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Investigation the effects of reservoir operation on providing different demands by System Dynamics (Case study: Kowsar dam in Iran)

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Abstract:***Nowadays, beside water shortage, we face with mismanagement in water resources. In this situation, optimal water management especially in arid and semi-arid areas is very important. Increasing water demands due to population growth, industrial and agricultural developments are inevitable. On the other hand, water resource limitations and principal of sustainability in water management, cause water allocation, very challenging work. So for answering to agricultural, municipal, industrial and ecological demands with high reliability, we need very exact programs. The purpose of this paper is to investigate the effect of storage dam on Kheirabad River in Tange-Dook area for floodwater collection at raining times and also providing so called demands. For modeling, we used VENSIM because of existence of dynamic relations between so called factors. Based on findings of this study, it was shown that beside simplicity and good accuracy, this model has a very good adaptability with various conditions of dam's water allocations.***

Keywords: Water resource management, System dynamic, VENSIM, Kowsar dam.

1. Introduction

In Iran, a country with an area of 165 million hectares, dry and semi-arid lands cover a major part of it. Due to that reason and by increasing use of limited water resources, in the very near future the country will face a serious crisis. So planning and management of resources in order to achieve the integrated management and sustainable development of water resources in the catchment basins is of utmost importance. For solving this problem, optimal operation of water resource systems and a duty to preserve, protect and predict the future demands of a system for the next generations cause a great emphasis on water allocation in recent years. Water allocation is determined by the amount of water that the resources (surface and groundwater) should allocate in order to meet the different needs of the catchment basins. But this allocation is not an easy work because there are too many stakeholders (such as farmers, citizens, industries…, that there needs have interactions and conflicts sometimes. In this respect, modeling and simulation of water resources systems that can incorporate all factors and interactions which act effectively in the allocation of water resources, is very important.

The application of systems analysis techniques for reservoir management and operations has been a major focus of research in water resources engineering during the past four decades [1]. Numerous models have been reported in the literature for sizing storage capacity and establishing release policy, both at the project planning stage and for real-time operations. Most of the techniques that have been developed or adapted to reservoir operations are described in several textbooks, e.g., Loucks et al. and Mays and Tung [2],[3]. Wurbs and Tibbets (1985), listing over 700 references, produced a state of the art review and an annotated bibliography of systems analysis techniques applied to reservoir operations [4]. Yeh (1985) provided an excellent review on various approaches to reservoir optimization and simulation and pointed out that, despite considerable progress, research related to reservoir systems analysis has been very slow in finding its way into practice, particularly at the level of the actual operators. He attributes this partly to the fact that operators usually have not been involved in the formulation and development of computer models [5]; partly to the fact that most applications deal with simplified reservoir systems and are difficult to adapt to real systems; and partly to institutional constraints. Also, operators and their managers are not comfortable with the degree of abstraction necessary for efficient application of simulation techniques to very complex systems [6]. This literature review suggests that systems analysis has its own place in the field of reservoir management, and simulation is an essential tool for developing a quantitative basis for reservoir management decisions [1]. However, there is a strong need to explore simulation tools that can represent the complex systems in a realistic way and where operators can be involved in model development to increase their confidence in the modeling process. A promising alternative is the system dynamics (SD) approach for modeling reservoir operations, which is efficient and simple to use compared with traditional systems analysis techniques and does not require complex mathematical description of the system. System dynamics, a feedback-based object-oriented simulation approach, is becoming increasingly popular for modeling water resource systems. Palmer and colleagues have done extensive work in river basin planning using SD [7]. Keyes and Palmer (1993) used SD simulation model for drought studies [8]. Matthias and Frederick (1994) have used SD techniques to model sea-level rise in a coastal area [9]. Fletcher (1998) has used system dynamics as a decision support tool for the management of scarce water resources [10]. Simonovic et al. (1997) and Simonovic and Fahmy (1999) have used the SD approach for long-term water resources planning and policy analysis for the Nile River basin in Egypt [11],[12].

System dynamics, a feedback-based object-oriented simulation paradigm, is presented in this paper as a powerful approach for modeling reservoir operations. The study deals with simulation of reservoir operations for best allocation of supplies to various demands. Alternative Operating rules have been investigated by changing reservoir storage allocation, reservoir levels and reservoir outflows. This paper outlines a general framework for modeling reservoir operations using the SD approach. The theoretical background of the SD simulation approach is given. Then, a general modeling approach for reservoir simulation is presented by introducing model structure and complex relationships among its components. The benefits of the proposed approach are demonstrated by application to a case study of a single multipurpose reservoir. Finally, a discussion on results is presented and conclusions are drawn. Suggestions for possible model application and extension conclude the paper. Reservoir operations, which is efficient and simple to use compared with traditional systems analysis techniques and does not require complex mathematical description of the system. System dynamics, a feedback-based object-oriented simulation approach, is becoming increasingly popular for modeling water resource systems.

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This paper outlines a general framework for modeling reservoir operations using the SD approach. The theoretical background of the SD simulation approach is given. Then, a general modeling approach for reservoir simulation is presented by introducing model structure and complex relationships among its components. The benefits of the proposed approach are demonstrated by application to a case study of a single multipurpose reservoir. Finally, a discussion on results is presented and conclusions are drawn. Suggestions for possible model application and extension conclude the paper. Application of SD has always been very wide, however, with an emphasis on socioeconomic applications. In recent years there has been a tendency to model small-scale systems in greater detail with more emphasis on quantitative results (Fletcher 1998). Continuity of mass, one of the basic concepts in SD, is also an important concept for reservoir representation. Thus, reservoir simulation problems are well suited for application of SD solution techniques.

2. System Dynamics

System dynamic is one of the new management tools that can simulate and analyze a wide variety of policy and decision making in complex systems of water resources. In this research, modeling, design, operation and optimal allocation of Kowsar dam is studied by using system dynamics. For this purpose after collecting data and analyzing them, the conceptual model is made in VENSIM DSS. By using that model, we can predict the behavior of dam and shortage of agricultural, industrial, environmental and municipal demands due to various scenarios. For analyzing, we use monthly data during the period of 2005 to 2012. Several statically analyzes was performed on data to have a trustable information for modeling. Based on findings of this study, it was shown that beside simplicity and good accuracy, this model has a very good adaptability with various conditions of dam's water allocations. Great shortage in ecological and agricultural needs was shown after simulation and it is necessary to propose new plans to defeat these shortages. In order to study the behavior of the model from different angles, two possible scenarios were simulated in the catchment area of the dam to meet the needs of agriculture, environmental, industrial and municipal. After simulation, we can predict the behavior of dam in respect to growing demands. Results show that due to increasing population that causes increase in municipal, agricultural and industrial demands, Kowsar dam cannot reply to all this growing demands and we should think about some new resources or use some plans to decrease the demands. The SD tool used in this study to model reservoir operation has four basic building blocks: stock, flow, connector, and converter.

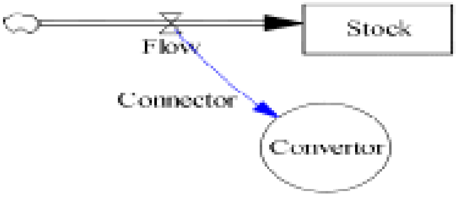


Figure 1: System Dynamics elements

Stocks (levels) are used to represent anything that accumulates; an example of stock would be water stored in a reservoir. Flows (rates) represent activities that fill and drain stocks; an example of flow includes reservoir releases or reservoir inflows. Connectors are used to establish the relationship among variables in the model. They are represented graphically by the software as arrows, and the direction of the arrow indicates the dependency relationships. They carry information from one element in a model to another element. This information can be a quantity, a constant, an algebraic relationship, or a graphical relationship. Converters transform input into output. Converters can accept input in the form of algebraic relationships, graphs, and tables. The concept of the stocks and the flows in SD is very appropriate to deal with a reservoir problem in water resources. The SD approach is based on theory of feedback processes. A feedback system is influenced by its own past behavior. This system has a closed-loop structure that brings results from past actions of the system back to control future actions. One class of feedback system—negative feedback—seeks a goal and responds as a consequence of failing to achieve the goal, e.g., thermostat. It is the negative feedback or goal-seeking structure of the system that causes balance and stability. A second class of feedback system—positive feedback—generates growth processes where action builds a result that generates still greater action, e.g., population growth. A positive feedback system structure amplifies or adds to change and thus causes the system to diverge or move away from the goal.

A feedback loop is the basic structure within the system, and levels and rates are fundamental variables within a feedback loop. The level variables describe the condition of the system at any particular time, and rate variables tell how fast the levels are changing. The feedback loops are also known as causal loops. The diagrams representing feedback loops and their variables are known as causal loop diagrams or influence diagrams. These diagrams show how levels and rates are interconnected to produce the feedback loops and how the feedback loops interconnect to create the system. The reading of these diagrams indicates how a given system might behave because of its internal feedback loops and the effect that positive and negative feedback loops have on a system. The convention for the diagram is that arrows depicting both the direction and sign of influence indicate links between state variables. Figure 2 are a part of causal loop diagram for a reservoir. The causal loop diagram in Figure 2 indicates that the inflow has a positive influence on reservoir storage.

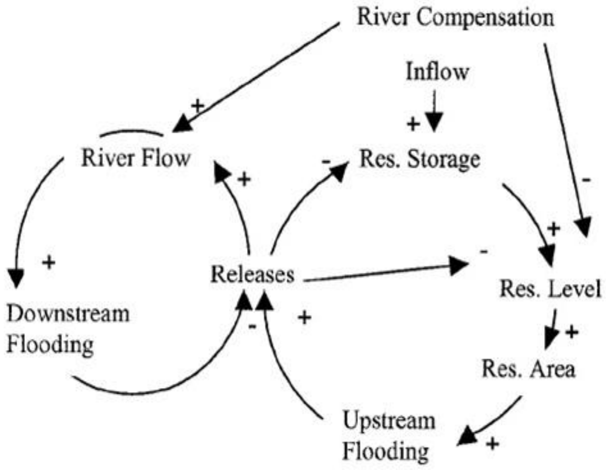


Figure 2: Causal Loop Diagram

The increase in reservoir storage causes an increase in the reservoir level, which leads to increase in area covered by the reservoir. Increased flooding upstream of the reservoir will trigger more release from the reservoir, thus reducing the reservoir storage. Similarly, increase in releases will increase river flow. Causal loop diagrams play an important role in describing the system behavior and the relationship between its components. The model of reservoir simulation presented in this paper, using the SD approach, has been implemented in the VENSIM environment. The modeling tool, which is an object-oriented simulation environment, allows the development of complex water resources models with significantly less effort than using traditional programming languages. It has a user-friendly graphical interface and supports modular program development. Using this tool, the modeler defines objects representing physical or conceptual system components and indicates the functional relationships among these objects. This mode of construction is analogous to drawing a flow chart or schematic of the system to be simulated. Building on these strengths, the general architecture of a reservoir simulation model is described in the next section.

3. Study region:

The proposed SD approach for modeling reservoir operations has been applied to the KOWSAR reservoir, located on the Kheirabad River in the border of four southern province of Iran. This dam is in distance of 60 kilometers of Gachsaran city and 42 kilometers of Behbehan City. The schematic plan of Kowsar dam and its region is shown in Figure 3.

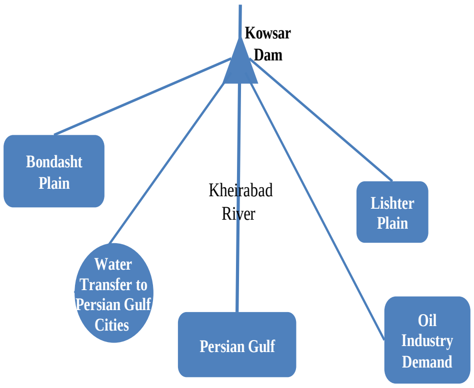


Figure 3: Schematic of Kowsar dam and demands

4. MODEL ARCHITECTURE

This paper deals with reservoir modeling operation using system dynamics. The model is developed for a single multipurpose reservoir with a focus demands role of the reservoir. The model also serves as a tool for studying impacts of changing reservoir storage allocation and temporal distribution of reservoir levels and outflows. The general architecture of the model is presented in this section, and model sectors and the complex dynamic relationships among these sectors are also discussed. The SD model of a reservoir can be constructed graphically on the screen by employing basic building blocks, i.e., stocks, flows, connectors, and converters available in the model development tool. In the reservoir model the storage is represented as a stock. Varying inflows and outflows cause changes in storage volume over time. Inflows and outflows are represented by building block ‘‘flow.’’ Converters are provided to extend the range of calculations that can be performed on flows, and they house data and logical/mathematical functions to operate the system. Reservoir operating rules are also implemented through converters. Connectors (directed arrows) link various elements of the model, i.e., converters, flows, and stock, to indicate relationships and influence. The simulation model uses differential and difference equations to describe the complex dynamic systems. These equations are solved with Euler’s method. Due to the modular nature of the simulation tool, the reservoir model is developed in sectors that are described in the next section.

5. Model Sectors

A general reservoir simulation model can be divided into three main sectors: the reservoir, the upstream area, and the downstream area. A Stock and flow model that built in VENSIM is shown in Figure 4.

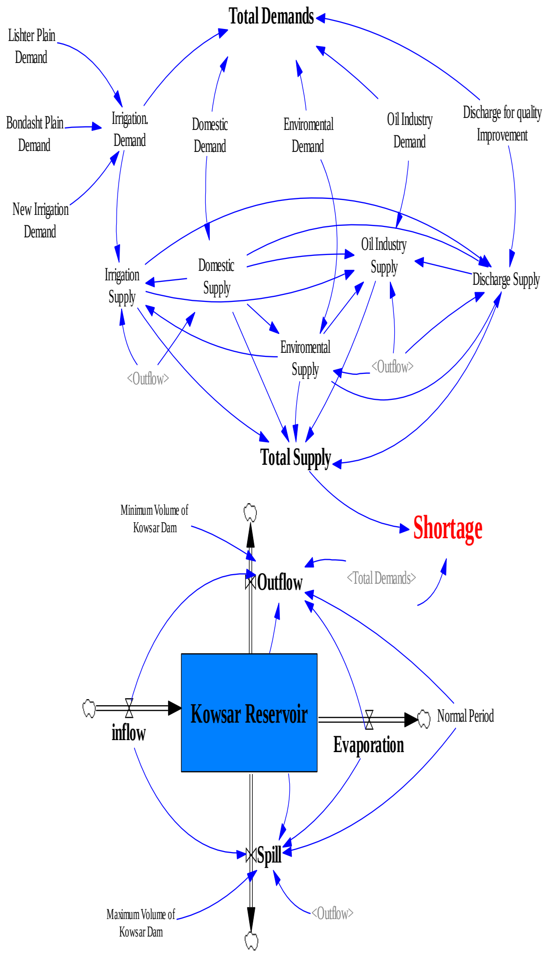


Figure 4: Stock and Flow model

5.1 Reservoir

This is the core sector of the reservoir model. Inflows and outflows from the reservoir are the main components of this sector. Flow from all tributaries directly contributing to the reservoir is considered as inflow to the system. Total reservoir outflow consists of reservoir releases, spill, and evaporation. Reservoir storage can be described in terms of mass balance equation:

$$\text{Storage}\ (t) = \text{Storage}\ (t - 1) + (Q_{\text{in}} - Q_{\text{out}})\ .dt \qquad (1)$$

Storage at time step t is equal to the storage at a previous time step plus the difference of inflow and outflow. The solution interval (dt) is selected to ensure stability within the computation process. Conduit flow and spillway modules govern the flow through the conduit and the spillway, respectively. System constraints, spillway curves, and conduit outflow capacity at different gate openings are provided to the model as part of its knowledge base. Reservoir operating rules are captured in this sector using IF-THEN-ELSE statements.

6. RESULTS AND DISCUSSION

After verification process, the model was run to find the result of dam construction on downstream inflow to Kowsar, reservoir. Time scale of the model is 7 years from 2005 to 2012 (84 months) which shows the ability of supply for a long time. The reservoir volume in this period is shown in Figure 5.

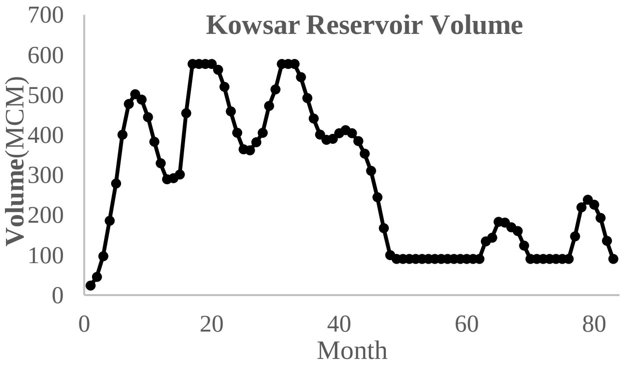


Figure 5: Reservoir Volume in modeling time period

In Figures 6,7and 8, the environmental, domestic and Agricultural demands and the water that can allocate to those demands are shown.

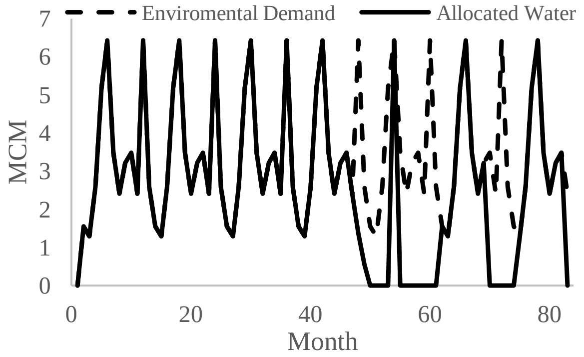
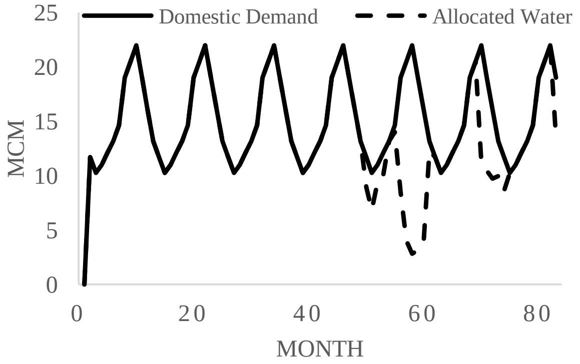
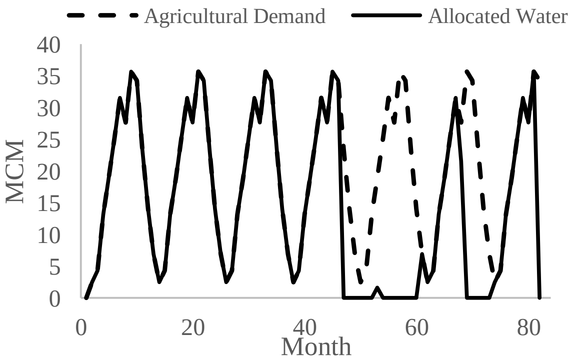


Figure 6: Environmental demand and allocated water



Figurer 7: Domestic demand and allocated water



Figurer 8: Agricultural demand and allocated water

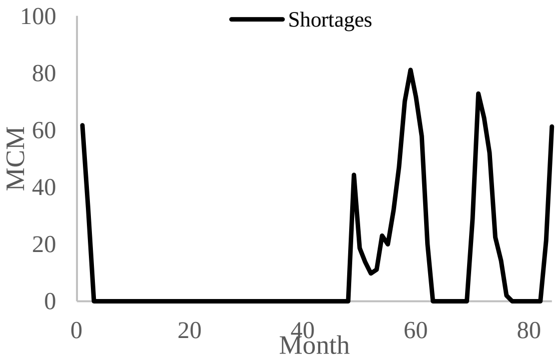


Figure9: shortages

Figures 6 and 7 Shows that Kowsar reservoir cannot answer to all demands and due to arid years shortages happen in most months. So new strategies must be considered to answer to increasing demands.

7. CONCLUSIONS

The research reported in this paper focused on the simulation of a single multipurpose reservoir using the SD approach. The proposed SD-based simulation approach is a valuable alternative to conventional simulation techniques. The increased speed of model development, ease of model structure modification, ability to perform sensitivity analysis and effective communication of model results are the main strengths of the reservoir simulation model based on the SD approach. Modeling effort can be directed to important tasks such as system conceptualization, data collection, and gaining input from system operators, and involving stakeholders.

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