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Simulation and its importance in reservoir planning — A case study*

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सार — इस अध्ययन में कर्नाटक राज्य में मौजूदा कृष्ण राज सागर जलाशय के संदर्भ में जलाशय आयोजना में अनुरूपण तकनीकों के अनुप्रयोग पर विचार किया गया है। इस अध्ययन से पता चलता है कि 1850 एम. सी. एम. की आधुनिकीकरण मांग को पूरा करने के लिये अधिक लाभ लेने हेतु सिंचाई में अधिक कमी तथा जलाशय से अधिक जलनिकासी के बिना भी मौजूदा 1240 एम. सी. एम. की क्षमता की तुलना में 1200 एम. सी. एम. भण्डारण क्षमता भी पर्याप्त हो सकती है। इसका कारण है कि अधिक क्षमता वाले जलाशय की लागत सिंचाई की कमी को पूरा करने के लिये अधिक जल आपूर्ति के लाभ से कहीं ज्यादा बैठ रही है।

ABSTRACT. The study deals with the application of simulation technique in reservoir planning in the context of existing Krishna Raj Sagar reservoir in Karnataka State. The study reveals that a storage capacity of the reservoir of 1200 M.C.M. may even be enough as compared to the existing capacity of 1240 M.C.M. to get more benefit to satisfy the modernisation demand of 1850 M.C.M. without, much irrigation deficit, and spill from the reservoir. The reason being that the high cost of reservoir for greater capacity is out weighing the benefit gain in supplying more water to meet the irrigation deficit.

1. Introduction

In achieving the optimal design in reservoir planning, usually three techniques (Srivastava 1976 and Jacoby & Loucks 1972) mathematical programming, simulation and a combination of these are generally used. The mathematical model is an abstract idealization of the system. There will be approximations and simplifications to fit into the model certain mathematical forms. Simulation is a descriptive technique (Hufschmidt & Fiering 1966). A simulation model incorporates the quantitative relationship among the variables and describes the out come or the response of the operating system under a given set of inputs and operating conditions. Most planners resort to simulation because, as it dealts effectively for the large complex problem, without much simplification and approximation of the real problems. The water resources planning is one such example. In simulation there is freedom to test different combinations of structures and targets. The simulation approach is essentially a search technique which resembles the trial and error approach used in traditional operation studies. There is no such flexibility for the operating procedure which is once fixed in the programme. Limited hydrological inputs in simulation model in reservoir planning may not represent the true configuration of the series of hydrologic events. This can be overcome by generated synthetic stream flows sequences for sufficiently long periods (Fiering 1967). In the well-known Harvard Water Programme, simulation techniques were applied to the economic analysis of water resource systems design (Maass *et al.* 1962). The U.S. Army Corps of Engineers simulated the *Columbia* river system using 25 storage dams and 45 runs of the river facilities (Lewis & Shoemaker 1962). The report of a seminar (1969) indicates that the simulation technique have gained wide acceptance in the actual design and operation of water resource projects. Four multipurpose reservoir in *Narmada* river system were simulated using systematic and random samplings (Srivastava 1976).

2. The Cauvery basin system

The *Cauvery* river (Modernization of K. R. Sagar system 1970) is an inter-state river system flowing through, Karnataka, Kerala and Tamil Nadu as shown in Fig. 1. The basin is bounded on the west by the Western Ghats, on the east and south by the Eastern Ghats, and on the north by the ridges separating it from Thungabhadara and Penner basins. It is rectangular in shape, maximum length and breadth being 360 km and 200 km respectively. The basin has a

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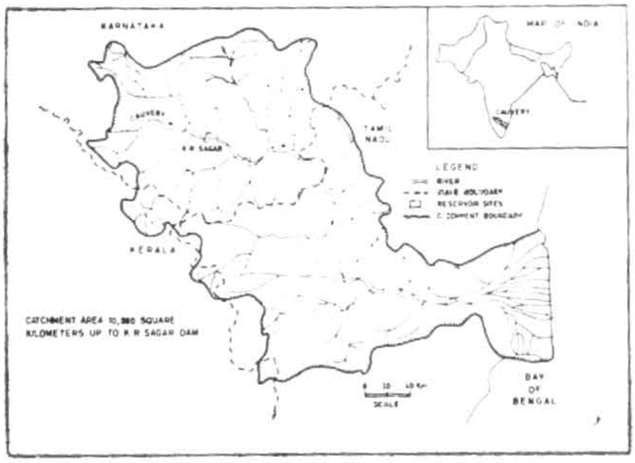

Fig. 1. Cauvery river basin map

TABLE 1

Monthly average flows for 40 years of river flows, percent irrigation requirement and Madras requirement at K.R. Sagar dam

Month	Percentage of annual irrigation requirements	Average river flows*	Madras requirements from reservoir*
(1)	(2)	(3)	(4)
January	5.4	32.40	135
February	4.6	24.68	
March	5.6	14.39	36
April	5.5	24.16	
May	4.0	84.06	
June	4.9	398.12	1366
July	10.3	2145.93	1840
August	13.3	1600.47	
September	12.4	598.00	1640
October	11.4	544.45	655
November	12.5	190.41	653
December	10.1	94.13	196

*In million cubic metres.

total catchment area of 87,900 sq. km. The annual rainfall varies from 508 mm to 2,415 mm over the catchment. The catchment area upto the K. R. Sagar dam site is 10,360 sq km and an estimated yield of 6,846 million cubic metres (M.C.M.). The cropping pattern is paddy, sugar cane, and semi dry crops. The average monthly river flows and the monthly percent distribution of annual irrigation requirement at K. R. Sagar dam are given in Table 1.

3. Identification of the problem

There is an abundant water potential available at the existing K. R. Sagar dam of about 6,846 M.C.M. The utilization at present is only 1,650 M.C.M. The utilization of water resources was restricted due to 1924 agreement clauses between the princely States of Mysore and Madras (Rep. Irrg. Comm. 1972). This 1924 agreement was in force upto 50 years, *i.e.*, upto 1974. There is a great demand from the farmers in the command of K. R. Sagar dam for further extension of the canals and to give assured water to the lands in the tail end of Visveswaraiah canal. The present K. R. Sagar dam is already 55 years old and from the existing base width of the dam, it is found that there is no scope for further increasing of the reservoir capacity. Only scope is to increase the command area with higher withdrawals through the existing canal system. A scheme known as Modernization of K. R. Sagar system has been proposed by Karnataka Government (1970) under which it is proposed to increase the utilisation from 1,650 to 1,850 M.C.M. and to supply assured water to the tail end of canal system.

The simulation studies (Sundar 1979) of K. R. Sagar dam were carried out firstly, to know that how best and by now further irrigation facilities can be provided in the proposed new scheme. Secondly, to see the applicability of simulation in the reservoir planning.

4. Search techniques

Having noted earlier that the simulation is a trial and error technique rather than an analytic process which converges to a global optimum, it is useful to ask how the analysis proceeds from trial to trial and how reliable are the results of a given number of trials. In other words, ask first if the iteration should continue, and if so, to which next sample point (or trial design). This is the general question of search techniques. Systematic, random and hybrid samplings are the three most commonly used search techniques (Srivastava 1976, Maass *et al.* 1962 & Meta System 1975).

Systematic sampling — In this system of sampling the decision variables are sub-divided into a number of steps or increments, the step-size depending primarily on the number of variables involved, the speed with which the computation can be performed and some judgement about the sensitivity of system response to small changes in the design variables. A coarse-mesh would be suitable for some variables, particularly those to which system response is sluggish, other variables would necessarily have to be subdivided on a finer grid. Except in most simple situation use of systematic sampling procedure is highly infeasible.

Random sampling — Random sampling technique is very much useful under two dimensional decision problems in which it is desired to maximize the response, measured in the third coordinated dimension. The difficulties involved in such a procedure is that random sample chosen may be on infeasible zones, and the total number of combination samples may be inadequate. In this technique ranges are selected for each variable. Combination samples are chosen at random by assigning values to all variables at random, within the ranges specified for them.

Hybrid sampling — This technique is a combination of systematic and random techniques. The basic strategy is very simple. A random sample is investigated, and the outcomes are ranked. Of all the outcomes, the top few (*say* 2 or 3) combination samples which resulted in maximum net benefits are selected for further investigation by hybrid sampling. A local optimum can be reached from each of the top few selected starting designs. There is no guarantee that the best of these optima is a global optimum, even if the initial 2 or 3 combinations converge to the same local optimum. This hybrid scheme utilizes derivatives of the benefit, B (response surface), with respect to the several decision variables in the multi-dimensional space, and design changes or steps are made in the direction of the largest derivative. A more general technique blends the several derivatives so that the step occurs along the gradient and is, consequently, more efficient in terms of convergence to a local optimum.

Let a decision vector contains m variables $(x_1, x_2, ..x_m)$ such that the net benefit, B, can be written as a function

$$B = f\ (x_1,\ x_2,\ \ldots\ldots\ldots, x_m).$$

Suppose dx_i is added to each variable in turn, and compute dB/dx_i for all variables. It is then required that the step in any direction be proportional to the improvement attained in that direction. Thus,

$$x'_i - x_i = c\ (dB/dx_i)$$

where x'_i is the succeeding value of x_i. The question is how to calculate c, the constant of proportionality. If b is a given constant corresponding to the step size in multi-dimensional space, its magnitude is the familiar Euclidean distance

$$b = \left[\sum_{i=1}^{m}(x_i' - x_i)^2\right]^{\frac{1}{2}} = c\ \left[\sum (dB/dx_i)^2\right]^{\frac{1}{2}}$$

where upon

$$c = b\left[\sum (dB/dx_i)^2\right]^{-\frac{1}{2}}$$

Cost-benefit functions — For the simulation model of the reservoir, along with the hydrologic data, the cost-benefit functions are required as input into the model. These functions are capital cost of reservoir, capital cost of irrigation works, irrigation benefit, loss in irrigation benefit due to irrigation deficit, and operation and maintenance cost. These developed function are given in Fig. 2.

Establishing an operating procedure — The operating procedure may be based on the inflow pattern of the *Cauvery* river into K. R. Sagar dam. The following characteristics (Modernization of K. R. Sagar system 1970) will establish the operating procedure.

(*i*) the hydrological character of the basin, which is dependent on the rainfall and the topography, is such that *Cauvery* river will be in floods during June to October months, the reservoir will be full and will spill during these months. The reservoir will start depleting from November to May; (*ii*) the irrigation withdrawals from the reservoir will be less during monsoon month from June to October, and high during non-monsoon months from November to May; (*iii*) as per the 1924 agreement clauses (Rep. Irrg. Comm. 1972) between the Madras and the Karnataka States, water has to be let out from the K. R. Sagar reservoir for Madras in the manner given in Table 1.

Operating procedure — The operation of reservoir will be carried out using the operating procedure, that is, rules for storing and releasing water from the reservoir in each month in the following manner:

(*i*) the simulation will start in the month of June in the first year of the study, and the initial reservoir content in the month will be equal to the dead storage, *i.e.*, zero live storage; (*ii*) the releases from the reservoir in any month will be made from the total available water, *i.e.*, sum of the initial reservoir content in the month *plus* the inflow *minus* the evaporation from reservoir during the month; (*iii*) the continuity equation will hold good in each month; and (*iv*) the reservoir content in any month cannot be more than the reservoir capacity.

5. Computations

Simulation calculations were carried out using the developed computer programme consisting of the main programme, three subroutines and one function subprogramme. Two design variables, *i.e.*, reservoir capacity, and annual irrigation requirement were sampled using systematic, random and hybrid sampling techniques. Number of sampled combinations were simulated and tested. Analysis period was for 40 years for which the river flows were taken from the report (Modernization of K. R. Sagar system 1970).

In the first systematic sampling the ranges for reservoir capacity and annual irrigation requirement selected are given in Table 2, keeping in view the present existing reservoir capacity and the future proposed irrigation requirement of 1,240 M.C.M. and 1,850 M. C. M. respectively. In all 24 combinations were simulated and it was observed from the results that the net benefits (present worth) obtained in all the combinations were negative. This was due to the fact that the Madras requirement, Table 1 was much more than the inflows resulting in heavy deficiencies in irrigation under K. R. Sagar dam. To avoid these deficiencies, fresh trials were taken without the Madras irrigation requirement and an average annual spill from K. R. Sagar dam of the value of nearly 3,000 M.C.M. was assumed as the new annual irrigation requirement for Madras. The monthly irrigation requirements at Madras were distributed in the ratio of average monthly flows. With the modified Madras irrigation requirement second systematic sampling was tried. The ranges of variables are given in Table 2. These ranges were selected in this fashion because the first systematic sampling had higher ranges and limits for annual irrigation target. However, the ranges and limits for the reservoir capacity were kept very near to the existing capacity as there is no possibility of its being changed. The results of 5 top combination samples which resulted in maximum net benefits in the second systematic sampling are given in Table 3, from Sl. Nos. 1 ot 5.

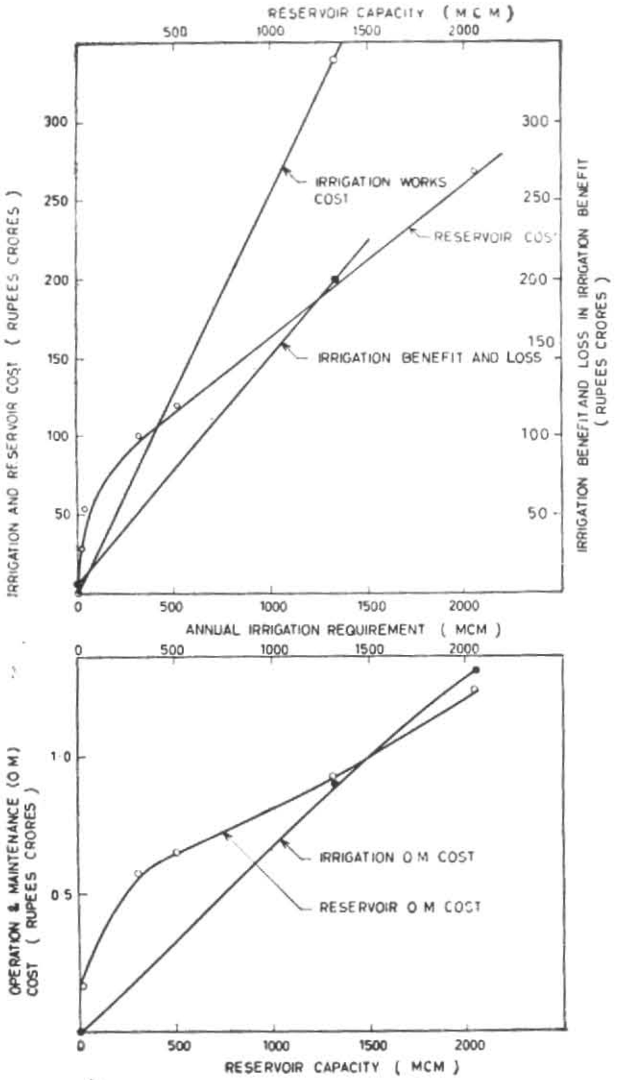

Fig. 2 Irrigation and reservoir, cost and benefit functions

TABLE 2

Ranges of variables for systematic and random samples

Variable	Systematic sample Range		Random sample Range
(1)	(2)	(3)	(4)
Reservoir capacity*	1,000-1,300**	1,200-1,250***	1,230-1,240
Annual irrigation requirement*	1,800-2,300**	1,550-1,850***	1,600-1,850

*In million cubic metres (M.C.M.).
**First trial.
***Second trial.

TABLE 3

Values of variables and results of various samplings***

Sl. No.	Reservoir capacity*	Annual irrigation requirement*	Average annual irrigation deficit*	Average annual spill from reservoir*	Net benefit**
(1)	(2)	(3)	(4)	(5)	(6)
1	1,200.00	1,850.00	148.45	881.00	184.43
2	1,210.00	1,850.00	146.59	876.00	183.49
3	1,220.00	1,850.00	144.80	872.00	182.51
4	1,230.00	1,850.00	143.17	868.00	181.49
5	1,240.00	1,850.00	141.67	864.00	180.38
6	1,238.00	1,840.00	137.90	870.00	179.82
7	1,238.65	1,848.73	141.37	865.00	180.44
8	1,239.23	1,841.70	138.41	869.00	179.81
9	1,235.01	1,832.42	133.63	875.00	179.44
10	1,210.00	1,820.00	134.69	890.87	181.05

***Sl. Nos. 1 to 5 are from systematic sampling, Sl. Nos. 6 to 9 are from random sampling, and Sl. No. 10 from hybrid sampling.
*In million cubic metres (M.C.M.), **Present worth in rupees crores.

In the random sampling a closer ranges of variables were tried. The ranges of variables, and the results of 4 top combination samples which resulted in maximum net benefits from Sl. Nos. 6 to 9, are given in Table 2, and in Table 3, respectively. For the hybrid sampling the initial values of the variables were selected based on the highest net benefit combination got from random sampling in Table 3. These values were 1,239 M.C.M. for reservoir capacity and 1,849 M.C.M. for annual irrigation requirement. The results of the 30th iteration in the hybrid sampling are given in Table 3, at Sl. No. 10.

Response of K. R. Sagar dam system — It can be easily observed from the results obtained from the simulation run by the three search techniques that the net benefit (present worth) increases with lower reservoir capacity and higher annual irrigation requirement. Average annual irrigation deficit is also on the increase, whenever there is a combination of lower reservoir capacity with higher annual irrigation requirement. The spillage is also considerable for lower capacities. Fig. 3 shows that how the net benefit, the percentage average annual irrigation deficit, and the percentage average annual spill from the reservoir change with the change in reservoir storage for the proposed new annual irrigation requirement of 1,850 M.C.M. There is a fast decrease in the net benefit as compared to other two items. Fig. 4 gives these

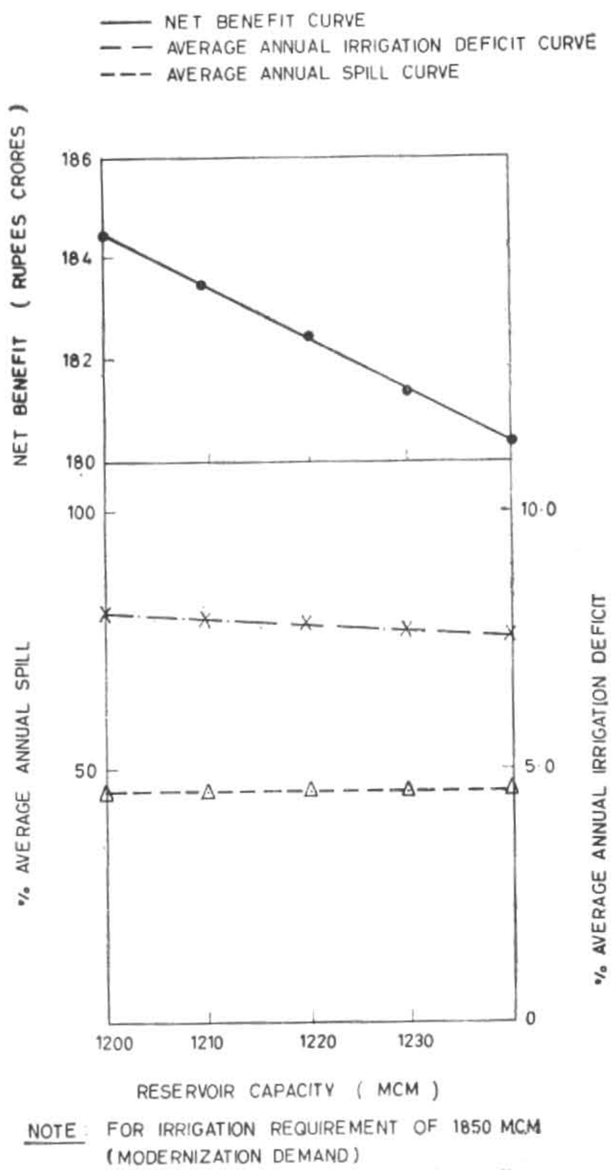

Fig. 3. Variation in net benefit, irrigation deficit and spill with reservoir capacity

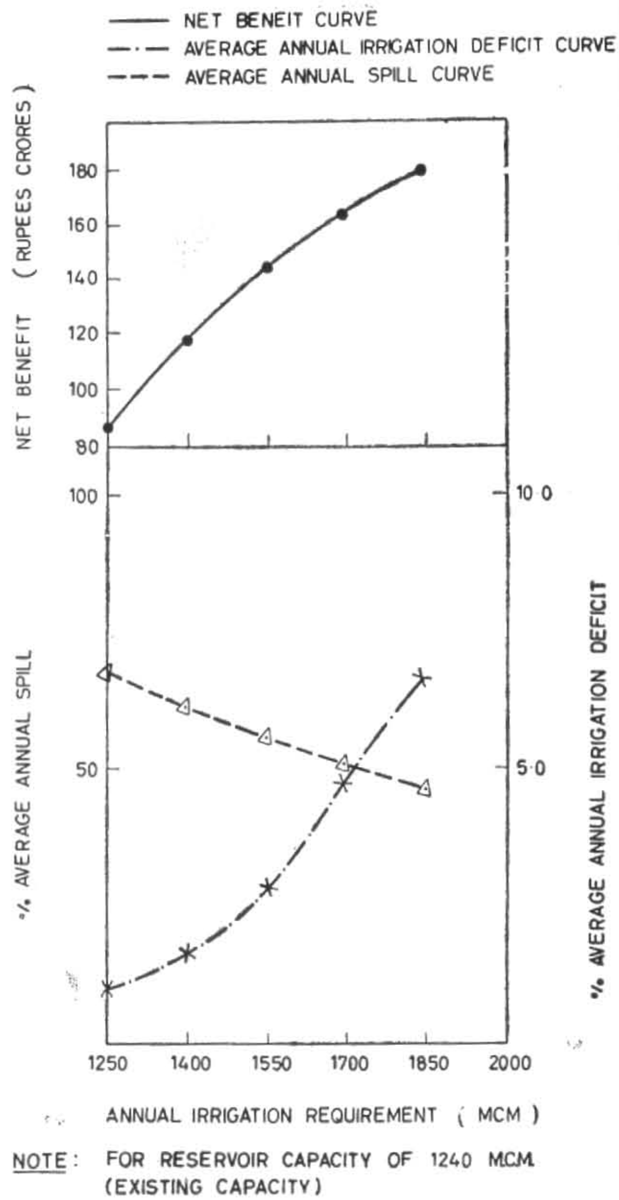

Fig. 4. Variation in net benefit, irrigation deficit and spill with annual irrigation requirement

variations for the existing reservoir capacity of 1,240 M.C.M. with changing annual irrigation requirement. In this case there are marked variations in all the three items. After further modernisation the K. R. Sagar dam would spill and would be emptied for 13% and 14% of the times respectively during its life.

Support for use of simulation — From the results as shown in Fig. 4, it is seen that if the annual irrigation target is kept constant and the reservoir capacity is increased the net benefit decreases and the variation is rapid. Same is the case with the average annual irrigation deficit and the average annual spill from reservoir, but the variation are slow. These behaviour seem to be due to the fact that the cost of reservoir is quite large as compared to the loss in irrigation benefit due to the irrigation deficit. Now, compare the combination of the new proposal at serial no. 5 (systematic sampling) in Table 3 having a reservoir capacity of 1,240 M.C.M. and annual irrigation requirement, of 1,850 M.C.M. which gives a net benefit of Rs. 180.384 crores with the combination at serial no. 1 having 1,200 M.C.M. reservoir capacity and 1,850 M.C.M. annual irrigation requirement which gives a net benefit of Rs. 184.431 crores. This comparison means that the new proposed annual irrigation requirement of 1,850 M.C.M. may as well be satisfied, even giving more net benefit, with a lower reservoir capacity than the existing capacity of 1,240 M.C.M. This could only be answered effectively by using simulation technique, as done here. Therefore, it is evident that if the planning of reservoir by simulation studies would have been carried out before construction of this reservoir, it would have been more appropriate.

Simulation which predicts the behaviour of the system in more detail or rather is more a descriptive than any of the mathematical techniques may provide answers to many such problems as discussed above which other methods of planning may fail to do so. In the light of the above findings the simulation technique may be a powerful tool for reservoir planning.

6. Conclusion

Simulation study was carried out here to see the applicability of it in the reservoir planning. An existing system of K. R. Sagar dam was analyzed for its future development. Three sampling techniques, *namely*, systematic, random and hybrid were used to explore the response (net benefit) surface. It was found that a lower capacity of 1,200 M.C.M. may only be required to satisfy the future annual irrigation requirement of 1,850 M.C.M., whereas the existing reservoir capacity is already in excess (1,240 M.C.M.) (see Table 3). This behaviour may only be predicted by simulation, making it the most feasible method for reservoir planning.

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Notations :

B net benefit (response surface);

b a constant or Euclidean distance corresponding to the step size in multi-dimensional space of m variables;

c a constant of proportionality;

dB/dx_i derivative of the net benefit with respect to x_i ;

dx_i step size of change in x_i, such that $dx_i = x'_i - x_i$;

m number of variables in the decision vector;

x_i ith variable of the decision vector containing m variables;

x'_i succeeding value of x and

$(x_1, x_2, \ldots x_m)$ a decision vector containing m variables.