Conjunctive stream-aquifer management using an object oriented model: Case study

K. Mohammadi[a] and H.R. Eslami[b]

[a]Dept. of Irrigation and Drainage Eng., University of Tarbiat Moddaress, P.O. Box ١٤١٥٥-٤٨٣٨, Tehran, Iran, kouroshm@modares.ac.ir

[b]Dept. of Research and Development, Jamab Consulting Engineers Company, ٨٠٤٤ Zartosht Street West, Tehran ١٤١٥٧ Iran, eslami@jamab.com

An object oriented model was used to simulate the conjunctive use of surface water and groundwater in Saveh watershed in central of Iran. Groundwater is as important as the surface water in Saveh but improper use of groundwater has caused water table drawdowns in recent years and has put that resource in danger. It was tried, in this research, to use a new approach in using ground water and surface water conjunctively to increase the water availability and it was analyzed by an object-oriented model. STELLA® was used to construct the object oriented model and several scenarios were tried to find the best management alternative for using surface water and groundwater properly.

١. INTRODUCTION

There have been many advances in modeling of conjunctive use of surface water and ground water for optimal management. Conjunctive use of surface water and ground water can usually increase yields at lower costs than more dams and reservoirs operated separately [١]. The reliability of ground water in a drought condition is more important than the volume of water, which it adds to total water quantity. The ground water aquifer provides a natural ready-made long-term water storage reservoir. Unlike most surface water reservoirs, the aquifer can store water for longer, even unlimited periods of time, making it available when needed in drought years. The coordinated and integrated management of the basin's surface and groundwater resources, under a conjunctive use management program, would aim to optimize the joint use of all water resources in the basin. This approach to water planning would require a comprehensive consideration of basin-wide water objectives and the matching of the characteristics of different supplies (such as quality, availability, cost, and reliability) to the requirements of different water demands as conditions change inside and outside the basin. In general, greater benefits from the conjunctive management of all water supplies together can be achieved over the isolated management of each individual supply system. The different roles these two types of water can play in conjunctively operated water systems result directly from their characteristics such as: availability, storage, access and distribution, quality, legal rights, cost, and etc [٢]. Surface storage can be filled and drained rapidly, while ground water pumping and recharge rates are limited and may entail additional operating costs [٣]. By taking advantage of the distinctly different characteristics of surface and subsurface storage, efficient operation policies can produce significant improvements in supply reliability. Also, surface and storage yield significantly different water supply benefits subsurface when added to an existing system. These benefits depend on the current mix of surface and subsurface storage [٤] and the uncertainty of water supplies [٥]. Ruud et al [٦] developed a conjunctive model for Tule river basin and used three GIS base model for surface water, groundwater, and land-atmosphere interface. A groundwater model with the interaction with ocean and river considering the quality of water was developed by Carabin and Dassargues [٧].

By using a mathematical model that simulates the conjunctive use of ground water-surface water system, different proposed management options could be evaluated in short time and efficient real-time control policy could be identified.

In this paper, an object-oriented model was used to simulate the role of precipitation, surface water, and ground water in water supply system of Saveh plain in Iran. Despite of existing of Saveh dam on Ghareh-Chi River, the stored water is insufficient for irrigation and industrial demands. Groundwater is as important as the surface water in Saveh but improper use of groundwater has caused water table drawdowns in recent years and has put that resource in danger. In this research was tried to use a new approach in using ground water and surface water conjunctively to increase the water availability and it was analyzed by an object-oriented model.

٢. PROJECT AREA DESCRIPTION

Saveh plain with ٢٢٩٢ square kilometers is located in center of Iran. Saveh dam with ٣٣٠ million cubic meters(MCM) reservoir volume has been constructed on Ghareh-Chi River with ١٠.٦ cubic meter per second average inflow. It is the source of controlled surface water in area. Another dam, Noubaran, is planed to be constructed in near future with ٧٠ MCM reservoir capacity on Mazlaghan River which it flows through Savah plain too. Irrigated lands are about ٤٧٩١٠ hectares. Grains, beans, potatoes, and alfalfas are the main crops being irrigated [٨].

Aquifer thickness is about ١٠٠ to ٢٥٠ m and water table depth is varied between ١ to ١٢٠ m. Area with water table depth less than ٥ m is limited, so the average depth is ٣٠ m. There are ٨٤٢ deep and semi-deep wells in the study area and total ground water discharge from these wells are ٤٣٠.٦٣ MCM/year. ١٥٢ Qantas and ٢٦ springs are discharging the aquifer with ٥٧.٥٢ and ٣.٤٢ MCM/year, respectively. ١٠.٨ MCM/year of the produced water is used for domestic, ٧.٥٢ for industrial and ٤٢٠ for agricultural purposes. Table ١ shows the water balance for Saveh aquifer [٨]. During dry periods water demands are met by release of water from Saveh reservoir.

٣. WATER RESOURCES MANAGEMENT MODELING

Over the past two decades the developments and application of mathematical models for design, planning, and operation of water resources systems have attracted growing attention among engineers, planners, and managers. Some of these models can analyze a hydrologic and hydraulic cycle in details and some models can be applied for potential evaluation. Complex models need several input data, which are difficult to gather them, but simple models can work with general information and less data. These simple models can help the engineers to evaluate the different policies and alternatives in a short time.

Table ١
Water balance for Saveh aquifer

Inflow (MCM)		**Outflow (MCM)**	
Subsurface flow	١٤٦.٠	Subsurface outflow	١٥.٠
Recharge from precipitation	٦٨.٢	Wells	٤٣٠.٦
Recharge from surface water	٧٠.٢	Qanats	٥٧.٥
Irrigation return flow	١٧١.٠	Drainage	٣.٨
Domestic and industrial return flow	١٣.٥	Storage changes	-٥٢.٠
Total	٤٦٨.٩	Total	٤٦٨.٩

In this research, an object-oriented model was used to simulate the groundwater surface water interactions. 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 resources models as follows:

- the increased speed of model development,
- the ease of model modification,
- the facility with which model results can be communicated,
- the possibility of group model development,
- the trust development in model.

The OOP environment chosen to develop the conjunctive model of Saveh watershed was STELLA®. This software is developed and marketed by High Performance Systems. Model development using OOP is both similar to and different from typical model development. Like typical development, the functions the model performs must be defined, the system must be conceptualized and a model constructed. The relationships of each component to one another must be established. In some cases, these relationships may be physical relationships. For instance, the storage behind a dam at a point in time is affected by the storage in the previous period, the volume of inflow during the ensuing period, the releases and spills made from the dam, and 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 more conventional languages such 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 is 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: Stocks, Flows, Converters and Connectors.

Stocks are used to represent system components that can accumulate material over time. Reservoirs are always represented as stocks. Stocks often represent other items as well (Figure ١).

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 ١).

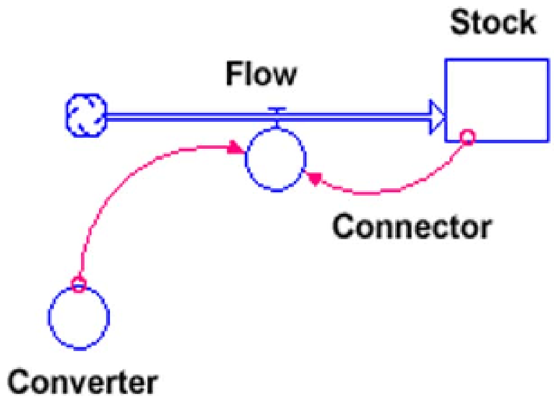

Figure ١. Basic tools in STELLA

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 modeler to sketch relationships between model variables without resorting to complex analytical expressions. A circular icon (Figure ١) 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 ١).

In the designed model for Saveh watershed the source and sink terms have been considered as follows:

- Evapotranspiration is calculating from Thornthwaite method and then the effective rainfall is calculated. After calibration the infiltration coefficient of the rainfall in mountain and plain were ٥٠ and ٤٥ percent, respectively (Figure ٢).
- The well discharges were variable during the year. A maximum allowable discharge from groundwater was considered for each month. This maximum allowable discharge was determined by trial and error during the calibration process.
- The return flow was considered as drainage to surface water and as infiltration to groundwater.
- The seepage of river was considered proportional to the river flow rate. The flow rate and infiltration coefficient relationship was shown in Figure ٣. This relationship was developed during the calibration process by running the model several times and using a trial and error approach.
- The model is able to consider the five different types of hydrological conditions for a year. These types are very moisten, moisten, average, dry and very dry year. Based on the year type, the maximum allowable discharge from groundwater will be reduced or increased. These reduction or increasing coefficients are ١.٣٥, ١.٢, ١.٠, ٠.٩٥, ٠.٩, respectively.

٤. RESULTS AND DISCUSSIONS:

When the model structure was ready, the model was calibrated for ٣٠ years using the national water master plan studies [٨]. The model consisted of nine blocks and the relation of these blocks is shown in Figure ٤. Figure ٥ shows, as a sample, the details of blocks of Nowbaran and Saveh dams.

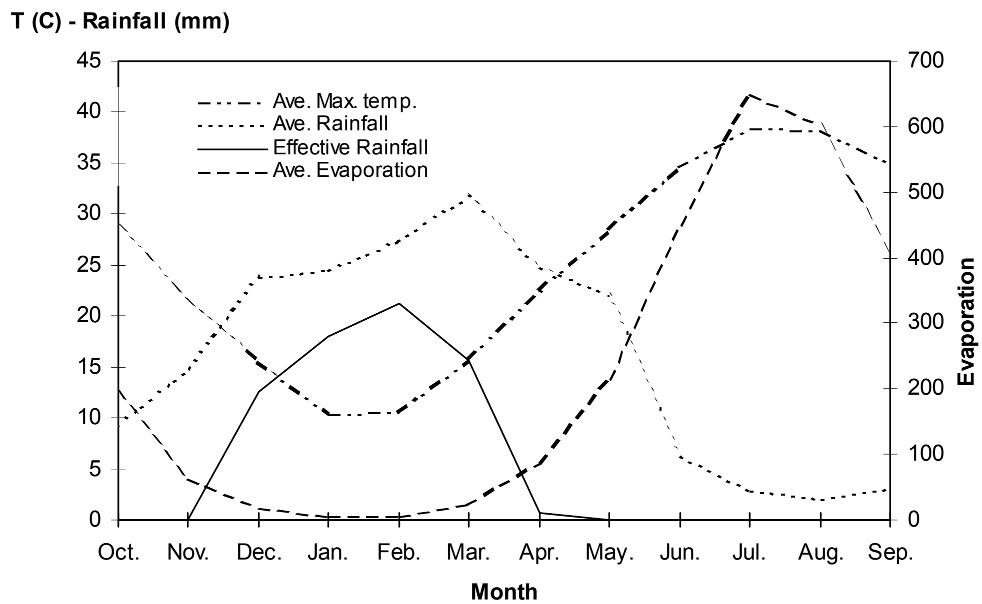

Figure ٢. Effective rainfall.

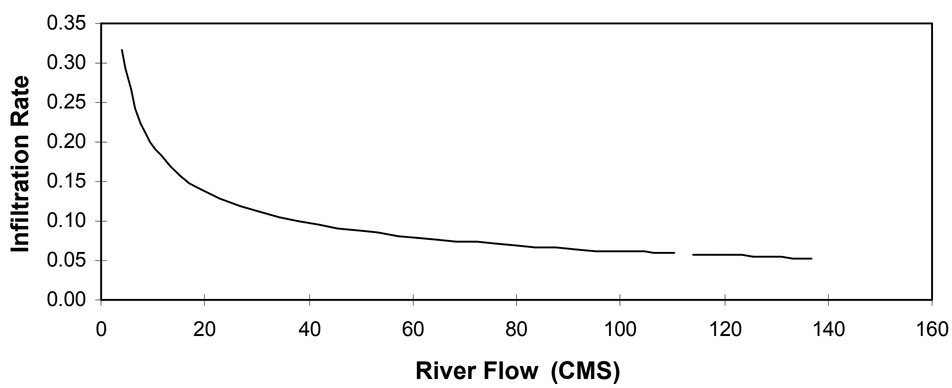

Figure ٣. Relationship between river flow and infiltration rate

At the beginning, all coefficients used in the model were calibrated. The control points for the calibration were the river flow rate at the Askar_Abad Bridge station at the end of the watershed, which has been shown in Figure ٦. Also, the averages of coefficients were almost similar with the values obtained from the national water master plan studies [٨]. For instance, the average of groundwater volume drawdown from ١٩٦٤ to ١٩٩٣ was ٥٤ million cubic meters per year, which was very close to ٥٢ million cubic meters per year resulted from the national water master plan studies.

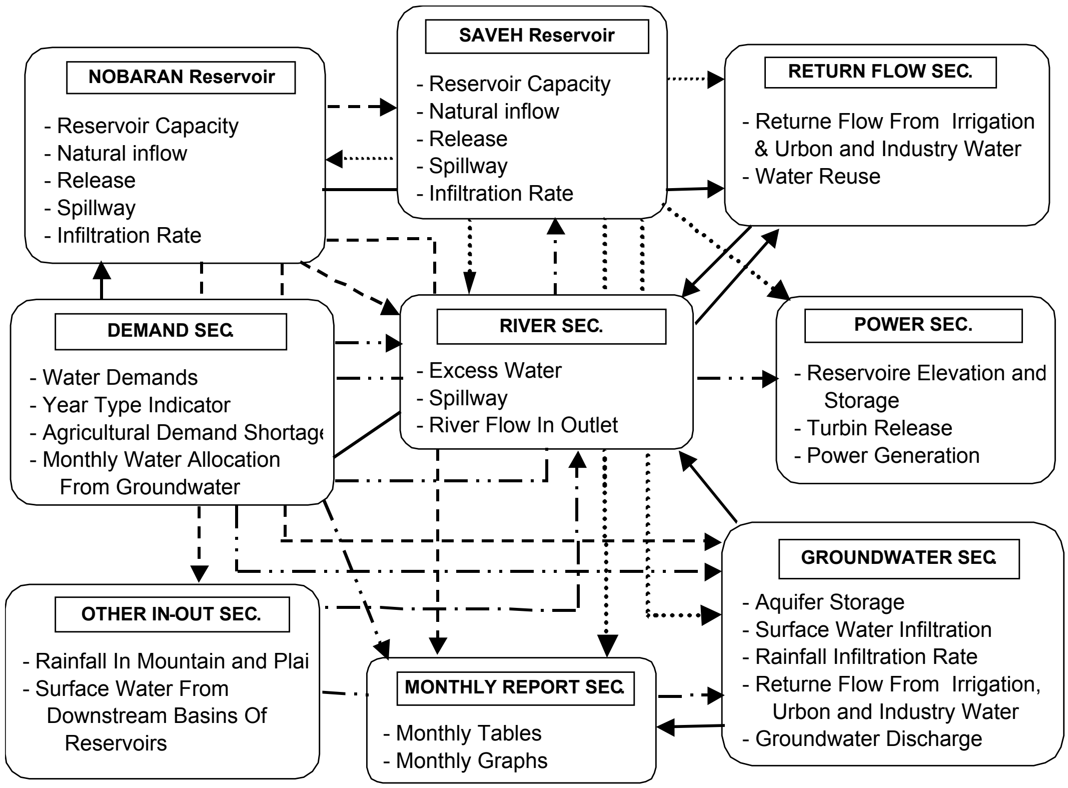

Figure ٤. Relationships between blocks used in Saveh model

After calibration, the model was run to obtain the optimal conjunctive use of surface and ground water resources to supply the agricultural, drinking, and industrial consumptions. Also, the storages in Nowbaran and Saveh dam, groundwater volume and hydropower generation were among the objectives to be optimized. The optimized condition was obtained by several trial and errors. The high speed of the constructed model is its main advantage, which allowed trying several alternatives in a fraction of hour.

To determine the hydrological type of the year and forecast it, different attempts were made and finally it was found that the amount of rainfall in March is a good indicator for Saveh watershed.

By using the above approaches and running the model for thirty years in optimal conjunctive use of surface and ground water, it was possible to increase the water availability up to ٨٠ million cubic meters per year from the groundwater and ٥٠ million cubic meters per year from surface water. Despite of increasing in groundwater discharges, the water level drawdown would be less than present condition (Figure ٧).

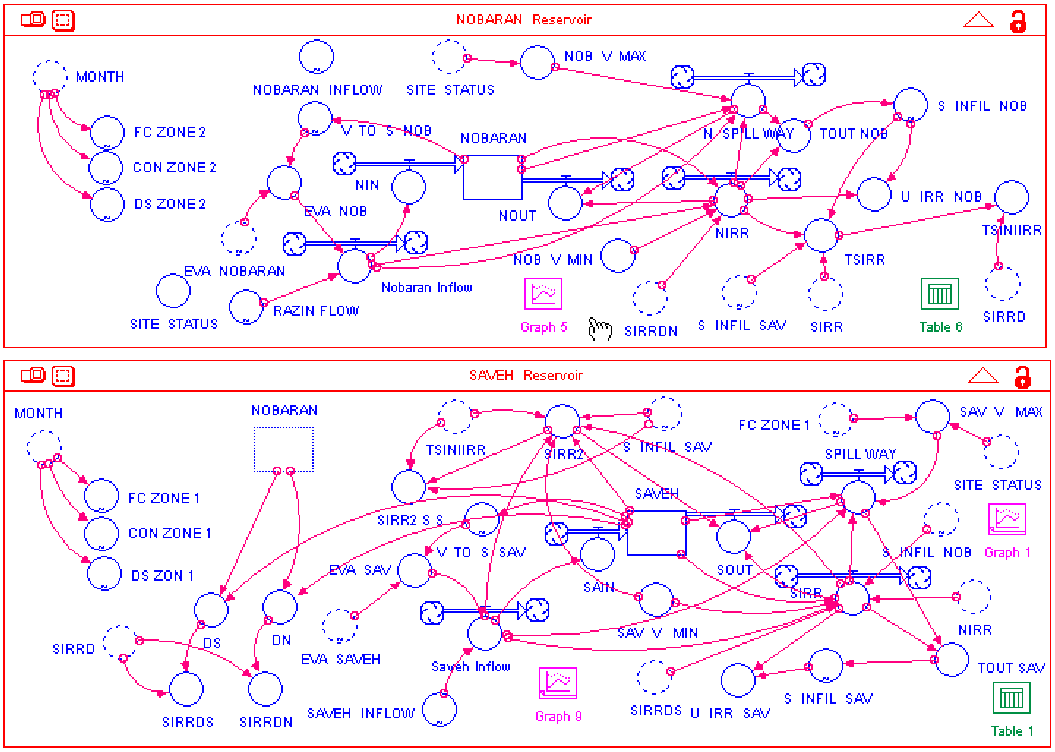

Figure ٥. Details of blocks for Nobaran and Saveh reservoirs

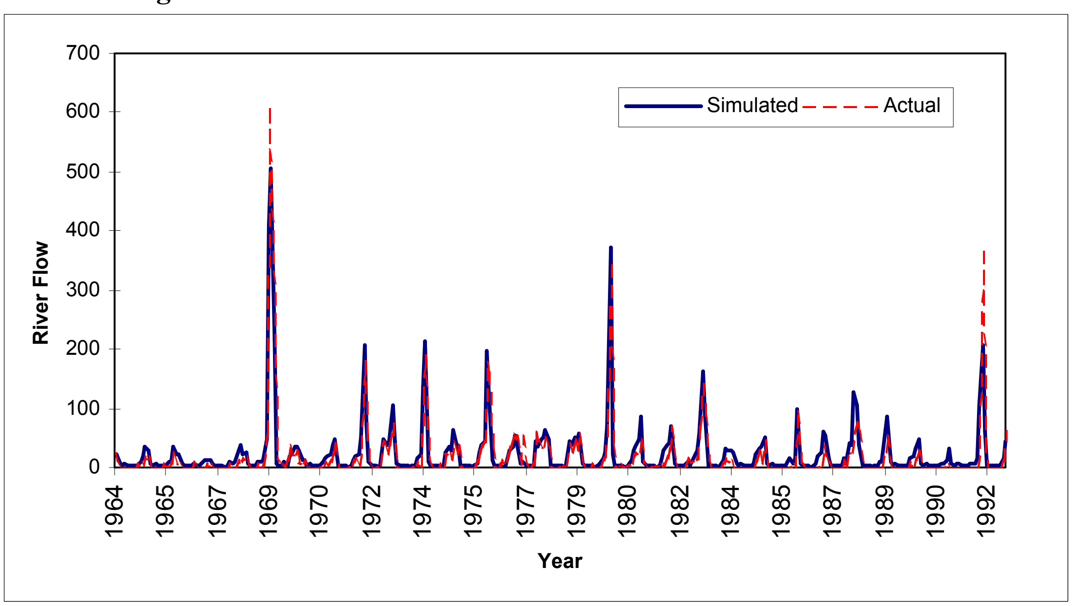

Figure ٦. Comparison between simulated and actual river flow in Askar_Abad station.

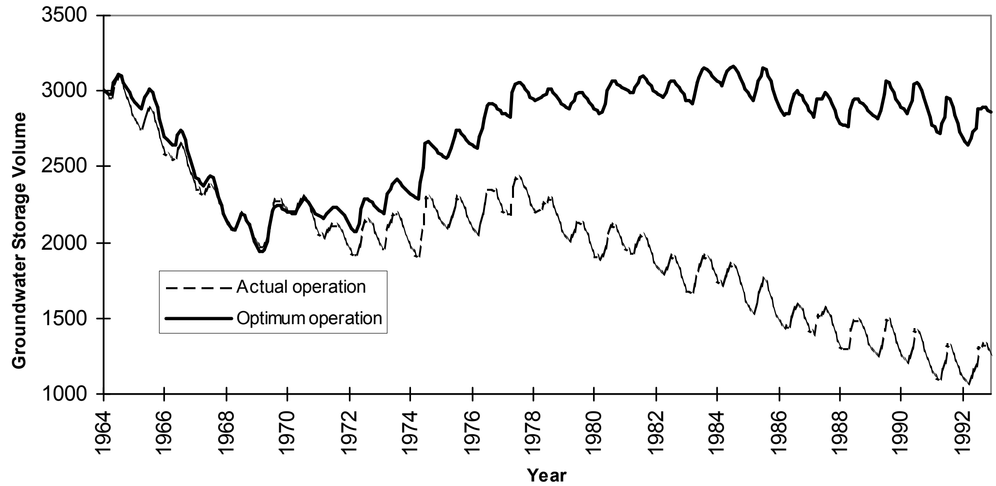

Figure ٧. Comparison between the actual and optimal operation of surface water and groundwater in ٣٠ years.

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