# Chapter 24
# Simulating Reservoir System Operation Under Given Scenarios to Determine Operating Policy with the 'Good' Resilience

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**Abstract** This chapter provides findings of authors in real-life engineering-style performed assessment of the resilience of complex multipurpose water systems with surface reservoirs. The chapter identifies main steps in modeling the problem in view of water users and operators needs arising in both planning and management phases of the system development and operation. A case study example from Serbia is provided to illustrate authors' approach in creating required input for running computerized river basin simulation models to determine satisfactory operation of reservoirs measured by achieving a 'good resilience' at given demand point within the system.

## 24.1 Introduction

The systems analysis methods and tools such as mathematical modeling, simulation, and optimization have been widely applied to solving problems in managing water resources for over five decades and obviously, they remain just as relevant today as hitherto. The problems related to operation of large scale water systems seem to have changed radically because of undesired climate changes and in the same time growing water demands subjected to conflicts of water users from different societal sectors. Context in which systems analysis might be applied assumes understanding the challenges related to anticipation of future requirements in front of water system, such as: emergence of stakeholders' participation, respect of environmental ethics, conducting life-cycle analysis, quantifying sustainability, taking

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care of industrial impacts on ecology, design for engineering resilience, evaluation and mitigation of risks, estimating vulnerability of technical parts of a system, etc. Although the application of systems analysis experiences permanent innovation, we have to acknowledge that we are still not able to encode all our currently available hypothetical knowledge into a model. Even when there is an obvious progress, this is not verifiable in the conventional, rigorous sense. For instance, in spite of apparently powerful mathematical formulations of the optimization problem, heuristics, metaheuristics and intuition are called upon to reach sufficiently good solutions, by expectation reasonably close to where the optimum is thought to lie.

Any mathematical modeling approach is restricted when describing the real problem. Uncertainty in input data, limitations in the mathematical description of the complex real-world physical phenomena, together with other factors affecting the overall decision-making process (like purely qualitative factors) makes their application, though essential, only part of the process. In modeling system operation strategies to enable simulation of water resources systems and evaluation of consequences of applied strategies, measuring system's resilience is one of very challenging tasks in both planning and implementing phase. Which modeling approach to choose depends greatly on the particular results expected from the analysis. Specific issues to consider are:

- Objectives of the analysis and rate of aggregation;
- Data (output) required to evaluate the strategies and resulted resilience;
- Time, data, money and computational facilities available for the analysis; and
- Modeler's knowledge and skill.

In this paper, we put a focus and discuss several important points related to planning the operation of water resources system with multipurpose surface reservoirs as main regulators of water regime in the river basin (catchment). A case study example from Serbia is used to demonstrate how systems analysis, supported by powerful river basin simulation computer models, can efficiently enable recognition of desired and un-desired system operation and in turn provide information on how much system, sub system or any other demand point in the system is resilient, i.e. capable to recover from undesired status.

## 24.2 Climate Change and Hydrologic Inputs to Reservoirs

The global temperature rise since the mid-past century has led to the global warming and today it is an important issue that many researchers have recognized as the climatic change which needs special attention in their case study assessments and evaluations of effective actions. Both regional and local scales of the effects of climate variation, together with hydrological uncertainty, are considered as a framework for analyzing human living and determining implications for water resource system management. For example, it is well known that the hydrological uncertainty of river catchment is beyond the certain level of expectation in both quantity and time scale which consequently makes a water resource management tough task to the proper operation. If the multi-purpose water resource system with surface reservoirs is to be properly managed over long periods of uncertain hydrological conditions, the final result could be the more or less mismanagement output with serious economic, political, environmental, and especially social consequences.

The severe drought events and flood damage occur in many local areas, while the increasing tendency of water requirement is likely to be a response to the economic growth, in many cases closely connected with the rising population. To enable a successful and sustainable water management, systems analysis must respect both availability of water and requirements of water users on a long-term base and suggest operators how to take into account limitations and set efficient operating policies according to each or most important local demands.

As far as reservoir system operation is concerned, it is mostly performed under uncertainty of hydrologic conditions and various encompassing factors. Systems approach must enable measurement of the performance of reservoirs by using the information of uncertainty expressed in terms of probability of failure (e.g., being in undesired status over time, so-called risk operation) or of probability of success which is commonly called the reliability (Elshorbagy 2006; Srdjevic and Srdjevic 2016a, b). Reliability is also considered as the complement of probability of failure, or risk.

Performance failure of the reservoir relates to its inability to perform in desired way within the period of interest. Reliability and risk are typical performance indices in evaluation of long-term reservoir behavior, likewise resiliency and vulnerability as two also very important concepts introduced in early 1980s. In (1995), Srdjevic and Obradovic applied the reliability-risk concept in evaluating the control strategies of multi-reservoir water resources system. As reported in Rittima and Vudhivanich (2006), Tsheko (2003) calculated reliability and vulnerability of rainfall data to define the severity and frequency periods of droughts and floods in Botswana. There are also reports from many other countries where assessments of water resources management strategies are conducted using reliability, vulnerability, and resiliency indices accompanied by the simulation models, sometimes all integrated in decision support systems (DSS). In some cases, for instance (Srdjevic and Srdjevic 2016a, b), strategies are evaluated within multi-criteria analysis frameworks supported by ideal-point, utility or outranking methods from the set of decision-making multi-criteria optimization methods.

Apart from evaluating the reservoir performance via many performance indicators such as reliability (risk), resilience, vulnerability, dispersion of reservoir levels from a rule curve, safe water (firm yield) or shortage index (McMahon et al. 2006; Rittima and Vudhivanich 2006; Srdjevic et al. 2004; Srdjevic and Srdjevic 2016a), it is correctly elaborated in many articles that main issue in systems approach is how to perform modeling by engaging both the art and the science and ‘apply a limited and imperfect understanding of the “real” world’ (Schaake 2002). In (Elshorbagy 2006) it is correctly said that ‘such an understanding requires knowledge of the physics of hydrologic processes at different spatial and temporal scales, and information on soils, vegetation, topography, and water and energy forcing variables.’

This paper presents specific modeling approach in assessing the reservoir performance from the resilience point of view. It is rather practical than theoretical approach; for theory, reader may consult multiple sources, e.g., (Hashimoto 1980; Hashimoto et al. 1980; Loucks 1997; Loucks and van Beek 2005; Moy et al. 1986; Sandoval-Solis et al. 2011; Schaake 2002; Srdjevic and Srdjevic 2016a; Srdjević and Obradović 1991, 1995).

## 24.3 Case Study Example

### *24.3.1 Background Information*

The authors of this paper participated in many studies in Serbia related to river basin planning and management, starting from mid-70-ties of the twentieth century until recently. For instance, the seven-reservoir system, located in central Serbia, is simulated with generic models SIMYLD-II, SIM IV, HEC 3 and HEC 5, delivered under UNDP project from two US sources: Texas Water Development Board (the first two models) and Hydrologic Engineering Center, USCE (the last two models), respectively. Many scientific and professional studies have been completed at that time for the Morava river basin, but also for Mirna river basin in Croatia and elsewhere in former Yugoslavia. Reported applications of aforementioned and many other computerized models, all written in Fortran programming language and installed at the IBM and UNIVAC mainframes, are without exception aimed at determining the best strategy for long-term development of water resources sector in parts of Yugoslavia.

### *24.3.2 System and Creation of Hydrologic Input to Computer Models*

To illustrate an approach in computing reliability and resilience of water resources system, the system in Morava river basin in Serbia with two reservoirs and two diversion structures (Fig. 24.1) is simulated over period of 20 years with typical rule curves at reservoirs (Fig. 24.2). Hydrologic input to the system is represented as incremental monthly net-inflow into reservoirs. It is generated as partially dependent of downstream monthly demands at three diversion structures estimated for the planning horizon. In other words, by assumption, inflow into a single reservoir depends on its natural inflow reduced for immediate downstream demand and proportionalized joint (with the other reservoir) more downstream demand. A proportion ratio is based on relative sizes of local and total catchment areas of two reservoirs. In addition, an assumption is adopted that from larger catchment area more inflow will occur and releases from the reservoir could also be larger. Modeling approach to generate inflows into reservoirs is given by relations shown in Fig. 24.1.

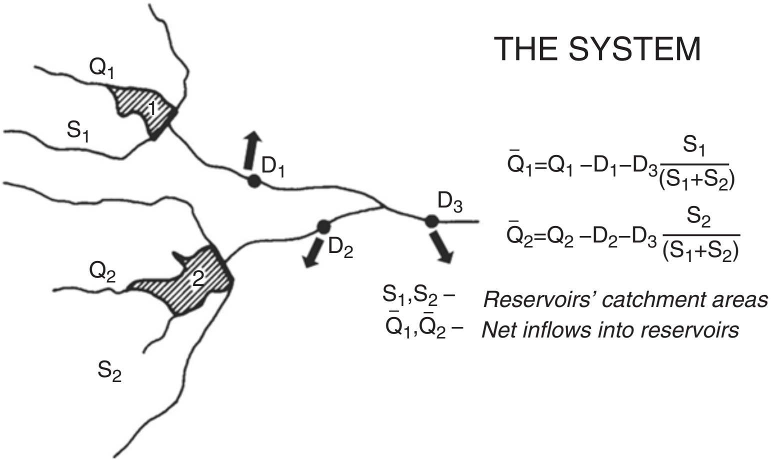


**Fig. 24.1** Two-reservoir multipurpose water resources system

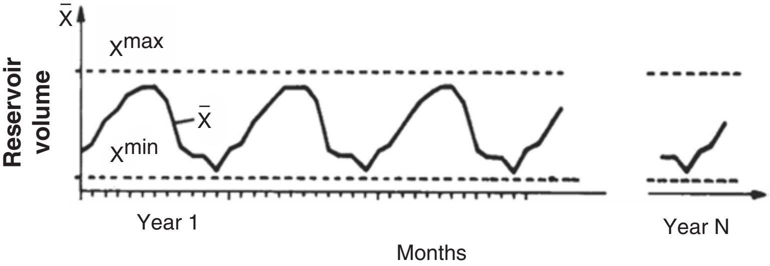


**Fig. 24.2** Typical rule curve for surface reservoir

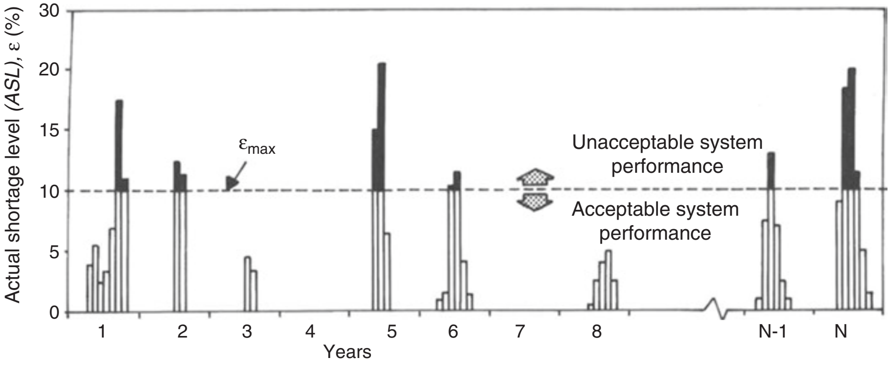
Diversion structures are aimed at supplying irrigation (diversion $D_1$), municipal ($D_2$) and combined municipal and industrial users ($D_3$). With properly defined priorities of demands and by setting operating rules for two reservoirs (with also defined priorities), a complete input data set is created for running two simulation models: (1) network model SIMYLD-II (IMP 1977; TWDB 1972) and (2) HEC-3 (HEC 1972). Worth to mention is that prescribed operating rules at reservoirs 1 and 2 were different because sizes and roles of reservoirs are also different. However, at any single reservoir rules are considered stationary, in a sense that in each year they are the same. In other words, rule for given reservoir does not change during multi-year period because 'deterministic assumption' should be violated, i.e. it is not reliable to predict reservoir inflows for more than a year ahead.

### 24.3.3 *Using River Basin Simulation Models SIMYLD-II and HEC-3*

The SIMYLD-II is a powerful generic river basin model for multiyear simulations (with monthly optimizations of water allocation) of complex water systems with surface reservoirs. It is predecessor of well known models MODSIM (Labadie 1986) and ACQUANET (LabSid 1996) developed in 1980s of the last century by following the same modeling philosophy introduced by Texas Water Development Board (TWDB 1971) and realized with SIMYLD-II together with various versions of SIM-4 and AL-III models among others.

The HEC-3 model is well known simulation model for water systems with reservoirs developed in parallel with the previous one in Hydrologic Engineering Center US Army Corps of Engineers. HEC-3 is based on balancing reservoirs operation in a way that discharges from reservoirs are made upon equalizing indexed levels within active storages. This model is also predecessor of well known family of several HEC-5 models with the same basic purpose but with some additions (for instance, computing flood damages). Both models SIMYLD-II and HEC-3 are open source codes written in Fortran programming language with 2100 and 3000 code lines, respectively.

Models SIMYLD-II and HEC-3 enable efficient re-programming for various systems analysis purposes. In described case study application, additional routines are written to ensure computing reliability and resilience at given locations within the system, for any sub-systems or for the system as a whole. Special routines are written to differentiate between so called acceptable (desirable) and unacceptable (undesired, or 'failure') status at given location, sub-system or system based on previously specified tolerance limits in meeting specified targets: desired storage levels at reservoirs and supplying demands at diversions. An illustration at Fig. 24.3 is given for a demand point $D_2$, where tolerant limit of 10% is defined for deficits that may occur at that point due to applied control (operating) policy for the system.



ε – **Percentual deficit; A- Acceptable performance; F – Failure (Unacceptable) performance**

**Fig. 24.3** Discriminating A/F system behavior for demand point $D_2$

Based on the criterion illustrated by discriminating dash line, computer in each model counts acceptable (*A*) and failure (*F*) states and 'recognizes' changes in the system performance at a given point from *A* (acceptable) to *F* (failure), count consecutive months of being in *A* or *F* state, and at the end computes various performance indicators (for points of interest), including reliability and resilience.

'State' variables can be defined in many ways, but they always may be considered as performance indicators, i.e. a consequence of applied control (operating) policy. In this case study example, the operating policy is represented by: (1) rule curves at reservoirs (for SIMYLD-II) and indexed zones within active storages of reservoirs (HEC-3), and (2) by overall priority scheme for water allocation which includes priorities among demand points ($D_1$, $D_2$, $D_3$) and reservoirs 1 and 2. Operating strategy for the system is that priority scheme determines whether and how much water in each month ($i = 1,\ldots,12$) and in each year ($j = 1,\ldots, N$) will be delivered at diversions or kept in the reservoirs while surpluses will be discharged for downstream users outside the system.

### 24.3.4 Reliability and Resilience

Reliability and resilience of the reservoir, sub-system, or system can be defined in different ways (see for instance Srdjevic and Srdjevic 2016a). Here we adopt definition based on works of Hashimoto et al. (Hashimoto 1980; Hashimoto et al. 1980): It is the indicator of how fast reservoir recovers from undesired (failure) into desired (satisfactory) status. For tolerant shortage specified in advance, reliability may be defined as the probability (or frequency) of satisfactory system performance for control point *k*:

$$\alpha(k) = \frac{\sum_{i=1}^{12}\sum_{j=1}^{N} Z_{i,j}(k)}{12N} \tag{24.1}$$

where Z is a discrete zero-one variable obtaining value 1 if system performance for point *k* was acceptable; otherwise, its value is 0 (Cf. this for months with black parts of histogram above dash line in Fig. 24.3).

A new zero-one variable, *W*, is used to identify changes of system performance at a given point from *A* (acceptable) to *F* (failure):

$$\begin{aligned} &W_{i,j}(k) = 1 \quad \text{if } x_{i,j}(k)\,\varepsilon A \textit{ and } x_{i+1,j}(k)\,\varepsilon F \\ &W_{i,j}(k) = 0 \quad \text{otherwise}^{*} \end{aligned} \tag{24.2}$$

(*The other cases are: $x_{i,j}(k)\,\varepsilon A$ and $x_{i+1,j}(k)\,\varepsilon A$; $x_{i,j}(k)\,\varepsilon F$ and $x_{i+1,j}(k)\,\varepsilon A$; $x_{i,j}(k)\,\varepsilon F$ and $x_{i+1,j}(k)\,\varepsilon F$)

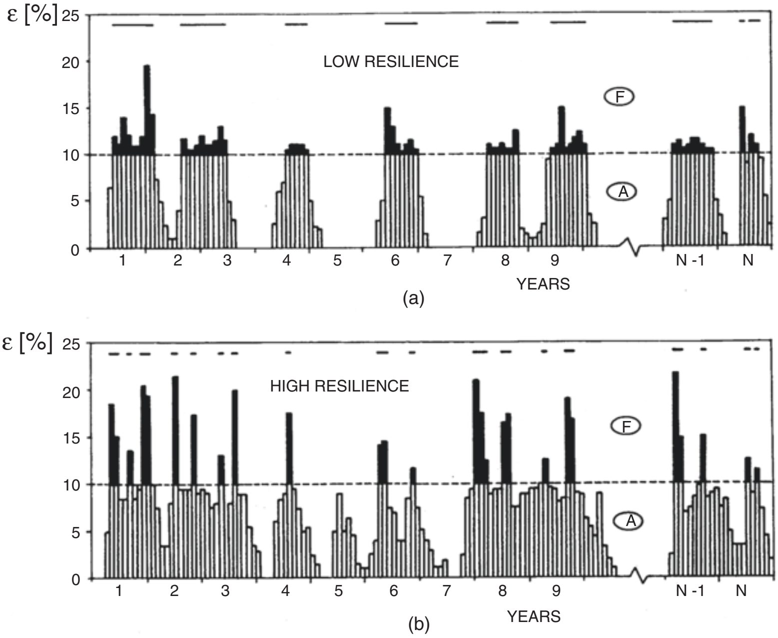
For sufficiently long period of *N* years, an average of variable *W* is equal to the probability that a system's performance for point *k* was in acceptable status (*A*) in a given month and in failure status (*F*) in the next month, i.e.:

$$\rho(k) = \mathrm{P}\left\{x_{i,j}(k)\varepsilon A, x_{i+1,j}(k)\varepsilon F\right\} = \lim_{N\to\infty} \frac{1}{12N} \sum_{i=1}^{12}\sum_{j=1}^{N} W_{i,j}(k). \tag{24.3}$$

Resilience for point *k* is now:

$$\gamma(k) = \frac{\mathrm{P}\left\{x_{i,j}(k)\varepsilon A, x_{i+1,j}\varepsilon F\right\}}{\mathrm{P}\left\{x_{i,j}(k)\varepsilon \mathrm{F}\right\}} = \frac{\rho(k)}{1-\alpha(k)} = \frac{\sum_{i=1}^{12}\sum_{j=1}^{N} W_{i,j}(k)}{12N - \sum_{i=1}^{12}\sum_{j=1}^{N} Z_{i,j}(k)}. \tag{24.4}$$

Differences in resilience indicator of system performance at two different locations is illustrated in Fig. 24.4. Note that reliability and resilience are sometimes, i.e. not necessarily, highly correlated. From the diagram (b) at Fig. 24.4 it also appears that although the diversion $D_2$ is highly resilient, it might be very vulnerable because of frequent and high deficits close to 20%, twice higher than tolerant.



ε – Percentual deficit; A-Acceptable performance; F– Failure (Unacceptable) performance

**Fig. 24.4** Low and high resilience

**Table 24.1** Performance of the system measured through the effects at the diversion $D_2$

| | Calendar months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | A | A | F | F | F | A | F | A | A | F | A | A |
| 2 | A | A | A | A | F | A | F | F | A | A | A | A |
| 3 | F | A | F | F | F | A | A | A | A | A | A | A |
| 4 | A | F | F | F | F | A | A | A | A | A | A | A |
| 5 | A | A | A | A | A | F | F | F | F | A | A | A |
| 6 | A | A | F | A | A | A | F | A | A | F | A | A |
| 7 | F | A | A | F | F | A | F | A | A | F | A | F |
| 8 | A | A | A | F | F | A | F | F | A | F | A | A |
| 9 | F | A | A | F | F | A | A | A | A | F | A | A |
| 10 | A | A | F | F | A | A | A | A | F | F | A | A |
| 11 | A | A | F | F | A | A | A | F | F | F | F | A |
| 12 | A | F | F | F | F | A | A | A | F | F | F | A |
| 13 | A | F | A | F | F | F | A | A | A | F | A | A |
| 14 | A | F | F | A | F | F | A | F | A | F | F | F |
| 15 | F | A | A | F | F | A | F | A | A | F | A | A |
| 16 | A | F | F | A | A | F | A | A | A | A | A | A |
| 17 | F | F | A | F | F | F | A | F | A | A | A | A |
| 18 | A | A | F | F | A | A | A | A | A | F | A | A |
| 19 | F | F | A | F | F | A | F | A | A | A | A | A |
| 20 | F | A | F | F | A | A | A | A | A | A | A | A |

### 24.3.5 *Measuring Resilience for Given Point in a System*

The diversion $D_2$ is selected to illustrate our approach in measuring resilience by evidencing realized supplies at the diversion by comparisons on month-by-month basis with specified requirements at this point. For specified 10% tolerant deficit, the performance of a system for that diversion is determined as shown in Table 24.1. Out of 240 months (for 20 years period of simulation), the system performed in a desired way (less than 10% deficits at control point $D_2$) during 149 months which gives reliability indicator for this diversion of 0.62 (Table 24.2) (see Eq. (24.1)).

$$\sum_{i=1}^{240} Z_i = 149 \quad \sum_{i=1}^{240} W_i = 51$$

According to relations (24.1) and (24.4) the values of reliability and resilience at point $D_2$ are:

$$\alpha = \frac{\sum_{i=1}^{240} Z_i}{240} = \frac{149}{240} = 0.62 \qquad \gamma = \frac{\sum_{i=1}^{240} W_i}{240 - \sum_{i=1}^{240} Z_i} = \frac{51}{240 - 149} = 0.56$$

**Table 24.2** Zero-one variables for computing resilience at diversion $D_2$

| | Zero-one variables Z/W | | | | | | | | | | | | Number of 1′ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year/Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Z | W |
| 1 | 1/0 | 1/1 | 0/0 | 0/0 | 0/0 | 1/1 | 0/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/0 | 8 | 3 |
| 2 | 1/0 | 1/0 | 1/0 | 1/1 | 0/0 | 1/1 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 1/1 | 9 | 3 |
| 3 | 0/0 | 1/1 | 0/0 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 8 | 1 |
| 4 | 1/1 | 0/0 | 0/0 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 8 | 1 |
| 5 | 1/0 | 1/0 | 1/0 | 1/0 | 1/1 | 0/0 | 0/0 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 8 | 1 |
| 6 | 1/0 | 1/1 | 0/0 | 1/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/1 | 9 | 4 |
| 7 | 0/0 | 1/0 | 1/1 | 0/0 | 0/0 | 1/1 | 0/0 | 1/0 | 1/1 | 0/0 | 1/0 | 0/1 | 7 | 4 |
| 8 | 1/0 | 1/0 | 1/1 | 0/0 | 0/0 | 1/1 | 0/0 | 0/0 | 1/1 | 0/0 | 1/0 | 1/1 | 7 | 4 |
| 9 | 0/0 | 1/0 | 1/1 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/0 | 8 | 2 |
| 10 | 1/0 | 1/1 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 1/1 | 0/0 | 0/0 | 1/0 | 1/0 | 8 | 2 |
| 11 | 1/0 | 1/1 | 0/0 | 0/0 | 1/0 | 1/0 | 1/1 | 0/0 | 0/0 | 0/0 | 0/0 | 1/0 | 6 | 2 |
| 12 | 1/0 | 0/0 | 0/0 | 0/0 | 0/0 | 1/0 | 1/0 | 1/1 | 0/0 | 0/0 | 0/0 | 1/0 | 5 | 2 |
| 13 | 1/1 | 0/0 | 1/1 | 0/0 | 0/0 | 0/0 | 1/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/0 | 7 | 3 |
| 14 | 1/1 | 0/0 | 0/0 | 1/1 | 0/0 | 0/0 | 1/1 | 0/0 | 1/1 | 0/0 | 0/0 | 0/0 | 4 | 4 |
| 15 | 0/0 | 1/0 | 1/1 | 0/0 | 0/0 | 1/1 | 0/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/0 | 7 | 3 |
| 16 | 1/1 | 0/0 | 0/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/1 | 9 | 3 |
| 17 | 0/0 | 0/0 | 1/1 | 0/0 | 0/0 | 0/0 | 1/1 | 0/0 | 1/0 | 1/0 | 1/0 | 1/0 | 6 | 2 |
| 18 | 1/0 | 1/1 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/1 | 0/0 | 1/0 | 1/1 | 9 | 3 |
| 19 | 0/0 | 0/0 | 1/1 | 0/0 | 0/0 | 1/1 | 0/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/1 | 7 | 3 |
| 20 | 0/0 | 1/1 | 0/0 | 0/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 1/0 | 9 | 1 |
| TOTAL | | | | | | | | | | | | | 149 | 51 |

## 24.4 Operating Reservoirs to Obtain 'Good Resilience'

The resilience of 0.56 indicates that the overall system performance was not that satisfactory, and that operating strategy for reservoirs or allocation priority scheme could be modified accordingly. To assess different strategies on how to ensure higher resilience in water supply at diversion $D_2$, more simulations are performed with generated hydrologic input and with alternative rule curves/indexed zones as shown in Fig. 24.5. Simulation of system operation is performed with models SIMYLD-II and HEC-3 and after multiple variation of operational strategies at both reservoirs, eventually the final set of rules and zoning is obtained (Fig. 24.6) that ensure high resilience (0.82) at selected location $D_2$.

In described case study example, different rule curves are used in SIMYLD-II for dry, average and wet seasons identified as moving 24-month averages of total net inflow into the system, Fig. 24.6. Zoning adjustments used in HEC-3 are aligned with the priority schemes for water allocation (same as for the SIMYLD model!). Both models are used within similar 'running framework', with the same net inflows to the system, as generated as a multi-year stochastic process represented by the sets of sequences of local monthly inflows into the reservoirs minus monthly demands at related downstream diversions.

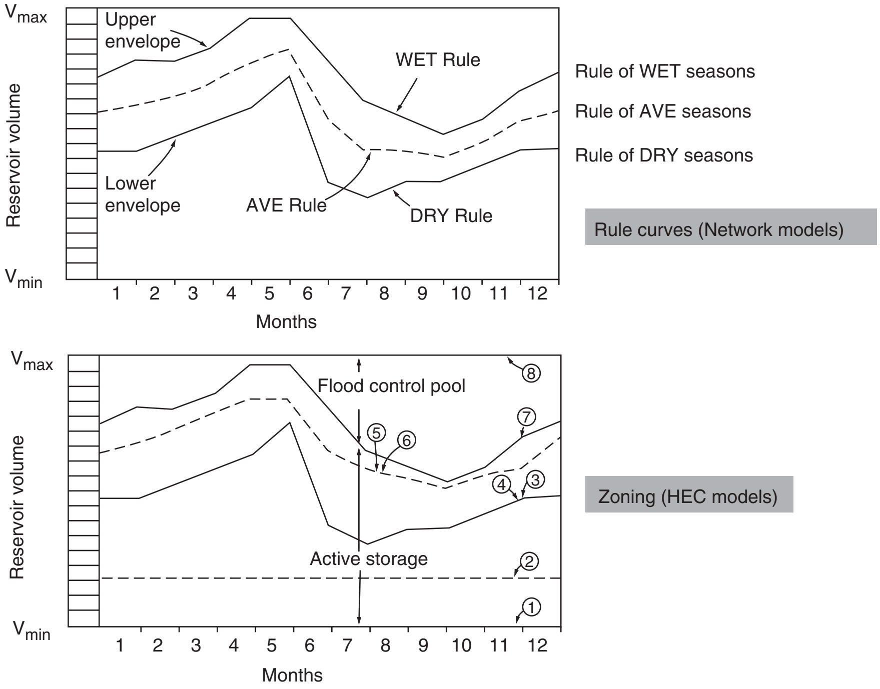


Fig. 24.5 Rule curves and simulated reservoir levels

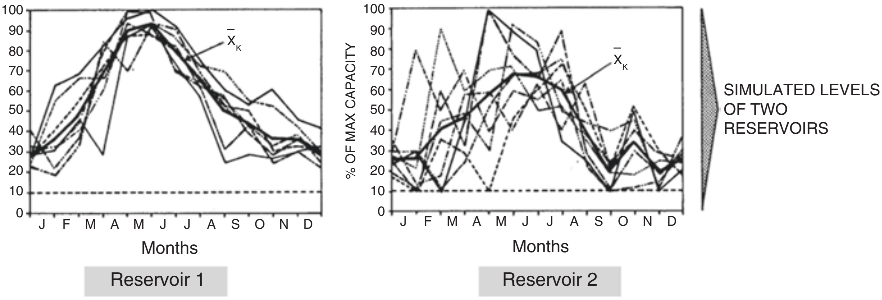


Fig. 24.6 Simulated levels and final rule curves for reservoirs ensuring the highest resilience at the diversion $D_2$

With representative hydrologic input to the system, manipulation of operating strategy led to determination of multiyear reliability and resilience at demand point $D_2$, but also at the other points in the system. Resilience at other locations varied between 0.40 (reservoir 2) and 0.75 (reservoir 1). Lowest resilience of reservoir 2 is obtained due to its forced deliveries for diversion $D_2$ immediately downstream, according to high priority given to this diversion.

## 24.5 Conclusions

Water resource systems with surface reservoirs are mainly controlled by discharging waters from reservoirs according to prescribed operating rules and priorities in water supply, whether these supplies are consumptive (e.g. industry) or no-consumptive (e.g. ecological minimum flow in the river). In the river basins where system infrastructure (dams, spillways, evacuation objects, diversions, intakes, canals, canals, lockers etc.) is located, water regime frequently experience severe droughts, flooding or other incident changes of normally established system operation. To ensure recognition of various natural or human impacts, generic simulation models are commonly used to simulate system operation in multiyear periods. Particular importance in evaluating system controllability is to identify and somehow measure consequences of changeable and hazard inflow conditions into the system, and especially to validate effects of planned operational policies or long term strategies for managing system. Performance of a system described by indicators of its robustness, reliability, resilience and vulnerability is essential for decision-making processes to be undertaken at various instances by engineers, scientists, stakeholders or politicians. With systems analysis instruments and computerized models such as those used in our study, or other referenced in (IMP 1977; Srdjevic and Srdjevic 2016a; Sulis and Sechi 2013) as SIMYLD-II(P) (Mihailo Pupin Institute), ACQUANET (University of Sao Paulo) AQUATOOL (Valencia Polytechnic University), MODSIM (Colorado State University), RIBASIM (DELTARES), WARGI-SIM (University of Cagliari) and WEAP (Stockholm Environmental Institute), it is possible to consistently evaluate long-term performance of multipurpose water systems and focus on particular indicators such as resilience of supply at any demand point, sub system or the whole system.

Our experience with measuring resilience as described in this paper shows that proper modeling of this performance indicator may help systems analysts to better identify reservoir operating rules and improve priority schemes in meeting local and system's demands. Computer models and specialized routines for internal or external computations of performance indicators based on simulation results (such as in this case indicator of resilience) can provide useful information for developing various mitigation measures. At least, models may be used for a preliminary analysis of system's potential in future conditions when multiple allocation schemes may occur as a request, or different sets of operating rules at reservoirs may be required to control the system with new users, changed types and volumes of demanded waters etc. As stated in (Sulis and Sechi 2013), system analysts at least must respect the fact that 'each model has its own characteristics and uses different approaches to define resources releases from reservoirs and allocation to demand centers' (Schaake 2002, p. 214).

Moreover, the understanding between different technical and social disciplines and interest groups involved in the resilience studies is a prerequisite for a minimum guarantee of success of the work carried out by analysts. Case study example briefly described in this paper, is one more indication of how much such understanding is important. The results obtained in the study of described system's performance are used later for making real-life decisions about the developments in water sector in the Morava river basin in Serbia.

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