Determination of Optimal Environmental Flow Acquisition in Kor Basin, Doroudzan Dam

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Abstract:

In current study, an irrigation examination and acquisition of environmental water in Kor River fields, that is dominated from Doroudzan dam to Bakhtegan Lake, was done by an integrated economy-environmental model. The model was considered by economic, hydrologic and agronomic components. In the economic component, an optimal harvesting of water was done using non-linear programming in two scenarios; with and without environmental water constraint. Solutions from simulation of environmental data in the hydrologic component, was used as initial data in the economic component. In the agronomic component, actual crop yield in wet, normal and dry years was determined using the relationship between crop yield and irrigation water amount. Results showed that, the current allocation pattern of surface water in wet, normal and dry years in Kor River basin is different from the optimal pattern. Water pricing without considering demand and supply and the absence of water markets in the region can be the causes of this difference. Additionally, optimal cropping pattern of the region was determined by the model that can be taken into account for preservation of surface water resources.

Key words: Expected Net Income, Hydrology, Non-Linear Programming Model, Deficit Irrigation

Introduction:

Water is becoming an increasingly scarce resource and therefore limiting agricultural development in many countries of the world, including Iran. Therefore, water resource management is considered as the most important socio-economic subjects and demonstrating approaches with regard to sustainable management of water resources is an essential viewpoint. Ineffective management of water demand in Iran has head to waist of this vital input. So, not only there is not enough water for the irrigation, the water quality is also decreasing.

Increased usage of water with low efficient rate of exploitation methods leads to environmental worries. Expanded inversions of water from rivers and canals for irrigation and other usages result to ecological and environmental unfavorable phenomena for downstream.

Globally, efficient and sustainable management of water resources is increasingly becoming a policy objective. However, the complexity of water resources management requires an integrated biophysical and economic modeling framework that allows for the development of efficient and sustainable use of water.

Several conjunctive use optimization models have been developed. In some studies, emphasis is given on economic theory by simulating the aquifer represented as a simple single tank or a bathtub (e.g., Provencher and Burt 1994). Some conjunctive use optimization models incorporate stream–aquifer interaction either with lumped-parameter aquifer simulation or using more detailed aquifer simulation through distributed-parameter models, generally employing influence functions as ground-water response equations (Maddock 1974; Basagaoglu *et al.* 1999). Azaiez (2002) developed a multistage decision model for the conjunctive use of surface and groundwater with an artificial recharge. By assuming a certain supply and random demand, Azaiez integrated opportunity costs for the unsatisfied demand and incorporated the importance of the weight attributed by the decision-makers to the final groundwater aquifer level at the end of the planning horizon. Mohan and Jothiprakash (2003) used a combined optimization–simulation approach to develop and evaluate the alternate priority-based policies for operation of surface and groundwater systems. Qureshi *et al.* (2006) developed an integrated analytical framework including hydrologic, agronomic and economic components, and investigated the costs imposed on irrigators by restricting groundwater use and the potential for more flexible annual extraction rules that account for seasonal variations in rainfall to reduce these costs. Pulido-Velaquez *et al.* (2006) presented an integrated hydrologic–economic modeling framework for optimizing conjunctive use of surface and groundwater at a river basin scale in Spain.

Also, several studies has been done on Murray Darling Basin such as Hall *et al*. (1994) developed a spatial equilibrium model of the southern Murray–Darling Basin and used it to estimate the effects of water trading between regions. Several simulations were carried out using the model. They found that unrestricted trade in water between all regions increased gross margins by about $48 million in aggregate, (4.6 per cent). The Salinity and Landuse Simulation Analysis (SALSA) model (Bell and Heaney 2001) is a model of long-run response to water market incentives in the southern Murray–Darling Basin. Eigenraam *et al*. (2003) developed a model of water trade for Victorian parts of the Basin. It is a linked series of gross margin linear programming models – called the Water Policy Model (WPM). The MDBC (2004) utilised the Water Policy Model and the SALSA model to evaluate the economic and social impacts of environmental flows options. Qureshi *et al.* (2007) developed an integrated biophysical and economic modeling framework to assess impact of various groundwater management options on seawater intrusion and waterlogging and ultimate impact on sugarcane profitability in a coastal region of North Queensland, Australia.

The objective of this study is to determine how agricultural and husbandry sectors opportunity costs of acquiring environmental flows are likely to vary depending on the mechanism used to source water and spatial patterns of water acquisition in Kor river fields, from Doroudzan dam to Bakhtegan lake.

Study Area

Doroudzan dam is established and located 75km from Shiraz city on Kor basin with 100km longitude and 35km latitude. The study area includes Marvdasht, Zarghan and Kharameh regions. Gross extent of the region is about 315000ha and is supplied by Kor River and two major branches of Sivand and Maien rivers (Ministry of Energy. 1975).

Area of activity includes two branches; Modern Doroudzan and Combined Korbal that is cultivated 77000ha crops. Area of region is approximately 4.5 million hectares that is equal to one third of Fars province. Kor River has the efficient irrigation potential of approximately 15000ha of lands, according to the past studies, that can be satisfied by applying new agricultural and irrigation methods (Ministry of Energy. 1975).

Changes in land and water uses and their management approaches in Kor Basin leads to several anxieties for allocation pattern of water and environmental health. Non-existence of Bakhtegan Lake is one of the main outcomes of these changes and irregular acquisition of water and land in the region. So doing several integrated studies of surface and ground water resources in the region is essential.

Methodology:

Two catchments in the southern part of the Kor Basin were modeled. Thirteen agricultural activities that occupy most of the Kor Basin were considered including: spring and winter wheat, barely, sugar beet, potato, tomato, alfalfa, corn, rapeseed, grapes, two husbandry and aviculture activities.

The model that is used in the current study is composed of hydrologic, agronomic and economic components that are demonstrated below:

1. Hydrologic component

Stochastic environmental flows

Applied scientific method is the stochastic environmental flows model using historical climatic data. Mont-Carlo simulation is one of the forecasting methods. Mont-Carlo method is based on cumulative distribution function (CDF) that chooses variable X with the P probability in a manner that is less than or equal to x. Figure 1 shows the CDF function.

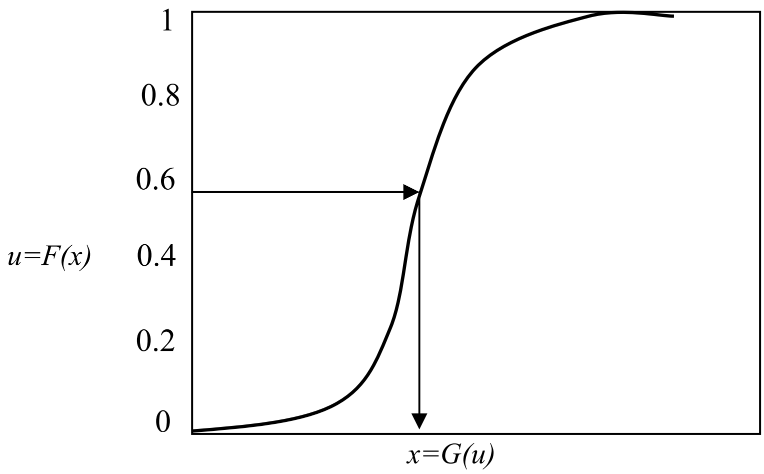

Figure 1: Main method of Mont-Carlo using CDF

The actual recommendation of the scientific panel investigating environmental flow options for the Kor was a pattern of environmental flows that varies considerably across years. This is because substantial flows in the some seasons is essential for the health of wetlands, while in other years additional flows have little value for the environment (Blackmore and Connell. 1997). Generally, additional water tends to have higher environmental value in wet years, as it can augment already significant capacity to inundate floodplains, while in dry years it would be difficult to create significant inundation even with large supplemental flows. Solutions from simulation model of cumulative distribution function were used as environmental flows of different states of nature in the economic component.

2. Agronomic component

Crop water yield functions and deficit irrigation

Crop water requirements depend on biophysical factors such as climate, soils and crop grown. At low water application rates, additional water results in yield increases. Beyond a certain level of water application, crop yields suffer due to lack of aeration in the root zone and the marginal product of water becomes negative (de Fraiture and Perry 2002). In the current study, water requirement of the crop has been calculated using Penman-Monteith Method. Total water requirement of the crop during month *t* (REQ_t) has been calculated using equation (1) (Evans, E. M 1998).

$$REQ_T = ET_O \times K_{ct} \qquad (1)$$

In which ET_o is reference evapotranspiration in month *t* and K_{ct} is the crop coefficient corresponding with its growth months. Gross water requirement of the crop *j* can be obtained using the following equation (Evans, E. M 1998):

$$w_j = \frac{REQ_t - EP_t}{IE} \qquad (2)$$

In which EP_t is effective precipitation in month t and IE is an index of efficiency level of water usage at farm level (or total basin). The observed yield at farm level and command area are influenced not only by climatic factors but policies ruling agricultural sector (for instance, pricing policies for two inputs namely irrigation water and fertilizers). Therefore, it can be stated that the observed yield is a deviational yield indeed and as a result it seems necessary to determine a yield which is not influenced by these policies and is merely a function of water, soil and plant to more exactly specify social benefits. To determine actual yield equation (4) (Allen *et al*, 1998) has been applied:

$$y_a = y_p \times \prod_{i=1}^{n} \left[1 - ky_i (1 - \frac{AET_i}{PET_i}) \right] \quad (3)$$

In which n is total growth stages of the crop and y_a and y_p are actual and potential yields respectively. AET_i and PET_i are the actual and potential evapotranspiration during various growths stages respectively and ky_i is response factor for the yield of the crop during its various growth stages.

Inclusion of a crop water production function allows modeling of deficit irrigation or applying less than the full crop water requirement and accepting less than the greatest possible yield. By reducing the water use per hectare, a greater area can be irrigated. However, the level of deficit irrigation depends on the type of crops. In general, pulses, oilseeds, cereals and grapes are tolerant to water stress to some extent. Rice is sensitive to water stress particularly at the flowering and the second half of vegetative period (Doorenbos and Kassam 1979).

3. Economic component

At the core of the framework is a model of irrigation response, costs and revenue that would be expected under alternative water demand and supply scenarios that was done using a nonlinear programming (*NLP*). The objective function of the model is to maximize the expected net revenue from water use for irrigation subject to the constraints explained below. The net revenue for each region for each state of nature is equal to the aggregate revenue for the region minus variable costs and water supply charges. The expected net revenue for the Basin (*Exp R*) is the sum across all regions of the probability weighted average net revenue across states of nature for each region:

Maximize:

$$ExpR = \sum_s \Pr_s * \left(\sum_r \sum_j P_{rj} Ya_{rj} A_{srj} - \sum_r \sum_j OC_{rj} A_{srj} - WCh \sum_r \sum_j A_{srj} w_{srj} \right) \qquad (4)$$

Where *s,* state of nature; *r* , irrigation demand sites (regions); *j*, cropping activities; *Pr*, probability of water allocations/supply; *P*, crop price (Rials/ha); *Ya*, actual yield (t/ha); *A*, irrigated area (ha) – the decision variables; *OC*, other cost (Rials/ha);*WCh*, water charge (Rials/mL); and *w*, water used (mL/ha). Water charges differ from region to region, for convenience; we assume that a single charging regime operates across the regions.

And the constraints are as follows:

$$\sum_j w_{srj} A_{srj} \le (1 - CLoss_r) * TotWat_{sr} - Env_{sr} \qquad \forall r, s \qquad (5)$$

$$\sum_j A_{srj} \le TotLand_r \qquad \forall s, r \qquad (6)$$

$$Dryland_{sr} = LandR_r - \sum_j A_{srj} \qquad \forall s, r \qquad (7)$$

$$A_{srj} = Area_{rj} \qquad if \;\; jp \qquad \forall s, r, j \qquad (8a)$$

$$\sum_j A_{srj} \le \sum_j Area_{rj} \qquad if \;\; jt \qquad \forall s, r \qquad (8b)$$

Equation (5) is the Irrigation water-use accounting and basin water constraint that ensure that the sum of the amount of water required by all crops *j* for each region, *r*, and state of nature, *s*, will not exceed the total amount of water available ($TotWat_{sr}$) after accounting for conveyance losses ($CLoss_r$) and allocating water for the environmental flows (Env_{sr}) for each region.

Equation (6) is land availability constraints where $TotLand_r$ is the total available area for irrigation. The land constraint ensures that for each state, *s*, the sum of the land areas required by regions, *r*, will not exceed the total available area for irrigation for all crops, *j*.

Equation (7) is Irrigated land use constraint and dry land constraint. These constraints are used to release irrigated land towards dry land activity ($Dryland_{sr}$) if it is not economic to irrigate. The land constraint ensures that for each state, the sum of the land areas of the crops converted to dry land and used for irrigation will be equal to the area available for irrigation land ($LandR_r$) in that region.

Equations (8a and 8b) are the Temporary and permanent activity constraints. A fixed land constraint (8a) is imposed on perennial cropping activities (*jp*) including grapes which involve substantial long run capital investment and thus can neither expand nor contract in the short-term. Temporary activities can release land for dry land activity if it is not economically viable to irrigate. Minimum area constraints are imposed on the temporary activities to prevent disappearance of activities with poor economic performance. Temporary activities include spring and winter wheat, barely, sugar beet, potato, tomato, alfalfa, corn and rapeseed. Temporary activities (*jt*) are allowed to take land from other temporary activities if it is economically viable to expand.

Constraint (8a) means that the permanent activities can only decrease water use through deficit irrigation and produce less than their maximum potential yield. The idea is to ensure that permanent crops such as grapes cannot expand from year to year, given that this would require significant capital investment which is only possible in the long-run. In contrast (8b) means that areas of crops such as cereals can expand in high-water-availability years using existing excess capital capacity of assets such as irrigation equipment and land.

Results and discussion:

In the current study, an integrated bio economical model was designed in the cultivated areas of Doroudzan dam to Bakhtegan Lake to assess how agricultural sector opportunity costs of acquiring environmental flows are likely to vary depending on the mechanism used to source water and spatial patterns of water acquisition.

Implementing Mont-Carlo simulation due to historical data of the basin and following the principles of "more water and less in dry years", simulation values of environmental flows using cumulative distribution function in each state of nature are presented in Table 1.

Table 1: Quantities of environmental flows allocations in each state of nature

State	25^{th} Percentile	50^{th} Percentile	75^{th} Percentile	Expected value
Environmental Flows allocation (MCM)	724.67	1017.92	1559	1129

This distribution is not based on an ecological assessment of when or where environmental flows would be required. However, the quantities of environmental flows vary in each state, in a way that is consistent with the 'more water in wet years and less in dry years' principle. The expected value of water for environmental flows allocations across states of nature is 1129 MCM/year, in line with the agreement by the government to supply 1129 MCM/year. The specification of stochastic environmental water requirements is used in the analysis to investigate efficiency gains that might result from acquiring more water for the environment when there is high rainfall and less when there are dry periods. The prior hypothesis is that in dry years irrigators will seek more water for production due to less effective rainfall and high evapotranspiration along with cuts in their actual water allocations. Therefore, the shadow price (or willingness to pay) for water is expected to be high in dry years. In the wet years, the opposite condition will prevail and the shadow price of water for irrigation is expected to be less providing greater opportunity to acquire water for environmental flows at low cost.

Two scenarios were modeled in the study. In the scenario 1, it is assumed that the farmers and ranchers do not have any environmental flows and scenario 2 is done with a consideration on environmental flows. Table 2 presents results of scenarios 1 and 2, including total used water, net revenue and shadow price of water.

Table 2: used water, net revenue and water shadow price under environmental scenarios

Scenario	Scenario 1 Without environmental constrain	Scenario 2 With environmental constrain
Water used (MCM)	1372.46	913.37
Net revenue (Rials 000)	4957.60	3369.80
Water shadow price (Rials/Mm)	482.00	518.00

The average current revenue of activities in the region was calculated 3146.29 thousand rials that is lower in comparison to the scenarios. With consideration to higher revenue and better usage of environmental flows in the second scenario, it was chosen as the best scenario.

Table 3 presents the available and used water and net revenue in each region due to the solutions from running the second scenario. Also, Table 4 and 5 present the comparison between current and optimal cropping pattern of Marvdasht and Karbal regions, respectively.

Table 3: Available water, used water and net revenue in Marvdasht and Karbal region

Region	Water available (MCM)	Water use (MCM)	Net revenue (Rials 1000)
Marvdasht	823.47	708.19	1901.40
Karbal	458.98	428.21	1267.60

Table 4: Current and optimal cropping pattern of crops and percent change in Marvdasht

crop	Current cropping pattern	Optimal cropping pattern	Change percent
Spring wheat	11520	12956	12.4
Winter wheat	7680	7294	-5.02
Barely	3780	2910	-23.10
Sugar beet	586.70	875.40	49.20
Potato	1928	2125	10.21
Tomato	1500	1657	10.47
Alfalfa	71	104	46.47
Corn	4140	3496	15.56
Rape	675	546	19.11
Grapes	5000	5089	1.78

Table 5: Current and optimal cropping pattern of crops and percent change in Karbal

crop	Current cropping pattern	Optimal cropping pattern	Change percent
Spring wheat	9000	10215	13.5
Winter wheat	6000	6283	4.72
Barely	3500	3644	4.11
Sugar beet	1021.25	1334	30.62
Potato	946.05	1062	12.26
Tomato	650	695	6.92
Alfalfa	280	352	25.72
Corn	2500	2365	-5.4
Rape	350	387	10.57
Grapes	1500	1694	12.93

According to Table 4, it should be mentioned that sugar beet and barely with 49.20 and -23.10 percents of change have the highest and the lowest values in Marvdasht region, respectively. Also, sugar beet and corn with 30.62 and -5.4 percents of change have the highest and the lowest values in Karbal region.

Conclusion:

In the current study, optimal acquisition of surface water of Kor River was done using integrated model, including hydrologic, agronomic and economic components. Results showed that harvesting pattern from surface waters was not optimal and leaded to inappropriate patterns in the Basin. Also, net revenues of water acquisition patterns were compared with the scenario that considered the environmental flows constraint. Results showed that the current revenue is less than the limited pattern.

Optimal and rational acquisition of resources is necessary due to the scarcity of vital input, water. Determination of water price with regard to demand and supply is recommended in different regions of the Basin.

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