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Toward Effective Water Diplomacy by Using System Dynamics: Case Study

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Abstract

Rapid urbanization and climate change along with expanding agricultural and industrial water rights are threatening all water resources, particularly lakes in arid regions such as Urmia Lake in Iran. When these systems are healthy, they provide valuable ecological and socio-economic benefits to current and future generations. However, many arid zone lakes are now subject to a high risk of depletion, pollution, salt water intrusion, and aeolian transport. These processes may have direct health consequences such as raising the risk of asthma, kidney stones, and some skin-related diseases. These risks require robust solutions in the face of significant uncertainties and potential conflicts among water stakeholders. The goal of this research is to propose sustainable lake management alternatives by using a system dynamics (SD) approach. A simulation model to compare the alternative rehabilitation options is developed focusing on feedback and the externalities of decisions made using the SD approach. The main aim of this modeling is to help trust building among conflicting stakeholders, which is a key aspect of water diplomacy and essential for effective water management. Results of the paper indicate that increasing irrigation efficiency by 4% annually would be most effective plan in saving Urmia Lake. Zaab inter-basin water transfer project could have more than 25% contribution in saving the lake, although that would require some of the sensitive diplomacy and negotiation. Aras water transfers have low feasibility in terms of water diplomacy. In addition, this study found that while decreasing 15% of cultivated area over a period of six years would be more effective than cloud seeding, reducing cropped area requires greater diplomacy than cloud seeding. This modelling approach is a first step toward long term processes of decision support and water diplomacy in the Urmia Lake basin and beyond.

Key words: System dynamics, Water diplomacy, Restoration, Urmia Lake.

1. Introduction

About 1.6 billion people, almost one quarter of the world's population, are facing economic water shortages due to hydro-political fragmentation and conflicts among stakeholders. This critical condition requires robust negotiations and solutions under conditions of great uncertainty. As long as the ambiguity of these problems and potential solutions persist, it induces conflict among stakeholders that results in further delay on any action to prevent loss of resources.

Water diplomacy is a process that involves joint-fact finding among stakeholders. The most powerful aspect of this process is the shared information that it produces about the problem and about cause-and-effect relationships between stakeholders' actions. When it employs simulation modeling, it provides a process to facilitate political negotiations and joint-understanding of the problem. Simulation modelling can help decision makers to see the outcomes of different policies in water management. Modelling interventions and feedback among system elements is an essential part of identifying sustainable development solutions. The main advantage of this modelling approach is that by simulating the effects of different policies on lake management problems, it helps build trust among conflicting stakeholders.

An object-oriented system dynamics (SD) approach is a useful tool for modeling this type of simulation problem (Forrester, 1973; Simonovic, 2009; Zarghami and Akbariyeh, 2012, Mirchi, 2013, Amir Rahmani and Zarghami, 2015). It allows us to conduct multi-scenario, multi-attribute analyses that result in relative comparisons of many alternative management strategies over time (Sahlke and Jacobson, 2005). A few lake management problems have been modeled using the SD approach, especially relating to sustainability issues. For example, Guo et al. 2001 used this approach to evaluate the environmental, social, and economic impacts of Chinese government policy on the quality of water in Erhai Lake. The SD approach has also been applied to allocate water in the Sun Juan Basin between Colorado and New Mexico (Ewers, 2005). Liu et al. (2008) used SD to understand the effect of urban population increase and economic development on the eutrophication of a lake.

The goal of this research is to generate sustainable lake management solutions to the water control problems that affect Urmia Lake in Iran. This approach can help to integrate economic prosperity, social equity and environmental health concerns into a single framework. To achieve this goal, a simulation model is first developed to model the socio-economic and ecological processes for the Urmia Lake case study, and to assess policies to achieve its sustainability for current and future generations. This approach can be generalized for other cases. The main advantage of this research is that by simulating effect of different policies on the lake management problem we may be able to avoid "fixes that fail." For example, the Urmia Lake Restoration Program has suggested nineteen solutions. These suggestions include hard and soft solutions, such as inter-basin water transfer projects, cloud seeding, increasing agricultural water efficiency and decreasing farmed land area. This paper simulates these restoration projects and compares the relative effectiveness of them. This simulation model can help stakeholders reach agreement and build trust through a process of water diplomacy modeling.

2. Problem Description: The Urmia Lake Case Study in Iran

Urmia Lake in northwestern Iran is the largest inland lake of the country and one of the largest saline lakes in the world. The lake basin presents a highly influential and valuable aquatic ecosystem. Approximately 1500 species of vascular plants, including the unique Artemia sp., inhabit the lake's wetlands, representing 15% of the total number of flora species found in the country. Because of its unique natural and ecological features, the lake and its surrounding wetlands have been designated as a National Park, Ramsar Site, and a UNESCO Biosphere Reserve (CIWP, 2008). The lake basin, as a socio-ecological region, has experienced extreme water shortages in recent years due to poor water management and climate change (Alipour, 2006; Zarghami, 2011). Because of intense agricultural development and rapid urbanization, the groundwater level in some parts of the basin has dropped by up to 16 meters. As a result, the water level of the lake and its surrounding area are now below the critical level (Fig. 1). Wind-blown salty dusts from dry areas of the lakebed can become a serious threat to the health of the people residing in the area if the water inflow falls short of its minimum level of 3 billion cubic meters to sustain the lake (Abbaspour and Nazaridoust, 2007).

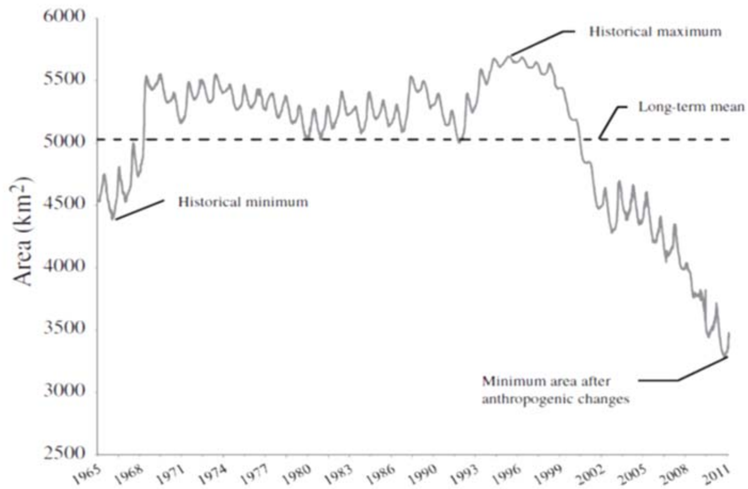

Fig. 1. Changes in the area of Urmia Lake (Sima and Tajrishi, 2013)

Given the severity of the situation, saving Urmia Lake is currently one of the top priorities of national and several international organizations (including UNDP, UNEP, and JICA). However, there is a lack of comprehensive research to evaluate the effects of alternative adaptation/mitigation strategies on the lake. The goal of this research, therefore, is to provide a technique to find the best, most robust strategies. This analysis can help build trust among the stakeholders and then will provide a base to start water diplomacy framework. This research deals with two important questions. The first set of questions concerns the condition of Urmia Lake in the near future, while the second evaluates effective strategies to survive the current conditions. Theoretically, the first question leads to an argument about "the tragedy of the commons," and the second toward an argument to prevent "fixes that fail." These two questions are detailed in the following.

Questions about the problem at Urmia Lake: Will the lake dry up due to the overuse of its water resources and climate change, as is happening in the Aral Sea? And if the lake does disappear, what are the social, economic, and environmental impacts on the region? What would be the effects on water quality and accessibility? Would this result in people from cities and villages around the lake migrating to other cities? When might such problems start?

Questions about possible solutions: Which combinations of strategies would be most effective and efficient in sustaining the basin? These options will be studied in two groups:

- *Soft solutions*: water conservation, water market tools like price signals, water allocation adjustments, and other organizational strategies.
- *Hard solutions*: Reducing agricultural water use, preventing the construction of new dams, inter-basin water transfer, and other infrastructural alterations.

3. Urmia Lake SD Model

The following steps were carried out to build this SD model: (i) describing the problem and its uncertainties; (ii) defining key variables to develop the lake's model; (iii) preparing casual loop diagrams and system archetypes; (iv) building a stock and flow model in the VENSIM software environment; and (v) calibration and validation. Some of the needed data were drawn from interviews and stakeholder meetings with local NGOs, national organizations and international institutions such as UNDP. The author’s close relationships with several associated institutions and corporations made it relatively easy to collect the remaining data. To validate the methodology, several tests including boundary adequacy, structure assessment, and dimensional consistency were performed. The modeled lake level is compared with the observed data in the last 20 years. Using the validated model, the hard and soft lake restoration strategies were simulated for the next 20 years, considering various tradeoffs among the different objectives. The main parts are the lake stock and water supply and extraction flows by the rivers and groundwater as shown in Fig. 2.

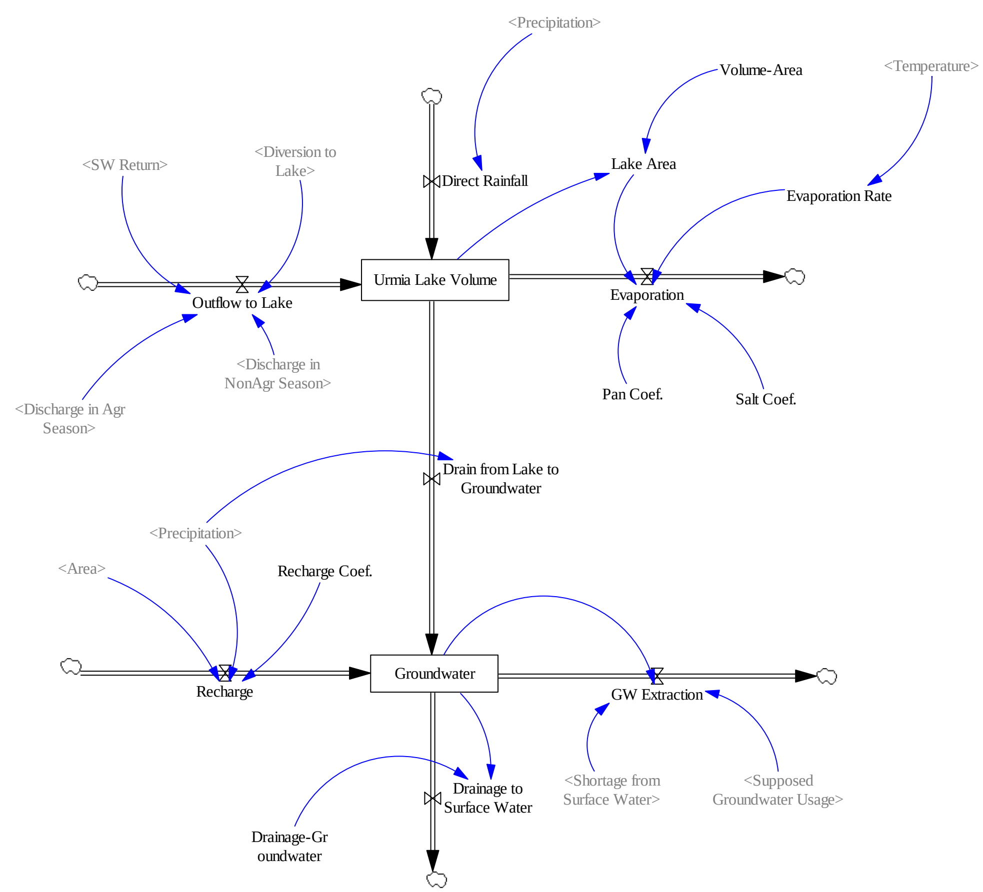

Fig. 2 The main sub-model in the Vensim environment

The second sub–model is for demand forecasting. It aggregates water user's demands including the agriculture, industrial and domestic sectors. For domestic users, the main driver is the population, which is modeled as shown in Fig. 3.

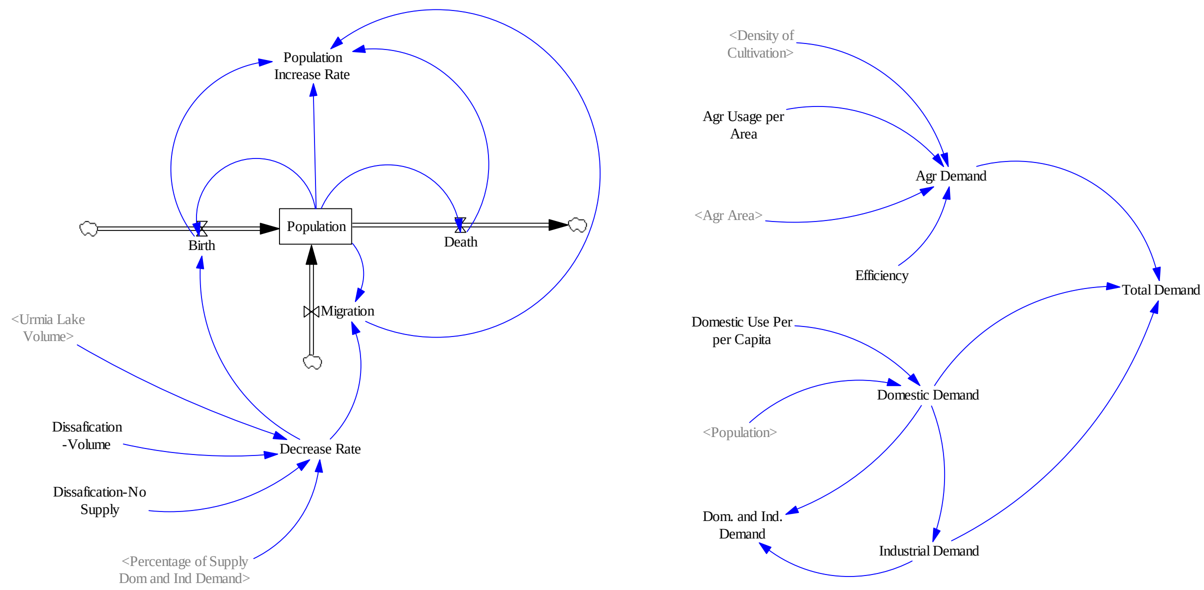

Fig. 3 The main sub-model of the water demand

In the water supply side, the most important element is the rainfall-runoff model. It is presented in Fig. 4. This sub-model includes the uncertainties in future rainfall due to cloud seeding and also different climate change models.

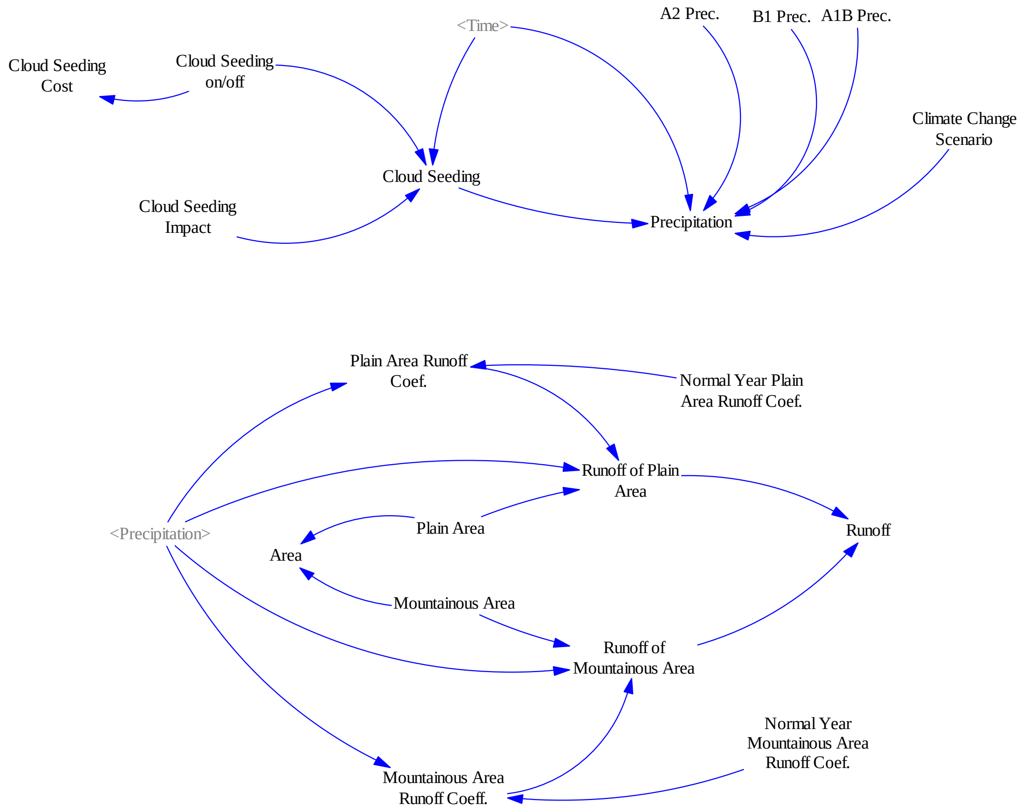

Fig. 4 The sub-models of rainfall and runoff

Finally the sub-model of conjunctive surface and groundwater use including percolating water resources is presented in Fig. 5.

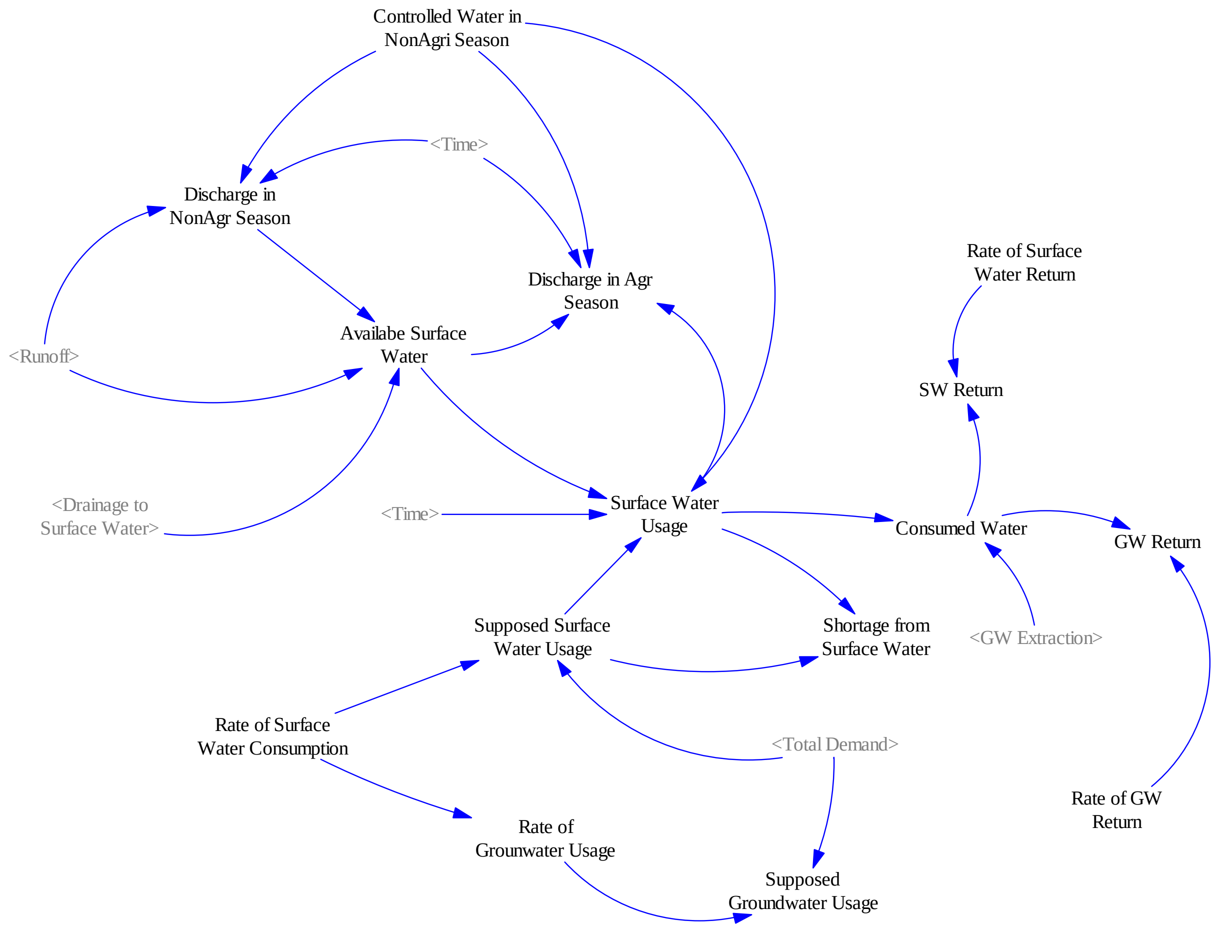

Fig. 5 The sub-model to explain the relations among water resources stocks and flow

Finally, simulation using the SyntheSim tool provides very valuable insight. It helps stakeholders see the outcomes of using different policies for restoring the lake. The view of this visual result is shown in Fig. 6. The initial model results presented here used stakeholder inputs from previous studies and reports. The next stage of research will involve iterative validation of the model by a group of regional and international experts in a water diplomacy simulation setting.

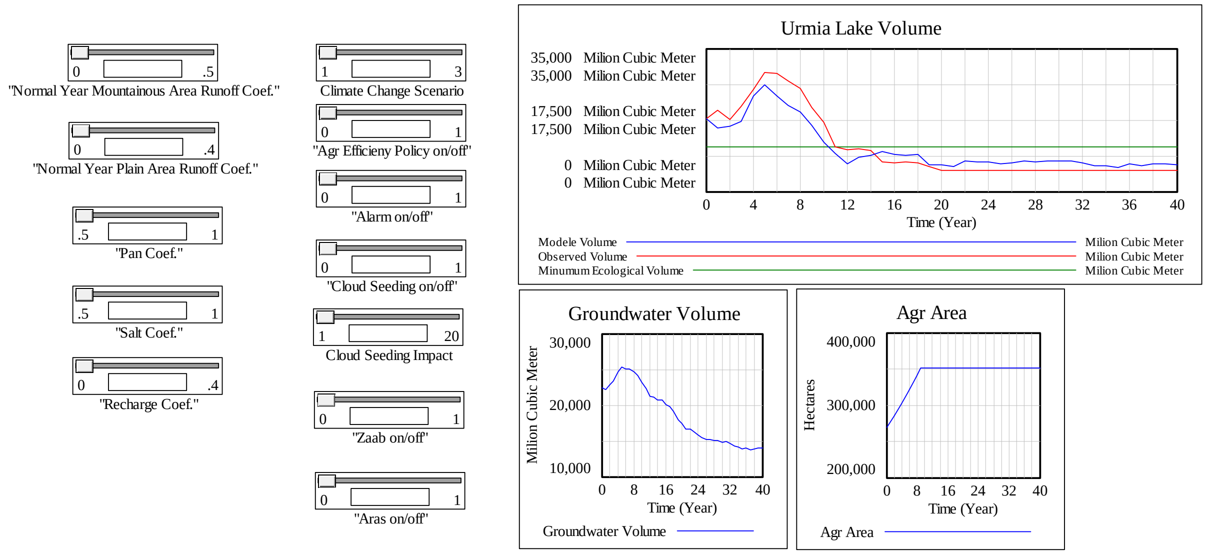

Fig. 6 “Control panel” provided by SyntheSim: Visual and dynamic representation of the Urmia Lake volume affected by changes in the policies and parameters

In this study six restoration plans are considered. These policies, strategies and projects are among the suggestions of the Regional Committee on Urmia Lake Basin, which is responsible for saving the lake. Different action plans are defined as restoration scenarios to investigate if the lake could be saved by various combinations of these plans. These projects and scenarios are summarized in Table 1 and Table 2.

Plan 1- Increasing irrigation efficiency: Most academics and engineers agree that agricultural water use efficiency is low in Iran. Hence, increasing water efficiency is considered as a solution for water scarcity problems. It is assumed in a ten-year plan that water efficiency could be raised to 70% in the basin (i.e., a 4% annual increase in this parameter). Changing crop patterns and improving irrigation systems could effectively increase water use efficiency.

Plan 2- Reducing agricultural area: Rapid growth in farm land area in the basin is a major factor for the Urmia Lake disaster. Therefore, stopping its growth and decreasing area are followed in plan 2. Since the area of decrease is a major source debate among stakeholders, an alarm variable is defined in the model. This variable represents the degree of vulnerability of the lake and of groundwater fall. The area of decrease is estimated by the alarm variable, but it is assumed to have maximum reduction about 5% considering the social resistance and sensitivity regarding this plan.

Plan 3- Cloud seeding: Cloud seeding to increase precipitation over an area could make an effective contribution toward reducing water stress in a basin. Consequently, adding some water to the basin by cloud seeding could help in lake restoration. Cloud seeding impact differs based on the seeding method, climate of the region, and type of clouds. But it is assumed here that cloud seeding could enhance annual precipitation by up to 7%. This effectiveness value is the average of numbers we found in the literature (Curic et al. 2007, Silverman 201, Acharya et al. 2011, DeFelice et al. 2014)

Plans 4 and 5- Water Transfer: The other way of adding water to a basin is via inter-basin water transfer projects. Two main water transfer projects considered here are from the Zaab and Aras basins. The Zaab basin could transfer 600 MCM annually to Urmia Lake basin to supply increasing water demands. Also there are plans to transfer 140 MCM annually from Aras basin north of Urmia Lake, though this is an international river basin tributary to the Caspian Sea that does not have clear water allocation agreements.

Table 1. Name of Plans and their action

Plan	Action	Horizon	Effect
P.1	Increasing irrigation efficiency	2015-2025	4% annually
P.2	Reducing agricultural area	based on drought intensity	0%-5% annually
P.3	Cloud seeding	2015-2030	7% annually
P.4	Transfer from Zaab	2015-2030	600 MCM/Y
P.5	Transfer from Aras	2015-2030	140 MCM/Y

In addition to the volume of the lake that serves best for measuring restoration success, two other indicators were selected to check if the plans lead the basin toward sustainability. Relative water stress indicator (RWSI) computes the demands on available water resources in a basin. RWSI formulation is presented in Equation (1).

$$RWSI = \frac{DIA}{Q} \tag{1}$$

which DIA is total demand (MCM) in a basin including domestic, industrial and agricultural water needs and Q total available surface and ground water (MCM). RWSI>0.4 for a basin indicates a highly stressed and critical condition. Second, groundwater dependency (GD) expresses the degree of groundwater participation in water supply in a basin. This indicator can be computed by Equation (2):

$$GD = \frac{total groundwater\ \ abstraction}{total\ surface\ and\ ground\ water\ supplies} \tag{2}$$

Favorable value for GD is less than 0.25. Represented GD for basins with high dependency to ground water is more than 0.5.

Modelling results: Fig. 7 illustrates lake level changes under each plan. Plan1 follows policy of increasing water efficiency by 4% annually. Hence, it is supposed to have 70% water efficiency by 2025 in the basin. It is seen improving this parameter could not save the lake on its own, because a direct feedback of this policy is increasing land area and crop density by farmers. It is estimated RWSI and GD are almost 0.85 and 0.34 in the basin under this plan. Hence, implementing only this plan neither restores the lake nor leads the basin to sustainability because of the socio-economic response of the basin.

Decreasing farmed land area which is Plan 2 is seen just saves the lake to minimum ecological level (MEL). This plan needs to lower area of cultivation 20% in a 5-year duration to lead the lake to MEL in 2020. RWSI and GD are estimated to be almost 0.54 and 0.43 in the basin under this plan. Certain crucial socio-economic consequences of this plan in the region would be considerable.

It is seen in Fig. 7 adding extra water to the basin by cloud seeding can save the lake to MEL on its own. It is assumed this project raises precipitation 15% in the basin, though the high scientific and technical uncertainties of this estimate must be acknowledged. Cloud seeding project improves GD to 0.28, but it makes RWSI worse in the basin.

Inter-basin transfer projects of Zaab and Aras are supposed to have considerable favor for restoration of Urmia Lake. Zaab basin is supposed to transfer 600 MCM under Plan 4 and Aras 140 MCM under Plan 5 to Urmia Lake basin. Based on Fig. 7 it appears these projects can help the lake from drying up and but save the lake. It must be noted that these international plans would require additional levels of water negotiation and diplomacy.

Fig. 7 Simulation of the individual effect of each plan by Urmia SD model

A combination of these plans is likely to be implemented to save Urmia Lake. Hence, assuming all of the plans are in action, estimating the contribution of each plan supports the objectives of this paper. In the scenario of implementing all 5 plans, RWSI is estimated to be almost 0.6 and GD almost 0.4. Although RWSI indicates the basin is still highly stressed based on international standards, it is below average RWSI in Iran, which could make it acceptable. When all plans are implemented, the dynamics of the basin are totally different from the situation in which each plan is applied alone. In this scenario there is more water in the basin because of inter-basin transfers and cloud seeding, and as a result, smaller area needs to be taken out of farming. The percent contribution of each plan is plotted in Fig. 8.

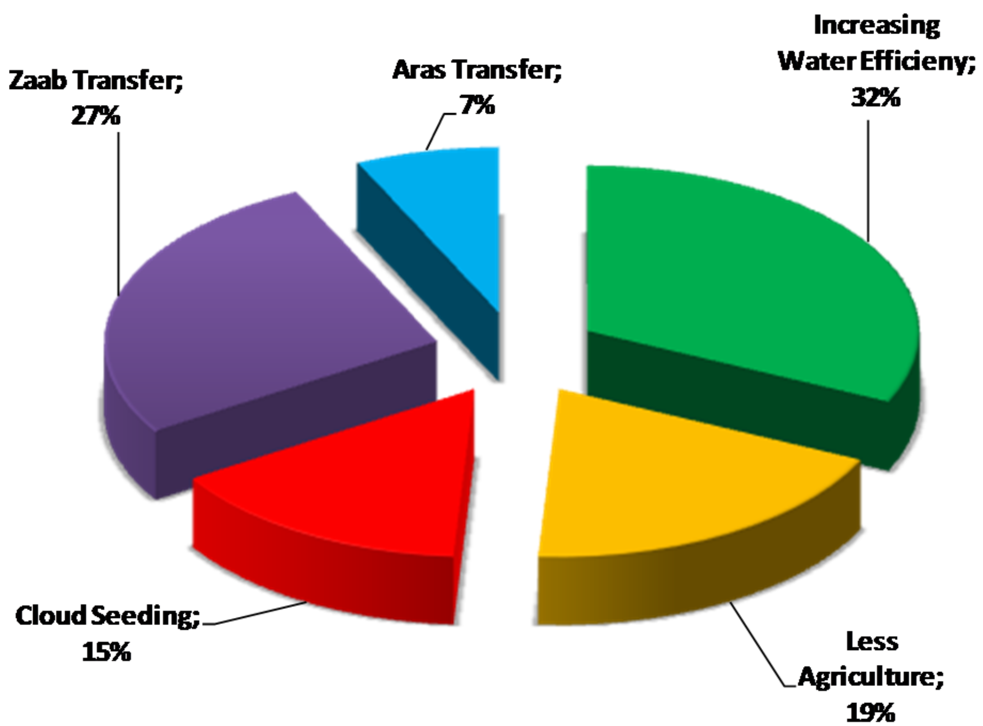

Fig. 8 Contribution of each plan in restoring Urmia Lake to its ecological level (%)

Based on the results of this paper, implementing all plans could cause Urmia Lake to be restored by 2022 even though some plans are not completed by that time. It is seen increasing water efficiency has the most important share in saving Urmia Lake. In the second place, Zaab Transfer project has ~ 27% effect in raising lake level. Stopping 15% of cultivated area from farming (in restoration period) has 19% contribution in reaching to minimum ecological elevation. Having 7% increase in annual precipitation by cloud seeding has a contribution about 15% in saving the Lake. Based on these results shown in Fig. 8, Aras transfer project has an impact less than 7% in the basin.

4. Conclusions

This paper presents the first results of Urmia SD model to support a process of water diplomacy. The authors drew upon stakeholder reports to generate this model, and plan to solicit comments from stakeholders and experts on the Urmia Lake to update the model. Based on these initial results, increasing water efficiency in a ten-year period is the most effective plan for restoring Urmia Lake, and may also be the most feasible among stakeholders. The Zaab water transfer has the second place among plans for restoring the lake to its minimum ecological level, but it would involve high levels of water diplomacy. Also, it is seen that decreasing agricultural area to keep it 85% of its existing area within a 6-year period (2016-2021) could make a contribution of almost 20% to lake level restoration. Although the modeling approach of this research differs from that of the Regional Council on Lake Urmia Basin Management, (2012), the results are close and affirming.

Using this system dynamic model can help the stakeholders see the effects of different policies. It can help build trust among them which is vital for long-term water diplomacy. However, since restoring the lake is a complex problem, more studies are needed. One important job that is in progress is comparing alternative plans by multi-criteria analysis. Finding near-optimal combinations of cultivated land areas to restore the lake and also improve agricultural sustainability is vital. Conflict resolution mechanisms and experiments with stakeholder groups need to be added to the model in future research.

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