88.0	88.0	85.0	82.0	79.0	78.0	80.0	83.0	86.0	88.0	85.0	87.0
Mean daily min. rel. hum. (%)	59.0	55.0	50.0	44.0	39.0	40.0	41.0	44.0	45.0	46.0	52.0	57.0
Mean daily M.S.L pressure (hpa)	1019	1017	1014	1011	1007	1001	998	999	1005	1012	1017	1019
Mean daily vap. pressure (hpa)	14.8	15.2	16.9	20.1	25.0	27.9	31.8	34.4	32.1	27.3	21.6	16.9
Prevailing wind direction	NW	NNW	NNW	N	NNW	NW	NW	NW	NNW	NNW	NNW	NW
Mean daily wind speed (Knots)	10.3	10.7	10.0	9.2	9.6	11.0	8.4	8.5	7.2	7.8	8.9	9.7
Mean evaporation (mm)	89.0	99.0	131.9	170.5	241.7	280.1	266.3	239.0	204.5	160.2	124.2	92.5
Mean daily hours of sunshine (h/day)	7.3	7.9	7.7	8.5	9.9	11.3	10.7	10.7	10.4	9.8	8.7	7.3
Mean total precipitation (mm)	14.6	16.0	13.9	10.0	1.1	Nil	Nil	Nil	Nil	0.5	3.8	10.9
Mean number of rain days (> 1mm)	2.0	1.9	1.9	1.4	0.2	Nil	Nil	Nil	Nil	0.1	0.7	1.7
Mean number of days per month with:												
Fog (visibility 1 km or less)	1.7	1.2	0.4	*	0.2	0.1	0.1	*	0.3	0.7	0.9	1.0
Dust (visibility 1km or less)	0.2	0.3	0.5	0.6	0.2	0.8	1.1	0.3	0.1	0.1	0.1	0.2
Thunderstorms	1.1	0.9	1.7	1.9	0.6	Nil	Nil	Nil	Nil	0.2	0.6	0.8

SOURCE: Meteorological Services

(*) indicates Less than 0.05 but more than zero.

The demand for water has increased substantially over the last four decades, leading to over-exploitation from the already limited renewable groundwater resources far beyond their annual safe yield. Despite the fact that the government has largely invested in the development of non-conventional water resources (desalinated water and treated sewage effluent (TSE)) to provide water supplies of pre-requisite quality for drinking and agricultural uses, and adopted a number of demand management policies to conserve water use, the imbalance between the available water supply and the projected water demand has been growing rapidly, imposing a major constraint on the country's socio-economic development. Groundwater withdrawal from the Dammam aquifer (the principal aquifer system in the country) increased from 138 million cubic metres (Mm^3) in 1979 to 219 Mm^3 in the year 2000, an increase of almost 59 percent. Moreover, the per capita share from the renewable groundwater resources dropped considerably from 220 m^3 per capita per year in 1991 to 172 m^3 per capita per year in 2001; this is expected to further decrease to 137 m^3 per capita per year by the year 2010, if the current rate of groundwater withdrawal is continued (Al-Noaimi, 2004). Total water use was 270 Mm^3 in 1990, increased to 347 Mm^3 in the year 2000, an increase of about 29 percent (Al-Noaimi, 2004). Even with the expected comprehensive developments in non-conventional water resources, future water demand is projected to substantially grow during the next ten years, leading to serious socioeconomic implications.

The objective of this paper is to provide an updated evaluation of the water resources and their uses in Bahrain, and to briefly discuss growth in water demand and various policy issues associated with the development and management of these resources.

Status of Water Resources

Groundwater

Bahrain depends principally on groundwater as the only natural water source. Topographic relief and the prevailing arid climatic conditions preclude any surface water and perennial streams in the country. The aquifer systems in Bahrain are primarily developed in the Tertiary (Palaeocene - Middle Eocene) carbonates rocks that are considered part of the Eastern Arabian Aquifer System; a regional aquifer system that runs from central Saudi Arabia to the Arabian Gulf waters, where Bahrain is located, and regarded as its major discharge basin (GDC, 1980; Zubari, 1987). The Tertiary Aquifer Systems of Bahrain crop out to the west in Saudi Arabia to receive meteoric recharge, implying that the groundwater flow regime has a north-west to south-east direction under an eastward dipping hydraulic gradient.

The aquifer system in Bahrain consists of three aquifers locally termed, in descending order, as Zones "A", "B", and "C". The aquifer Zones "A" and "B" are, respectively, developed in the Alat limestone/dolomitic limestone, and Khobar dolomite/*Alveolina* limestone members of the Dammam Formation (Middle Eocene), and are collectively termed the Dammam Aquifer System. The Aquifer Zone 'C' is developed in the chalky limestone/dolomitic limestone of the Rus Formation and the dolomitic limestone/calcarenite rocks of the upper part of the Umm Er Radhuma Formation (Palaeocene - early Lower Eocene); and is, therefore, designated the Rus - Umm Er Radhuma Aquifer System.

The quality of groundwater in terms of total dissolved solids (TDS) in the Dammam aquifer varies from 2,300 - 4,800 milligrams per litre (mg l^{-1}), whilst the Rus - Umm Er Radhuma aquifer contains brackish water with a TDS concentration of between 7,000 - 15,000 mg l^{-1}. These values represent the normal salinity distributions in these aquifers; in many cases, however, salinity in both aquifers may reach up to 30,000 mg l^{-1} due to seawater intrusion and upconing from deeper saline zones. The estimated annual safe yield of the Dammam aquifer system is between 90 - 112 Mm^3. The Rus - Umm Er Radhuma aquifer is a lens type aquifer and, apart from the minor rainfall recharge to the Rus outcrops near the central basin, this aquifer receives virtually no recharge.

Desalinated Water

The desalination programme was commenced in 1976 with a dual-purpose seawater steam turbine/multistage flash (MSF) plant consisting of two 2.5 million gallons per day (mgd) units constructed as part of the Sitra Power and Water Station Project. This was followed by several plants for seawater and brackish groundwater desalination.

Currently (2003), the total installed desalination capacity is about 74.6 mgd (123.8 Mm^3 $year^{-1}$). This is expected to reach around 144 mgd (238.9 Mm^3 $year^{-1}$) by nearly the end of 2007 when Hidd Phase III expansion, and the proposed expansion and improvement programmes at Ras Abu-Jarjur, Alba Coke Calcining and Ad-Dur Desalination Plants are implemented. The existing and proposed desalination plants and their production capacities are summarised in Table 2.

Owing to the shortage in the desalination capacity, water from the desalination plants is blended with groundwater in about 3:1 ratio before being supplied to the consumers. The quality of blended water put into the public water supply is normally below the desired level of 1,000 mg l^{-1} TDS set by the World Health Organisation (WHO, 1993) for drinking use. The total cost of producing, transmitting, and distributing one unit of blended water at the subsidised energy price is estimated at BD 0.370/m^3 - US$ 0.98/m^3 (Al-Mansour, 1999).

Treated Sewage Effluent

The Government of Bahrain has embarked on a phased construction of sewage treatment plants to provide additional source of water for agriculture and landscaping purposes in order to alleviate pressures on the Dammam groundwater and to retain it for blending and other priority uses. The re-use of TSE for agriculture and landscape irrigation started in 1985. The main wastewater treatment plant in Bahrain is the Tubli Water Pollution Control Centre (Tubli WPCC). There are also eleven minor wastewater treatment plants with a total designed capacity of about 9,720 m^3 day^{-1}.

The existing wastewater treatment facilities at Tubli WPCC include screening and grit removal for primary treatment; an extended aeration activated sludge process, and settling by clarifiers as secondary biological treatment; and dual-medium filtration, pre-chlorination, disinfection by ozone followed by post-chlorination for tertiary treatment. The ozonation facility was added to the system in 1987 to ensure high standard treated effluent.

Table 2 The existing and proposed desalination plants and their annual production capacities

Desalination plant	Type of desalination	Production capacity (Mm^3/year)
Existing plants		
Sitra Power and Water Station	Multistage flash	41.5
Ras Abu-Jarjur Desalination Plant	Brackish groundwater reverse osmosis	22.4
Ad - Dur Desalination Plant	Seawater reverse osmosis	5
Hidd Power and Water Plant (Phase I)	Multistage flash	49.8
Alba Coke Calcining Desalination Plant	Multistage flash	5
Total existing output		123.7
Proposed plants		
Hidd Power and Water Plant (Phase III)	Multistage flash	99.5
Total output by nearly the end of 2007		238.9

Modified from Al-Noaimi, 2004.

Notes: Total outputs by the year 2007 is obtained based on the proposed extension at Ras Abu-Jarjur (26.5 Mm^3), and assuming maximum output from Ad-Dur Desalination Plant of 9.9 Mm^3 (6 mgd), and full output from Alba Calcincing of 11.6 Mm^3 , or 7 mgd.

The Tubli plant is currently (2005) producing about 160,000 m^3 day^{-1} of secondary treated effluent. Out of this amount, around 60,674 m^3 day^{-1} receives tertiary treatment; the balance of about 99,326 m^3 $day^{-1}$of secondary effluent is dumped to the sea. Of the quantity that receives tertiary treatment, only 44,619 m^3 day^{-1} (16.3 Mm^3 $year^{-1}$) is re-used for agriculture and landscape irrigation. The rest (16,055 m^3 day^{-1}) is also dumped to the sea due to the limitation in the transmission and storage facilities. By the year 2010, the Tubli plant is envisaged to produce about 200,000 m^3 day^{-1} (73 Mm^3 $year^{-1}$) of treated effluent.

The chemical quality of the tertiary treated effluent from Tubli is of good standard when compared to the available groundwater resources. Table 3 presents monthly chemical analysis of the inorganic constituents of the TSE from Tubli for the year 2003. It shows that the average total dissolved solids of the TSE is 3,639 mg l^{-1} with domination of chloride and sodium ions, confirming the domestic origin of this water source. Apart from the well-known *Strongyloides* (Parasites) problem, the microbiological quality of the treated effluent from Tubli is of high standard, and is in line with the local and international requirements. The microbiological quality of the TSE from Tubli for the year 2003 is given in Table 4.

The average unit cost of tertiary treated wastewater reaching the end-user is estimated at BD 0.046/m^3; this is equivalent to US $ 0.12/m^3 for the 1997 output level, and at BD 0.045/m^3 for the anticipated output level for year 2010 (PES, 1995).

Water Uses

Total water use in Bahrain represents total pumpage from the aquifer systems for agricultural (including livestock and poultry), municipal, commercial and industrial uses, and water flowing or withdrawn from natural springs for agricultural and rural uses (Al-Noaimi, 2004). It is also made up of blended water delivered from the public supply facilities for municipal purposes, treated sewage effluents supplied to agricultural areas and landscaping, and agricultural drainage water re-used for irrigation (Al-Noaimi, 2004).

Up to 1975, water use in Bahrain was almost exclusively met by groundwater resources. Groundwater withdrawal from the Dammam aquifer for municipal, agricultural, and industrial uses has increased significantly from about 63.2 Mm^3 in 1952 to about 187.7 Mm^3 in 2001, leading to over-exploitation from this aquifer well in excess of its safe yield. This has led to a continuous lowering in water levels and a progressive salinisation by seawater intrusion and upconing of salty water from the deeper saline aquifer. Figures 2 and 3, respectively, show the water level and salinity distributions in the Khobar aquifer for the year 2004. Clearly, the figures reflect serious groundwater depletion and salinisation.

The total amount of groundwater withdrawn during 2003 was about 239.5 Mm^3. Of that amount, about 195.4 Mm^3 (81.6 percent) was withdrawn from the Dammam - Neogene aquifer, and 44.1 Mm^3, or 18.4 percent, from the Rus - Umm Er Radhuma aquifer. Agriculture was the largest user of groundwater from the Dammam aquifer at almost 70 percent. The municipal sector claimed about 54.4 Mm^3, or nearly 28 percent. The balance of 5.1 Mm^3 (2.6 percent) was used by the industrial sector. Hist-

Table 3 Monthly averages of the inorganic constituents in the tertiary treated effluent from Tubli WPCC January – December 2003

Month	Temp. °C	pH	TDS	Alkal.	Hardn.	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	Cl^{-}	PO_4	NO_3^{-}	NO_2^{-}	B
January	25	7.2	3656	128	955	194	79	838	49	361	1560	1.4	2.81	0.062	0.76
February	13	6.8	3660	155	950	183	78	840	46	437	1580	1.5	0.69	0.074	0.75
March	26	7.2	3764	140	910	158	53	782	40	428	1410	1.1	0.79	0.030	0.60
April	28	7.2	3346	137	897	177	57	712	42	413	1520	3.2	1.02	0.324	0.72
May	29	7.3	3490	126	850	200	72	921	38	440	1580	2.5	1.88	0.464	0.68
June	31	9.5	3932	154	955	215	73	833	47	461	1720	2.8	1.87	0.453	0.74
July	32	7.0	3524	126	800	200	58	756	41	430	1850	2.0	2.02	0.134	0.75
August	33	7.0	3916	110	920	192	82	947	41	461	1700	3.5	2.01	0.197	0.74
September	32	7.2	3422	148	885	183	70	970	183	362	1460	3.3	2.84	0.008	0.61
October	30	7.0	4052	157	940	187	64	817	40	426	1580	3.1	2.78	0.028	0.90
November	30	7.1	3900	157	940	---	---	---	---	421	1480	3.1	2.05	0.209	0.70
December	26	7.1	3504	146	800	---	---	---	---	399	1580	4.1	2.62	0.039	0.65

SOURCE: Tabulated from data made available by Tubli WPCC.
Notes: All values are in mg l^{-1}, except pH in pH unit, and temperature as indicated. Alkal. is alkalinity, and Hardn. is hardness.
A dash indicates parameters not analysed.

Table 4 Monthly average microbiological analysis of the TSE from Tubli WPCC January – December 2003 (after Tubli WPCC)

Months	Temp. (°C)	pH (pH unit)	Turbidity (Turb. Unit)	E.Cond. (μSm^{-1})	TSS	VSS	COD	BOD	NH_3-N	F. Col. Num./100 ml	Parasites Num./litre
January	25	7.2	1.7	5288	9	3	35	1.5	0.63	3	15
February	13	6.8	2.6	4984	8	3	34	1.6	3.49	2	7
March	26	7.2	2.1	5000	11	3	29	2.0	4.64	5	8
April	28	7.2	1.4	5028	8	3	33	1.9	1.95	16	17
May	29	7.3	1.2	5023	11	4	31	3.5	1.36	32	16
June	31	9.5	2.4	5277	8	3	30	2.2	2.23	20	14
July	32	7.0	2.3	5077	9	3	33	1.4	0.88	18	6
August	33	7.0	1.4	4768	6	2	30	1.2	0.33	12998	72
September	32	7.2	1.0	4629	7	3	26	1.1	0.34	11533	51
October	30	7.0	1.8	5042	8	3	32	1.2	0.52	0	0
November	30	7.1	1.0	5250	10	4	39	1.2	0.50	381	7
December	26	7.1	2.1	5628	12	4	38	1.3	1.46	1469	15

Notes: TSS and VSS are total suspended solids and volatile suspended solids, respectively. All values are given in milligram per litre (mg l^{-1}) except where indicated.

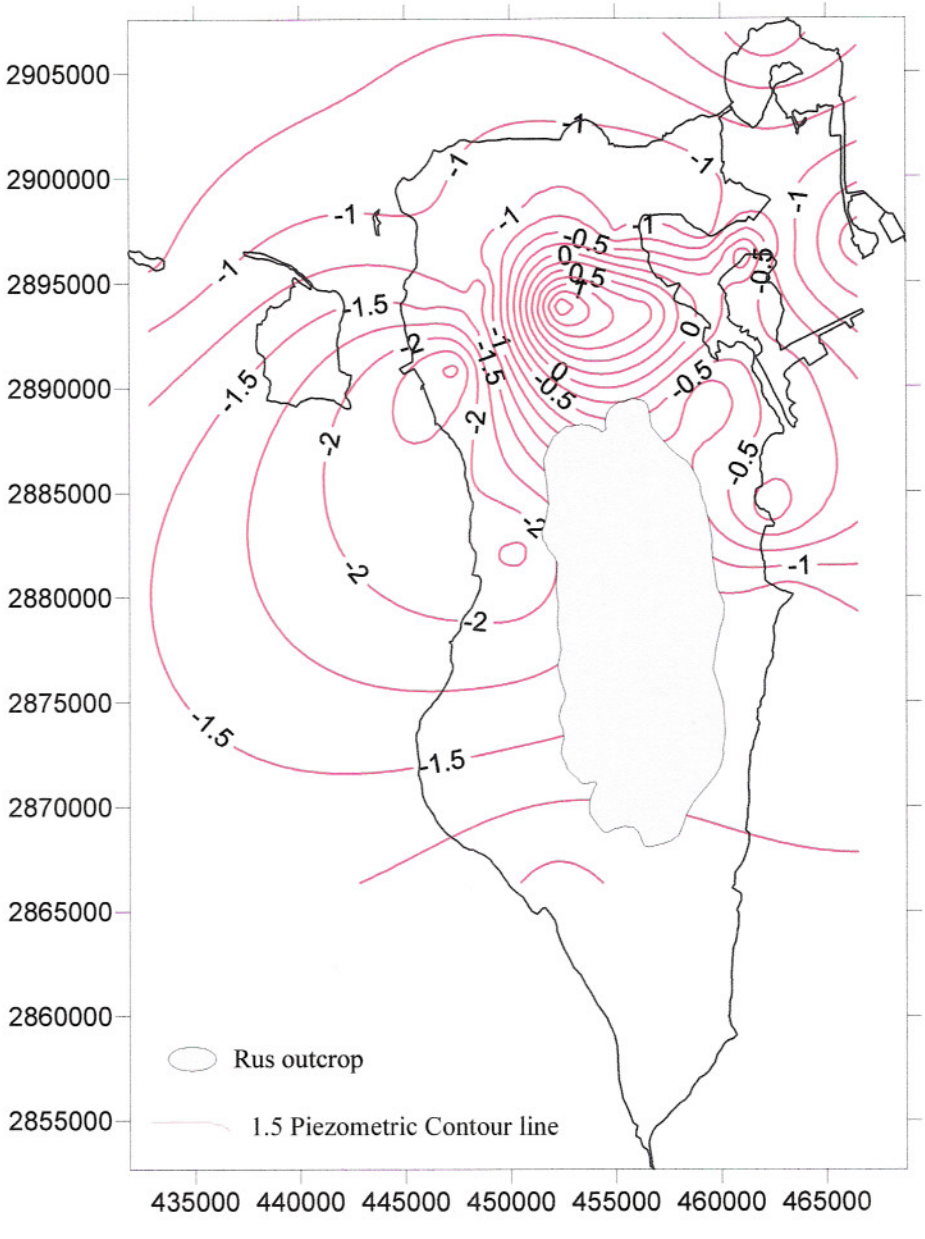

Figure 2 Piezometric contour map of the Khobar aquifer 2004

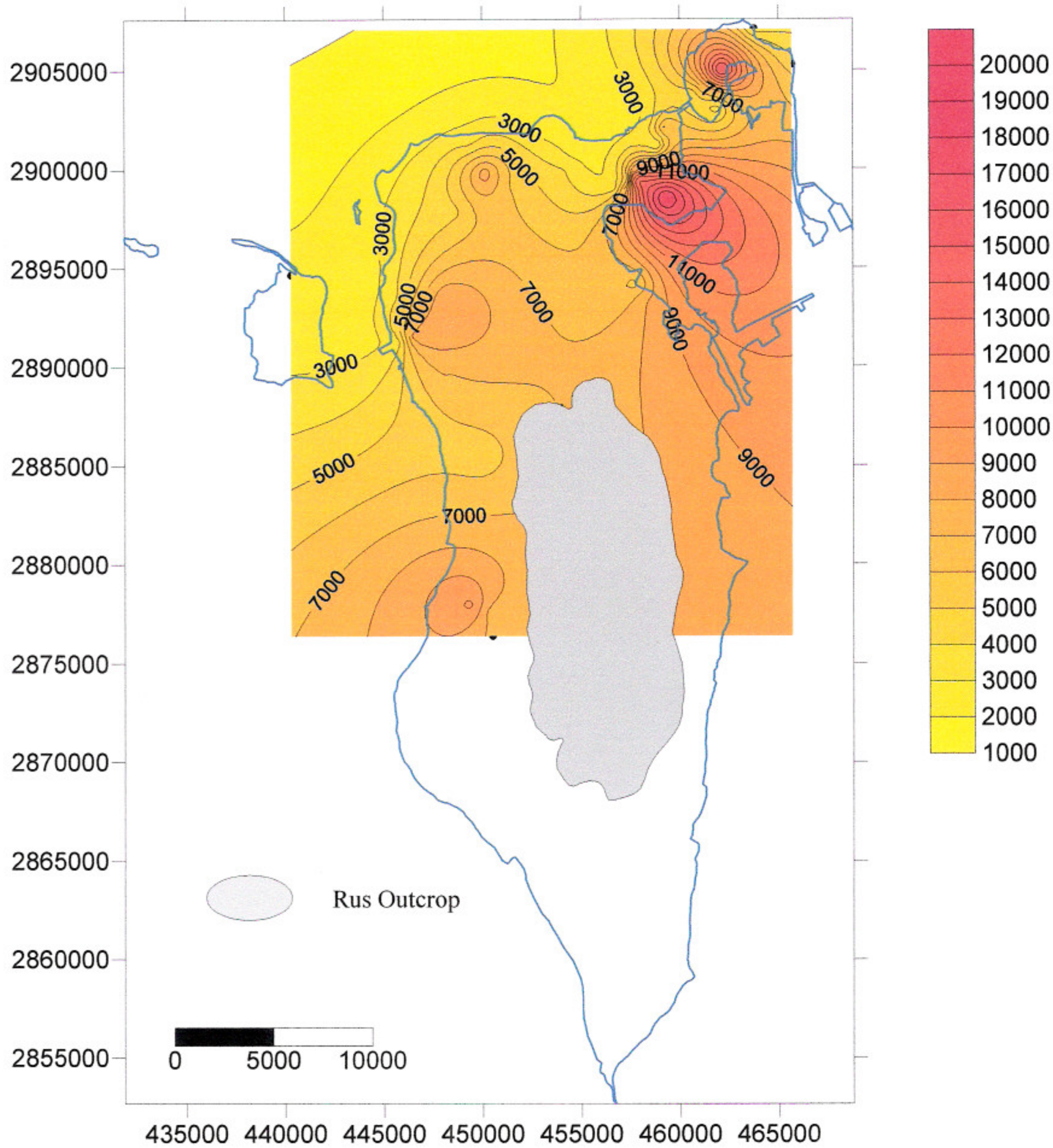

Figure 3 Total dissolved solids distribution in the Khobar aquifer 2004

oric trends of annual groundwater withdrawal by user sectors and aquifer source for the period 1952 - 2003 are given in Table 5.

Figure 4 illustrates the total annual production from the desalination plants during the period 1980 - 2003. It shows that the installed desalination capacity increased substantially from 3.3 Mm^3 during 1980 to 102.4 Mm^3 during 2003. The fluctuations in the desalination output during the period 1991 – 1997 were closely related to the unstable outputs from the Ad-Dur Desalination Plant (Al-Noaimi, 2004).

The total amount of TSE supplied for productive agriculture and landscape irrigation rose by about 98 percent from 8 Mm^3 in 1990 to 15.8 Mm^3 in 2004. During 1997, this amount was estimated at 12.8 Mm^3, out of which 10.5 Mm^3 was for agriculture and 2.3 Mm^3 for landscaping. The vast majority (nearly 74 percent), or 11.7 Mm^3 of treated sewage effluent used in 2004 was for irrigating crops and the remaining quantity of 4.1 Mm^3, or 26 percent, went for landscape irrigation. Table 6 gives estimates for TSE utilisation for the years 1990, 1997, and 2004.

The amount of water used during 2003 for the three principal categories of use totalled about 357.4 Mm^3. Of this quantity, municipal uses had the largest share of 177.9 Mm^3, or 49.8 percent. About 159.2 Mm^3, or 44.5 percent, was used for agriculture. Industrial users consumed about 20.3 Mm^3, or 5.7 percent. Table 7 presents the total water uses in Bahrain per sources and categories of use for the year 2003.

Table 8 presents data on the available water resources in relation to the exploited resources for the year 2003. It shows that a total of 334.6 Mm^3 was exploited that year against an available quantity of 269.1 Mm^3, indicating a net deficit of 65.5 Mm^3, or 24 percent.

Future Water Demand

Water demand projections are an integral part of the decision-making process for water resources planning and management. Rapid urbanisation, aggravated by an increasing population with an average yearly growth rate of about 2.9 percent, have substantially increased the demand for water. The population increased from 89,970 inhabitants in 1941 to 650,604 inhabitants in 2001, a more than seven folds increase. The population of Bahrain is projected to increase to 818,876 during 2010 and to 926,483 in the year 2015 (Al-Noaimi, 2004).

Total water use was about 270 Mm^3 in 1990, increased to 347 Mm^3 in the year 2000. By the year 2005, the demand for water is projected to be 363 Mm^3. Total water demand is forecasted to reach about 458 Mm^3 in 2010, and to increase to 547 Mm^3 by the year 2015. The total sectoral future water demand in comparison with the available supply in the form of water balance for the years 1990, 2000, 2005, 2010, and 2015 is summarised in Table 9. As the table shows, despite the proposed major investment programmes in non-conventional water resources, considerable water deficits will be facing the Kingdom over the next ten years due to the expected huge urban and economic developments. However, these deficits will continue to be covered by mining groundwater from the Dammam aquifer and by abstraction from the non-renewable brackish groundwater from the Rus - Umm Er Radhuma aquifer.

Table 5 Historical records on groundwater pumpage by aquifers and user sectors 1952 – 2003 (updated from Al-Noaimi, 2004)

	Groundwater abstraction in million cubic metres (Mm^3)								
Aquifer system/categories	1952	1966	1971	1979	1985	1990	1993	1997	2003
Dammam - Neogene aquifer									
Agricultural uses	48.0	89.0	96.0	90.0	99.9	124.7	139.0	178.3	135.9
Municipal uses	5.1	16.5	20.9	41.1	47.4	56.8	61.1	65.2	54.4
Industrial uses	10.1	8.2	8.2	7.0	4.9	5.9	6.0	7.4	5.1
Rus - Umm Er Radhuma aquifer									
Agricultural uses	---	---	---	1.3*	2.5	5.0	6.1	6.4	7.8
Municipal uses	---	---	---	---	25.7	23.1	27.3	26.9	29.2
Industrial uses	2.0	2.0	2.0	8.0	4.6	4.0	3.5	3.7	7.1
Total withdrawal	65.2	115.7	127.1	147.4	185.0	219.5	243.0	287.9	239.5

Notes: [1] 1952 data are after Bapco, 1966 after Sutcliffe, 1971 from Italconsult, 1979 are after GDC, 1985 to 2003 are data obtained from WRD files, data on agriculture and industrial abstraction from the Rus Umm Er Radhuma aquifer for 2000 are estimates by the present study.
[2] *Estimated by Al-Noaimi 1993.
[3] A dash indicates zero withdrawal.

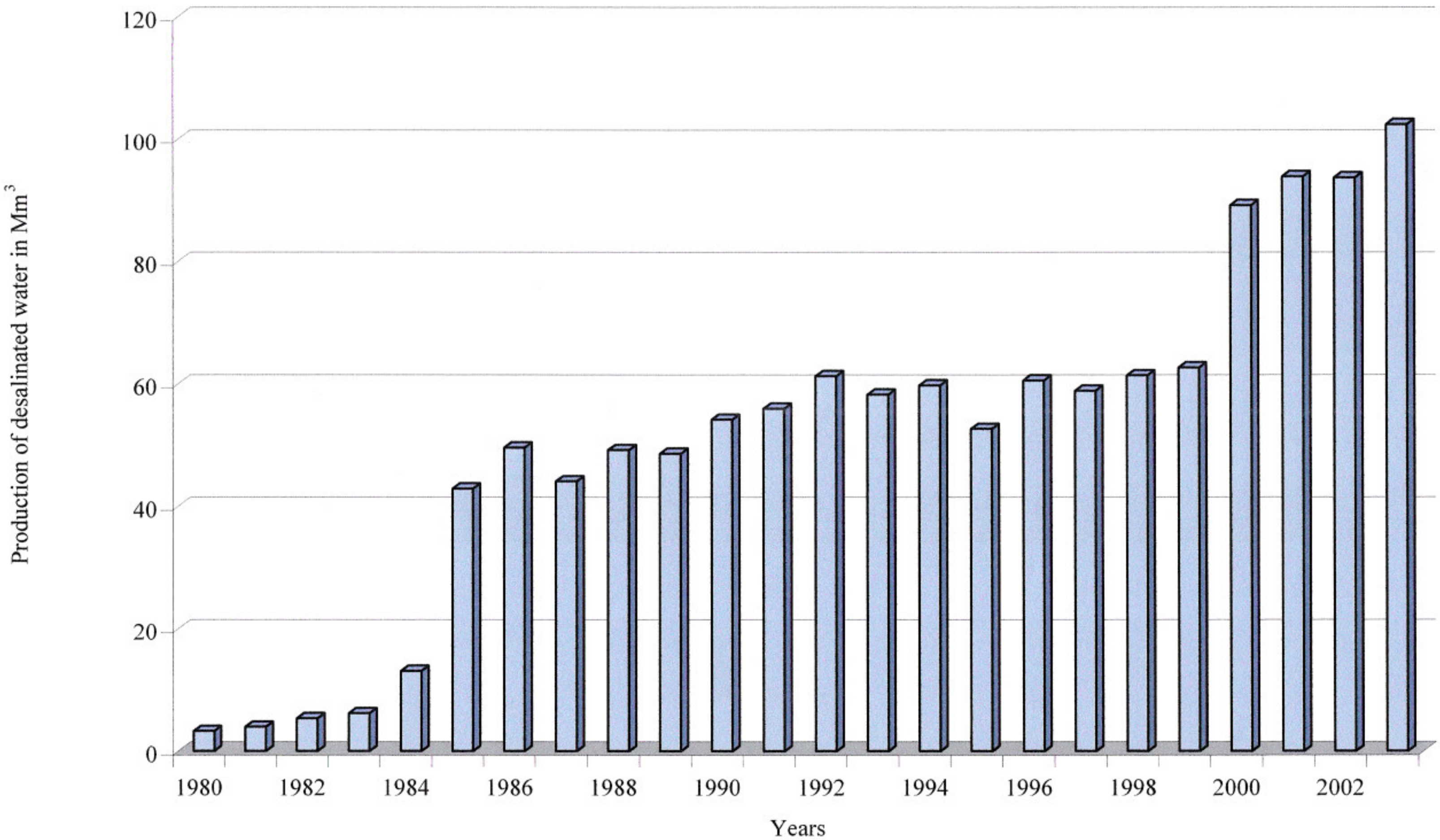

Figure 4 Annual production of desalinated water 1980 - 2003

Table 6 Estimates for TSE utilisation during 1990, 1997 and 2004 (Mm^3)

Year	Agriculture	Landscaping	Total
1990	6.9	1.1	8.0
1997	10.5	2.3	12.8
2004	11.7	4.1	15.8

Note: 1990 estimates are after Al-Noaimi (1993).
Source: Updated from Al-Noaimi (2004).

Table 7 Water uses in Bahrain by sources and categories of use for the year 2003 in Mm^3

Source	Municipal	Agriculture	Industrial	Total uses
Groundwater	83.6	143.7	12.2	239.5
Desalinated water	94.3	---	8.1	102.4
Treated sewage effluent	---	15.5	---	15.5
Total		357.4		

Notes:
1 - A small amount of desalinated water is used for agriculture, but could not be easily isolated from the municipal use.
2 - The small amount (0.19 Mm) of agricultural drainage water is excluded from these estimates.
3 - A dash indicates source is not used for the particular category of use.

Water Resources Management

A well-defined National Master Water Plan (NMWP) for sustainable water resources development and management does not exist in Bahrain. This is evident from the unsatisfactory progress made in the implementation of the IWRM tools as shown in Appendix A. However, a number of rather fragmented water policies and water conservation measures has been initiated over the last three decades to solve the escalating water shortage problems in the country. These include, but are not limited to, the following:

Supply Augmentation

Realising the magnitude of the groundwater shortage and continuous deterioration in its quality, and the need to provide drinking water of pre-requisite quality and additional sources of water for irrigation, the government of Bahrain embarked on a major desalination and wastewater treatment programmes to supplement the groundwater supplies (Al-Noaimi, 2004). As mentioned earlier, at present, a total

Table 8 Distribution of the available and exploited water resources by source and percentages and their relationship for the year 2003

Source	Available quantity (Mm^3)	Percentage (%)	Exploited quantity (Mm^3)	Percentage (%)	Exploited/available water resources
Groundwater	126.6[(1)]	47	195.4[(2)]	58.4	1.54 (-68.8)
Desalinated water	123.7	46	123.7	37	1.0 (0)
Treated sewage effluent	18.8	7	15.5	4.6	0.82 (3.3)
Total resources (Mm^3)	269.1		334.6		
Total percentages (%)		100		100	1.24 (-65.5)

Notes:

[(1)] Based on the total inflows (through flow from the Saudi Arabia mainland plus the estimated local recharge to the Dammam aquifers after Al-Noaimi (2004).

[(2)] Based on the total abstraction from the Dammam aquifers.

Bracketed figures are the difference between the exploited and available water resources in Mm^3 – figures in minus indicate deficits.

The small amount (0.19 Mm3) of agricultural drainage water currently (2003) in use is excluded from these estimates. The available quantity of this Source was also excluded from this analysis due to its high salinity.

Data are updated from Al-Noaimi (2004).

Table 9 Projections of population, and water demand, supply, and deficits until 2015 (Mm^3)

	1990	2000	2005	2010	2015
Population	508037	650604	723767	818876	926483
Water demand					
• Municipal	112	144	156	235	273
• Agriculture	147	186	181	184	220
• Industrial	11	17	26	39	54
Total water demand	**270**	**347**	**363**	**458**	**547**
Water supply					
• Groundwater	144	126.6(1)	126.6	124.6	122.6
• Desalinated water	54	89	123.7	238.9(2)	288.6
• Treated sewage effluent	8	15	23.3	73	73
Total water supply	**206**	**230.6**	**273.6**	**436.5**	**484.2**
Net dificits	64	116.4	89.4	21.5	62.8

Source: Updated from Al-Noaimi (2004).

(1) Based on the calculated total inflows (through flow from the mainland and local recharge) to the Dammam aquifers after Al-Noaimi (2004).

(2) See the notes to Table 2.

of 123.8 Mm^3 of desalinated water is used to meet municipal and industrial water demands. This is expected to grow to 238.9 Mm^3 by the year 2007. In addition, the quantity of treated sewage effluent that would be available for re-use for agriculture and landscape irrigation is projected to increase from its present level of 16.3 Mm^3 to about 73 Mm^3 by the year 2010. Supply augmentation policies have also been considered through the implementation of some artificial groundwater recharge projects.

Demand Management Measures

Several water conservation and regulatory measures have been in practice over the last two decades. In the municipal sector, there have been considerable efforts to cut down the water consumption through an ambitious water conservation programme that includes the introduction of water saving and flow limiting devices, supply ceiling and rationing system policies, leak detection and pressure control programmes, economic incentives, and the launch of public awareness campaigns. Agriculture has always been the largest water user of groundwater resources mainly because of the wasteful and inefficient water uses. The government, through a subsidy programme, has promoted the use of modern irrigation techniques as well as improving the traditional irrigation practices to increase irrigation efficiency and minimise water losses. Among the demand modification policies in this sector, measures such as improving the agricultural drainage systems and farming practices, as well as changing the crop patterns (particularly alfalfa) to less water consuming crops, have also been considered.

Water Pricing

In 1990, the government imposed a rising block pricing structure to promote water conservation in the municipal sector, with different rates set for domestic and non-domestic consumers, and blended and brackish groundwater supplies. Unfortunately, however, this tariff structure has been modified and significantly reduced since May 1992. An incremental tariff structure for charging for groundwater use in agricultural, industrial, and tourism sectors has also been proposed but is yet to be implemented.

Institutional and Legal Reforms

Institutional weakness and fragmentation of responsibilities is one of the major reasons for water policy failure. Responsibilities for water development, use, and management in the country are distributed among several water authorities. In 1982, the government established The High Water Council, a ministerial body responsible for drawing up the country's water policy, and coordinating among the concerned authorities in all aspects related to water resources development and management. However, the Council does not seem very active, and responsibilities are still fragmented with lack of a proper coordination among the concerned water authorities. The government has also issued numerous laws and legislation to regulate, administer, and control groundwater use; the most important of which is the Amiri Decree No. 12 of 1980, Governing the Use of Groundwater, which was amended and substantially improved by the Amiri Decree No. 12 of 1997. Several Ministerial orders and legislative decrees were issued at different stages to enhance enforcement of these laws. Capacity building is one of the institutional issues that have been given little importance; this result in inadequate technical capabilities, especially in the areas of groundwater development and management.

Enhancing the State of Monitoring and Information Systems

The availability of reliable information systems and databases is necessary to support the decision-making process required for effective water planning and management (Al-Noaimi, 2004). The Water Resources Directorate (WRD) of the Ministry of Municipalities and Agriculture has file records of well completion reports since 1930s, many of which provide detailed information of high credibility. In 1984, the government has embarked on a phased programme to install water meters on all groundwater wells in order to monitor abstraction. This was considered to be the first step towards pricing groundwater. Currently, the majority of these wells are being metered and their abstraction is monitored on regular basis. In terms of monitoring groundwater levels, the WRD has established a well-designed country-wide observation network consisting of about 68 monitoring wells. All data from these wells are already stored in computers and can be easily retrieved in various forms. Data on groundwater quality are normally collected on an ad-hoc basis, although the Ministry of Electricity and Water carries out somewhat systematic salinity surveys. However, efforts are being made at the WRD to design a regular and more reliable groundwater quality observation network to monitor the salinity of the Dammam aquifer. Medium to long-term metrological data are available from the Bahrain International Airport Metrological Station (see Table 1). A reliable short-term metrological data are also available from Shiekh Isa Air Base Station and, to a less extent, from other minor metrological stations.

Although the existing hydrogeological information system in the Kingdom may be considered to be of adequate quality, there is still a need to upgrade it in terms of data collection, processing, retrieval, and presentation. The preparation of a comprehensive computerised groundwater database is presently under consideration at the WRD.

Conclusion and Recommendations

Bahrain is facing serious water shortage problems due to the rapid population growth and substantial urban and economic developments. Groundwater resources, the only natural resources in the country, have been extensively exploited beyond their reliable safe yield. In spite of the government efforts to develop expensive additional water supplies and to adopt various demand management measures to conserve water use, the gap between the available water supplies and the anticipated water demand has been continuously growing. It appears that the policy objectives of these supply-demand management efforts are rather fragmented and are inconsistent with the principles of sustainable water resources development and management. Therefore, there is a desperate need to formulate a clearly-defined and properly integrated water management policies that take into consideration various socio-economic and political issues related to water resources development and planning.

Unfortunately, investment in expensive desalination and sewerage treatment facilities need to be continued. Treated sewage effluent is a strategic water source for agriculture. Careful planning and management of this source, including setting up of a national policy on TSE reuse is, therefore, essential. Because institutional weakness is one of the main reasons for water policy failure, responsibilities for water resources development, monitoring and management should be strengthened and properly coordinated among the concerned authorities through an appropriate form of a central body. There is a need to establish a comprehensive computerised groundwater/water resources database that can be made accessible by researchers and water resources planners to enable better understanding and to enhance decision-making processes. Legal reforms, including enforcement of water laws and legislation without exceptions must be considered. Capacity building should keep pace with the progress in research and escalating water problems. Price reform to reflect the real values of water supply is badly needed. Policy instruments for water allocation and charging for water use for agriculture should be put into practice. Active involvement of stakeholders and the public at large is necessary for effective water management.

Appendix 1 Progress made in the implementation of Integrated Water Resources Management in the Kingdom of Bahrain

Rating	1- Policies: setting goals for policy use, protection and conservation		2- Legislative framework: water policy translated into law			3- Financing and incentive structure: financial resources to meet water needs			
	a) Preparation of national water policy	b) Preparation of water strategy	a) Water rights	b) Legislation for water quality	c) Reform of existing legislation	a) Investment policies	b) Institutional reform in the public sector	c) The involvement of private sector	d) Application cost recovery of water policy
A			×					×	×
B	×	×					×		
C				×	×				
D						×			
E									

Appendix 1 (Continued)

Rating	4- Creating an institutional framework forms and functions							5- Building institutional			
	a) River basin organi-zation	b) National apex organiz-ation	c) Agency for manage-ment of shared water resources	d) Regulatory bodies and enforcement agencies	e) Logical author-ities	f) Service provi-der and IWRM	g) Civil society initiations and local community organisation	a) Training to build IWRM cap-acity of wat-er prof.	b) Regulat-ory capacity	c) Participation in knowledge	d) Particip-atory capacity for empowere-ment
A			×	×			×				×
B						×		×	×	×	
C		×									
D											
E											

Appendix 1 (Continued)

Rating	6- Water resources assignment: water availability and development				7- Plans for IWRM			8- Efficiency in water use: managing demand		9- Efficiency in water use: managing demand		
	a) Establishment of water data knowledge base	b) Asset water resources	c) Modeling in IWRM	d) Developing water management indicators	a) Improved efficiency in water use	b) Recycling and reuse	c) Improved efficiency of water supply	a) Basin management plans	b) Risk assessment and management	a) Improved efficiency of use	b) Recycling and reuse	c) Improved efficiency of water supply
A				×					×			
B					×	×				×	×	
C	×	×	×				×					×
D												
E												

Appendix 1 (Continued)

Rating	10- Information management and exchange: better knowledge for better water management		11- Social change instruments: encouraging a water-oriented society						12- Conflict resolution		
	a) Information management system	b) Sharing national and international data	a) Education curricula on water manag.	b) Training of water professionals	c) Training of trainers	d) Communication with stakeholders	e) Water campaigns and awareness raising	f) Broadcasting of the participation base	a) Conflict management	b) Shared vision planning	c) Consensus-building
A		×			×	×			×	×	×
B	×		×	×				×			
C							×				
D											
E											

Appendix 1 (Continued)

Rating	13- Regulatory instruments				14- Economic instruments: using value prices for efficiency and equity			
	a) Regulations for water quality	b) Regulations for water quality indicators	c) Regulations for water services	d) Land-use planning controls and nature protection	a) Pricing of water and water services	b) Pollution and environmental charges use	c) Water marks and tradable permits	d) Subsidies and incentives
A				×		×	×	
B		×						
C	×		×					
D					×			×
E								

Notes:

1. Ratings are those of the author and do not necessarily represent the official view.
2. Rating tools left blank indicate that tools are not applicable.

Ratings:
Rating of A: The country did not apply any of IWRM tools.
Rating of B: The country has begun to apply less than 25%.
Rating of C: The country applied most (50%) of the management tool but not satisfactorily.
Rating of D: The country applied more than 50% of the tools.
Rating of E: The country applied all the tools satisfactorily.

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