Expert system application for real-time risk management during drought

J. J. NAPIÓRKOWSKI*
Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland
F. A. WOLBRING & G. A. SCHULTZ
Institute of Hydrology, Water Resources Management and Environmental Techniques, Ruhr University Bochum, Germany

Abstract A risk-based intelligent decision support method for real- time operation during droughts is presented along with the application to a part of the Wupper Reservoir System in the Federal Republic of Germany. The reservoir system consists of two reservoirs in series with additional inflow to the lower reservoir. The tasks of these reservoirs are flood control, recreation hydropower and low flow augmentation with the aim of water quality improvement. A two step procedure for managing droughts is proposed. In the first step standard operating rules are developed with the aid of a simulation program using data on a monthly basis. These operating rules provide a good long range strategy for drought prevention. In the second step special operating rules for damage reduction in case of drought are derived with the aid of a simulation program working with daily data. Risk of failure to meet defined low flow augmentation targets serves as decision criteria.

INTRODUCTION

A decision support system, supplemented with rule based inferencing, for real time reservoir operation is presented. The focus here will be on the application of rule based inferencing and the application of Monte Carlo Simulation for risk assessment, especially for drought management.

This decision support system is tested along with data of a real world system, the upper Wupper Reservoir System in Germany and it is working on a PC. For better understanding, first the reservoir system will be described, then the role of rule based inferencing in the decision support system and at last the risk assessment procedure with Monte Carlo Simulation.

DESCRIPTION OF THE WUPPER RESERVOIR SYSTEM

The catchment of river Wupper is located in the southern part of North Rhine Westfalia and is mainly a part of the mountainous region of the Rheinischen Schiefergebirge. Settlement of this region has taken place in the nineteenth century and is strongly influenced by the industrialization of the nearby Ruhrgebiet. But in contrast to the

*Presently on leave as Humboldt Fellow at the Institute of Hydrology, Water Resources Management and Environmental Techniques, Ruhr University Bochum, Germany.

Ruhrgebiet this region has attracted those branches of industry that depend on a reliable water supply. Today the catchment of river Wupper has with the exception of the Emscher catchment the highest population density in Germany.

The hydrological features of this catchment are characterized by a massive rocky underground covered only by a small soil layer and an average yearly precipitation of about 1300 mm per year. The missing ability of storing water in underground leads to dangerous floods as well as to extreme droughts. Both have happened several times in the last century. The relation of their extremes is abut 600:1 (Brechtel & Renner, 1988).

To achieve the ability to handle these problems several reservoirs were built. Here we are just interested in the management of the two reservoirs governing the discharges in the city of Wuppertal which lies about 20 km downstream of reservoir No. 1. Figure 1 shows the simplified Wupper Reservoir system. It contains two reservoirs located in series, the control centre at Reservoir No. 1, several runoff gauges and one rainfall gauge. The release of the reservoirs depends on the runoff at the control gauge in Wuppertal. The runoff of 5 m^3/s at this gauge is sufficient for the demanded water quality standard II (stable ß-mesoaprobic), runoff less than 3.75 m^3/s should be avoided and runoff less than 1 m^3/s has to be regarded as ecological disastrous.

The gauges are connected to the control centre, so that real-time information is available for decision making.

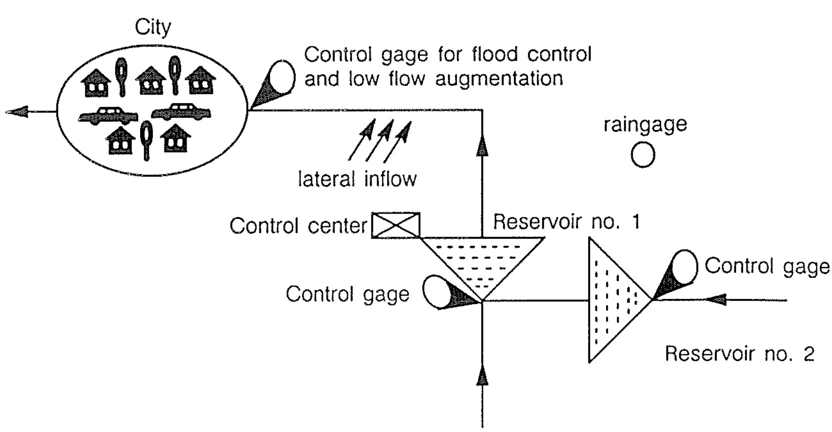

Fig. 1 Basic structure of reservoir system.

DECISION SUPPORT SYSTEM FOR WUPPER DROUGHT MANAGEMENT

The general idea of system design used here was to extend usual decision support systems, including data bases, model bases and a shell for organizing interactions (Salewicz & Loucks, 1990) with rule based inferencing (Fig. 2). The aim was to use simulation programs and rule based inferencing together in order to combine their advantages: clearness and flexibility of simulation techniques and transparency, use of heuristic knowledge, and ability of justification of rule based inferencing (Fedra & Loucks, 1985; Simonovic & Savic, 1989; Simonovic, 1991).

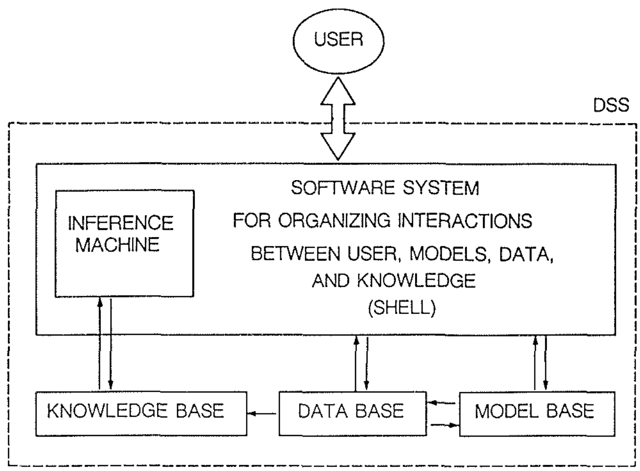

Fig. 2 Structure of applied decision support system.

In the first step a long range operation rule was developed by simulation technique on the basis of a historical record of 39 years monthly data and ten synthetic records of 50 years (Schultz & Harboe, 1989). This operation rule takes account of the contents of the two reservoirs and the runoff at the control gauge in the city of Wuppertal. Therefore the contents of the two reservoirs were divided into five levels and four low flow augmentation targets between the desired runoff of 5 m^3/s and the disastrous runoff of 1 m^3/s at the control gauge were defined. In an iterative process, in which the subdivisions of reservoir contents and the choice of augmentation target was improved, the probability of occurence of the lowest augmentation target was minimized.

This long range operation rule was transferred to rule bases. Mainly numeric information for description of reservoir contents, according to simulation program, is used. The developed rules have a form like:

> IF "it is September" AND "reservoir No. 1 in level 4" AND "reservoir No. 2 in level 3" THEN "augmentation target is 5 m^3/s".

For assessing the strong seasonal influence of lateral inflow, which is necessary for establishing the adequate releases from reservoir No. 1 in order to meet the augmentation target at the control gauge, pure heuristic information is processed, for example:

> IF "rain is falling in the intermediate catchment" THEN "adaption of release to augmentation target is requested".

For handling these rule-bases a special symbol processing inference machine was programmed in PDC PROLOG, that transforms numeric information in a symbolic form. This inference machine allows explanations during process, for example why a special information is needed, and enables justification after process, for example why a special recommandation was made. The inference machine has direct access to the data base, which is connected on line to the gauges, and to the operating system. In usual situations all the necessary numeric information is directly available, for additional heuristic information the system will ask the user.

In standard situations no simulation run is necessary, only rule-based inferencing is employed.

For controlling risk of failure (method will be described in next paragraph), the demand of which might arise either in April, when reservoirs are not filled after winter as they should be, or during summer when reservoir contents are below the usual mark, a Monte Carlo simulation program, working on daily basis is implemented. This program is simulating from the beginning of April or any other desired day in the summer to April the following year. This procedure has the advantage, that with one simulation information can be obtained about:

(a) reservoir contents during summer;
(b) low flow augmentation during the critical period in winter; and
(c) resulting reservoir contents at the end of April.

The change of time scale from monthly to daily basis is necessary because even failures of the duration of some days effect the fauna of the river. When risk of failure becomes too high the change of operation rule is indicated. At that point two kinds of operating rules are proposed:

(a) A standard drought operating rule, that is developed on the basis of historical and synthetical records. That rule has to be regarded as a solid operating rule, usually providing sufficient safety.
(b) New operation rules that are to be developed during drought. In those cases in which the standard operation rule does not seem to be appropriate (for example an additional requirement like water quality in one reservoir has to be taken into account), a new operation rule is to be developed. For that case an advisory system, again in the form of a knowledge base, is installed. Experience gained during development of the standard drought operation rule is transferred to a knowledge base. Recommendations are given to change standard operation rule in order to improve operation according to current situation.

APPLIED RISK ANALYSIS TECHNIQUES

In our case risk is understood as probability of failure to meet given augmentation targets at the control gauge. Interest is focussed on simple probability, calculated from daily values, as well as on duration of failure, calculated from the number of consecutive days. Since long range forecasts are not available in Germany - weather depends on several fast changing influences - a stochastic model for calculating possible future system inflows was developed.

For preserving regional features it was decided to use the composition methods with double sampling for simulating hydrological series, which takes into account the within-the-year runoff distribution, namely the method of fragments developed by Svanidse (1964;, 1980). That method makes use of canonical decomposition (Pugachev, 1962) of random processes. Any random function X(t) can be represented as a linear combination of elementary random function in the form of:

$$X(t) = \Theta f(t)$$

where Θ is a general (random) variable and f(t) a general (non-random) function. The essence of the method is contained in double sampling: the average annual runoff Qi (first sampling) and the monthly fragments qi(t) (second sampling). By multiplying the mean annual discharge Qi by the daily normalized (divided by the annual average) records (fragments) we obtain a new monthly hydrograph. Twelve new monthly hydrographs selected randomly add to one year.

The method ensures that a large variety of hydrographs can be obtained, regardless of the fact that in the simulation we do not exceed the range limits in the historic fluctuations.

Synthetic hydrographs for two reservoir inflows and the lateral inflow, that preserve the correlation between the three inflows and the distribution of annual flows, are created in real-time on the basis of 38 annual records on request. Knowing the distribution of annual average flow generation of synthetic records for any given probability is possible. These synthetic records serve as input to system simulation program, that calculates probability of failure for augmentation targets.

For completeness the possibility of using historical records (scenarios) directly is implemented (Moore et al., 1989).

EXAMPLE: DROUGHT OF 1959

For presentation of an example it is assumed that reservoir No. 1 had existed already in the fifties, even though its construction was not finished until 1987.

The 1959 drought began in early summer, when both reservoirs were filled after winter, and lasted up to the middle of December. Flows during June, July, and August proved to be among the lowest on record. Application of the standard operation rule leads to severe drought conditions in October, November till the middle of December (Fig. 3).

The calculated risk assessment for this particular year is plotted in Fig. 4. For

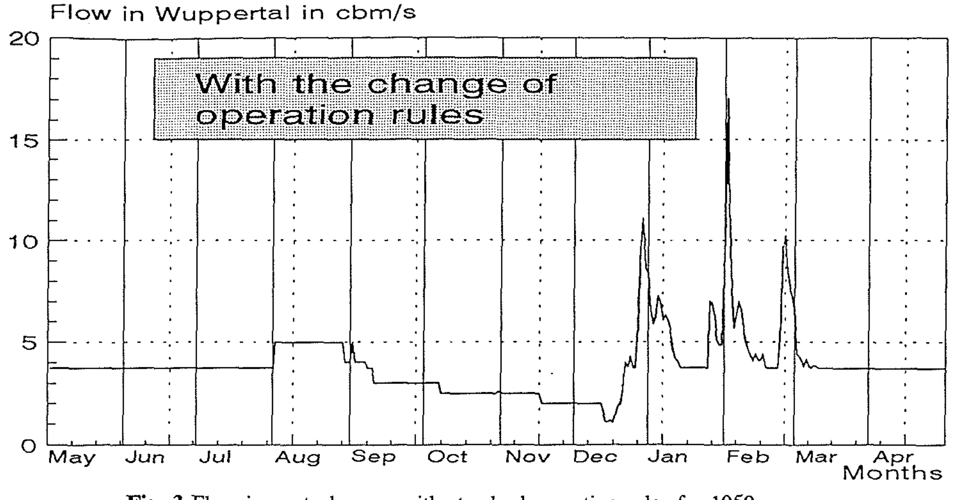

Fig. 3 Flow in control gauge with standard operating rules for 1959.

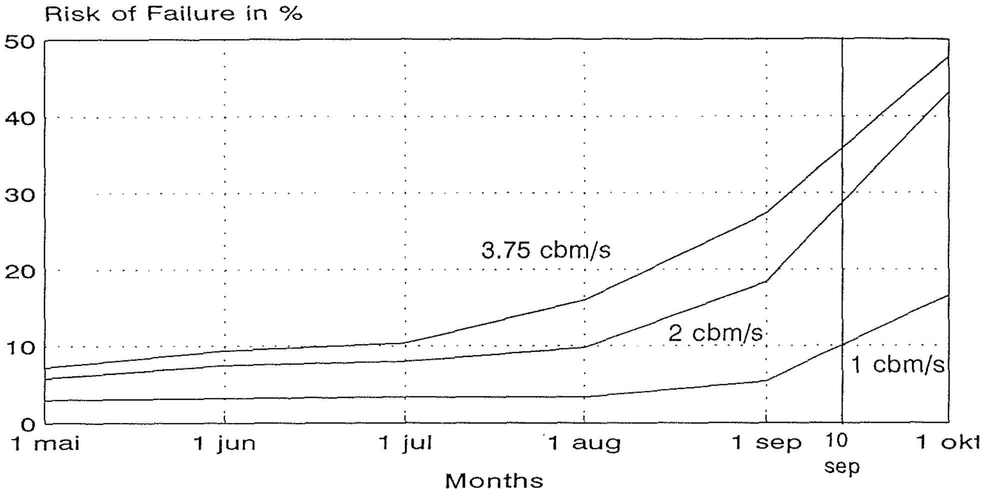

Fig. 4 Risk of non-exceedance of flows at control gauge in the city of Wuppertal in the year 1959.

each day in summer the risk of a future failure to meet an augmentation target (up to April) is calculated under the assumption that inflow is only known up to current day and standard operation rule is working. Calculation is based on 500 synthetical hydrographs. For this example an obligatory threshold for changing operation rule is assumed. It is crossed when probability of non exceedance of runoff of 1 m^3/s is equal to 10%. Here it is crossed on 10 September (Fig. 4). For that day the expected number of consecutive days with runoff below assumed thresholds is plotted in Fig. 5.

With the aid of the knowledge base a special operation rule is designed taking into account also water quality requirements in reservoir No. 1. Therefore the standard drought management rule is changed in so far as additional water is shifted from reservoir No. 1 to reservoir No. 2. This rule is checked by risk analysis method.

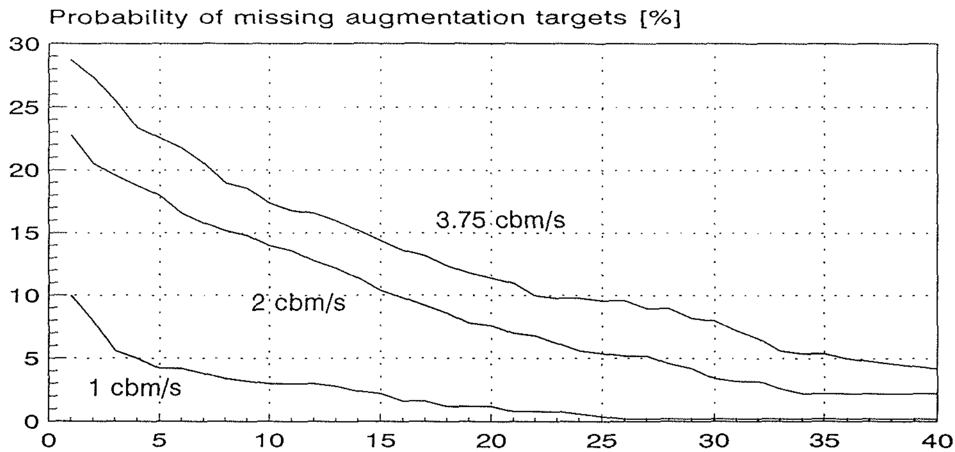

Fig. 5 Probability of non exceedance versus duration of failure for the 10th of December.

Resulting runoff at control gauge is shown in Fig. 6. By comparison of Figs. 6 and 4 it can be seen that during the extreme drought situation (Oct.-Dec. 1959) the low flow conditions at the control gauge in the city are improved.

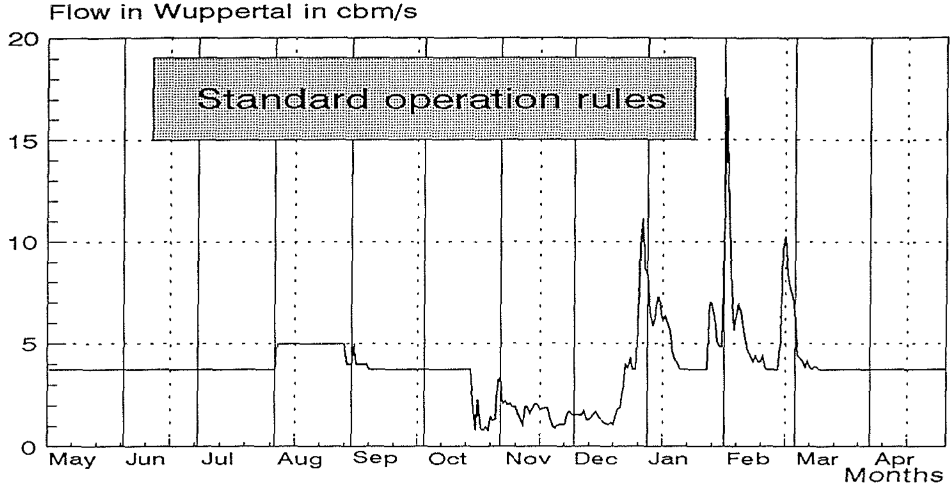

Fig. 6 Flow in control gauge with modified drought management rule.

CONCLUSIONS

Rule based inferencing has proved to be a strong technique for reservoir operation in standard situations. It enables a dialog with decision support system, makes argumentation transparent and meets so far requirements of responsible decision making. The use of rule based inferencing as an advisory system for operation rule design is just in the beginning of development, but it looks promising.

In future rule based inferencing will be used together with window technique to support the users during application of risk analysis based on Monte Carlo Simulation and scenario technique.

REFERENCES

Brechtel, H. & Renner, J. (1988) Der Wupperverband und die Wupper-Talsperre, (Wupper Authority and Wupper Reservoir) Kommunalwirtschaft (Sonderheft), 4-12.

Fedra, K. & Loucks, D. P. (1985) Interactive computer technology for planning and policy modeling, *Wat. Resour. Res.*, **21**, 114-122.

Moore, R. J., Jones, D. A. & Black, K. B. (1989) Risk assessment and drought management in the Thames basin, *Hydrol. Sci. J.*, **34**, 705-717.

Pugachev, V. S. (1962) *Teoriya Sluchainykh Funktsiy* (Theory of Random Functions), Fizmatgiz, Moscow.

Salewicz, K. A. & Loucks, D. P. (1990) Development and application of an interactive decision support system for river management - some experiences at IIASA, In: *Water Resource Systems Application*, ed. by Simonovic, S. P. et al.

Simonovic, S. P. & Savic, D. A. (1989) Intelligent decision support and reservoir management and operations, *J. Comput. Civ. Engng*, **3**, 367- 385

Simonovic, S. P. (1991) Knowledge-based systems and operational hydrology, *Can. J. Civ. Engng*, **18**, 1-11.

Schultz, G. A. & Harboe, R. (1989) Entwicklung von Betriebsregeln für die Wupper-Talsperre in Niedrigund Hochwasserzeiten (Development of reservoir operation rules for Wupper Dam during floods and low flow periods). *Wasserwirtschaft*, **79**, 1-4.

Svanidze, G. G. (1964) *Principles of Estimating River-Flow Regulation by the Monte Carlo Method*, Metsniereba Press, Tbilisi, USSR.

Svanidze, G. G. (1980) *Mathematical Modelling of Hydrologic Series*, Water Resources Publications, Fort Collins, Colorado, USA.