RELIABILITY-RISK CONCEPT IN EVALUATING CONTROL STRATEGIES FOR MULTIRESERVOIR WATER RESOURCES SYSTEM

B. Srdjevic[1] **and D. Obradovic**[2]

[1]Professor, Institute for Water Resources Management, Faculty of Agriculture,
University of Novi Sad, 21000 Novi Sad, Trg. D. Obradovica 8, Yugoslavia
Fax/Pho:+381-2-55713, Email:bojans@polj.ns.ac.yu

[2]Professor, Computer, Control and Measurement Institute, Faculty of Technical Sciences,
University of Novi Sad, 21000 Novi Sad, Fruskogorska 11, Yugoslavia
Fax/Pho:+381-21-55-144, Email: dacha@ns.ac.yu

Abstract: The reliability-risk (*RR*) concept is discussed with respect to a problem of evaluating reservoirs' performance within large-scale water resources system. Particular attention is given to an issue of adopting the 'demand priority matrix' (as part of the simulation model), and applying it to determine so-called acceptable and unacceptable system's states where system states are reservoirs' storage levels. Starting from relative importance of each demand point for a system and it's functional relation to upsteram source points (reservoirs), different approaches has been suggested for determining RR and other relevant performance descriptors for the integral system, subsystems and single reservoirs.

Keywords: Reliability, risk, system, performance

1. INTRODUCTION

The modern planning of large-scale water resources systems with multi-purpose surface reservoirs faces planners and system analysts with an issue of formulating control concept and related operating policy in order to evaluate consistency of proposed goals and various planning alternatives. Recent developments indicated that network modeling and mixed simulation and optimization models may help to solve this problem (Yeh W.W.-G., 1985)

Another important issue is adopting certain performance criteria and evaluating (with reference to them) how system behaves over time. Previous works in this field (Hashimoto, 1982; Hashimoto *et al*., 1982; Fiering, 1982) indicated that some performance criteria may become an important task themselves, staying the same time edge points in system analyses of long-term surface reservoir operation within complex water resources systems.

Recent developments particularly indicated *reliability, risk, resiliency* and *vulnerability* as an efficient modern performance descriptors (*MPD*). These descriptors are commonly formulated by taking into consideration stochastic nature of the overall control process, particularly that part related to implementation of operating policies for system's reservoirs which furthermore assume long-term forecasting of very different system's parameters and data (capacities, inflows, evaporations, demands, priorities, etc.). Both rigorous and relaxed mathematical formulations of above mentioned descriptors are well theoretically funded and published in pertinent literature. However, their use in real on-field studies is documented to a very limited extent.

In the same time, traditional performance descriptors (*TPD*) such as *mean, variance, shortage index* etc., are in wide use due to their simplicity and easy understanding. Formulated in strictly statistical manner, they appear to be more than *MPD* acceptable for professionals (engineers and politicians) involved in decision making process, and therefore are more present in real life.

Investigations by Srdjevic (1987) and Srdjevic and Obradovic (1991) indicated an efficient way to combine selected *MPD* and *TPD* and create the aggregated performance descriptors (*APD*). *APD*'s definition and internal structure implied coverage of different system's states and particularly preferences (priorities) and levels of satisfaction of system's demands, as well as reservoirs' status through time. Since aggregation of some *MPD*s and *TPD*s into *APD* inherently bear a dozen of redundancy, systems approach is stipulated, or at least very careful investigation of relevant performance issues.

This paper presents a brief discussion on use of the reliability-risk (***RR***) concept which already has been successfully applied within the original method for identifying long-term control strategies for surface reservoirs in complex multipurpose water resources systems (Srdjevic, 1987). Two situations in applied ***RR*** approach has been recognized: (1) system analysts have to derive strategies, and (2) such strategies are already derived (given in advance). It was shown that both cases imply variety of approaches in performing ***RR*** analysis itself. How such analysis should be used in consequent evaluation of prespecified (or actually derived) control strategies is an important question, but is out of scope here. However, it is well documented in (Srdjevic, 1987; Srdjevic and Obradovic, 1991).

The ideas proposed here for implementing ***RR*** concept into systems analysis of large-scale water resources systems are based on anticipation of the stationary structure of control strategies to be applied in either case, and implied stationarity of both multivariate synthetic hydrology and applied deterministic mixed simulation-optimization network models. This approach assumes that deficits of water may be evaluated on local, subsystem and system level on month-to-month basis in multiyear period. The way of formulating tolerant (acceptable) and actual (simulated) shortages at each of three mentioned system's levels is considered as the crucial moment in later computations of valuable RR performance descriptors. Equal importance and priority rankings of system's demands, from the point of view of centralized and decentralized control of reservoir system, are taken to highlight two global different policies in performing valuable systems analysis of system's dynamic performance toward planning horizon.

2. RELIABILITY AND RISK

Reliability is widely used concept in evaluating how water resources system with reservoirs behaves during the long-term operation. It may be defined as probability, or frequency, α, of system being in such a states that can be somehow denoted as acceptable:

$$\alpha = P\{\mathbf{X}(t) \, \varepsilon \, \mathbf{X}_A(t)\} \tag{1}$$

where $\mathbf{X}(t)$ is system state vector (with dimension equal to total number of reservoirs in a system) at time t, and $\mathbf{X}_A(t)$ is related vector of so-called acceptable systems states.

Risk is performance parameter usually defined as directly opposite to the reliability, i.e.

$$\begin{aligned} r &= 1 - \alpha = 1 - P\{\mathbf{X}(t) \, \varepsilon \, \mathbf{X}_A(t)\} \\ &= P\{\mathbf{X}(t) \, \varepsilon \, \mathbf{X}_F(t)\} \end{aligned} \tag{2}$$

where $\mathbf{X}_F(t)$ is vector of unacceptable systems states.

To simplify discussion of proposed approach, let assume that planning period has N years, with calendar months as discrete time frames. Therefore, related simulation of system operation should be performed over 12N months. State variables may be defined as end-of-month volumes of water in reservoirs, and if number of reservoirs is M, it follows

$$x_m(i) \varepsilon \mathbf{X}(i), \quad m=1,2,...,M, \quad i=1,2,...,12N \tag{3}$$

Simulated end-of-month volumes of water in the *m*th reservoir fall somewhere within interval bounded by min/max capacities:

$$x_m(i) \varepsilon [x_{m,min}, x_{m,max}], \quad i=1,2,...,12N \tag{4}$$

If for *m*th reservoir *stationary* (12 month) rule curve

$$x_m(j), \quad j=1,2,...12 \tag{5}$$

was applied, simulated end-of-month storages are in some relation with curve (below, above or exactly on it), as indicated on Fig. 1.

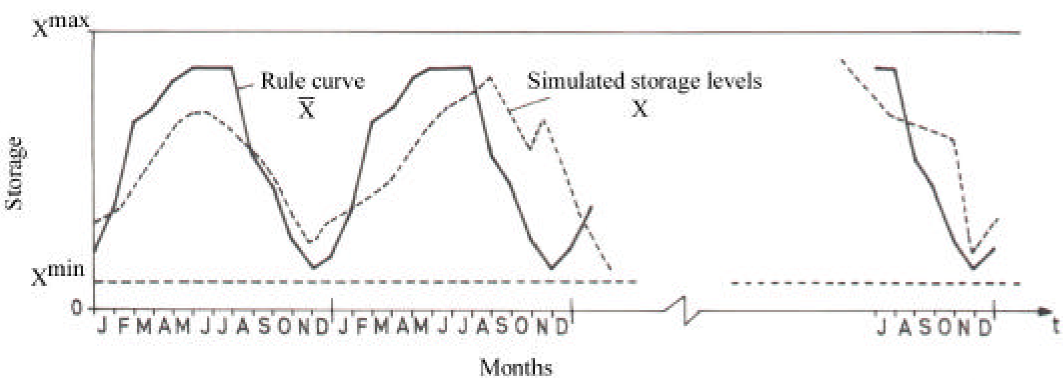

Fig. 1. Reservoir rule curve and simulated reservoir states

Having in mind that generally: (1) operating rule curves are applied for other reservoirs too, (2) local, regional and system demands have different monthly and yearly quantities, distributions and priorities, and (3) local and global goals for system operation are defined at least on descriptive level -- then each-month-outcome of system performance may be evaluated and eventually assigned to one of two distinguished system's status: *acceptable* and *not acceptable*. What criterium or criteria should be used for this distinguishing is a particular matter to be discussed later.

Let analyze the following situation: For given month i there are defined demands at K control points in the system; note that demand may not be related just to consumption of water, but also to some water quantity which may be denoted as 'water preference' (for example: low flow augmentation, volume of water in reservoir which is equal to specified value on the rule curve, etc.). Neglecting for the moment priorities and locations of demand points in relation to reservoir sites, let the sum of all system demands be D_i. At the end of a month, after water is distributed under some operating policy and reservoirs are filled to some level, total amount of water, Q_i, delivered to demand points is known and following relation holds

$$0 \leq Q_i \leq D_i \quad \text{for } i=1,...,12N. \tag{6}$$

If tolerant (maximum) shortage level (*TSL*), ε_{max}, should now be introduced denoting an acceptable maximum shortage in fulfilling water needs on K demand points throughout the system, and actual (simulated) shortage level (*ASL*) for *i*th month is defined as

$$\varepsilon_i = (D_i - Q_i)/D_i \tag{7}$$

system's status in the *i*th month may be described in the following way (Fig. 2):

1) for $\varepsilon_i \leq \varepsilon_{max}$ (8)
system performance was <u>*acceptable*</u>*; counter* n_A *of months when system was in acceptable status should be increased by 1;*

2) for $\varepsilon_i > \varepsilon_{max}$ (9)
system performance was <u>*not acceptable*</u>*; counter* n_F *of months when system was in unacceptable status should be increased by 1.*

<u>Reliability α</u> of a system in assuring all systems demands over complete time period is now easy to compute as

$$\alpha = n_A/12N \tag{10}$$

<u>Risk *r*</u> may be obtained straightforward as

$$r=1-\alpha = 1 - n_A/12N = (12N-n_A)/12N=n_F/12N \tag{11}$$

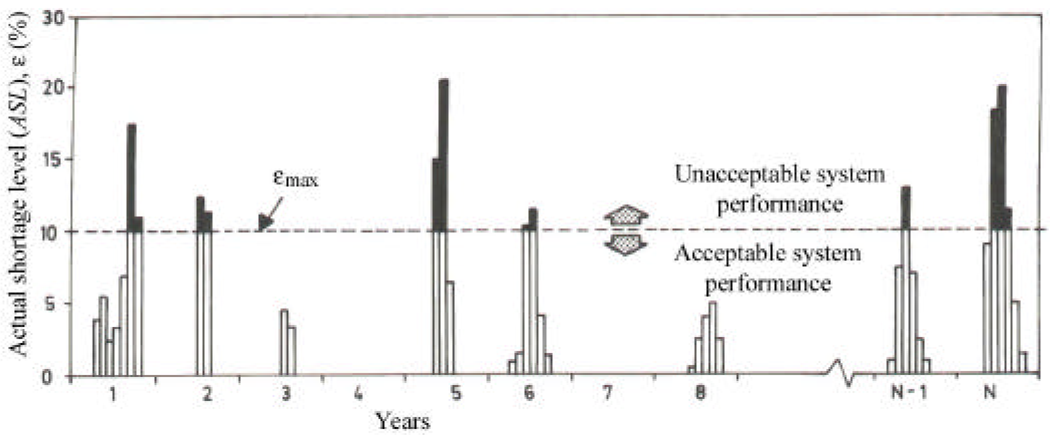

Fig. 2. System status over time based on tolerant shortage level of 10% (TSL=0.1)

3. IMPLEMENTATION OF THE RELIABILITY-RISK CONCEPT

The reliability-risk concept defined in above manner in practice assumes, beside others, implementation of the following 3 sets of activities:

1. <u>*Modeling the system*</u>; defining priority scheme of all system demands and preferences; deriving or adopting reservoir rule curves and supplying them as principal input to selected simulation model.

2. <u>*Adopting criteria for evaluating applied control policy(ies),*</u> i.e. for separating acceptable from unacceptable system states and related preferred from unpreferred system performance over time.

3. <u>*Computing reliability and risk*</u> due to (10) and (11) through simulation of system operation and automatically counting months n_A (or n_F) by applying criteria (8) and (9).

The <u>first step</u> is out of scope of this paper. However, interesting ideas and practical applications may be found in rich pertinent literature.

The <u>third one</u> is quite simple and straightforward if simulation model is 'good' enough and analysis stands only for a system as a whole. 'Good' here means that model is armed against possible excesses during the simulation such are infeasible solutions, bad data (for example, outlayers or formal mistakes in chains of numbers, etc.) or other hazardous interrupts. Of course, a priori assumption is that simulation model is really good from the modeling and computer point of view. On the other side, counting months and computing reliability and risk may be faced with difficulties only if they should be computed not only for the whole system, but also for it's parts. In later case need for some additional programming may arise; this generally may happen if second step of the procedure includes some of ideas to be discussed in turn.

Second step is the undoubtedly the heart of a procedure. It consists of important issues which imply careful investigation of relevant parameters influencing system operation. Some of them will be discussed with more details.

RR concept is dominantly problem oriented which means dependent on system configuration and priorities in water use. With relation to system configuration and locations of demand points, *ASL* may be derived for each reservoir and/or delivery point in a system, as well as for the whole system due to relation (7). Two cases should be underlined.

1. Water demands are usually of different importance and therefore may be assigned to different priorities within priority matrix. Similar to relation (7) which stands for a system as a whole, for each particular demand point a value

$$\varepsilon_{i,m} = (D_{i,m} - Q_{i,m})/D_{i,m} \tag{12}$$

may be associated denoting local supplying conditions at *m*th demand point during the *i*th month.

Implementation of appropriate weighting coefficients for all demand points

$$w_m \ \varepsilon \ [0,1], \qquad m=1,...,M \text{ (demand points)} \tag{13}$$

establishes such priority map (matrix) which reflects relative importance of each particular water demand within the system. Obviously, a redefinition of actual shortage level (*ASL*) is in consistence with establishment of so-called weighted actual shortage level (*wASL*).

This idea will be explained on simple example. Let assume system with only two demand points (K=2). Demands at points 1 and 2 in *i*th month are equal to 50 water units, so total system demand is 100. Demand point 1 is of higher prority, which may be denoted as z=1, compared to demand at point 2 (z=2). If demands are satisfied with 40 units and 30 units at points 1 and 2 respectively, due to (7) it follows for the system

$$\varepsilon_i = [100 - (40 + 30)]/100 = 0.3$$

which means that total system demand is satisfied 70%, i.e. unsatisfied 30%.

Local situation, due to (12), is

$$\varepsilon_{i,1} = (50 - 40)]/50 = 0.2$$
$$\varepsilon_{i,2} = (50 - 30)]/50 = 0.4$$

which means that first demand is unsatisfied 20% and second 40%. Furthermore, for the system it follows that

$$\varepsilon_i = (\varepsilon_{i,1} + \varepsilon_{i,2})/2 = 0.3$$

which implies that ε_i may be understood as *averaged actual shortage level* (*aASL*) and denoted as ε_i^a.

Let now define weighting coefficients w_1 and w_2 as reciprocal values of z_1 and z_2, i.e.

$$w_m = 1/z_m, \quad m=1,2$$

and define *weighted actual shortage level* (*wASL*) for a system as

$$\varepsilon_i^w = \left(\sum_{m=1}^{M} w_m \varepsilon_i\right) / \left(\sum_{m=1}^{M} w_m\right) \tag{14}$$

By including above defined values into last relation, it follows

$\varepsilon_i^{\,w}$ = (1/1x0.2 + 1/2x0.4) / (1/1 + 1/2)
= (0.2 + 0.2) / 1.5
= 0.267

Parameter ε_i^w computed in described manner is obviously more real than previous one (ε_i^a=0.3) because it contains built-in priority map.

2. Positions of demand points within a system are of the highest importance for system operation and performance evaluating process. Since spatial distribution of supplies and demands is an example *par exelance* of complex functional relationship which governs implementation of control policy, priority ranking becomes very important issue in evaluating system's performance.

Fundamental and easiest way is to apply equal priority strategy and deal with *aASL*s (ε_i^a) assuming averages for the whole system. This strategy, although reasonable and in consistence with some important practical reasons (for example, real situation to find equilibrium of different economical and political influences) is appropriate only if conservative approach to a problem is chosen. The other strategy, more difficult but very attractive, is to exploit recognizable relations between supplying and demanding points, create appropriate subsystems and then, within each subsystem, apply the weighting method described above. This idea may be applied from the very beginnig of a planning process because it is in consistence with other major activity: defining global, regional and local goals, interests and priorities in water resources system. Also, it may become interesting to analyse a posteriori what should be consequences if some goals should change. Recomposition of subsystems should lead only to few additional simulations to 'repeat' system operation and compute RR paremeters once more and for redefined parts of a system.

It was shown (Srdjevic, 1987, Srdjevic and Obradovic, 1991) that there are not significant problems to compute *wASL*s on different system's levels (local points, subsystems, integral system). For example, if subsystem approach is used (clarify Fig. 3), the only thing left is to specify weighting coefficients for subsystems and finally compute *wASL* for a system.

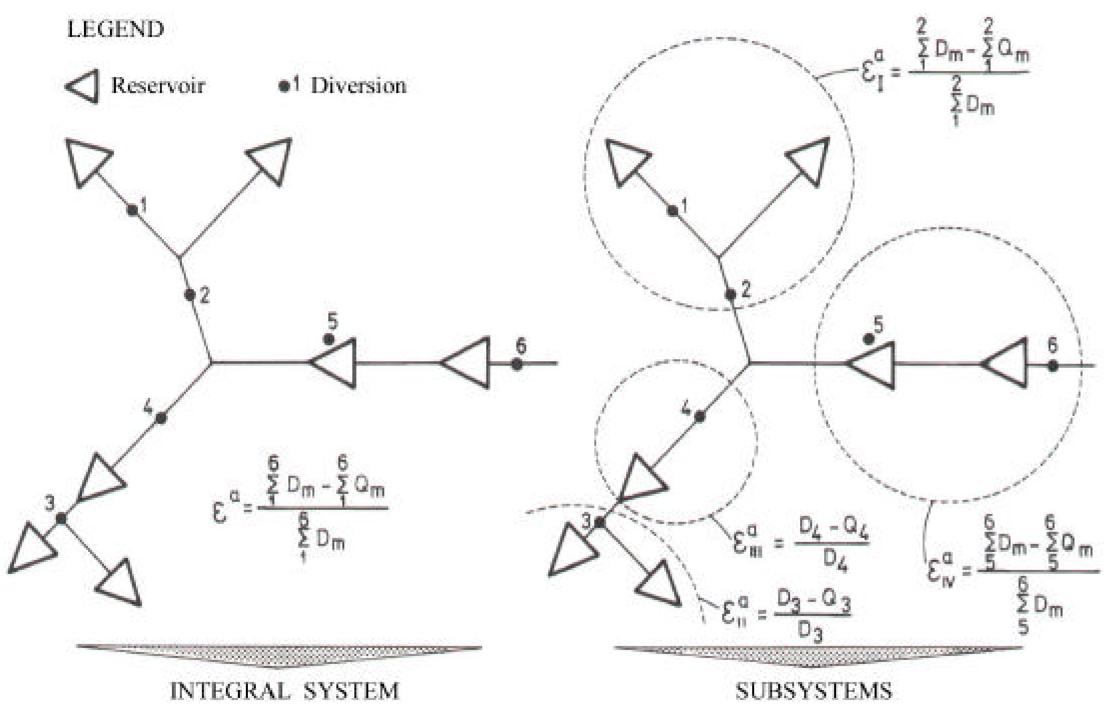

Fig. 3. Conservative and modern approach to a problem of determining averaged and weighted actual shortage level(aASL and wASL)

4. CONCLUSIONS

Appropriate formulation of a control problem for large-scale water resources system starts with extraction of control and state variables. Later on, when optimization or simulation of the system's performance should start, together with operating policy (set of rule curves for reservoirs, demands' priorities, etc.) additional criteria and related descriptors for measuring system's performance --such as reliability, risk, resiliency and vulnerability-- may be introduced. How they should be formulated and used may be easily found in pertinent literature.

This paper deals only with one, but very important issue: how to measure reliability and risk on local, subsystems' and system level, and with what consequences. Given simple example underlines how different priorities of demand points within system lead to different formulation of so-called acceptable system status, and furthermore to computation of reliability/risk performance parameter. Weighting coefficient method is used to illustrate principle idea: "Priority matrix of system demands may be efficiently included into process of evaluating system's performance, with the same quality of analysis and results whatever level of interests is: global, regional or local".

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