WATER RESOURCES MANAGEMENT FOCUSING ON DROUGHT MITIGATION IN IRAN: THE CASE OF THE SISTAN REGION

Abstract

This paper presents a study of water management in the Sistan Region of Iran. The region, in the southeast of Iran, is an important case study not only because of the normal conflicts between water users, but also because of international conflicts between Iran and Afghanistan. Lake Hamoun, a significant international wetland listed under the Ramsar Convention, is in the study area and it competes with domestic and agricultural water users. The Hirmand River, which originates in Afghanistan, provides the main supply of water for domestic, agricultural and environmental uses in the region. The main problems in the region are the scarcity and unreliability of the Hirmand River flow, which is affected by natural fluctuations as well as by the activities of people in Afghanistan. This paper presents a stochastic simulation model of water management in the region. The model is calibrated based on historical monthly data on water flows (1957-2001) and is used to study the consequences of alternative management actions on three water-user groups: domestic, agriculture and environment. Tradeoffs between users are estimated in terms of expected values and probabilities.

Ahmad Ali Kehkha
Oscar Cacho
Brian Hardaker

Agricultural and Resource Economics,
School of Economics
University of New England
Armidale, NSW 2351

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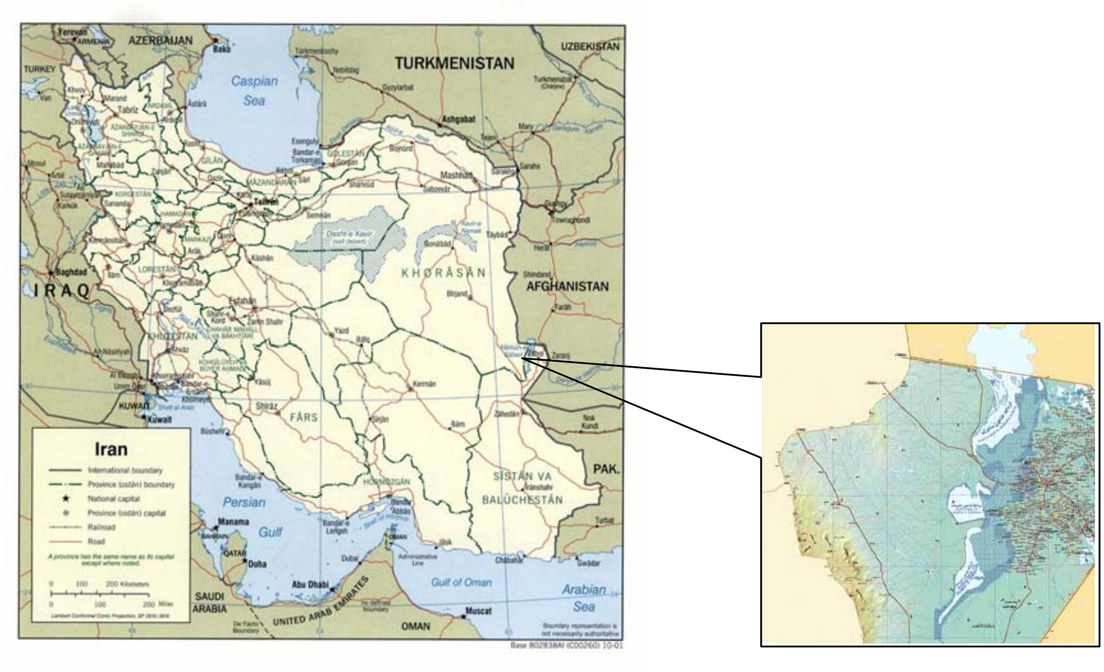
Introduction

Water lies at the centre of all development. It is important for agricultural, domestic and industrial uses and maintaining ecosystems and biodiversity. About one-half of the population of the world lives under water stress especially in Africa, the Middle East and South Asia. It is obvious that water resources management and development today will determine water availability in the future (World Bank 2003).

This research paper focuses on water resource management in the Sistan region in the southeast of Iran (Figure 1). Lake Hamoun, which is a significant international wetland listed under the "Ramsar Convention", is located in the study area (UN 2002). The Hirmand River, which originates in Afghanistan, is the main water provider for agricultural, environmental and domestic water uses in Sistan. Sistan depends almost exclusively on the Hirmand River for its water. Scarcity and unreliability of the Hirmand water flow have caused disastrous floods and continued droughts during past years. This problem affects the population and environment of the area in different ways. As a result of a dramatic reduction in the Hirmand water flow during the recent prolonged drought, all activities in the region have stopped and the lake is completely dry now.

The main concern in the area is how to allocate scarce and unreliable water resources among different water users to mitigate the negative effects of water shortages and fluctuations in the region. The unreliability of the Hirmand water flow occurs naturally because of precipitation decrease at the Hirmand source in Afghanistan, or artificially as a result of the activities of the Afghan people due to conflict between the two countries. The study reported here is designed to develop a decision support model for the whole region to help decision makers manage more effectively the water resources. In this paper only a sub-model for the Sistan River (the internal branch of the Hirmand River) is presented. The effects of several policies and actions that can be taken by the government and people in order to mitigate water unreliability problems will also be discussed.



Source: The University of Texas at Austin (2003)

Source: S.D.O.(2000)

Figure 1. Map of Iran and the area of study

Description of the study area

According to the Sistan Development Organisation (SDO, n.d.) and Soltani and Karbasi (2001), Sistan, in the north of the Sistan and Baluchestan province (SBP) lies in the southeast of Iran between 60.15 and 60.50 degrees longitude and between 30.50 and 31.28 degrees latitude. Sistan is about 500 meters above sea level. It is surrounded by Afghanistan to the north and east, Zahedan, the capital of the SBP to the south, the Lut Desert to the west and the Khorasan province to the northeast (Figure 1). Sistan has two major cities Zabol and Zahak. The former is the capital of the Sistan region. The region is divided into five districts named Shibab, Poshtab, Miankangi and Shahraki va Narooei, each of which includes a number of rural sub-districts. A rural sub-district covers several villages. Sistan includes 17 rural sub-districts and 908 villages. The population of Sistan is about 335 000 of which about 100 000 live in Zabol, 30 000 in Zahak and the rest in rural areas.

The portion of Sistan to which this study relates, covers about 8117 km^2; 3500 km^2 of which is occupied by lake Hamoun, and 2550 km^2 by the Sistan plain (Akbari n.d.).

Akbari explains that the Sistan plain is nearly all flat land which is mostly used for agriculture.

Conceptual model of the research problem

The conceptual model on which this study is based (Figure 2) provides a general picture of the problem studied.

All water flowing into the region comes from the Hirmand River, which originates in the Baba-Yaghma Mountains about 40 km west of Kabul in Afghanistan. At the border with Iran, the Hirmand River divides into two branches, the Sistan and Parian. The Parian branch forms the common border between the two countries and, after travelling about 20 km to the north, it divides into two branches. The west branch is the internal Parian or Shirdel Canal, which refills with water in flood situations and flows into the Niytak Canal. The other branch of the common Parian flows to the north and, at a place called Borj-e-As, divides into two branches again. One of them is named the Sikhsar River. Nowadays it operates as a small irrigation canal and all of its water is used to irrigate a strip of Miankangi's farming lands. The second branch flows to the east at times of floods and, after irrigating the lands located in its path, forms the Eshkini swamp in Afghanistan. The swamp is about 500 km^2,and connects to the Hamoun-e-Puzak in the Zaranj area of Afghanistan. The Niytak Canal and the Maleki Canal, that are fed by the internal and common Parian, irrigate the farming lands in the Miankangi district and terminate in the marginal lands of the lake. Several traditional and modern canals and pumping stations are also used to irrigate the farming lands in the above-mentioned district. Important among these are the new Golmir Canal, and Canal Number One at Miankangi.

The Sistan River flows to the north-west into the Sistan plain. Some 2 km from the branching point, the Sistan River divides into two branches. The left branch flows

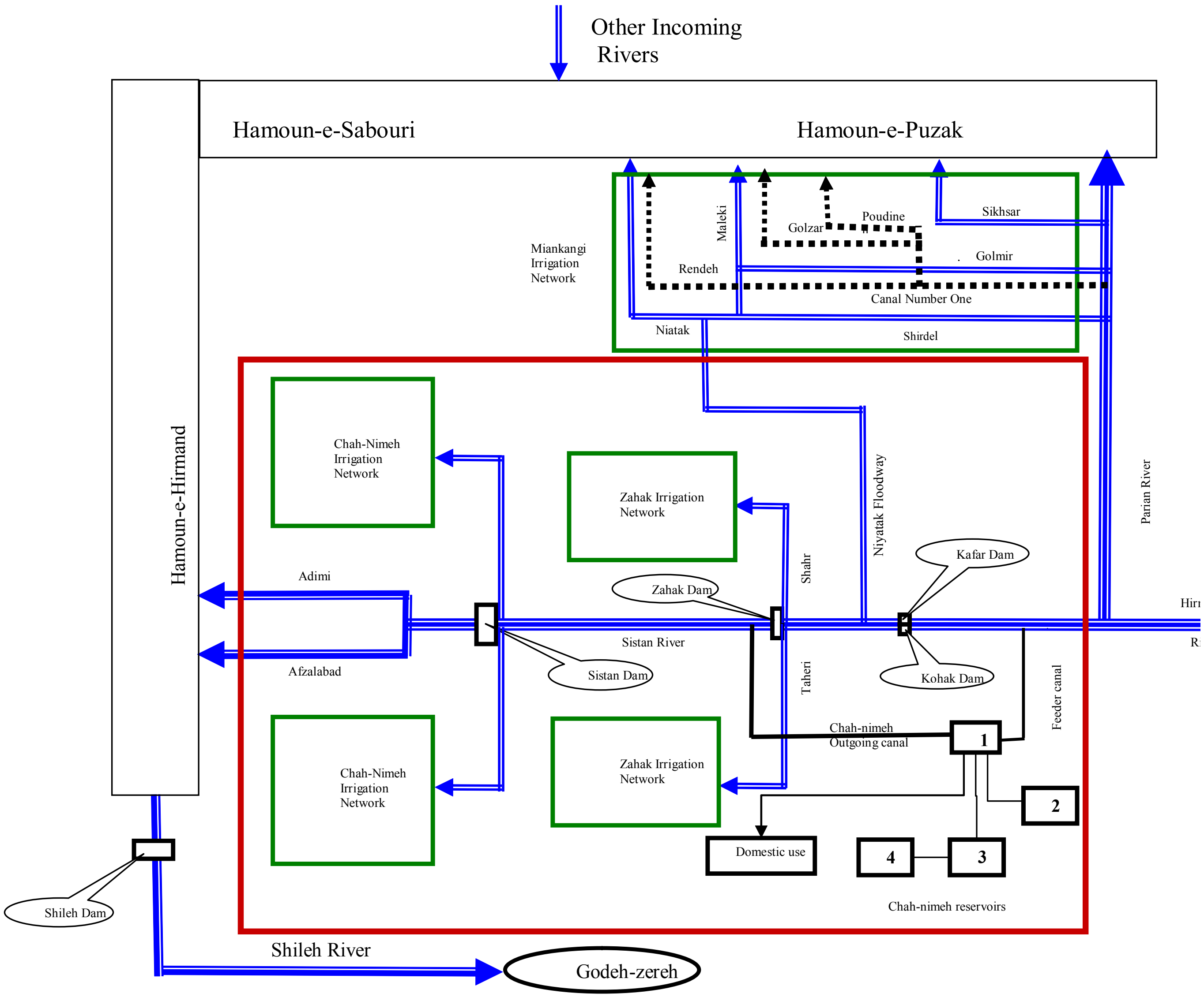


Figure 2. Conceptual model of the water system in the study area

into the Kohak Dam and the right branch flows into the Kafar Dam . The Kafar Dam was built in 1992 in order to prevent excess water from the Hirmand from entering the Sistan plain at flood times. The Zahak diversion dam is located 17 km further down the Sistan River. The Taheri and Shahr Canals branch out to the left and right sides of the dam respectively. The Sistan River then continues into the plain and flows into the Sistan Dam 33 km from the border. This dam is used to irrigate farming lands in the Shibab and Poshtab districts, fed via a modern network of irrigation canals. At 47.5 km from the branching point of the Hirmand River the Sistan River divides into two branches, the Afzalabad on the left and the Adimi on the right, both of which eventually flow into Lake Hamoun.

About 15 km from the border, between the Kohak and Zahak Dams, there is a diversion canal, which connects the Sistan River to the Niatak Canal. This canal is used to transfer large volumes of water from the Sistan River to the lake in times of flood. It causes the volume of the water flowing in the Sistan River to decrease and so prevents floods from occurring in the central parts of the Sistan region.

Another important component of the water system in the area is the Chah-nimeh water reservoirs. Chah-nimeh is located 3 km from the south bank of the Sistan River between the border with Afghanistan and Zahak City. These water reservoirs are fed by a feeder canal which branches from the Sistan River immediately after the border and before the Kohak Dam. Moreover, a canal has been built from the Chah-nimeh to the Sistan River in order to exploit the Chah-nimeh water for agricultural use. Drinking water for the urban areas including Zabol, Zahak and recently Zahedan, and for the rural areas, is obtained from the Chah-nimeh reservoirs by two pumping stations and pipelines.

The Shileh River in the south part of Lake Hamoun acts as a spillway for the lake. This river is about 100 km long and it flows into the Godeh-zereh in Afghanistan. According to Saadat (2001), about 15 600 million m^3 of water were transferred from Lake Hamoun to the Godeh-zereh by the Shileh River in 1991.

Model and Method

The model used in this study represents the Sistan branch of the water system in the study area. The model was implemented with Simulink (Mathworks, 2000a) and Matlab (Mathworks, 2000b). The model equations are presented below and the variable and parameter definitions are in Table 1.

$$\mathrm{Re}\,q_t = Min\{(RC - WS_{t-1}), Min(mflow_t - TC)\} \tag{1}$$

$$Div_t = Min\{\mathrm{Re}\,q_t, mflow_t\} \tag{2}$$

$$FlowBK_t = mflow_t - Div_t \tag{3}$$

$$FlowAK_t = Min\{FlowBK_t, TC1\} \tag{4}$$

$$Flood_t = FlowBK_t - FlowAK_t \tag{5}$$

$$FlowAN_t = Min\{FlowAK_t, TC2\} \tag{6}$$

$$FlowN_t = FlowAK_t - FlowAN_t \tag{7}$$

$$FlowL_t = FlowAN_t - AgFlow_t \tag{8}$$

$$AgFlow_t = Min\{Ag\,\mathrm{Re}\,q_t - FlowAN_t\} \tag{9}$$

$$P_t = P_{t-1}(1+r) \tag{10}$$

$$L_t = l(WS_{t-1} + Div_t) \tag{11}$$

$$RS_t = 2.46 + 0.09(WS_{t-1} + Div_t - L_t) \tag{12}$$

$$E_t = RS_t e_t \tag{13}$$

$$DWd_t = P_t.DWC \tag{14}$$

$$DWs_t = Min\{(WS_{t-1} + Div_t - L_t - E_t), DWd_t\} \tag{15}$$

$$AgArea = La.Cp \tag{16}$$

$$Ag\,\mathrm{Re}\,q_t = AgArea.NMWR_t.IWE \tag{17}$$

$$AgWd_t = Ag\,\mathrm{Re}\,q_t - AgFlow_t \tag{18}$$

$$AgWs_t = Min\{(WS_{t-1} + Div_t - L_t - E_t - DWs_t) - RW, AgWd_t\} \tag{19}$$

$$WS_t = Div_t + WS_{t-1} - L_t - E_t - DWs_t - AgWs_t \tag{20}$$

$$TAWA_t = AgFlow_t + AgWs_t \tag{21}$$

$$AgHa_T = Min\{TAWA_t / Ag\,\mathrm{Re}\,q_t\}.La \tag{22}$$

$$CropArea_T = AgHa_T.Cp \tag{23}$$

$$TAGM_T = CropArea_T.GM \tag{24}$$

Table 1. Variables and parameters in the model

Parameter	Description	Parameter	Description
AgArea	Area under crop(ha)	L	Leakage coefficient (%)
$AgFlow_t$	Available water for agriculture from the River[1]	La	Total cultivable land(ha)
$AgHa_T$	Possible cultivable land (ha)	L_t	Leakage from the reservoirs[1]
$Ag\,\mathrm{Re}\,q_t$	Demand for agriculture use[1]	$mflow_t$	Monthly water flow in the Sistan River[1]
$AgWd_t$	Agricultural water demand from the reservoirs[1]	$NMWR_t$	Net monthly water requirements (m^3)
$AgWs_t$	Agricultural water supply from the reservoirs[1]	P_0	Initial population(people)
Cp	Crop proportion in the cropping pattern (%)	P_t	Population(people)
$CropArea_T$	Possible area under crops (ha)	r	Population growth rate (%)
Div_t	Diverted water into the reservoirs[1]	RC	Reservoirs capacity[1]
DWC	Domestic water consumption (l/d/person)	$\mathrm{Re}\,q_t$	Request for reserve water in the reservoirs [1]
DWd_t	Domestic water demand[1]	RS_t	Reservoir surface (m^2)
DWs_t	Domestic water supply[1]	RW	Reserve water in reservoirs
e_t	Monthly evaporation coefficients (mm)	$TAGM_T$	Total agricultural gross margin (Rials)
E_t	Evaporation from the reservoirs[1]	$TAWA_t$	Total available water for agriculture[1]
$FlowAK_t$	Sistan river flow after Kohak Dam[1]	TC	Transmission capacity of the reservoirs feeder canal[1]
$FlowAN_t$	Sistan river flow after Niytak floodway[1]	TC1	Transmission capacity of the Sistan River between Kohak Dam and Niyatak floodway[1]
$FlowBK_t$	Sistan river flow before Kohak Dam[1]	TC2	Transmission capacity of the Sistan River after Niyatak floodway[1]
$FlowL_t$	Flow into the lake[1]	WS_0	Initial water stock[1]
$FlowN_t$	Overflow into the Lake[1]	WS_t	Water stock in the reservoirs[1]
GM	Agricultural activities gross margin (Rials)		

1- Units in million m^3

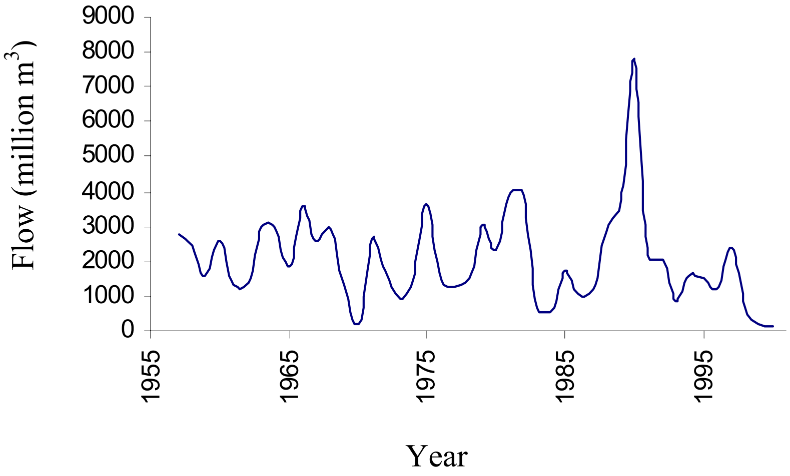
The model was used to analyse the consequences of various policies and actions by water users. Ten scenarios were simulated (Table 2). Scenario 1, the base case, represents the current situation. The remaining scenarios are in line with the Sistan Region Development Plan. Scenarios 2 to 9 represent single actions or policies at different levels and scenario 10 (integrated scenario) represents the combination of the 'best' alternatives in terms of water saving.

Table 2- Scenarios simulated

Scenario	Reservoir capacity (RC) (million m^3)	Irrigation water efficiency (IWE) (%)	Domestic water consumption (DWC) (l/dy/person)	Reserve water in reservoirs (RW) (million m^3)
1. Base	634	37	170	0
2. Build reservoir	1454	37	170	0
3. Medium IWE	634	48	170	0
4. High IWE	634	58	170	0
5. Medium DWC	634	37	125	0
6. Low DWC	634	37	75	0
7. Low RW	634	37	170	170
8. Medium RW	634	37	170	316
9. High RW	634	37	170	500
10. Integrated scenario	1454	58	75	316

The effects of each scenario on three water users (agriculture, domestic and environment) were estimated through Monte Carlo analysis, involving 100 iterations of 100-year simulations. Simulated water flows were randomly selected based on historical monthly data for a period of 46 years. So each year had 1/46 probability of being selected.

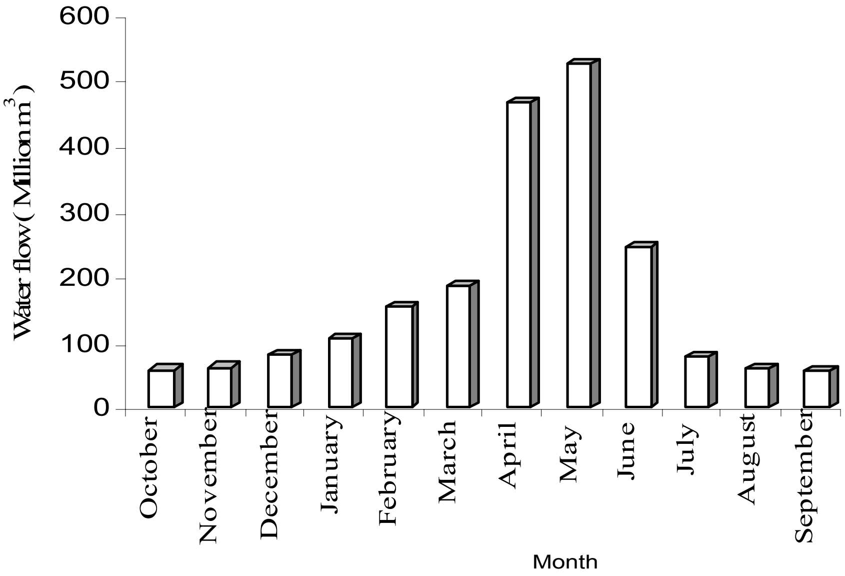
The annual water flows in the Sistan River (the internal branch of the Hirmand River) between 1957 and 2001 are presented in Figure 4. As can be seen, there is considerable fluctuation in flow from nearly zero in 2000 to 7,100 million m^3 in 1990-91. These significant fluctuations have caused frequent droughts and floods.



Source: The RWC (2002).

Figure 4 The total annual flow of the Sistan River

In addition to fluctuations in annual flows, there are considerable fluctuations in monthly flows. On average, about 60 per cent of the flow typically occurs during the four months of March to June (Figure 5), but this can change considerably between years.



Source: The SBP Regional Water Organization (2002).

Figure 5 Average annual distribution of water flow in the Sistan river

For each scenario the means of the following variables were calculated: area under crops, total agricultural gross margin, water flow into the lake, and domestic water deficit. The stochastic results were also used to calculate the probabilities of (i) a domestic water deficit occurring; (ii) the area under crops being below the historical average of 75,175 ha; (iii) the flow of water into the lake being above the historical average.

Results and Discussion

The mean results (Table 3) indicate that, under the base case 29,000 ha of crops are planted, yielding a gross margin of 157 billion Rials; 63 million m^3 of water flow into the lake per year and there is a domestic water deficit of 4 million m^3. Water-saving scenarios (2 to 10) result in reduced domestic water deficits, with expected values ranging from 3.5 million m^3 (scenario 3) to zero (scenario 10).

Table 3- Summary results for the simulated scenarios

Scenario		Scenario number	Mean			
			Area under crops (1,000ha)	Agricultural gross margin (1,000million Rials)	Flow into the lake (million m^3)	Domestic water deficit (million m^3)
Base		1	29	157	63	4.00
Increasing RC (million m^3)	1454	2	47	255	44	3.00
Increasing IWE (%)	48	3	45	243	73	3.50
	58	4	53	286	80	3.00
Decreasing DWC (lt/dy/person)	125	5	34	182	65	2.00
	75	6	41	223	67	0.80
Increasing RW (million m^3)	170	7	19	105	69	2.00
	316	8	14	74	75	1.50
	500	9	8	43	82	1.20
Integrated scenario	all	10	71	385	70	0.00

The effect of the different scenarios on agriculture varies. Scenarios 7, 8 and 9 result in reduced crop areas and gross margins (19,000 ha, 14,000 ha and 8,000 ha respectively), whereas all the other scenarios result in an increase, the highest being 71,000 ha in scenario 10. Flows into the lake tend to increase relative to the base case under all scenarios, except scenario 2, which involves an increase in the capacity of the reservoir, resulting in less water available for environmental (lake) flows.

The average results discussed above do not tell the whole story, because the probabilities are not always symmetrical. Hence, the cumulative distribution functions (CDF) derived from the Monte Carlo simulations were used to calculate the probabilities that events affecting different water users will occur. A selection of results is presented in Table 4.

Table 4- Probabilities of various events occurring which affect different water users

Scenario		Scenario number	Probabilities of various events		
			Domestic water deficit	Below average agricultural area[1]	Above average flow into the lake[2]
Base		1	0.14	0.83	0.18
Increasing RC (million m^3)	1454	2	0.11	0.59	0.13
Increasing IWE (%)	48	3	0.13	0.63	0.23
	58	4	0.11	0.49	0.25
Decreasing DWC (lt/dy/person)	125	5	0.10	0.83	0.19
	75	6	0.07	0.74	0.20
Increasing RW (million m^3)	170	7	0.04	0.93	0.20
	316	8	0.03	0.95	0.23
	500	9	0.02	0.96	0.27
Integrated scenario	all	10	0.00	0.27	0.22

1-Average area under crops = 75,175 (ha)

2-Average flow into the lake is about 10 per cent of the Sistan River flow

Under the base case there is a 0.14 probability that a domestic water deficit will occur in any given year, a 0.83 probability that the area under crops will be below the average, and only a 0.18 probability that the lake will receive above average flows (Table 4). The results in Tables 3 and 4 can be summarised as follows:

Increasing the reservoir capacity increases the average area under crops significantly (from 28,850 to 46,920 ha/yr), and decreases the probability of a below-average crop area by about 25 per cent compared to the current situation.

Increasing irrigation water efficiency has positive effects on all water users, with the agricultural sector benefiting the most. If the target irrigation water efficiency in the Sistan development plans (58 per cent) can be achieved, the average area under crop increases to 52,587 ha/yr, an 82 per cent increase over the current situation.

Decreasing daily water consumption per person from the current 170 L/d, to the 75 l/d recommended by the World Health Organization, influences all water users positively.

Keeping more water in the reservoir as insurance against drought benefits domestic and environmental users, but causes considerable losses to the agricultural sector.

If the whole set of stated targets are achieved (scenario 10), the probability of water shortage drops towards zero.

The probabilities presented in Table 4 change as combinations of scenarios change, and some obvious conflicts between water users arise. These conflicts can be illustrated by plotting the tradeoffs between the probability of domestic water deficits, or of favourable environmental flows, against water allocated to agriculture. To accomplish this, the model was run for a series of reserve-water targets (RW) ranging from zero to 500 million m^3 per year. The results are plotted in Figures 6 to 8.

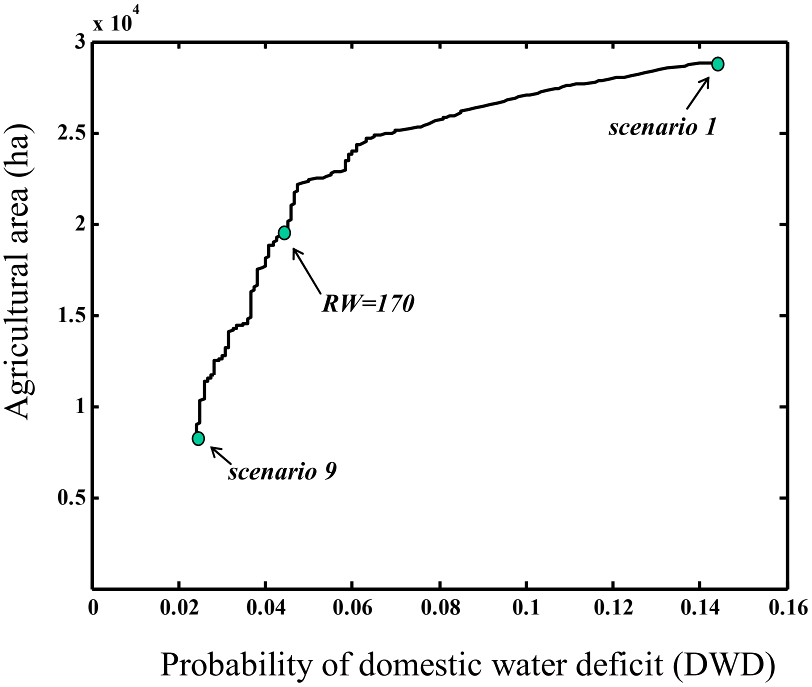


Figure 6. Tradeoff between domestic water use and agriculture

In the base case (Figure 6), it is obvious that the only way to increase the irrigated crop area is by increasing the probability that domestic water deficits (DWD) will occur. This competitive effect between agriculture and domestic use is especially strong at probabilities of DWD below 0.06. The curve in Figure 6 shifts as model assumptions are changed, but the general pattern remains (Figure 7). Not surprisingly, reductions in domestic water demand (Figure 7A), or increases in water-use efficiency (Figure 7B), allow a larger area of agriculture to occur.

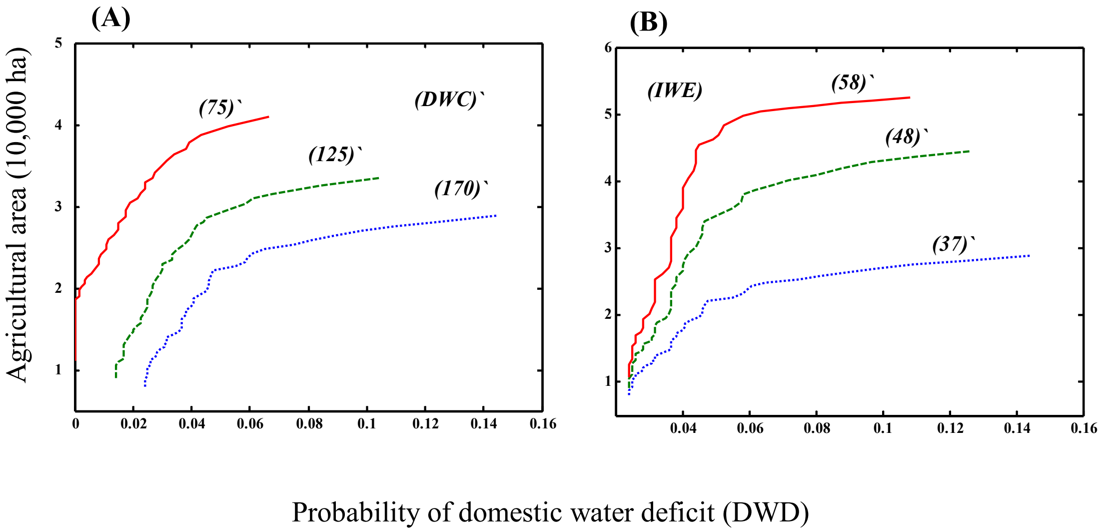


Figure 7. Tradeoff between domestic water use and agriculture under three different levels of domestic water consumption (A), and irrigation water efficiency (B).

Figure 7 indicates that the opportunity cost (in terms of losses to agriculture) of decreasing the probability of domestic water shortages decreases as the amount of the water consumption per person decreases, or as water-use efficiency increases. Therefore,combining these polices would be more effective to confront drought and will impose a lower cost on the agricultural sector.

The competition for water between agriculture and the environment is represented in Figure 8. Increasing the probability of good environmental water flows can only occur at the expense of agriculture. Interestingly, this competitive relationship is stronger for initial increases in environmental water flows (moving from left to right in Figures 8 A and B). The opportunity cost of increasing environmental flows decreases as domestic water consumption decreases (Figure 8A) or as water-use efficiency increases (Figure 8B), with IWE having the larger effect. Increasing IWE from 37% to 58% results in agricultural area increasing from 29,000 ha to over 50,000 ha, while increasing the probability of good environmental flows from 0.8 to 0.27 (Figure 8B).

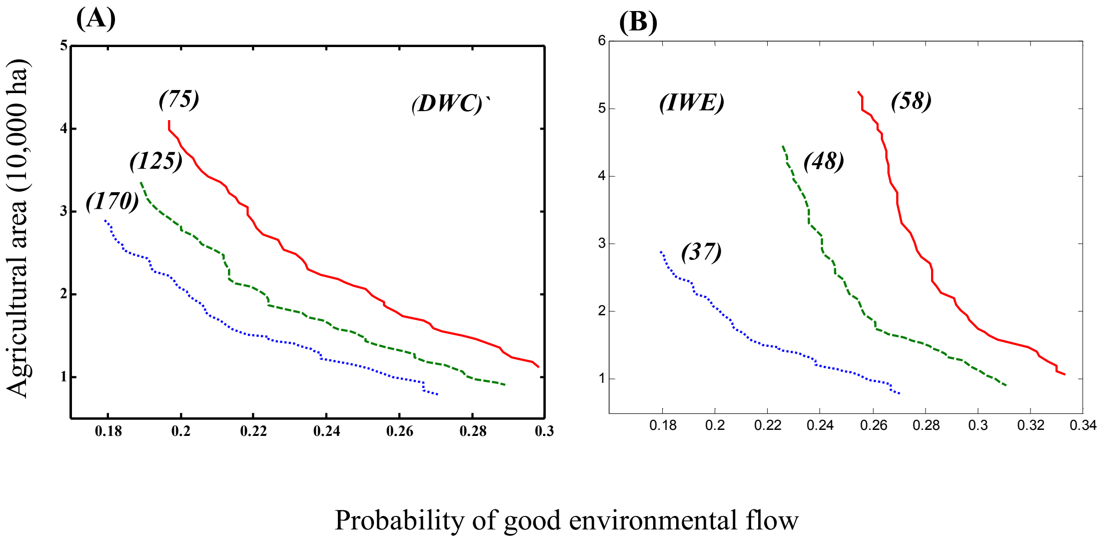


Figure 8. Tradeoff between environmental flows and agriculture under three different levels of and irrigation water efficiency.

Summary and Conclusions

This paper presents a simplified model of water use in the Sistan region of Iran. The model was used to explore the effects of various water-management alternatives on three types of water users: domestic, agriculture and environment. The obvious tradeoffs between agriculture and domestic use and between agriculture and environmental flows were identified. The value of the analysis presented here is that these tradeoffs are evaluated in terms of probabilities. The next step in the research effort is to estimate the welfare changes associated with the different water management policies explored in this paper.

There are also opportunities to extend the model in other directions. Some obvious examples include (i) representing the wider irrigation area associated with the Hirmand River; (ii) including other factors such as sediment transfer into the reservoirs with the consequent decrease in water-storage capacity; (iii) variations in population growth rate during the planning horizon; (iv) the implications of using daily, rather than monthly, water flows to estimate probabilities of drought and floods; and (v) seasonal variation in domestic water consumption during the year.

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