CHAPTER 4 FUTURE SCENARIOS BASED ON SOCIO-ECONOMY AND WATER DEMAND IN SANA'A BASIN

4.1 GENERAL

In this Chapter, at first, future water demand is projected in accordance with information provided by organizations concerned in order to make clear that how much quantity of water will be deficit and how long the limited water resources will be able to be consumed inside Sana'a Basin. Then, the possible scenarios to mitigate severe condition of water resources are considered. Based on these results, one scenario to be taken is chosen.

4.2 FUTURE WATER DEMAND

Water sector in Sana'a Basin is classified into five sectors as follows: 1) urban area water supply composed of domestic and institution purpose, 2) domestic purpose in rural area, 3) industrial purpose, 4) tourist purpose and 5) irrigation purpose. Projection of future water demand of each sector was conducted in this study based on the existing information provided by organization concerned. The results are described in the following sections.

4.2.1 POPULATION FORECAST FOR SANA'A BASIN

(1) Population Forecast for Sana'a City

Population forecast for Sana'a City has been done by Dar Al-Handasah (2000), adopting three growth scenarios reflecting high, moderate and limited growth. The assumed rate under the high growth scenario was 6.1% in 1997 (base year of study carried by Dar Al-Handasah) and decease to 4.2% in 2020. Assumed rates under the moderate and limited growth scenarios were 5.6% and 5.1% respectively in 1997 and decrease to 3.3% and 2.4% respectively in 2020.

Since that the study carried by Dar Al-Handasah (2000) is the master plan for urban water supply and sanitation projects for Sana'a City, followed by SWSLC, and no suitable updated data or report was available during the study period, in this study, population forecast was estimated based on growth rates mentioned above. Population growth rate for Sana'a City during the period between 1994 and 2004 was 5.5% and this rate is decreasing up to 4.2%, 3.3% and 2.4% respectively for high, medium and limited growth in the year of 2020.

Population forecast for Sana'a City is shown in *Table 4.1* and *Figure 4.1*. According to the results of population forecast, the population of Sana'a City under the moderate growth rate which was adopted for project planning purpose, for the year of 2006, the base year of this study, is 1.9 million inhabitants and for 2020, 3.4 million inhabitants is estimated.

Table 4.1 Population Forecast for Sana'a City by Scenario

Year	High Growth Rate		Moderate Growth Rate		Limited Growth Rate	
1994	1,003,627		1,003,627		1,003,627	
2004	1,747,834	5.50	1,747,834	5.50	1,747,834	5.50
2005	1,842,545	5.42	1,841,562	5.36	1,840,578	5.31
2006	1,940,891	5.34	1,937,783	5.23	1,934,678	5.11
2007	2,042,909	5.26	2,036,368	5.09	2,029,840	4.92
2008	2,148,629	5.18	2,137,168	4.95	2,125,750	4.73

Year	High Growth Rate		Moderate Growth Rate		Limited Growth Rate	
2009	2,258,075	5.09	2,240,019	4.81	2,222,073	4.53
2010	2,371,261	5.01	2,344,740	4.68	2,318,455	4.34
2011	2,488,194	4.93	2,451,133	4.54	2,414,526	4.14
2012	2,608,871	4.85	2,558,983	4.40	2,509,900	3.95
2013	2,733,282	4.77	2,668,059	4.26	2,604,178	3.76
2014	2,861,404	4.69	2,778,117	4.13	2,696,952	3.56
2015	2,993,208	4.61	2,888,894	3.99	2,787,806	3.37
2016	3,128,650	4.53	3,000,117	3.85	2,876,319	3.18
2017	3,267,680	4.44	3,111,496	3.71	2,962,069	2.98
2018	3,410,232	4.36	3,222,732	3.58	3,044,636	2.79
2019	3,556,233	4.28	3,333,513	3.44	3,123,607	2.59
2020	3,705,595	4.20	3,443,519	3.30	3,198,573	2.40

Source: Statistical Year Book 2005 (population of 1994 and 2004)

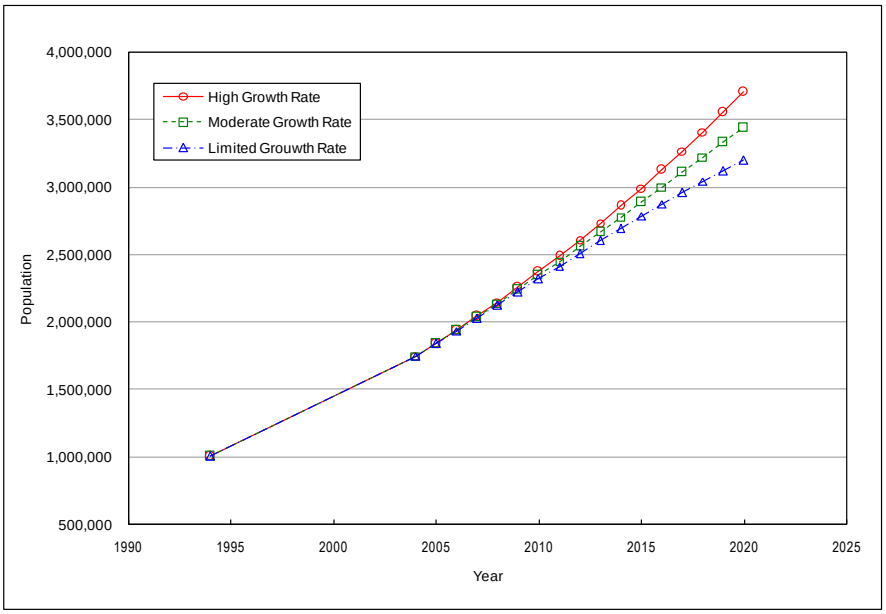

Figure 4.1 Chart of Population Forecast for Sana'a City

(2) Population Forecast for Rural Areas within the Basin

The population within the Basin for the year of 2004 was calculated according to the percentage of the area of each district included in the Basin and the population of each district based on results of 2004 Census as shown in *Table 4.2*. For this calculation, it was assumed that the population is uniformly distributed within the district.

In this study, population forecast for districts of Bani Husheish, Sanhan and Bani Bahloul, Hamdan, Arhab, Nehm, Al Taial, Bani Matar and Jahana was calculated based on the growth rate of 2.5% that is adoped by GARWSP. Results of projections are shown in *Table 4.3*.

(3) Population Forecast by Sub-Basin

The population within each of 22 sub-basins for the year of 2004 was calculated according to the percentage of the area of each district included in the sub-basin and population calculated above. Growth rate adopted for rural areas is 2.5% and for the urban area, moderated growth

rate was adopted. Results of estimation are shown in *Table 4.4*.

Table 4.2 Estimated Population within the Basin by District (2004)

District	District		Area of the district within the Basin		
	Area (km^2)	Population (inhabitants)	Area (km^2)	%	Population (inhabitants)
Sana'a City	404.2	1,747,834	404.2	100.0	1,747,834
Bani Husheish	340.7	73,957	340.7	100.0	73,957
Sanhan and Bani Bahloul	600.0	80,399	483.8	80.6	64,832
Hamdan	589.9	84,882	442.1	74.9	63,612
Arhab	1,288.4	90,038	556.5	43.2	38,891
Nehm	1,961.0	41,502	474.7	24.2	10,046
Al Taial	395.8	36,253	128.6	32.5	11,779
Bani Matar	1,117.5	100,012	319.6	28.6	28,605
Jahana	617.8	50,747	36.6	5.9	3,009
Area within Amran Gov.*	49.9	---	49.9	100.0	---
Total	6,911.1	2,305,624	3,236.7	---	2,042,565

*Based on natural boundary for the catchment area of the Basin. This area is considered uninhabited

Table 4.3 Projection of Population by Districts Within the Sana'a Basin

District / Year	Bani Husheish	Sanhan and Bani Bahloul	Hamdan	Arhab	Nehm	Al Taial	Bani Matar	Jahana	Total
1994	54,375	60,999	47,415	27,061	8,397	***	34,370	***	232,617
2004	73,957	64,832	63,612	38,891	10,046	11,779	28,605	3,009	294,733
2005	75,806	66,453	65,203	39,864	10,298	12,074	29,320	3,084	302,101
2006	77,701	68,114	66,833	40,860	10,555	12,375	30,053	3,161	309,653
2007	79,644	69,817	68,504	41,882	10,819	12,685	30,805	3,240	317,395
2008	81,635	71,562	70,216	42,929	11,089	13,002	31,575	3,321	325,330
2009	83,676	73,351	71,972	44,002	11,367	13,327	32,364	3,404	333,463
2010	85,767	75,185	73,771	45,102	11,651	13,660	33,173	3,490	341,799
2011	87,912	77,065	75,615	46,230	11,942	14,002	34,003	3,577	350,344
2012	90,109	78,991	77,506	47,385	12,241	14,352	34,853	3,666	359,103
2013	92,362	80,966	79,443	48,570	12,547	14,710	35,724	3,758	368,081
2014	94,671	82,990	81,429	49,784	12,860	15,078	36,617	3,852	377,283
2015	97,038	85,065	83,465	51,029	13,182	15,455	37,532	3,948	386,715
2016	99,464	87,192	85,552	52,305	13,511	15,842	38,471	4,047	396,382
2017	101,951	89,372	87,691	53,612	13,849	16,238	39,432	4,148	406,292
2018	104,499	91,606	89,883	54,953	14,195	16,644	40,418	4,252	416,449
2019	107,112	93,896	92,130	56,326	14,550	17,060	41,429	4,358	426,861
2020	109,790	96,243	94,433	57,735	14,914	17,486	42,464	4,467	437,532

* Growth rate: 2.5%, rate adopted by GARWSP Unit: inhabitants

Table 4.4 Population Forecast by Sub-Basin

Sub-Basin \ Year		2005	2006	2010	2015	2020
1	Wadi Al Mashamini	5,480	5,617	6,200	7,014	7,936
2	Wadi Al Madini	14,016	14,366	15,858	17,941	20,299
3	Wadi Al Kharid	10,647	10,950	12,238	14,020	15,991
4	Wadi Al Ma'adi	2,419	2,479	2,736	3,096	3,503
5	Wadi A'sir	4,560	4,674	5,159	5,837	6,604
6	Wadi Khulaqah	1,687	1,729	1,908	2,159	2,443
7	Wadi Qasabah	4,624	4,740	5,232	5,919	6,697
8	Wadi Al Huqqah	17,053	17,622	20,035	23,337	26,900
9	Wadi Bani Huwat	1,104,206	1,161,546	1,403,916	1,728,142	2,058,854
10	Wadi Thumah	148,600	156,316	188,929	232,556	277,057
11	Wadi As Sirr	47,314	48,822	55,224	64,010	73,556
12	Wadi Al Furs	10,185	10,440	11,524	13,038	14,752
13	Wadi Al Iqbal	26,191	26,845	29,632	33,526	37,932
14	Wadi Zahr & Al Ghayl	73,755	76,512	88,198	104,083	120,944
15	Wadi Hamdan	55,268	57,953	69,306	84,537	100,186
16	Wadi Al Mawrid	440,583	463,330	559,482	688,139	819,450
17	Wadi Sa'wan	31,035	32,131	36,778	43,115	49,896
18	Wadi Shahik	92,620	96,700	113,963	137,228	161,407
19	Wadi Ghayman	18,321	18,779	20,729	23,453	26,535
20	Wadi Al Mulaikhy	7,459	7,646	8,440	9,549	10,803
21	Wadi Hizyaz	10,761	11,030	12,175	13,775	15,585
22	Wadi Akhwar	16,835	17,255	19,047	21,550	24,382
	Total	2,143,619	2,247,483	2,686,707	3,276,023	3,881,712

Unit: inhabitants

4.2.2 DOMESTIC WATER DEMAND

(1) Urban Water Supply

SWSLC has prepared the Development Program namely Sana'a Water Supply and Sanitation Projects (SWSSP). Future water demand for urban area is projected in this Development Program with four alternative options and conditions as mentioned in the section 5.8.2 in Supporting Report, and includes water demand of both domestic and non-domestic water use supplied by both public and private suppliers. According to SWSLC, water supply for urban area is forwarded in accordance with the Option 1, that is, 35 l/c/d for domestic consumption for entire city population. Designed physical loss is planned 20%. Future water demand for urban water supply is shown in *Table 4.5*.

Table 4.5 Water Demand for Urban Areas

	Unit	2005	2006	2010	2015	2020
Population	(no)	1,841,562	1,937,783	2,344,740	2,888,894	3,443,519
Public water supply		672,141	696,141	1,104,115	1,763,511	2,582,639
Private water supply		1,169,421	1,241,642	1,240,625	1,125,383	860,880
Unit Consumption						
Domestic						
Option 1	(l/c/d)	Pub. Supply	Pub. Supply	35.0	35.0	35.0
Option 2		50.8	51.6	59.7	69.9	80.0
Option 3, 4						
Public water supply		Priv. Supply	Priv. Supply	80.0	80.0	80.0
Private water supply		70.0	70.0	35.0	35.0	35.0
Non-domestic						
Option 1	(% of total)	---	---	30%	30%	30%
Consumption						
Domestic						
Option 1	(MCM)			30.0	36.9	44.0
Public water supply		12.5	13.1	32.2	51.5	75.4
Private water supply		29.9	31.7	15.8	14.4	11.0
Non-domestic						
Option 1	(MCM)	1.3	1.6	12.8	15.8	18.9
Total Consumption						
Option 1	(MCM)	43.7	46.4	42.8	52.7	62.8
Total Supply Requirement Including Physical Losses @ 20% of Production						
Option 1	(MCM)	54.3	55.8	53.5	65.9	78.6

*Population estimated based on results of 2004 Census, under the moderate growth rate scenario

*Population covered by the public water supply for 2005 and 2006 based on SWSLC annual report (2006)

*Unit consumption of 2005 and 2006: based on SWSLC's annual report (2006) for public water supply and for the private water supply was estimated based on the Development Programme (2000)

*Water consumption for non-domestic use was based on SWSLC's annual report (2006)

*Total Supply Requirement for 2005 and 2006 shows the total of water produced between the public water supply (based on SWSLC's annual report(2006)) and assuming water consumption = water production, for the private water supply

(2) Rural Water Supply

GARWSP is of the responsible body for planning and implementation of rural water supply. However, there is a lack of available information related to the projection of future water supply. Future water demand for this sector, therefore, is calculated based on the standards adopted by GARWSP for water supply projects, that is, a population growth rate of 2.5% and unit water consumption of 40 l/c/d by sub-basin as shown in *Table 4.6*.

Table 4.6 Future Water Demand for Rural Area by Sub-Basin

Sub-Basin		2005		2010		2015		2020	
		Population	Water Demand	Population	Water Demand	Population	Water Demand	Population	Water Demand
1	Wadi Al Mashamini	5,480	0.08	6,200	0.09	7,014	0.10	7,936	0.12
2	Wadi Al Madini	14,016	0.20	15,858	0.23	17,941	0.26	20,299	0.30
3	Wadi Al Kharid	9,294	0.14	10,515	0.15	11,897	0.17	13,461	0.20
4	Wadi Al Ma'adi	2,419	0.04	2,736	0.04	3,096	0.05	3,503	0.05
5	Wadi A'sir	4,560	0.07	5,159	0.08	5,837	0.09	6,604	0.10
6	Wadi Khulaqah	1,687	0.02	1,908	0.03	2,159	0.03	2,443	0.04
7	Wadi Qasabah	4,624	0.07	5,232	0.08	5,919	0.09	6,697	0.10
8	Wadi Al Huqqah	11,834	0.17	13,389	0.20	15,149	0.22	17,139	0.25
9	Wadi Bani Huwat	15,013	0.22	16,986	0.25	19,218	0.28	21,744	0.32
10	Wadi Thumah	2,058	0.03	2,329	0.03	2,635	0.04	2,981	0.04
11	Wadi As Sirr	35,392	0.52	40,043	0.58	45,305	0.66	51,258	0.75
12	Wadi Al Furs	10,185	0.15	11,524	0.17	13,038	0.19	14,752	0.22
13	Wadi Al Iqbal	26,191	0.38	29,632	0.43	33,526	0.49	37,932	0.55
14	Wadi Zahr & Al Ghayl	40,281	0.59	45,574	0.67	51,563	0.75	58,339	0.85
15	Wadi Hamdan	7,539	0.11	8,530	0.12	9,650	0.14	10,919	0.16
16	Wadi Al Mawrid	10,830	0.16	12,253	0.18	13,863	0.20	15,685	0.23
17	Wadi Sa'wan	19,312	0.28	21,850	0.32	24,721	0.36	27,970	0.41
18	Wadi Shahik	28,010	0.41	31,691	0.46	35,855	0.52	40,567	0.59
19	Wadi Ghayman	18,321	0.27	20,729	0.30	23,453	0.34	26,535	0.39
20	Wadi Al Mulaikhy	7,459	0.11	8,440	0.12	9,549	0.14	10,803	0.16
21	Wadi Hizyaz	10,761	0.16	12,175	0.18	13,775	0.20	15,585	0.23
22	Wadi Akhwar	16,835	0.25	19,047	0.28	21,550	0.31	24,382	0.36
	Total	302,101	4.41	341,799	4.99	386,715	5.65	437,532	6.39

Unit: Population: inhabitants,
Water demand: milion cubic meters

4.2.3 AGRICULTURAL WATER DEMAND

Irrigation water demand was estimated by GAF (2007) calculating the actual evapotranspiration (ETa) based on FAO approach and results from satellite data analyses. ETa reflects the gross amount of water consumed by the vegetation (crop), i.e. the minimum amount of water necessary to the plant. However, it must be considered that more water is used by farmers to irrigate his land than the plants itself. This difference is expressed in the irrigation efficiency. As it is mentioned in section 2.3.2 in Chapter 2, 40% is applied for the irrigation efficiency.

Projection of future water demand was estimated based on results of GAF (2007) which has calculated the total ETa of each crop. In this study, ETa per unit of irrigated area of each crop was calculated to calculate the water demand in relation to the increase of irrigated land projected above. *Table 4.7* shows the total water demand by sub sub-basin.

Table 4.7 Irrigation Water Demand (IE=40%)

		Total Water Demand (MCM) at IE = 40% for 2004/2005				
Sub-Basin		2004/2005	2006	2010	2015	2020
1	Wadi Al Mashamini	0.89	0.90	0.95	1.02	1.10
2	Wadi Al Madini	4.53	4.59	4.86	5.20	5.58
3	Wadi Al Kharid	3.03	3.07	3.24	3.47	3.72
4	Wadi Al Ma'adi	1.29	1.31	1.39	1.48	1.59
5	Wadi A'sir	7.65	7.76	8.20	8.79	9.42
6	Wadi Khulaqah	2.33	2.36	2.50	2.67	2.87
7	Wadi Qasabah	2.40	2.43	2.57	2.76	2.95
8	Wadi Al Huqqah	14.48	14.66	15.39	16.36	17.40
9	Wadi Bani Huwat	48.67	49.01	50.43	52.31	54.32
10	Wadi Thumah	1.26	1.27	1.32	1.38	1.45
11	Wadi As Sirr	24.74	24.93	25.75	26.83	27.98
12	Wadi Al Furs	8.61	8.69	9.02	9.46	9.92
13	Wadi Al Iqbal	19.67	19.94	21.03	22.49	24.05
14	Wadi Zahr & Al Ghayl	16.30	16.49	17.26	18.30	19.41
15	Wadi Hamdan	10.16	10.31	10.89	11.67	12.51
16	Wadi Al Mawrid	8.76	8.86	9.26	9.80	10.37
17	Wadi Sa'wan	10.05	10.13	10.47	10.91	11.38
18	Wadi Shahik	10.30	10.40	10.78	11.30	11.85
19	Wadi Ghayman	5.50	5.55	5.77	6.07	6.38
20	Wadi Al Mulaikhy	3.47	3.52	3.71	3.96	4.23
21	Wadi Hizyaz	2.64	2.68	2.83	3.02	3.23
22	Wadi Akhwar	2.45	2.48	2.62	2.81	3.01
Total		209.20	211.35	220.24	232.06	244.71

Unit: million cubic meters

4.2.4 INDUSTRIAL WATER DEMAND

Studies and information of water consumption by industries is very scarce because most of industries are not connected to the public network and water for their consumption is supplied by own well, where abstraction of water is supposed to be unregulated and unrecorded.

WEC (2001) has estimated the water demand using "Gross Water Requirement Method" to calculate the water demand for the year of 1995. This method depends on identifying 1) the physical outputs of the different industrial products, and 2) the average water requirement per unit of physical output in various industrials sub sector. In this study, future water demand was estimated based on the estimations carried out by WEC (2001) with assumed conditions mentioned in section 5.8.5 in Supporting Report. Results of projection on industrial water demand are shown in *Table 4.8*.

Table 4.8 Industrial Water Demand by Scenarios

Year	Historical Growth Rate			Programmed Growth Rate		
	Manufacturing	Mining and Quarrying	Total	Manufacturing	Mining and Quarrying	Total
2005	4.75	0.00336	4.76	4.75	0.00336	4.76
2010	5.98	0.00452	5.99	7.12	0.00485	7.12
2015	7.53	0.00608	7.53	10.65	0.00700	10.66
2020	9.47	0.00818	9.48	15.94	0.01009	15.95

Unit: million cubic meters

In this study, future water demand for industry in accordance with Programmed Growth Rate is adopted since it is officially planned in the Socio-Economic Development Plan for Poverty Reduction (2006-2010).

4.2.5 TOURISTIC WATER DEMAND

Suitable studies and/or information were not available for detailed demand projection of water

for the touristic sector, which is increasing in number of tourists arrivals as shown in a previous paragraph. Water demand projection for touristic sector in this study was calculated assuming the following conditions:

- It is supposed the increasing rate observed between 2004 and 2005 will not continue at the same rate in the future. It is supposed to decrease few percents yearly however; studies or official projections were not available. For the period of 2006-2010, DPPR has settled as an indicator for the tourism sector an average annual growth of 12% for tourists' arrivals and in this study, the same rate was assumed that it would continue until 2020.
- Due to a lack of information, water demand for touristic sector estimated in this study have, considered only the yearly increase of number of beds, and bed occupancy rate at 40%. Increasing rate of beds was settled at 22%, according to the DPPR.
- Unit water consumption was settled according to hotel classification as 350 l/c/d for five and four stars hotels, 180 l/c/d for three to one star hotels. Quantities which were adopted from studies carried in Jordan for classified hotels depending on possession of pool. Water consumption in traditional hotels is supposed to be lower than other hotels and was settled at 120 l/c/d.
- It was assumed that all hotels of governorate of Sana'a are located within Sana'a Basin, around the City.

Projection of touristic water demand is shown in *Table 4.9*.

Table 4.9 Touristic Water Demand Projection

Item		2005	2010	2015	2020
Water demand	Traditional Hotel	0.06	0.17	0.47	1.26
	1 Star Hotel	0.12	0.31	0.85	2.29
	2 Stars Hotel	0.07	0.18	0.49	1.33
	3 Stars Hotel	0.03	0.09	0.24	0.65
	4 Stars Hotel	0.03	0.09	0.24	0.66
	5 Stars Hotel	0.05	0.13	0.34	0.93
	Total	**0.36**	**0.98**	**2.63**	**7.12**

Unit: million cubic meters

4.3 FUTURE WATER BALANCE

The projected future water demand described in the previous section and the totaled amount of these water demands are summarized in *Table 4.10*. Totaled amount is gradually increased from 269.7 MCM in 2005 to 352.8 MCM in 2020. On the other hand, renewable groundwater resources was estimated to be only 50.7 MCM/year in the previous study as described in Chapter 2. The balance between renewable resources and demand is minus 219 MCM in 2005 and minus 302.1 MCM in 2020, if the recharge amount is not changed. It means that the non-renewable water resources will continue to be depleted.

Table 4.10 Future Water Balance

Purpose		Water Demand (MCM/year)				Remarks
		2005	2010	2015	2020	
Urban Area Water Supply (Domestic and Institution)	a	-	42.8	52.7	62.8	Water demand in accordance with the Sana'a Water Supply and Sanitation Project (SWSSP) of SWSLC. Option 1, unit water consumption is 35 l/c/d
	b	54.3	53.5	65.9	78.6	**Production amount** from 2010 to 2020 including physical loss with 20% of production, which is adopted by SWSLC. Demand in 2005 is the actual production.
Domestic Use in Rural	c	1.1	5.0	5.7	6.4	Demand from 2010 is calculated by using 2.5% of population growth rate with 40 l/c/d, Value of 2005 is 25% of estimated demand
Industrial Use	d	4.8	7.1	10.7	16.0	Programmed Growth Rate according to DPPR (2006-2010)
Touristic Use	e	0.4	1.0	2.6	7.1	growth rate of 10% for traditional to three stars, 3% for four and five stars. Unit water consumption is 350l/c/d for five and four stars, 180l/c/d for three to one stars, 120l/c/d for traditional
Irrigation Use	f	83.7	88.1	92.8	97.9	Actual Evapotranspiration (ETa), GAF (2007) Growth rate depends on cultivated are of each type of crop
	g	209.2	220.2	232.1	244.7	**Calculated Consumption** with present irrigation efficiency (40%). This efficiency is continued until 2020
Total Consumption	h	**269.7**	**286.8**	**316.9**	**352.8**	Total Consumption (h) =(b) + (c) + (d) + (e) + (g)
Recharge	i	50.7	50.7	50.7	50.7	Based on A.Norman and W.Mulat (2007), Water Balance and Hydrological Monitoring
Balance	j	**-219.0**	**-236.1**	**-266.2**	**-302.1**	Balance(j) = Recharge(i) - Total Consumption(h)

As described in Chapter 2, the groundwater storage has been roughly estimated in the previous studies. The estimated amount of usable groundwater by WEC (2001) is 5,212 MCM, which is adapted to this study. Therefore, if the water consumption is continued in accordance with the projected future water demand as shown in *Table 4.10*, the usable groundwater would not be able to meet the demand in the year of 2020 as shown in *Figure 4.2*.

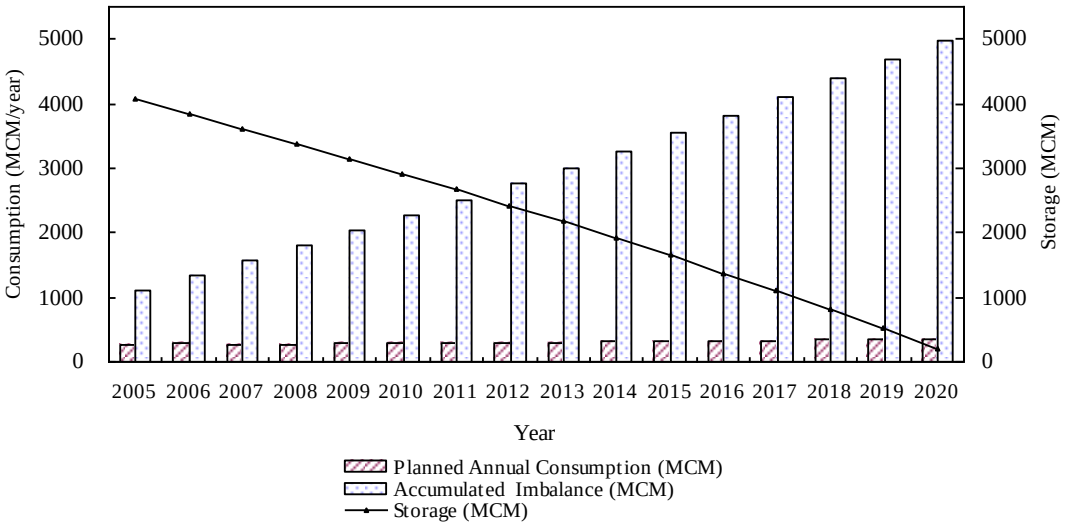

Figure 4.2 Decreasing of Storage with Planned Future Demand

Even if the present water consumption of 269.7 MCM/year is remained as it is, the usable groundwater would expect to be depleted within 23 years from the year of 2001.

It means that by the year of 2020 at the very latest, groundwater abstraction has to be drastically reduced to the recharge amount, that is, from 269.7 MCM/year at present to 50.7 MCM/year.

In order to achieve this goal, all farmers are required to completely stop irrigation activity that is using groundwater and water consumption for domestic purpose must be almost half. Implementation of water saving in accordance with the schedule shown in the table is obviously unrealistic. However, it is also obvious that all of stakeholders are strongly required to reduce water consumption immediately so as to extend the life of limited water resources.

4.4 FUTURE SCENARIOS

4.4.1 BASIC POLICY FOR FUTURE SCENARIO SETTING

As mentioned in the previous sections, the water resources in Sana'a Basin is in the crucial condition. In order to keep sustainability of water resources in the Basin, water consumption should be drastically reduced to 50.7 MCM/year in 2020 that is the equal amount of recharge amount. In order to achieve this, all farmers have to stop irrigation and the water to be supplied for urban areas should be nearly half. It is unrealistic way considering that economic activities rely on the agriculture sector. Therefore, all stakeholders are strongly required to reduce water consumption by 2020 at the very latest so as to obtain the opportunity to approach to next step. Considering this situation, the water resources management for Sana'a Basin is required to show the direction towards reducing water consumption. For this purpose, the future water demand should be projected considering the low growth rate of each sector and possible reduction of water consumption of each sector. In this study, from the view point of this, the scenarios for water demand are considered.

Considered scenarios with target figure in the year of 2020 are summarized in *Table 4.11* and shown in *Figure 4.3*. These four scenarios are prepared in combination with scenarios of five sectors. Scenarios of each sector are prepared considering existing economic growth plan and some of are set by the study team considering the possibility.

Table 4.11 Summarized Scenario of Water Demand

	Urban Area Water Supply (Domestic and Institution)	Domestic Use in Rural Area	Industrial Use	Touristic Use	Irrigation Use	Total[*8)] Consumption
Scenario 1	Population: 3,198,573 LPGR[*1)] Physical Loss: 14.6 MCM (20%)[*2)] Unit water consumption : 35 l/c/d[*3)]	Population: 437,532[*5)] Unit water consumption: 40 l/c/d[*5)]	Historical growth rate, DPPR[*6)]	Based on DPPR	No expansion of irrigated area since 2005 IE: 60%[*7)] Actual requirement: 83.68 MCM/year	***235.5***
MCM/year	**73**	**6.4**	**9.5**	**7.1**	**139.5**	
Scenario 2	Population: 3,198,573 LPGR Physical Loss: 10.3 MCM (15%)[*4)] Unit water consumption: 35 l/c/d	Population: 437,532 Unit water consumption: 40 l/c/d	Historical growth rate, DPPR	Based on DPPR	No expansion of irrigated area since 2005 IE: 70% Actual requirement: 83.68 MCM/year	***211.2***
MCM/year	**68.7**	**6.4**	**9.5**	**7.1**	**119.5**	
Scenario 3	Population: 3,198,573 LPGR Physical Loss: 10.3 MCM (15%) Unit water consumption: 35 l/c/d	Population: 437,532 Unit water consumption: 40 l/c/d	No growth in Industry inside the Basin since 2005	No growth in Tourism inside the Basin since 2005	No expansion of irrigated area since 2005 IE: 70% Actual requirement: 83.68 MCM/year	***199.8***
MCM/year	**68.7**	**6.4**	**4.8**	**0.4**	**119.5**	
Scenario 4	Population: 3,198,573 LPGR Physical Loss: 10.3 MCM (15%) Unit water consumption: 35 l/c/d	Population: 437,532 Unit water consumption: 40 l/c/d	No growth in Industry inside the Basin since 2005	No growth in Tourism inside the Basin since 2005	Reduce 11,111 ha irrigated area out of 18,954 ha Install improved irrigation system to7,843 ha	***130.3***
MCM/year	**68.7**	**6.4**	**4.8**	**0.4**	**50**	

*1) LPGR: Limited Population Growth Rate set in Sana'a Water Supply and Sanitation Project (SWSSP)

(Dar Al-Handasah, 2000)

*2) Physical Loss, 20% is set in SWSSP

*3) Option 1 set in SWSSP, Minimum option, water is supplied of entire city population

*4) Physical Loss, 15% is set by the Study team

*5) Population growth rate in rural area, 2.5% and unit water consumption, 40 l/c/d are provided by GARWSP.

*6) Calculated value based on the Socio-economic development plan for poverty reduction (DPPR, 2006-2010)

*7) Irrigation efficiency

*8) Total consumption includes loss of water supply and overuse in irrigation

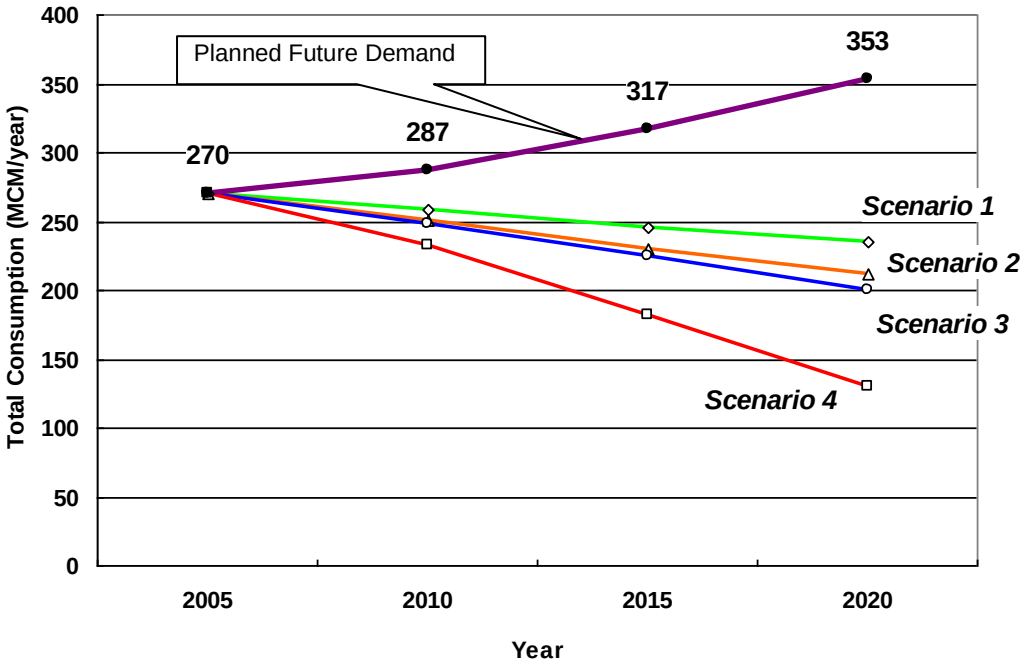

Figure 4.3 Scenarios for Water Demand (2005 – 2020)

4.4.2 URBAN AREA WATER SUPPLY

(1) Population

Since the future water demand described in section 4.2.2 is projected by using "moderate growth rate", "limited growth rate" is applied for the scenario so as to make the population growth rate low as shown in *Table 4.12*.

Table 4.12 Population Forecast with Limited Growth Rate

Year	2005	2010	2015	2020
Population	1,840,578	2,318,455	2,787,806	3,198,573
Growth Rate	5.31 %	4.34 %	3.37 %	2.40 %

*1) Growth rate is quoted from Dar Al-Handasah (2000).

*2) Population is projected based on the population in the Statistical Year Book 2005

(2) Scenario of Water Demand

Two types of scenarios of water demand which are shown in *Table 4.13*, are prepared for urban

area water supply with the following conditions.

- Population growth rate is decreased from "moderate" to "limited".

- Unit water consumption is 35 l/c/d in order to cover the entire population in Sana'a city, which is in conformity with the direction of SWSLC

"Scenario 1" is calculated by applying the physical loss of 20% in accordance with SWSSP with assuming to be continued until the year 2020. "Scenario 2, 3 and 4" is calculated by applying the physical loss of 20% until the year 2020, then assuming to be improved to 15% in the year 2015.

By implementing these scenarios, 5.6 MCM/year in 2020 in scenario 1 and 9.9 MCM/year in 2020 in scenario 2, 3 and 4 are saved comparing projected future water demand that is 78.6 MCM/year as mentioned in section 4.2.2.

Table 4.13 Scenario for Urban Water Supply

Scenario 1

Year	2005	2010	2015	2020
Unit water consumption (l/c/d)	50.8	35	35	35
Consumption of Institution (30% of total)	-	15	15	15
Demand	-	50	50	50
Production amount including loss (l/c/d)	-	62.5	62.5	62.5
Leakage (%)	-	20	20	20
Population to be covered (LGR)	-	2,318,455	2,787,806	3,198,573
Production amount (MCM/year)	54.2	52.9	63.6	73.0

Scenario 2, 3 & 4

Year	2005	2010	2015	2020
Unit water consumption (l/c/d)	50.8	35	35	35
Consumption of Institution (30% of total)	-	15	15	15
Demand	-	50	50	50
Production amount including loss (l/c/d)	-	62.5	58.8	58.8
Leakage (%)	-	20	15	15
Population to be covered (LGR)	-	2,318,455	2,787,806	3,198,573
Production amount (MCM/year)	54.2	52.9	59.9	68.7

4.4.3 DOMESTIC USE IN RURAL AREA

Since the useful information about population growth rate in rural area is not available and the priority of the allocation of water resources is given to domestic purpose, the growth rate of 2.5% that is adopted by GARWSP, is applied and is assumed to continue until the year 2020.

4.4.4 INDUSTRIAL USE

As for water demand of industry, two kinds of scenarios are considered. The growth rate mentioned in the DPPR is applied for scenario 1 and 2. No further expansion of industrial activities inside Sana'a Basin is applied for scenario 3 and 4. These scenarios are shown in *Table 4.14*.

Table 4.14 Scenario for Industrial Use

Scenario 1 & 2

Year	2005	2010	2015	2020
Manufacturing (MCM)	4.75	5.98	7.53	9.47
Mining and Quarrying (MCM)	0.00336	0.00452	0.00608	0.00818
Demand (MCM)	4.8	6.0	7.5	9.5

Scenario 3 & 4

Year	2005	2010	2015	2020
Manufacturing (MCM)	4.75	4.75	4.75	4.75
Mining and Quarrying (MCM)	0.00336	0.00336	0.00336	0.00336
Demand (MCM)	4.8	4.8	4.8	4.8

As for scenario 1 and 2, since the future water demand for industrial use described in section 4.2.4 is projected by applying "Programmed growth rate (PGR)" in accordance with DPPR (2006-2010), "Historical growth rate (HGR)" which is observed from 2001 to 2005 and lower than "PGR" is applied.

By implementing these scenarios, 6.5 MCM/year in 2020 in scenario 1 and 2, and 11.2 MCM/year in 2020 in scenario 3 and 4 are saved comparing projected future water demand that is 16.0 MCM/year as mentioned in section 4.2.4.

4.4.5 TOURIST USE

Since the available information about future water demand for tourism sector is limited, two kinds of scenarios are considered. The growth rate of 12% for tourists' arrivals set in DPPR (2006-2010) is applied for scenario 1 and 2. No further expansion of tourism is applied for scenario 3 and 4. The scenarios are shown in *Table 4.15*. By implementing only scenario 3 and 4, 6.7 MCM/year in 2020 is saved comparing projected future water demand that is 7.1 MCM/year as mentioned in section 4.2.5.

Table 4.15 Scenario for Tourist Use

Scenario 1 & 2

Year	2005	2010	2015	2020
Demand (MCM)	0.4	1.0	2.6	7.1

Scenario 3 & 4

Year	2005	2010	2015	2020
Demand (MCM)	0.4	0.4	0.4	0.4

4.4.6 IRRIGATION USE

Irrigation is the main activity for income generation for farmers. Water consumption for irrigation purpose accounts for 77% of total water consumption inside Sana'a Basin in the year 2005. Though saving water in this sector much contributes for reducing total water consumption, it is necessary to secure farmers' livelihood by minimizing the adverse impact on and economic structure in Sana'a Basin. Considering the importance and sensitivity of the sector, three types of scenario are considered as shown in *Table 4.16*.

Table 4.16 Scenario for Irrigation Use

Scenario 1

Year	2005	2010	2015	2020
Substantial Demand (MCM)	83.7	83.7	83.7	83.7
Irrigation Efficiency (%)	40	-	-	60
Total Requrement (MCM)	209.2	193.1	166.3	139.5

Scenario 2 & 3

Year	2005	2010	2015	2020
Substantial Demand (MCM)	83.7	83.7	83.7	83.7
Irrigation Efficiency (%)	40	-	-	70
Demand (MCM)	209.2	188.5	154.0	119.5

Scenario 4

Year	2005	2010	2015	2020
Areas to be reduced annualy (ha)	0	855	855	855
Total of reduced area (ha) out of 18,954 ha	0	2,564	6,838	11111
Possibler saved amount (MCM)	**0**	**28**	**75**	**122**
Areas where improved irrigation system shall be installed (ha)	0	603	603	603
Total of installed area (ha) out of 7,843 ha	0	1,810	4,826	7,843
Possible saved amount (MCM)	0	9	23	37
Total saved amount	**0**	**37**	**98**	**159**
Demand (MCM)	**209.2**	**172.2**	**111.2**	**50.2**

Scenario 1 and Scenario 2 and 3 shown in *Table 4.16* are set to reduce water consumption by improvement of irrigation efficiency from present efficiency 40% to 60% and 70%, respectively. It is required for all farmers not to expand their own irrigated land. In these scenarios, the present situation of economic structures related to irrigation activity will not be damaged. Production is expected to be increased.

Scenario 4 is set to reduce water consumption to 50 MCM/year considering that around 50 MCM/year of treated wastewater will become available in the year 2020. In this scenario, irrigation activity on two thirds of present irrigated land that is 11,111 ha should be stopped, and the improved irrigation system should be disseminated to a third of present irrigated land that is 7,843 ha. In this case, alternative income generation should be secured for the farmers who have to stop irrigation activity to fill the reduced income.

By implementing these scenarios, 105.2 MCM/year in 2020 in scenario 1, 125.2 MCM/year in 2020 in scenario 2 and 3, and 194.5 MCM/year in 2020 in scenario 4 are saved comparing projected future water demand that is 244.7 MCM/year as mentioned in section 4.2.3.

Irrigation improvement activity composed of social mobilization and enhanced community water management, physical intervention on irrigation schemes, and technical assistance and implementation support has been already started as a part of SBWMP from the year of 2004. Saving amount was estimated to be 7.12 MCM/year by conducting the rehabilitation of existing piped conveyance systems, the conversion of existing piped conveyance systems and localized

irrigation system in this component, which seems to be not enough to be in line with above scenario. As it is mentioned in section 3.2.6 (4) in Chapter 3, poor progress is observed in installing and converting improved irrigation system with only 211 ha, or less than 5% of the project target. Therefore, enhanced and concentrated activities for implementation of these scenarios are necessary.

4.5 FUTURE SCENARIO TOWARDS MAXIMUM SUSTAINABILITY

4.5.1 EXPECTED PERIOD OF USABLE GROUNDWATER RESOURCES IN EACH SCENARIO

As mentioned in section 2.2.2 (1) and (2) in Chapter 2, recharge amount was estimated to be 50.7 MCM/year and usable storage inside Sana'a Basin was estimated to be 5,212 MCM. In addition to recharge amount, as it is mentioned in section 2.2.3 in Chapter 2, expansion of capacity of wastewater treatment plant has been launched and reuse of treated wastewater for irrigation purpose is planned to be achieved in the year 2020. Expected quantity of treated wastewater is 56.6 MCM/year in maximum. Therefore, around 50 MCM of treated wastewater can be regarded as new water resources, and should be made certain.

Based on these estimation, expected usable period of groundwater resources is estimated in each scenario. *Table 4.17, Figure 4.4 and 4.5* show the results of the estimation.

Table 4.17 Expected Period of Usable Groundwater Resources in Each Scenario

Scenario 1

	2005	2010	2015	2020	Period of depletion (by the year of)		
Urban	54.3	52.9	63.6	73	without Recharge	with Recharge	Reuse of treated wastewater from 2020
Rural	1.1	5	5.7	6.4			
Industry	4.8	6	7.5	9.5			
Tourism	0.4	1	2.6	7.1	2021	2027	2030
Irrigation	209.2	193.1	166.3	139.5			
Total Consumption	269.8	258	245.7	235.5			

Scenario 2

	2005	2010	2015	2020	Period of depletion (by the year of)		
Urban	54.3	49.8	59.9	68.7	without Recharge	with Recharge	Reuse of treated wastewater from 2020
Rural	1.1	5	5.7	6.4			
Industry	4.8	6	7.5	9.5			
Tourism	0.4	1	2.6	7.1	2022	2029	2034
Irrigation	209.2	188.5	154	119.5			
Total Consumption	269.8	250.3	229.7	211.2			

Scenario 3

	2005	2010	2015	2020	Period of depletion (by the year of)		
Urban	54.3	49.8	59.9	68.7	without Recharge	with Recharge	Reuse of treated wastewater from 2020
Rural	1.1	5	5.7	6.4			
Industry	4.8	4.8	4.8	4.8			
Tourism	0.4	0.4	0.4	0.4	2023	2030	2036
Irrigation	209.2	188.5	154	119.5			
Total Consumption	269.8	248.5	224.8	199.8			

Scenario 4

	2005	2010	2015	2020	Period of depletion (by the year of)		
Urban	54.3	49.8	59.9	68.7	without Recharge	with Recharge	Reuse of treated wastewater from 2020
Rural	1.1	5	5.7	6.4			
Industry	4.8	4.8	4.8	4.8			
Tourism	0.4	0.4	0.4	0.4	2028	2045	after 2045
Irrigation	209.2	172.5	111.2	50			
Total Consumption	269.8	232.5	182	130.3			

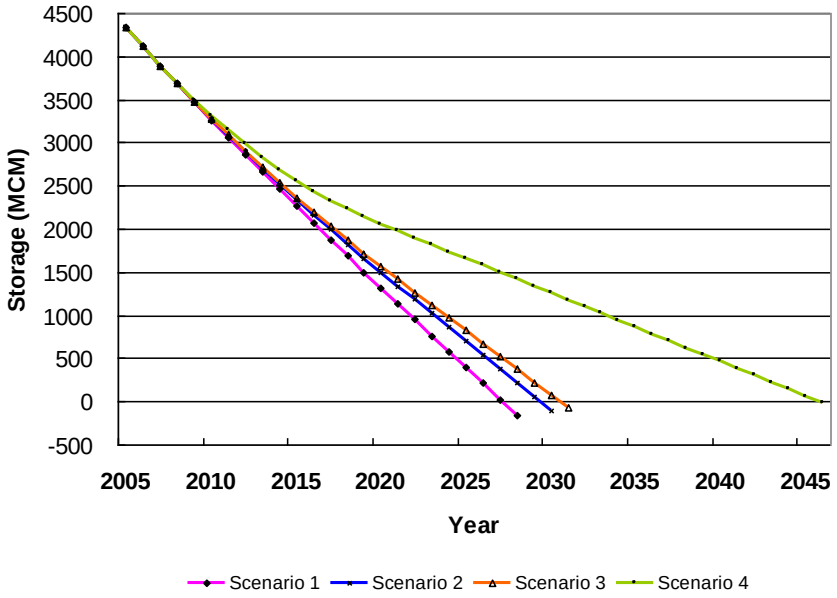

Figure 4.4 Expected Period of Usable Groundwater Resources with Recharge

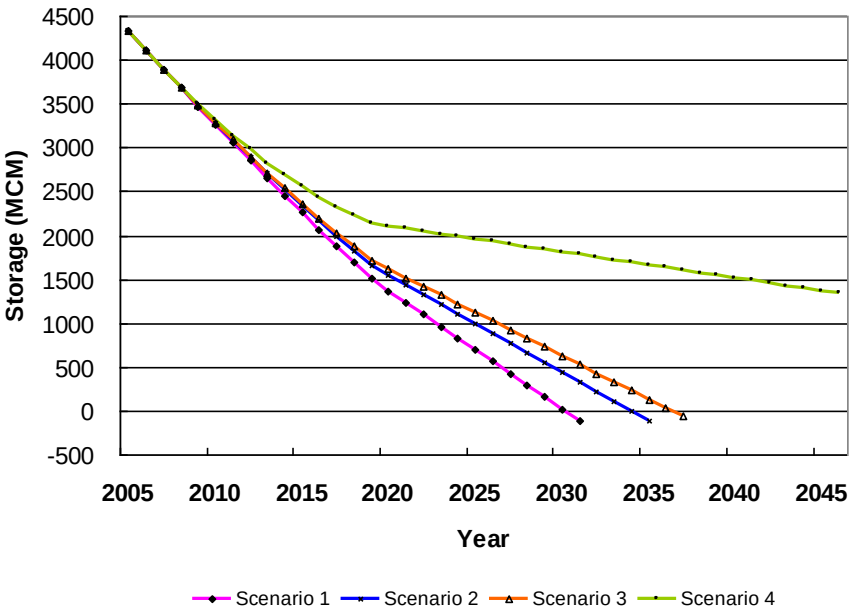

Figure 4.5 Expected Period of Usable Groundwater Resources Considering Reuse of Treated Wastewater from the year 2020

It should be noted that even if the scenarios considered based on the socio-economic condition are implemented, groundwater resources will continued to be gradually decreased and over time will be depleted.

4.5.2 SELECTION OF FUTURE SCENARIO TOWARDS MAXIMUM SUSTAINABILITY

As described in section 4.3 in this Chapter, if the water consumption is continued in line with projected water demand, usable groundwater would be depleted in the year of 2020. It means

that economic activity will be definitely damaged, and even the domestic water will not be able to supply to those who live inside Sana'a Basin in the year 2020. As for transferring water from outside Sana'a Basin as an alternative water source for Sana'a City, it is regrettably concluded to be not feasible except that the financial aspect is solved as mentioned in section 2.2.4 in Chapter 2.

Therefore, the ultimate solution is to reduce water consumption to the recharge amount by the year 2020 at the very latest so as to keep minimum sustainability inside Sana'a Basin. For the achievement of the ultimate solution, all of irrigation activity should be stopped and domestic consumption should be reduced to around two thirds of demand in 2020. However, it is obvious that tremendous effort is required for all stakeholders and is unrealistic.

Considering the difficult situation, it should be concluded that all of stakeholders are strongly required to take necessary actions in conformity with the Scenario 3 by the year of 2020 as shown in *Figure 4.6*. Because, the Scenario 3 is prepared considering the utmost possibility of the implementation of scenario of each sector and maximum effect on reducing water consumption. By implementing the Scenario 3 with saving water resources of 153 MCM in 2020, such very severe condition of water resources will be mitigated as much as possible, and the period of the depletion of water resources will be expanded until the year of 2036 that is around 30 years later from 2007.

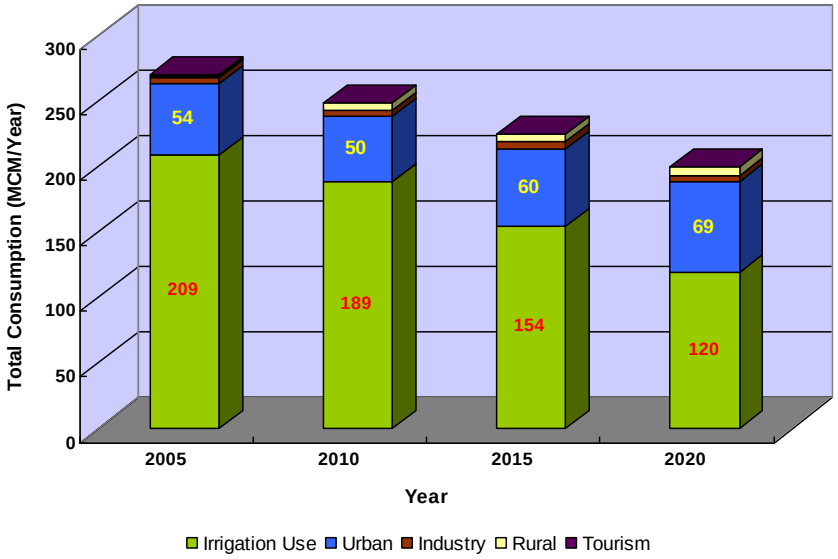

Figure 4.6 Reducing Schedule of Scenario 3

Followings are the actions to be taken with top priority by the year of 2020 in conformity with the scenario 3. Since the contribution towards reducing water consumption is very high and implementation of each component is practicable.

- Improvement of the irrigation efficiency from 40% to 70% by the year 2020 and no further expansion of irrigated land, which can save 125.2 MCM/year of groundwater resources comparing the projected water demand based on the tendency of the expansion of irrigated land studied in the previous study.

- Improvement of the physical loss in the water supply in urban area from the 30% (inferred

value) to 15% by the year 2015, which can save 9.9 MCM/year of groundwater resources

- Reuse of the treated wastewater for irrigation purpose and improvement of capacity of sewage system. Around 50 MCM of treated wastewater is expected to be reused in the year of 2020 in accordance with the plan of SWSLC.

Detailed activities for actions mentioned above are described in Chapter 5.

However, it should be mentioned again that though the Scenario 3 is completely implemented, the precious groundwater resources will be definitely depleted in the year 2037 as shown in *Figure 4.7*.

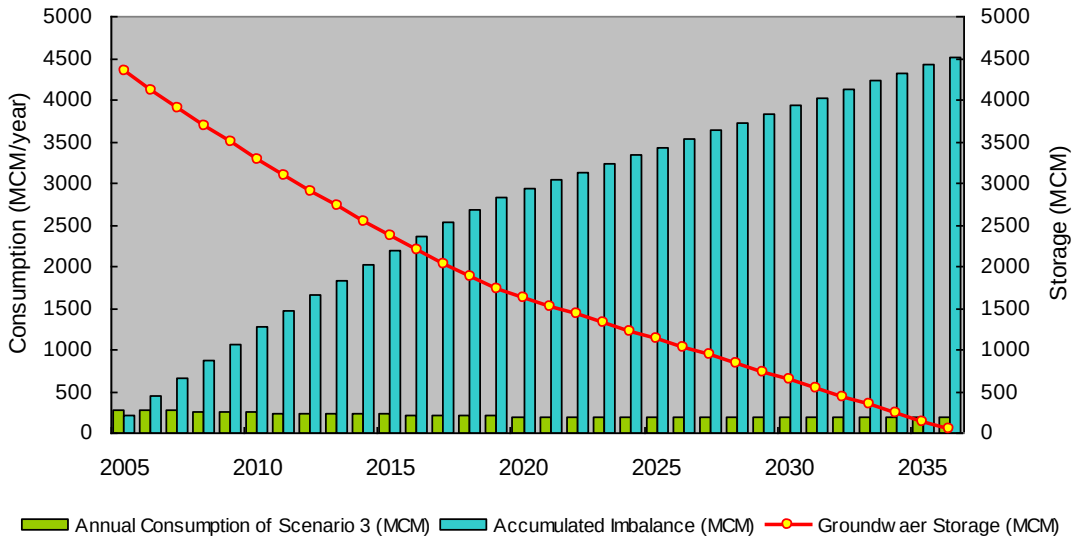

Figure 4.7 Expected Period of Usable Groundwater Resources for Scenario 3

REFERENCES

National Water and Sanitation Authority (2000) Sana'a Water Supply and Sanitation Project Development Program, main report, NWSA, Sana'a, 224p