Water Resources Modelling Using System Dynamic in Vensim

(A case study: Risk analysis of Sefīd-Rūd Dam Reservoir intake decrease on downstream agricultural water demand)

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***Abstract*-In this paper, we discuss the use of system dynamics (SD) techniques as a methodology by which to study dynamically complex problems in water resources management. A dynamic system method with objective modelling is based on feedback; hence it can model complicated water resources systems and can act as a useful management tool. In this study, a dynamic system model is applied to the Sefīd-Rūd Watershed in northern Iran. This model includes the river catch basin, dam reservoir and the irrigation system of the studied area. Finally, the liability of the model is tested and verified with observed data and statistics criteria. The risk analysis of water demand deficit in the water supply of the Sefīd-Rūd provided by the Sefīd-Rūd dam is simulated and analysed according to three different scenarios of 15%, 30% and 45% of the reservoir intake water deficit as a result of constructing new dam on the Qizil Uzun River, using dynamic system analysis with a Vensim model. The results indicate that the liability of water demand provisions in normal conditions (75%) in case of a water intake deficit varies; in abnormal conditions such as 15%, 30% and 45%, the liability adjusts to 48, 57 and 35, respectively. This has the potential to cause serious troubles and challenges for farmers in the region, struggling to meet their water demands**

Keywords- Sefīd-Rūd Da; Vensim; Irrigation Water Demand

I. INTRODUCTION

Water resources all over the world are used extensively, and population growth and climate changes cause increasing challenges to provide the vital demand of water [4]. There are many complicated and co-dependent factors vital to the establishment of a coherent water system management plan. To achieve this goal, it is necessary to use methods that not only analyse these systems but can also yield an approximate evaluation of reality by modeling these systems. Dynamic system science is the answer to this necessity. Dynamic simulation and modeling of various water resources in rea time is a legitimate scientific base from which to enforce management strategies [5]. Faster model generation, the capability to enhance a group or series of models, simple modification and correction capability according to changes in the systems are some of the advantages of this method [6].

The study of dynamic systems suffers from high scientific and application liability in academic society. It is also an official course in most respectable universities, and several professional and expert teams have conducted applied studies regarding system dynamics in numerous parts of the world such as Japan, the European Union, and the United states [3].

Among the commonly used system analysis methods, objective dynamic modeling based on feedback is a simple and effective method, which does not require complicated mathematical components to define the system. This method has been used extensively in the past decades to model the variety of problems in water resources management.

II. HISTORY PREVIOUS STUDIES AND METHODOLOGY

Ciesilk and McAlliston studied the path of the Missouri River considering its six reservoirs over the course of a few years of application in 1994. These reservoirs were used for flood control, hydropower plants, water quality, irrigation, shipping, reclamation and rehabilitation. Saysel and Barlas used the dynamic system method to determine the capacities of hydropower plants, the development of agriculture and farming, planting choices and preferences, environmental issues, and agricultural products in southeast Turkey in 2001.

A. Methodology

The process of dynamic system modeling is as following. The issues in these systems are dynamic and feedback affiliated structures. The quantitative and qualitative characteristics of the system are dynamic (not constant) over time, and yield data and information before and after variation. Based on a feedback structure, the effective items in the process interact with one another during each time step. Dynamic system study as a systematic method is a means to enhance the research in accordance

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with complicated systems. The significant advantage to this method is the objective feedback structure. In this method, saving, flow, interfaces and convertor tools are used in the process.

The Guilan plain stretches from the west coast of the Caspian Sea, including areas of 26 to 100 meters in altitude, and has a Mediterranean climate with 1200 mm of annual rain, 70% of which occurs in autumn and winter. Guilan's main agricultural product is rice, which encompasses 95% of the annual planting. The Sefīd-Rūd River is the main water resource in the area, and has a long-term average flow (1964-2001) of 4500 million cubic meters. However, the base flow of the river during the primary irrigation period (May to September) plunges, which caused a significant loss of crops and economic problems prior to the construction of Sefīd-Rūd dam. Recent drought also caused a water deficit in the Sefīd-Rūd River, posing the same threat. The Sefīd-Rūd Dam, one of the largest and most important hydraulic structures of Iran, is located near the city of Manjil, approximately 100 km south of the Caspian Sea on the Sefīd-Rūd River, on the confluence of the Shahroud River and Qizil Uzun River. The dam was built for flood control, to fuel a hydropower plant, and to provide drinking and irrigation water oto the Guilan plain. The Sefīd-Rūd Dam construction was begun in 1945 and was completed in 1961, at an expense of 5533 million rials, and became operational in January of 1962.

III. MODELING STEPS

There are no hard and fast rules or instructions for successful modeling, yet a clear definition of the problem is necessary to the development of an efficient model. Modeling experts use these well-defined steps:

A. *Precise Definition of the Problem*

This step includes definition, choosing variables, key issues and time horizon, and dynamic definition of the problem.

It is recommended to write down all potentially important items and grade the based on importance for choosing variables and key issues.

To define the correct time horizon to include the basic causes of the problem in the model, we decide how long to consider the past history of the problem.

It is essential to consider past history of the key issues and variables and to have a general idea of their behavior in the future.

B. *Dynamic Mathematical Assumption*

This step includes the following items

Defining the preliminary assumptions

Mathematical formulation of dynamic assumptions

Provide a sketch of the problem in accordance with the preliminary assumptions

Distinguish the key variables and other existing data.

Dynamic assumptions can be in the form of cause-and-effect cycles or flow-and -eposit charts. As for other assumptions, dynamic assumptions can be false, and the correction of these assumptions is an important part of model enhancement.

C. *Introduction of Software*

Vensim is one of the software tools that employ dynamic system study to model and provide solutions to a proposed problem. This modeling tool uses an objective modeling method which enables the software to model complicated water resources problems in a less complex way than other common programming languages. The physical and conceptual attributes of the model are defined for the executive plan of the problem solution with the help of existing analytical functions in Vensim software. The results are presented visually and checked for case sensitivity that supports a variety of decision capabilities.

D. *Key Variables*

The key variables vital to modeling are: Sefīd-Rūd reservoir intake time series, the lake surface evaporation, and the water intake deficit of the reservoir.

E. *Time Period*

A time period of 33 years (396 months) of Sefīd-Rūd Dam function has been identified (1997-2030).

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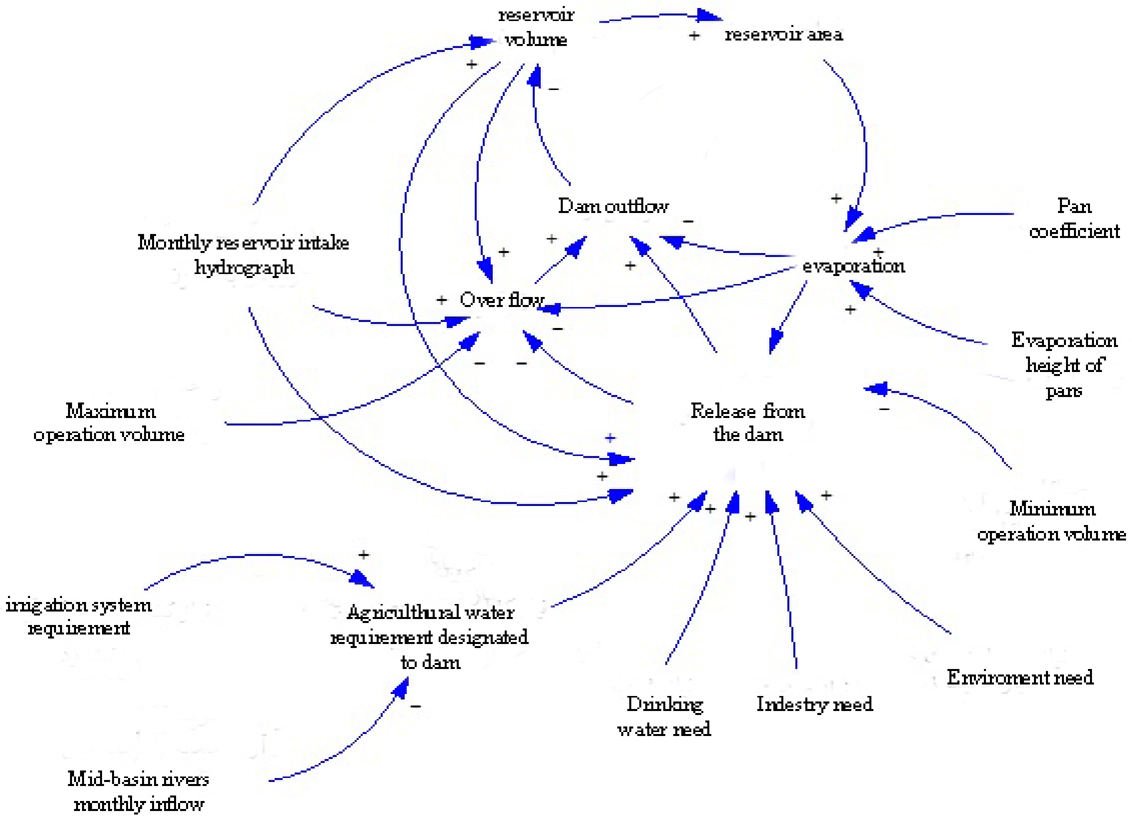

Fig. 1 Cause-and-effect chart of dam reservoir

The Sefīd-Rūd dam operation modeling and the river flow along its path is presented in Fig. 1, using cause-and-effect and flow-and-deposit charts. The final model consists of the following primary components:

1. Prepare the input variable file for the software.
2. Define the required irrigation water assigned to the dam.
3. Define the outflow of the reservoir
4. Water flow, extraction and return along the river path.
5. Sefīd-Rūd dam water requirements fulfillment reliability assessment.

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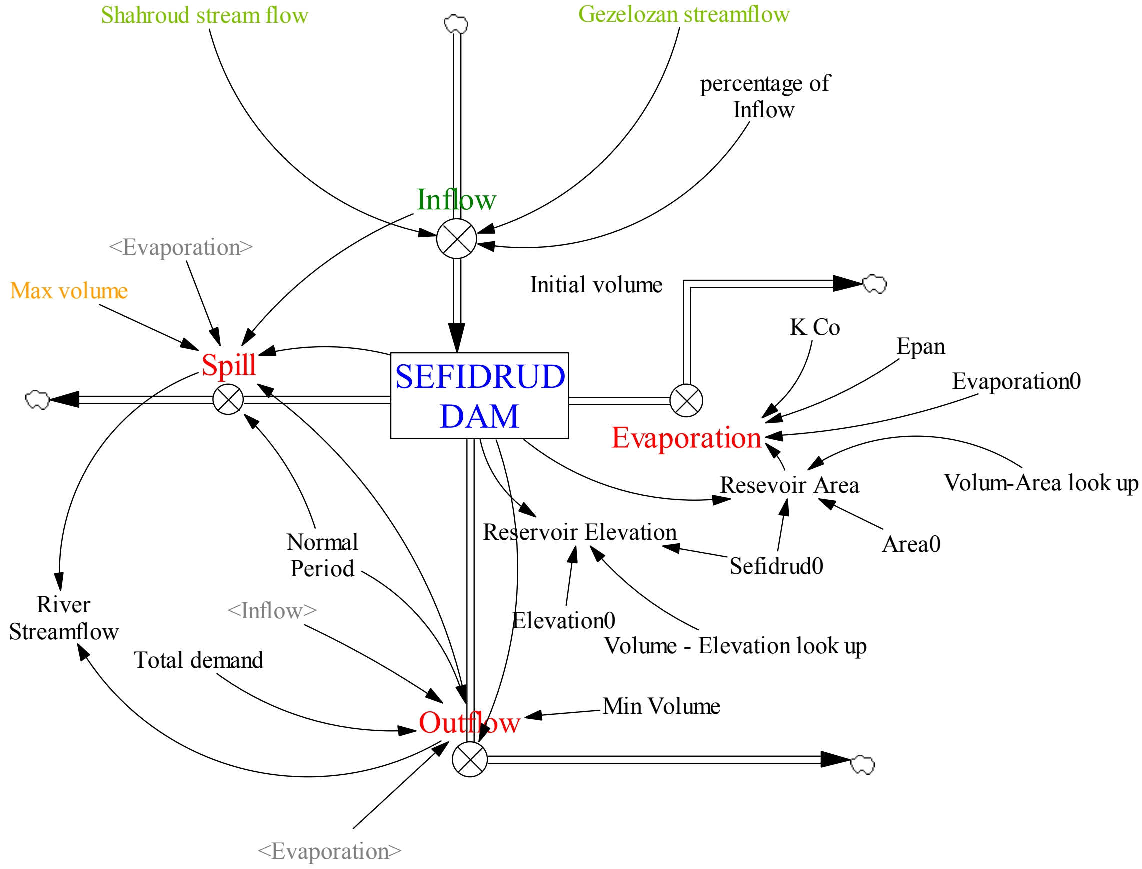

Fig. 2 Main part of the model to assess reservoir outflow volume

Increasing water extraction from the Sefīd-Rūd River and the construction of several dams on the Qizil Uzun River since 1962 have caused a significant decrease of inflow to the Sefīd-Rūd dam reservoir. We examine the effect of an inflow decrease of 15%, 30% and 45% on water requirement fulfillment. Fig. 3 shows the resultant reliability assessment which indicates that the reliability of water requirement fulfillment varies from 75% in normal conditions to 57%, 48% and 35% percent for a 15%, 30% and 45% decrease, respectively, which would cause serious problems for the farmers in the region (Fig. 3).

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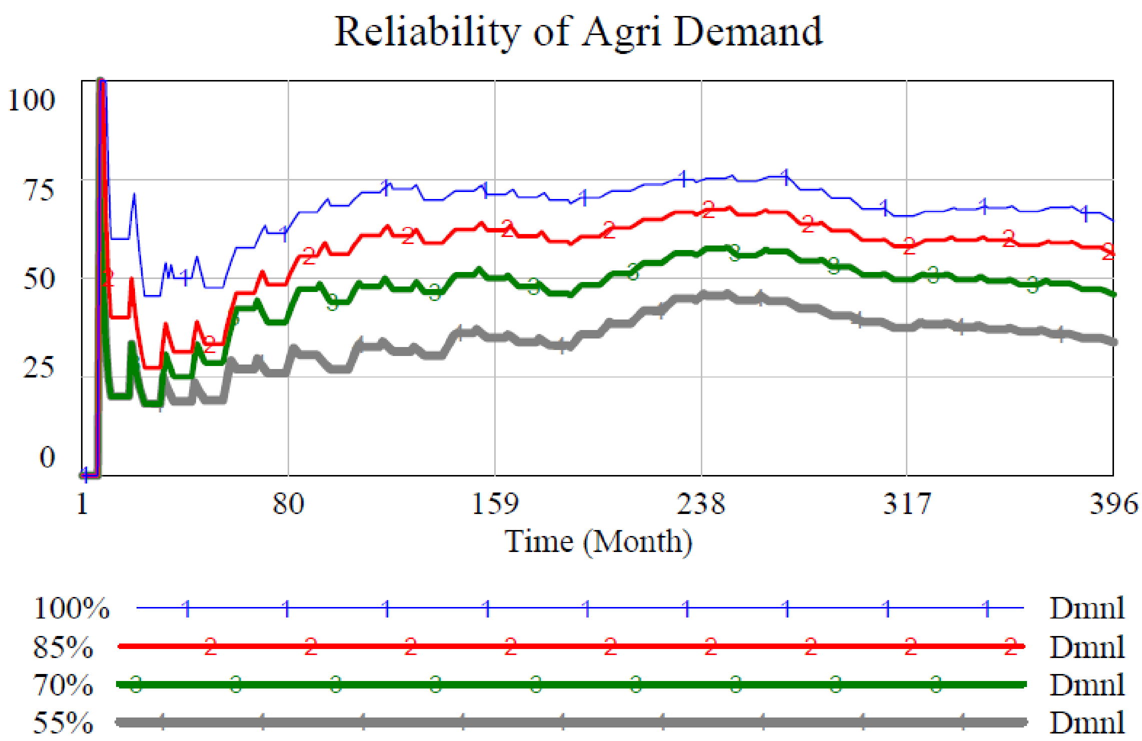

Fig. 3 The effect of inflow decrease to the Sefīd-Rūd dam reservoir on water requirement fulfillment

IV. CONCLUSIONS

In this study, the operation of the Sefīd-Rūd dam was modeled using dynamic system study. Reliable modeling requires a precise assessment of the Sefīd-Rūd watershed including the mid-basin river characteristics, irrigation system requirements, etc. After validation and calibration of the model, the effects of different factors on water requirement fulfillment reliability were evaluated. Three scenarios in which the water inflow of the reservoir is decreased have been used as modeling assumptions which showed a significant decrease in water requirement reliability which is counterproductive to the basic goal for the Sefīd-Rūd Dam construction.

A. Suggestions

Several physical, management and structural obstacles have arisen since the Sefīd-Rūd irrigation system became operational. The most important obstacle is the inflow decrease upstream of the Sefīd-Rūd Dam and loss of reservoir volume due to sedimentation.

It is of a great importance to have a general plan to use existing water resources and create a balance between water resource availability and requirements. It is also suggested that water systems management teams consider the rehabilitation and maintenance of the Sefīd-Rūd irrigation system to be a priority since the system was exposed to high erosion due to inappropriate application and inadequate maintenance services.

One of the advantages of dynamic system study is its capability to convert and adapt easily, as through the addition of new effective parameters such as: increasing utilization of ground water, construction of new dams, etc. The effect of these new variables can also be used to evaluate performance in dynamic system study. In the end, the following suggestions are proposed in consideration of downstream water requirements and water rights:

1. Accurate identification and study of existing and future water consumption downstream of the Sefīd-Rūd Dam.
2. A general study of water in the great Sefīd-Rūd watershed including the Shahroud and Qizil Uzun Rivers.

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