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Object Oriented Simulation; Its Application in Water Reservoir Management and Operation

S. Javadi[1], M. S. Kiapasha[1], and K. Mohammadi[1*]

ABSTRACT

Reservoir dams are among the main storage systems employed in agriculture for the several past decades. Proper operation of these reservoirs is important for irrigation especially in such arid and semi-arid areas like Iran, and particularly during dry years. A computational framework for reservoir simulation and flood routing is hereby presented. A key aspect of the reservoir simulation is the ease of use by managers and model users. In this paper, an object-oriented toolkit for building computer models for simulation of reservoir operation and flood routing in Boukan reservoir dam is used. The modeling approach taken in this paper is significantly different from that typically employed in the development of water resources planning and management models. The medium in this kind of model provides a graphical object-oriented interface that allows the user(s) to model complex systems without even requiring a profound proficiency in computer programming. The Object Oriented Programming (OOP) environment chosen to develop the model of Boukan dam reservoir was STELLA Software. The probability of flood occurrenceis also taken into account for a prediction of more accurate results.

Keywords: Flood routing, Modeling, Object oriented, Reservoir operation, Simulation.

INTRODUCTION

Applications of simulation techniques in water resources have been used for several decades. Computer advancement has had great influence on this application. It is possible to simulate complex systems using advanced numerical methods and high speed computers. With the recent advance of object oriented programming techniques computer based application of this kind of model has been greatly facilitated.

A number of studies have been found simulation to be one of the most practical and effective problem analyzing and solving techniques. A simulation can be defined as hypostatical operation of a system under certain conditions (Estuti and Lipovszki, 1997). The fields of computational hydraulics and hydrology are well researched, and many models and algorithms are already implemented to solve different aspects of hydrological systems (Abbott, 1993). Most dams built on rivers in Iran are intended for supplying agricultural irrigation water and for hydropower generation. The proper operation of the reservoirs therefore plays an important role in water distribution in the system, both for flood management and for the flow regime in the regulated river. (Samani and Solimani, 2008). Use of a computer is mandatory for system simulation in most cases. Researchers can choose any of several ways to solve a mathematical model by a computer. It can be accomplished by using one of the high level programming languages such as FORTRAN, PASCAL, or C such as HEC-5 (Anonymous, 1979) which is written in FORTRAN. It is also possible to use the application programs, which have been written for such specific fields as HEC-

[1] Department of Irrigation, College of Agriculture, Tarbiat Modares University, P. O. Box: 14115-336, Tehran, Islamic Republic of Iran.
[*] Corresponding author, e-mail: kouroshm@modares.ac.ir

ResSim (Klipsch, 2003) for reservoir simulation. These programs are useful for those who intend to work in the specific field that the program can handle. Some other techniques such as fuzzy techniques and artificial intelligence have also been used to simulate and optimize reservoir operation in recent years (Chaves *et al.*, 2004; Haseb and Nagayama, 2002; Mousavi *et al.*, 2004).

In this paper, an object-oriented model was employed to simulate reservoir operation and flood routing in Boukan dam reservoir. The modeling approach taken in this project is significantly different from that typically taken in the development of water resources planning and management models. The environment of this kind of model provides a graphical object-oriented interface that allows the user to model complex systems without requiring proficiency in computer programming. An understanding of important system components and their interactions are the primary prerequisites for model development. Thus, the start up time for model development in these environments is minimal.

The developer interface for object-oriented models is very different from those for such traditional programming languages as FORTRAN. Rather than writing instructions line by line, the user builds a model using a set of object icons. Each object represents a type of action or process and has specific attributes that define how it interacts with other objects in the system. To create a model in this environment, the user selects the appropriate icons for an emulation among important system components. Relations between objects are then established by graphically drawing the appropriate connections. Once these connections are established, the user specifies the functional relationships among components and initial values to complete the model. This user interface is more efficient than the traditional programming in terms of time required for developing the model.

This Object-Oriented Programming (OOP) environment allows for the participation of non-programmers in the modeling process. There are five primary advantages in using OOP for construction of water resource models as follows:

- Increased speed of model development,
- Ease of model modification,
- Facility with which model results can be communicated,
- Possibility of group model development,
- Trust development in model.

This type of model is essentially directionless in that, information "flows" between objects in the direction of the very variables that need to be solved for. As such, the network structure of the objects is independent of whether a model is supply or demand driven. Which variables are solved for is exclusively a function of how the objects are equipped with data; topological sorting of the network being not necessary (Behrens, 1991; Reitsms *et al.*, 1994; Zagona *et al.*, 1995). To facilitate modeling, object classes can be equipped with libraries of dynamics or methods, of which individual instances can be selected by users. For instance, reservoir objects can be equipped with several methods for computing tail water, evaporation or elevation-area-storage relationships.

The OOP applications in water resources have also been studied. STELLA (Anonymous, 2003) software has been employed as OOP environment in water resources modeling. Two examples of reservoir operation models were developed using STELLA (Royston, 1999). The first model was employed to evaluate the effects of various withdrawal and release scenarios on the safe yield of a proposed water supply reservoir. The existing system, which consists of five reservoirs, was simulated as a single large reservoir connected to the proposed reservoir. The model predicted the system's safe yield under a variety of operating conditions and determined which factors had the greatest impact on the safe yield. The second model, which simulated the upper Black Warrior River Basin in Alabama, was developed in part to determine whether additional system storage was required to accommodate multiple uses, including power generation, navigation, flood control, and drinking

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water supply. Another example of OOP use in water resources management was the conjunctive use of surface/ground water in Saveh plain, central Iran (Mohammadi and Eslami, 2002). Object oriented modeling was also successfully used in surface water quality management (Elshorbagy and Ormsbee, 2006). The authors used this approach for surface water quality management in southeastern Kentucky, USA using STELLA software and identified the potential use of the proposed approach. Cheng *et al.* (2004) and Li *et al.* (2006) developed a web-based flood forecasting system for reservoirs using Java 2 Platform Enterprise Edition. The system was more focused on the on-line analysis of model-based forecasting of floods, and provided opportunities for improving the transfer of information and knowledge from the hydrological research scientists and managers to decision makers.

MATERIALS AND METHODS

Boukan Reservoir

Boukan dam is located in west of Iran on Zarrineh Rud. It is a multi purpose reservoir dam for agriculture, flood control and drinking water supply. The reservoir and dam specifications are presented in Table 1. The release of water is controlled by a spill weir along with four gates. Every two gates are connected to one tunnel. The elevation of the gates is 1378 m above sea level. Maximum capacity of each gate is 55 CMS and in total 220 CMS.

Table 1. Bookan dam and reservoir specifications.

Dam and reservoir specifications	Value
Dam crest length	720 m
Total height	48 m
Spillway width	140 m
Max. spillway capacity	4300 CMS
Active storage volume	532×10^9 m^3
Total storage volume	600×10^9 m^3
Watershed area	6890×10^6 m^2
Average watershed elevation	1950 m
Average watershed slope	5 %

Stella Software

The OOP environment chosen to develop the model for Boukan reservoir was STELLA (Anonymous, 2003). STELLA has been proven suitable for use as an object oriented environment for various modelings with water science being no exception to it (Royston). Model development using OOP is both similar to and different from typical model development. Like typical development, the functions must be defined and the system conceptualized for the construction of a model. The relationship of each component with respect to another must be established. In some cases, these relationships may be physical ones, for instance, the storage behind a dam at a point in time is affected by the storage volume in the previous period, the volume of inflow during the ensuing period, the releases and spills made from the dam, as well as the dam's capacity. In other cases, these relationships may be more conceptual in nature. However, the manner in which these components are incorporated into the programming environment in OOP is remarkably different from such more conventional languages as FORTRAN. Using OOP, once a component is identified, it is incorporated into the model by defining it as a unique object. In this fashion, it will be assigned a specific label or name.

Initial stages of model development are similar to using computer drafting or drawing software in which the user simply selects from a series of existing icons or templates and draws what is desired. When initiating the modeling process, the model builder is presented with a blank page onto which all of the components necessary to model the system are placed. There are four basic tools in the STELLA environment for model diagram development namely: stocks, flows, converters and connectors.

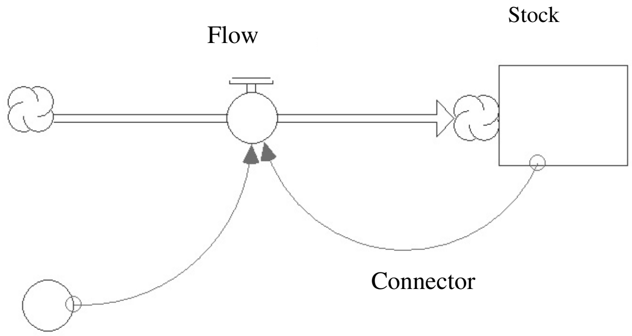

Figure 1. Basic tools in STELLA.

Stocks are used to represent system components that can accumulate material over time. Reservoirs are always represented as stocks (Figure 1).

Flows represent components whose values are measured as rates. These rates may be a constant, a function of time or a function of some other components in the system. A flow can supply or drain a stock by flowing into or out of it. For example, inflows, spills and releases from reservoirs are flows. The flow icon is the directed pipe with a flow regulator attached. Flows can also be bi-directional, indicating that flow can go in either direction (Figure 1).

Converters can represent constants, variables, functions, or time series. They also can transform stocks and flows into other values. Converters can be represented as graphical functions. This enables the modeller to sketch relationships between model variables without resorting to complex analytical expressions. A circular icon (Figure 1) represents converters.

Connectors indicate the cause/effect relationship between diagram components. If a connector is drawn from one component (circle end) to another (tip of the arrow) then the first component defines (or influences) the value of the second component (Figure 1).

RESULTS AND DISCUSSION

Flood Routing in Reservoir

To use reservoir flood routing using object oriented model, Equation (1) as based on water balance was employed (Linsley *et al.*, 1982).

$$\frac{I_i + I_{i+1}}{2}\Delta t - \frac{O_i + O_{i+1}}{2}\Delta t - O_R \Delta t = S_{i+1} - S_i \quad 1)$$

where S_i [L^3] is the storage volume at time step i, O_i [L^3 T^{-1}] is the controlled outflow, O_R is the regulated outflow, Δt [T] is the time step and I_i [L^3 T^{-1}] is the inflow to the reservoir. Equation (1) can be rewritten as:

$$G_2 = G_1 + G_3 \quad 2)$$

where $G_1 = \frac{S_i}{\Delta t} - \frac{O_i}{2}$, $G_2 = \frac{S_{i+1}}{\Delta t} + \frac{O_{i+1}}{2}$ and $G_3 = \frac{I_i + I_{i+1}}{2} - O_R$. Figure 2 shows the module of reservoir flood routing in STELLA environment. Two components are considered as the main structures of the model in this part. These two sections are as follows:

Section 1, model generates the relationship between the spill discharge, S, and G. In order to calculate these values, it is necessary to have the elevation-volume function and elevation above spill crest. Two converters are considered for these calculations. A flow

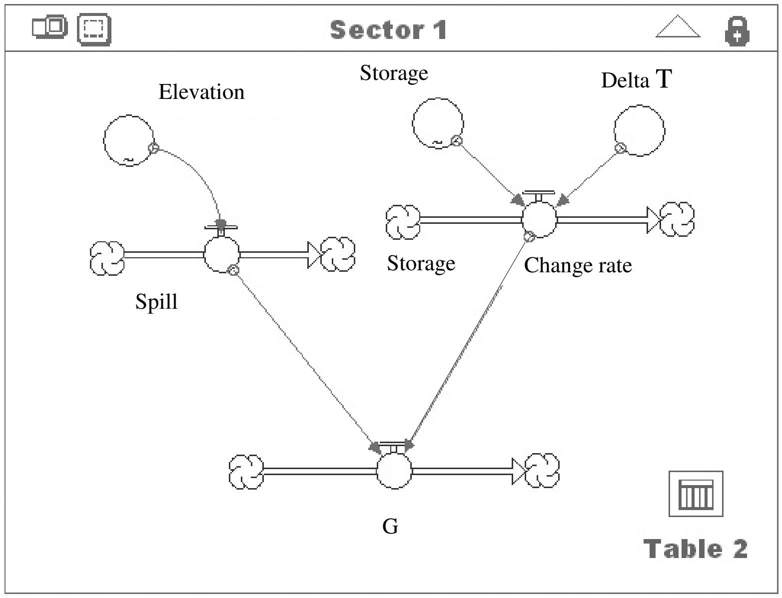

Figure 2. Relationship between spill, storage and G in reservoir.

object, spill in Figure 2, is considered to calculate spill discharge as a function of elevation above spill crest (Figure 2).

Section 2, flood is routed using results from section 1 and outflow hydrograph is generated. Inflow hydrograph, initial water level in reservoir and initial water discharge are the main data for flood routing calculations. Using equation (1) and calculating G1, G2 and G3 parameters, the outflow hydrograph is obtained (Figure 3). The results for one of the floods with the return period of 50-year is illustrated in Figure 4. In this figure, the first month is October which is the beginning of the hydrological year in Iran.

Reservoir Operation

For simulating the reservoir behavior, five sections namely demand, spill, inflow, evaporation, and occurrence probability have been implemented into the model (Figure 5).

Demand is on a monthly basis and is entered into the model through a converter object. In order to consider the increase in demand, a growth factor was considered, too. Two other converters for inflow and outflow were used. Equations (2) and (3) are employed to calculate the outflow.

If $D_i > I_i+S_i-E_i$ then $O_i= I_i+S_i-E_i$ 2)

If $D_i \leq I_i+S-E_i$ then $O_i= D_i$ 3)

where D_i is the demand in month i, I_i is the water inflow into the reservoir, S_i is the active storage volume, E_i is the evaporation from reservoir surface, and O_i the outflow.

The spill is used to discharge the overflow during floods or low demand seasons. In order to evaluate the operation of reservoir with the limited historical data, the probability of the unregulated inflow was assigned to the corresponding computed outflow hydrograph. The normal distribution was selected based on 50 years of historic data. Mean and standard deviation were entered into the model through two converters. In order to find the outflow for different occurrence probabilities, frequency coefficients are entered. Occurrence probabilities of 50, 60, 70 and 80 percents were selected. Fifty percent was considered as the minimum probable inflow while 80 percent selected as the climatologically wet year. Figures in between these val-

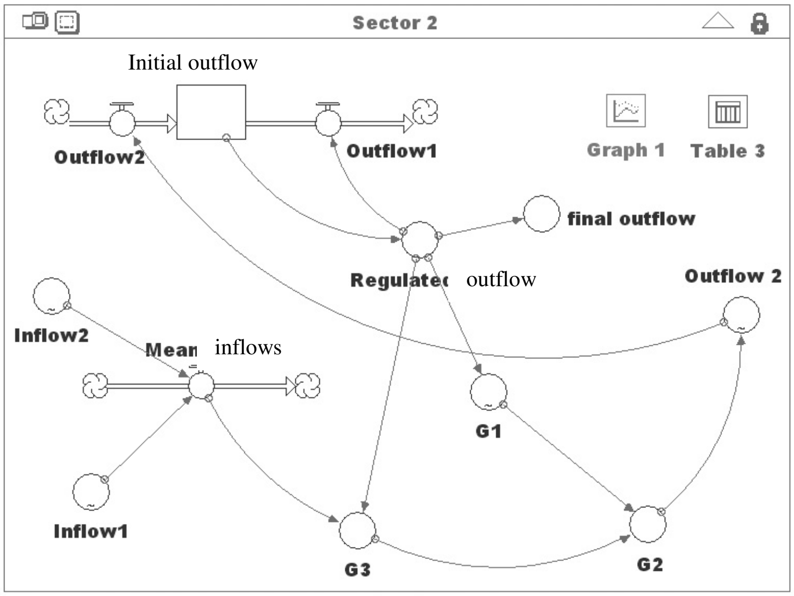

Figure 3. Flood routing module.

ues were used to test the effects of different inflows on reservoir operation.

One of the major reasons for water loss in reservoirs is evaporation which is a function of surface area and potential evaporation. In every time step, surface area of the reservoir will be computed using surface-elevation function and monthly potential evaporation.

After a completion of the construction of the model, it can be used to calculate outflow at the end of each time step, using initial storage volume. The model is of the ability to show the results in graphs and tables.

Figure 6 shows the monthly inflows into the

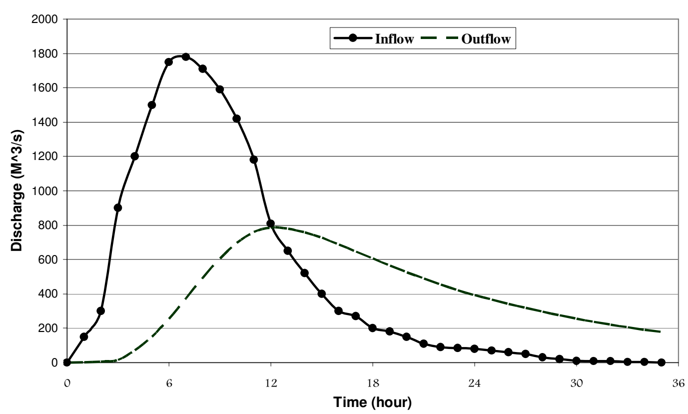

Figure 4. Inflow and outflow hydrograph during the flood.

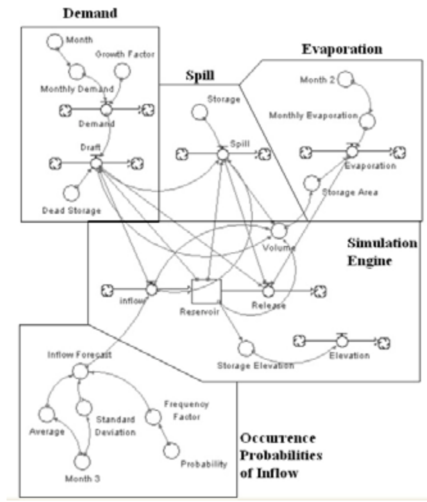

Figure 5. Modules used in simulation model of Boukan reservoir.

reservoir for figures 50, 60, 70, and 80 percent of inflow occurrence probabilities while Figure 7 shows the release discharges from reservoir for those occurrence probabilities. As evident, release is almost the same for different probabilities. With regard to these values, the reservoir volume and spillway discharges are shown in Figures 8 and 9, respectively. As evident from Figure 8, by increasing the occurrence probabilities and therefore decreasing the inflow into the reservoir, and since the consumption is assumed to be constant for each month, the necessary time for the reservoir to be filled, would be increased. This caused the curves, when proceeding from left to the right, to move from lower to higher levels of probabilities.

The reservoir storage and elevation at the beginning of each time step equal those values at the end of the previous time step. Reservoir volume is more sensitive to the inflow, especially during the wet season and reservoir filling period. Spills were observed only during the spring season namely from March to June.

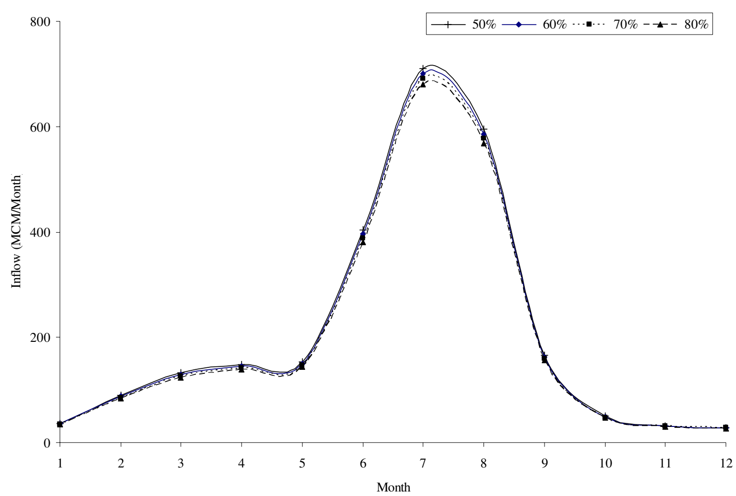

Figure 6. Inflow to the reservoir for different occurrence probabilities.

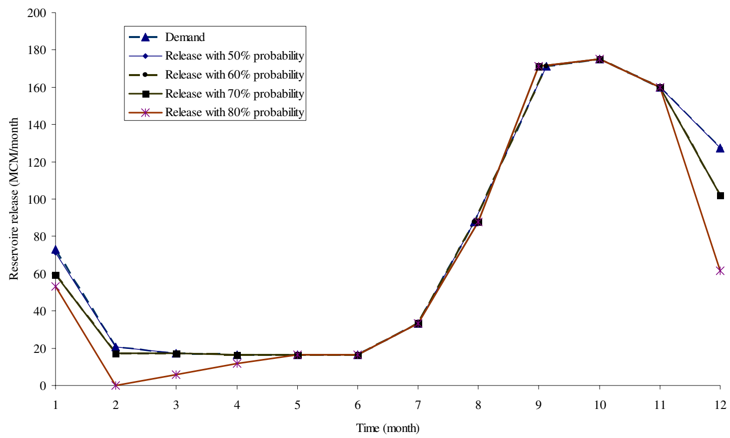

Figure 7. Reservoir storage volume corresponding to different inflow probabilities

CONCLUSIONS

Object-oriented simulation was not presented in this paper as a replacement for traditional hydrologic models but rather as a feasible alternative and as a potential candidate when involvement of decision-makers is crucial for the modeling exercise. Object-oriented model provides the ability for a user of limited knowledge of programming to simulate a system.

Boukan reservoir operation simulation was modeled using STELLA environment. In this simulation, different inflow probabilities were taken into account to consider the effects of drought, normal and wet climate conditions on the operation. In certain months of the year, the reservoir may not be able to meet the demand. In order to prevent that, or reduce the risk of high shortage of water in a specific month, it was possible to find optimum operation policy using several simulation scenarios.

The developed model was of the capacity to easily test these scenarios and in a short period of time. Evaluations could be interactively defined, modified and conducted by making them part of the object network. Definitions could consist of simple algebraic functions or complex conditional relationships. In addition, evaluations could be truly

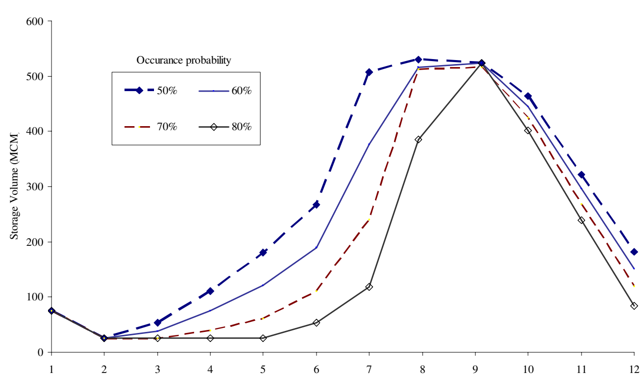

Figure 8. Spillway discharge corresponding to different inflow.

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interactive and users could define new or alternative functions at any time during the modeling and evaluation processes. The STELLA model was easily understood and used by individuals not involved in the model development process. It was also more easily modified to simulate alternate operating procedures. Since optimization has not been considered in this study, it is recommended to add the optimization module for any future development.

REFERENCES

1. Abbott, M. B. 1993. The Electronic Encapsulation of Knowledge in Hydraulics, Hydrology and Water Resources, *Advances in Water Resources*, **16**: 21-39.
2. Anonymous. 2003. *STELLA 8.0 Technical Documentation*. High Performance System, INC., USA.
3. Anonymous. 1979. *HEC5: Simulation of Flood Control and Conservation System*. U.S. Army Corp of Engineers, Davis, CA, USA.
4. Behrens, J. 1991. Application of the PCRSS Reservoir Simulation Model to the Salt River Project. In*: "Water Policy and Management, Solving the Problems"*, (Eds): Fontane, D. G. and Tuvel, H. N., New York, N.Y.: *American Society of Civil Engineers*, PP. 295-298.
5. Chaves, P., Tsukatani, T. and Kojiri, T. 2004. Operation of Storage Reservoir for Water Quality by Using Optimization and Artificial Intelligence Techniques. *Mathematics and Computers in Simulation*. **67**: 419-432.
6. Cheng, C. T., Chau, K. W., Li, X. Y. and Li, G. 2004. Developing a Web-based Flood Forecasting System for Reservoir with J2EE. *Hydrological Sciences Journal,* **49(6)**: 973-986.
7. Elshorbagy, A. and Ormsbee, L. 2006. Object-oriented Modeling Approach to Surface Water Quality Management. *J. Envi. Mod. Software*, **21**: 689-698.
8. Estuti, A. A. and Lipovszki, G. 1997. Object Oriented Programming Approach of Simulation to Analysis of Water Hydraulic Problems, *Proc. 4th International Symposium on Fluid Power Transmission and Control*, Wuhan, China.
9. Haseb, M. and Nagayama, Y. 2002. Reservoir Operation Using the Neural Network and Fuzzy System for Dam Control and Operation Support. *Advances in Engineering Software*, **33**: 245-260.
10. Klipsch, J. D. 2003. *HEC-ResSim: Reservoir System Simulation*. US Army Corps of Engineers, Davis, CA, USA.
11. Li, X. Y., Chau, K. W., Cheng, C. T. and Li, Y. S. 2006. A Web-based Flood Forecasting System for Shuangpai Region. *Advances in Engineering Software*, **37(3)**: 146-158.
12. Linsley Jr, R. K., Kohler, M. A. and Paulhus, J. L. H. 1982. "*Hydrology for Engineers*", McGraw-Hill, Inc. Singapour.
13. Mohammadi, K. and Eslami, H. R. 2002. Conjunctive Stream-aquifer Management Using an Object Oriented Model: Case study, *Proc. Int. Conference on Computational Methods in Water Resources*, Delft, The Netherlands, June 23-28.
14. Mousavi, S. J., Mahdizade, K. and Afshar, A. 2004. A Stochastic Dynamic Programming Model with Fuzzy Storage States for Reservoir Operations. *Advances in Water Resources.* **27(11)**: 1105-1110.
15. Reitsma, R. F., Sautins A. M. and Wehrend, S.C. 1994. RSS: a Construction Kit for Visual Programming of River Basin Models. *Journal of Computing in Civil Engineering*, **8**: 378-384.
16. Royston, W. J. C. 1999. Use of Object-oriented Programming in Water Supply System Modeling. *Proc. 26th Annual Water Resources Planning and Management Conference*, Tempe, Arizona.
17. Samani, J. M. V. and Solimani, A. 2008. Uncertainty Analysis of Routed Outflow in Rockfill Dams. *J. Agric. Sci. Technol.***,** **10(1)**:55-66
18. Zagona, E. A., Shane, R. M., Goranflo, H. M. and Waffel, D. 1995. The INTEGRAL Project*:* The PRSYM Reservoir Scheduling and Planning Tool. In: "*Computing in Civil Engineering*", (Ed.): Mohsen, J. P., New York, N.Y.: *American Society of Civil Engineers*, PP. 210-217.

شبیه‌سازی مخزن سد با استفاده از سامانه‌های شی‌گرا و کاربرد آن در مدیریت و بهره‌برداری

س. جوادی، م. ص. کیاپاشا و ک. محمدی

چکیده

مخازن سدها امروزه به عنوان مهمترین منبع تأمین آب در کشاورزی مورد استفاده قرار می‌گیرند. بهره‌برداری درست از این مخازن در نواحی خشک و نیمه‌خشک همچون ایران به‌ویژه در فصول خشک سال از اهمیت زیادی برخوردار می‌باشد. در این تحقیق به شبیه‌سازی و روندیابی مخزن سد بوکان با استفاده از سیستمهای شی‌گرا پرداخته شده است. مدل مورد استفاده در این تحقیق کاملاً با مدلهای مرسوم و مورد استفاده در منابع آب متفاوت می‌باشد. ویژگی این نوع مدلها (شی گرا) نسبت به مدلهای قبل در این است که کاربر از تعدادی شی برای شبیه‌سازی استفاده می‌نماید و احتیاجی به دانستن زبان‌های برنامه-نویسی نمی‌باشد. در این تحقیق برای شبیه‌سازی و روندیابی مخزن سد بوکان با مدلهای شی‌گرا، نرم‌افزار STELLA مورد استفاده قرار گرفت. در پایان برای پیش‌بینی درست نتایج، احتمال وقوع سیل نیز در نظر گرفته شد.