WATER RESOURCES SYSTEMS

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INTRODUCTION

The purpose of this chapter is to document the important reported works in the area of water resources systems carried out by Indian scientists and engineers. This paper provides a broad overview of the applications of operations research techniques for better management of India's water resources; it will also be useful as a reference material. Some time ago, a similar review was presented by Mohile and Jagannathan(1984).

The various journals which are published in India dealing with hydrology and water resources were scanned and those papers which deal with water resources systems were selected. In addition to these, a large number of proceedings of various seminars, symposia, and conferences were also scanned and relevant papers were picked up. It is, however likely that some publications have been inadvertently missed. It may be mentioned that although a large number of papers have been published in this area, both in India and abroad, the applications of these techniques to actual planning, design and operation are rather limited. Vedula(1990) has discussed this aspect in details; he also provides the likely reasons for the same.

PRACTICES OF DAM DESIGN AND OPERATION

The various aspects of storage reservoirs in India were discussed by Patel(1979). Pattegar(1979) provides a lucid discussion on dependability criteria used in India in the context of planning of water resources development projects. Mistry (1987) has discussed the various aspects of the never ending controversy of small vs. big dams and has concluded that both have their advantages and disadvantages and the selection should be made after careful consideration of a number of factors. The controversy continues to persist.

The proceedings of a workshop on dam safety contain a number of interesting papers on various related aspects. Mohile(1988) provided a comprehensive review of hydrologic aspects of dam safety and Reddy (1988) discusses the various aspects of spillway design. Murthy(1988a) has discussed about the operation of Sriramasagar dam with reference to dam safety, Singh(1988) has suggested methods for improving operational efficiency of spillway gates, Pattanaik(1988) has discussed safety aspects of operation of Hirakud dam and Sundaryaiya and Subramanyam(1988) describe the operation procedure for DVC reservoirs. Bapat and Kulkarni(1988) and Murthy(1988b) explain the difficulties in operation of spillway gates. Desai(1988) has discussed about the determination of design flood of Sardar Sarovar and design of spillway. Purohit (1988) explains various measures to be taken while operating a reservoir, highlighting the safety aspects.

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Singh (1990) describes a system for automatic operation of spillway gates. Murthy and Reddy(1990) provide a comprehensive review of spillway design practices being followed in India and other countries. Some case studies have been reviewed and various aspects like PMF and difficulties in implementing the IS guidelines have been discussed. A scan of the literature brings out the need of a document describing the various policies, criteria and practices of design and operation of water resources projects. This document will be useful for both field engineers and researchers.

APPLICATIONS OF SYSTEM ENGINEERING TECHNIQUES

The system engineering techniques which have been used for solving various problems related to development and management of the water resources systems are classified in categories : Linear Programming (LP), Nonlinear Programming(NLP), Dynamic Programming (DP), Simulation, and Other Techniques. All these techniques have been quite frequently used by Indian investigators. The following review has been classified according to the solution technique used and the applications are being presented in a chronological order. A summary of the applications is given in Table 1.

APPLICATIONS OF LINEAR PROGRAMMING

Chaturvedi and Srivastava (1975) presented a deterministic continuous LP screening model for Narmada basin. The storage capacities of six dams were to be decided such that net annual benefits are maximized. The model had four time periods of 3 months each and mean flows were used as input. Chandra and Pandey (1975) studied conjunctive use of surface and ground water in Upper Ganga canal command area in U.P. A LP model was used to get the optimal cropping pattern and schedule of releases for conjunctive use after the anticipated additional supplies from Tehri dam become available. Varma and Kardia (1976) used LP for the land-crop-water allocation problem in the Jadhol irrigation project. Only surface water resources were considered.

Mohanty et al (1976) analyzed the operation of the Hirakud dam for irrigation, power and flood control. A two step optimization was attempted. The land-crop-water allocation was optimized in the first step and keeping these as constraints, energy production and flood control operation was optimized in the second step. Mohanty and Patnaik (1977) analyzed a case similar to the Hirakud Project considering flood control, irrigation, and power objectives. The system objectives were optimized using a LP formulation after assigning preference coefficients for the objectives. Trade-offs were obtained by changing the preference co-efficients.

Lakshminarayana and Rajagopalan (1977) used LP for land-crop-water allocation problem of the Bari Doab area considering conjunctive use of water. Srivastava and Chaturvedi (1978) studied the optimal configuration for Narmada river basin having 32 proposed reservoir sites. A LP formulation was used as a screening model and the system was simulated dividing the year in four three-monthly periods. The problem was solved for different hydrologic conditions. The operation of selected configurations resulting from the LP problem was simulated and smaller changes in the system design and operation procedures for the system were tested through the simulation runs.

Yoganarasimhan and Chand (1979) used a LP model for conjunctive use of resources. Chauhan et al (1980) used LP for optimization of hourly operation of the Bhakra-Beas system for hydropower generation. The maximization of the daily power generation was subject to constraints on mass balance, reservoir capacity, water conductor capacity, installed capacity of power house, and peak power. Singh and Chauhan (1980) maximized the power generation in the Beas-Sutlej system for a mean year using LP and considering the irrigation requirements, continuity at each node, and capacities as constraints. The power head was considered as constraint for each power station. Sinha and Charyulu (1980) used LP for the land-crop-water allocation problem of Gomti Kalyani doab. The crop response functions relating irrigation water and yield were linearised for this purpose. Tyagi and Dhruvanarayan (1980) used chance constrained LP for land-crop-water allocation problem for a part of Western Yamuna canal command area. The formulation ensured the probability of meeting crop water requirement at a given risk level while optimizing the cropping pattern to maximize income. Reddy et al(1980) studied the planning of Pochampad reservoir in Godavari basin. The linear decision rule was used to find the required minimum storage capacity and the operating rules for the reservoir.

Chaturvedi and Rogers (1981) used LP for planning of water resources development of the Ganga basin to maximize the returns form irrigation and hydropower subject to availabilities of surface and ground water, agricultural considerations and capacity constraints. The year was divided in three time periods of winter, summer and monsoon. The problem was decomposed using a consistency model, a sub problem model and a master problem model. Reddy and Vedula (1981) used LP to optimize the monthly operation of Hemavati and Krishnarajasagar reservoirs in the Cauvery basin. The objective of the formulation was to optimize the sum of irrigation diversions from the two reservoirs. Purushottam(1981) studied the problem of reservoir sizing and operation for five reservoirs in the Godavari basin. The multipurpose reservoirs serve for irrigation, hydropower and flood control. The synthetically generated streamflows were used in the study.

Ramaseshan (1981a) studied the optimization of operation of Bhakra-Beas system for maximizing power output. The constraints on meeting target power, turbine capacity, irrigation levels, and reservoir capacity were imposed. The target firm power and the reservoir factor were varied each year to obtain a trade-off between irrigation and power for that year. Ramaseshan (1981b) studied the operation of the Bhakra-Beas system using the SIMLYD-2 program of Texas Water Development Board. In this program, the allocation in each period is done by optimizing using the out-of-kilter algorithm. Different rule curves for dry, average, and wet conditions were used for reservoir operation.

Vedula and Rogers (1981) developed a LP model to find the cropping patterns for in the Upper Cauvery basin to maximize the net economic benefits and the irrigated cropped area. The monthly deterministic model was applied to a four reservoir system. The objectives of maximizing net benefits and irrigated cropped area were found to conflict with each other. The transformation curve between the two objective was developed and the trade-off estimated at the level of irrigation development proposed by the planning agency.

Padhi and Dhruva (1981) analyzed the operation of Ramganga project using LP technique to obtain optimum irrigation and power benefits. The irrigation releases were

set to follow a fixed monthly pattern. At least 70 percent of the total power generated was to be firm and follow a fixed monthly pattern. The objective function was a weighted sum of the irrigation and power production. The weighing factors were changed to develop trade-off production possibility curve.

Duggal and Khepar (1981) used a LP model for conjunctive use of surface and ground water for irrigating an area in the command of Talwandi distributary of the Abohar branch of Sirhind Canal system. The net return from crop was maximized considering various levels of irrigation for each crop. The output was the various cropping patterns as well as the optimum mix of canal and tube well water. Lakshminarayana et al(1982) simulated the operation of Krishna river basin system consisting of 15 reservoirs, 5 diversions and power stations. The HEC-4 program was used to extend data series. The results of the simulation studies were used to formulate rule curves for dry, wet and average year for each reservoir. Kumar et al (1982) used LP for maximizing the benefits to the cultivators in the Gandak command area through conjunctive use of water.

Radhey Shyam et al (1983) proposed a LP model to maximize aggregate return through integrated use of surface and ground water for Bhabar part in the Haldwani block of Nainital district. The optimization was carried out only for Rabi and hot weather crops. Crops with different irrigation levels were considered as separate crop activities. Two different water supply levels --from tube well and 48 hours canal water supply per month -- were considered.

Mohile and Jagannathan (1983) presented a LP formulation for optimal operation of a large water resources system in northern India. The land-crop water allocation problem was embodied in the system in which the energy production at the power house, energy requirement for ground water pumping, modeling of the surface and ground water system and conjunctive use possibilities were considered. By changing the system and social constraints, a number of optimum cropping patterns and reservoir operation possibilities were brought out. Raman and Vasudevan(1991) applied LP, DP and geometric programming to develop optimal operation policy for Krishnagri reservoir.

APPLICATIONS OF DYNAMIC PROGRAMMING

Banerjee and Harikrishna (1975) presented a state incremental dynamic programming model to determine the optimal operating policy for the DVC system using the critical period of observed flows. The objective was to maximize hydropower output from this multipurpose multireservoir system serving for irrigation and flood control. The study indicated the possibility of 20 % increase in hydropower output without reducing benefit of irrigation and flood control.

Rao and Shah (1980) studied the operation of the Girna reservoir in Maharashtra which serves for irrigation and power. Monthly operation of the reservoir starting from full storage at end of monsoon was considered. The expected value of the irrigation and power from the release were optimized through a stochastic DP formulation. The transition probability method was used for generating future storage state. Srinivasan and Thandeswara (1981) presented a flood damage model linking the heights of submergence with the area of submergence for the Adyar river basin. The damage frequency curve was computed to yield an economic model to link flood damage with various return periods.

Harikrishna et al (1981) studied the integrated operation of Bhakra-Beas system using incremental DP technique. The annual power generation from the five power stations was maximized subject to physical constraints ensuring that the power releases should equal irrigation requirements. The trade-off between irrigation and power was studied by changing the reservoir factor. Jain, Yoganarasimhan and Seth(1990) presented an approach for development of flood control operation policy of a multipurpose reservoir. The algorithm tries to maximize reservoir storage contents at the end of a flood season while keeping the risk of an overflow below a specified level. The problem was solved using the stochastic DP.

APPLICATIONS OF OTHER OPTIMIZATION TECHNIQUES

Chauhan et al (1981a) studied the operation of Bhakra-Beas system to meet the variable demand of power within 24-hour cycle, subject to installed capacity. The capacity limitations of the transformer, need for auxiliary power supply, minimum discharge required for tailrace maintenance etc. were also considered. The problem was first formulated as a mixed integer programme which was decomposed into integer programming and NLP. The constrained NLP problem was reformulated using Langrangian multiplier.

Chauhan et al (1981b) optimized the operation of the Bhakra- Beas system for irrigation and hydropower generation subject to penalties for not meeting the irrigation targets and reservoir storage targets. The problem was formulated as a complex non linear problem decomposed in two levels. At the first level, the minimization of the pseudo objective function for a known value of the pseudo variable was attempted. At the second level, the main objective function was minimized over the unknown value of the pseudo variable. The iterative procedure was used for both the levels of optimization. Jain et al (1988) presented a formulation, based on goal programming, to determine the reservoir operation rules. Ramanmurthy and Joseph(1990) have presented a Non-linear programming model to determine optimum firm power from a system of reservoirs.

APPLICATIONS OF SIMULATION TECHNIQUE

Minhas et al (1972) studied the trade-off between hydropower and irrigation aspects of the Bhakra project using monthly simulation with historic flows. The firm power potential was estimated subject to target irrigation demand represented by reservoir factor. Gupta and Shrahatti (1975) studied the effect of hydrologic uncertainty on the performance of Kopilli hydroelectric project. Synthetically generated sequence of data were used in monthly simulation to evaluate project performance. It was been shown that the hydrologic uncertainty was reflected in the deficit index computed for each synthetic series. Ranganathan et al (1976) used decision theoretic approach for the sizing of Karjan reservoir in Gujarat state. Considering the uncertainties in inflows, simulation runs were taken to study the performance of the system in terms of meeting the irrigation demand vis-a-vis the reservoir capacity. The determination of operation policy for Hirakud reservoir in Orissa during monsoon season was studied by an Expert Committee (1976), Government of India. This reservoir serves for hydropower, irrigation and flood control. Simulation was used to study the project performance using 22 years of 10-daily data. The operation policy attempted to fill the reservoir to the maximum extent by the end of monsoon season.

Desai(1977) presented a new approach for flood control operation using simulation. The data of Ukai reservoir was used as a test case. The future operation was based on assuming the flood to have crested and calculating the empty reservoir storage space.

Kapila and Sisodia (1978) simulated the operation of the Ravi-Beas-Sutlej system on 10-daily and monthly basis to determine the operation that would enable maximum power generation while considering the irrigation aspects. Srivastava and Chaturvedi (1978) used simulation to test the output of a screening model. Khaliquzzaman and Mohile(1980) applied the HEC-5 program and studied various problem in applying this program in Indian context. Srivastava and Chaturvedi (1980) simulated the operation of four reservoirs in Narmada basin on monthly basis for a period of 16 years. The simulation was repeated varying gross reservoir capacities, annual irrigation targets, energy targets and power plant capacities within the range to plan the system for maximum net benefits. Srivastava and Bhandary (1980) studied the operation of a flood detention basin in the Jhelum valley in Kashmir.

Mohanty and Patnaik (1982) studied the conflict between flood control and conservation aspects of Hirakud reservoir using monthly simulation with trail rule curves. A heuristic approach was used in selecting the best rule curve. Prasad(1988) used HEC-3 to find the optimum firm yield in a conjunctive use environment. Rema Devi and Arun Kumar (1983) used the transition probability approach to analyze the performance of a reservoir project using simulation. Simulation was also used by Seth and Jain(1990) to develop the operation policy of the Machhu II reservoir in Gujarat.

Venugopal and Prasad(1990) used simulation for assessing the firm power potential for the Narmadasagar complex. Venugopal et al(1991) simulated the operation of Periyar-Vagai system consisting of reservoirs and irrigation canals. The interbasin transfer of water was also involved in this problem. Raman(1991) applied the HEC-3 programme to study the operation of the Adyar system. Sud and Kumar(1991) applied the Acres reservoir simulation program to the Bango-Hirakud-Manibhadra system and Sud and Sivadas(1991) applied the same program to the Vellar basin. Khaliquzzaman and Chander(1991) presented an algorithm for real-time control of a reservoir during floods. The methodology was applied to the Hirakud reservoir. WAPCOS(1987) used simulation to develop the operation policies for the Damanganga project; Seth and Jain(1991) used it to develop the operation policies for the Machhu II reservoir. Rao and Kumar(1991) simulated the operation of a system of 15 reservoir to evaluate the potential of future development at each reservoir and the extent of inter-basin transfer from flood prone areas to drought prone areas.

APPLICATIONS OF OTHER TECHNIQUES

Dhason and Seth (1984) used the method proposed by the HEC for construction of spillway gate regulation curves. Pendse et al (1988) describe a two-level multiobjective planning approach for water resources development. One another multi-objective planning approach has been proposed by Raman et al(1990). Krishnamoorthi(1990) presented a system analytic technique for irrigation water management. The Chembarambakkam tank in Adyar basin was taken as case study. Thangaraj(1991) used multiobjective approach to study operation of a two reservoir system. A LP model was formulated to maximize the firm power for the different assumed demand patterns. For each pattern, a trade-off

analysis was performed for different satisfying levels of irrigation. Mohan and Raipure(1991) used multiobjective approach to evaluate the project alternatives of Chaliyar river basin. The ELECTRE I and ELECTRE II ranking schemes were used.

With the advent of personal computers, their use in solving hydrological problems is growing rapidly. A number of PC-based software have also been ingenuously used for this purpose. Tirupathi and Ramaseshan(1990) used electronic spreadsheet (LOTUS 1-2-3) to solve various hydrological problems including mass curve analysis. Senthilkumar and Venugopal(1991) presented a real-time operation model for a distributary of an irrigation system using Lotus 1-2-3. Jain(1992) has shown that spreadsheets can be conveniently used for reservoir operation simulation and planning.

Since the PCs are easily to install and maintain, they can be conveniently used as a decision support tool. Jain(1991) has developed a menu-based software for decision support for real-time reservoir operation.

The applications of artificial intelligence to water resources systems are growing rapidly. A number of books are available on these techniques; Ramaseshan(1990) provides a review of the techniques with reference to hydrology. Raman et al(1990) have provided a preliminary blue print of such a system for management of a water resources system during droughts.

A System Engineering Unit was formed in the Central Water Commission where a number of studies, e.g. Mahanadi Reservoir Project, Hirakud Reservoir Project, and Bango-Hirakud-Manibhadra System, were taken up under the guidance of some renowned experts. Only those studies under this programme which were published by individuals have been referred above. The results of the studies by this unit have been summarized in SEU(1987).

CONCLUSIONS

It is evident from the above presentation that considerable developments have taken place in India in the area of water resources development. However, in spite of these, the utilization of our resources is still not up to the desired level. Chaturvedi (1991) gives the following reasons for this :

* The technological performance over the spectrum in terms of planning, design, construction and management is poor.
* Activity regarding modernization of the work already undertaken for scientific and efficient water resources development is not up to desired.
* Adequate institutional support is very crucial and is not available at present.

According to Chaturvedi (1991), the issue is not of obtaining computers and computer programs but developing indigenous self-sustaining capability in the field at the frontiers of knowledge. There are, however, reasons for one to be optimistic on this count and hope for environmentally friendly, optimum, and sustainable development of India's water resources.

Table 1 Summary of Applications of System Engineering Techniques

Authors	Year	Purpose	Technique
Banerjee & Harikrishna	1975	Oper	DP
Chandra & Pandy	1975	Opt-Aloc	LP
Chaturvedi & Rogers	1981	Planning	LP
Chaturvedi & Srivastava	1975	Planning	LP
Chauhan et al	1980	Oper	LP
Chauhan et al	1981a	Oper	NLP
Chauhan et al	1981b	Oper	NLP
Desai	1977	Oper	SIM
Dhason & Seth	1984	Gate regulation	SIM
Duggal & Khepar	1981	Conj-use	LP
Expert Committee	1976	Oper	SIM
Gupta and Sirhatti	1975	Oper	SIM
Harikrishna et al	1981	Oper	DP
Jain et al	1988	Oper	Goal Prog.
Jain,Yoganarasimhan & Seth	1990	Oper	DP
Jain	1991	D S S	
Jain	1992	Oper, Planning	Spreadsheet
Kapila & Sisodia	1978	Oper	SIM
Khaliquzzaman & Mohile	1983	Oper	SIM
Khaliquzzaman & Chander	1991	Oper	SIM
Krishnamoorthy	1990	Irrigation	SIM
Kumar et.al.	1982	Oper	LP
Lakshminarayana & Rajgopalan	1977	Opt-Aloc	LP
Lakshminarayana et al	1982	Oper	SIM
Minhas et al	1972	Oper	SIM
Mohan & Raipure	1991	Proj Evaluation	Multi-Obj.
Mohanty & Patnaik	1977	Oper	LP
Mohanty & Patnaik	1982	Oper	SIM
Mohanty et al	1976	Oper	LP
Mohile & Jagannathan	1983	Opt-Aloc, Oper	LP
Padhi & Dhruvanarayan	1981	Oper	LP
Pendse et.al.	1988	Planning	Multi-Obj.
Prasad	1988	Firm yield	SIM
Purushottam	1981	Planning, Oper	LP
Radhey Shyam et al	1983	Opt-Aloc	LP
Remadevi & Kumar	1983	Oper	SIM
Raman	1991b	Oper	SIM
Raman et.al	1990	Planning	Multi-Obj.
Raman & Vasudevan	1991	Oper	LP, DP
Ramanmurthy & Joseph	1992	Firm yield	NLP
Ramaseshan	1981a	Oper	LP
Ramaseshan	1981b	Oper	LP, SIM

Authors	Year	Purpose	Technique
Ranganathan et al	1976	Planning	SIM
Rao and Shah	1980	Oper	DP
Rao & Kumar	1991	Oper	SIM
Reddy	1980	Oper	LP
Reddy and Vedula	1981	Oper	LP
Reddy et.al.	1980	Planning	LP
Seth & Jain	1991	Oper	SIM
Senthil Kumar & Venugopal	1991	Oper	Spreadsheet
SEU	1987	Planning, Oper	LP, DP, SIM
Singh & Chauhan	1980	Oper	LP
Sinha & Charyulu	1980	Opt-Aloc	LP
Srinivasan & Thandeswara	1981	ComEco	PRM
Srivastava & Chaturvedi	1978	Sys-conf	LP, SIM
Srivastava & Chaturvedi	1980	Oper	SIM
Srivastava & Bhandary	1980	Oper	SIM
Sud & Kumar	1991	Oper	SIM
Thandeswara	1981		DP
Thangaraj	1991	Oper	Multi-Obj.
Tirupathi & Ramaseshan	1990	General	Spreadsheet
Tyagi & Dhruvanarayan	1980	Conj-use	LP
Varma & Kardia	1976	Opt-Aloc	LP
Vedula & Rogers	1981	Crop Pattern	LP
Venugopal & Prasad	1990	Firm Power	SIM
Venugopal. et.al.	1991	Oper	SIM
WAPCOS	1987	Oper	SIM
Yoganarasimhan & Chand	1979	Conj-use	LP

Oper - Reservoir Operation, Opt-Aloc - Optimal Allocation
Conj-use - Conjunctive Use, DSS - Decision Support System

REFERENCES

Banerjee,B.K., and Hari Krishna, "Optimization of hydropower output from a 5 reservoir system by incremental dynamic programming", Proceedings of the National Symposium on Hydrology, Univ. of Roorkee, 1975.

Bapat,V.V., and V.H. Kulkarni, "Difficulties in operation of spillway gates". Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988.

Chandra,S., and P.K. Pandey, "Conjenctive water planning A case study", National Symposium on Hydrology, University of Roorkee, 1975.

Chaturvedi,M.C., and D.K. Srivastava, "Systems analysis of complex water resources systems", Proceedings of National Symposium on Hydrology, University of Roorkee, 1975.

Chaturvedi,M.C., and P. Rogers, "Large scale water resources systems planning approach and screening model", Proceedings of the XIX IAHR Congress, Vol. IV, Subject-C, New Delhi, 1981.

Chaturvedi,M.C., "Water resources planning & management in India", Proceedings of National Seminar on Use of Computers in Hydrology & Water Resources, Vol. I, Central Water Commission, New Delhi, 1991.

Chauhan,R.C., O.D. Thapar, G.N. Yoganarasimhan, "Daily optimal operation of cascade reservoirs and power plant", Proceedings of International Symposium on Water Resources Systems, WRDTC, University of Roorkee, 1980.

Chauhan,R.C., O.D. Thapar, and G.N. Yoganarasimhan, "Optimum Scheduling in dam power stations", International Symposium on Real Time Operation of Hydrosystems, University of Waterloo, Ontario, Canada, 1981a.

Chauhan,R.C., O.D. Thapar and G.N. Yoganarasimhan, "Optimum scheduling of generation in dam power station", Proceedings of International Symposium on Real-Time Operation of Hydrosystems, Vol. I, University of Waterloo, Ontario, Canada, 1981b.

Desai,N.C., "A new method for flood control operation of reservoirs", Proceedings of the 46th Research Session of CBIP Vol. II - Hydraulics, Trivendrum, 1977.

Desai,N.B., "Design flood for Sardar Sarovar spillway and energy dissipater", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988.

Dhason,S.R.B., and S.M. Seth, "Flood routing through multipurpose reservoir", HYDROLOGY, Journal of Indian Association of Hydrologists, Vol. VII, No. 1, 61-65, 1984.

Duggal,K.N., and S.D. Khepar, "A linear programming model of conjunctive use of surface water and groundwater", Journal of Institution of Engineers(I), Vol. 61, Pt. C15, 284-288, 1981.

Expert Committee(1976), Operation of Hirakud Reservoir During Flood Season, Report of Expert Committee, Govt. of India, 1976.

Gupta,L.N., and P.P. Shirahatti, "Effect of hydrologic uncertainty on system performance, A case study", Proceedings of National Symposium on Hydrology, University of Roorkee, 1975.

Harikrishna, Satish Chandra and R.S. Gaikwad, "Optimal operating policy for Bhakra Beas system", Proceedings of the XIX IAHR Congress, Vol. IV, Subject-C, New Delhi, 1981.

Jain,S.K., B. Soni, and P.V. Seethapathi, "An optimization technique for water resources management", Journal of Institution of Engineers(India), Vol. 69, 1988.

Jain,S.K., G.N. Yoganarasimhan and S.M. Seth, "Flood control operation policy analysis of a multipurpose reservoir", Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Jain,S.K., "A PC-based menu driven system for reservoir operation", Proceedings of Fourth National Symposium on Hydrology, Madras, 1991.

Jain,S.K., "Reservoir operation simulation and planning using spreadsheets", Accepted for Publication, Irrigation and Power Journal, CBIP, 1992.

Kapila,I.P., and B.S. Shishodia, "Computer simulation model of water and power studies", Journal of Irrigation and Power, CBIP, Vol. 35, No. 1, 1978.

Khaliquzzaman and A.D. Mohile, "Reservoir system simulation- use of HEC-5 package in Indian condition", Proceedings of National Symposium on Planning and Design of Water Resources System, Vol. II, Bihar College of Engineering, Patna, 1983.

Khaliquzzaman and S. Chander, "Real time control of a reservoir during floods", Proceedings of National Seminar on Use of Computers in Hydrology & Water Resources, Vol. II, Central Water Commission, New Delhi, 1991.

Krishnamoorthi,S., "Systems analysis for irrigation water managements on farms", Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Kumar,D., Anil Kumar, and R.R. Mishra, "Optimal cropping pattern for Gandak command area, A systems approach" Journal of Institution of Engineers (India), Vol. 62, Pt. CI5, 1982.

Lakshminarayana,V., and S.P. Rajagopalan, "Optimal cropping pattern for a basin in India", Journal of the Irrigation and Drainage Division, ASCE, Vol. 103, 1977.

Lakshminarayana,V., K. Ramamurthy, and K.V. Jayakumar, "System studies of Krishna river basin", Department of Civil Engineering, Indian Institute of Technology, Kanpur, 1982.

Minhas,B.S., K.S. Parikh, T.N. Srinivasan, S.A. Margin, and T.E. Weisskopf, Scheduling the Operations of the Bhakra System, Statistical Publishing Society, Calcutta, 1972.

Mistry,J.F., "Major & minor storage dam - A realistic perspective", Journal of Irrigation & Power, CBIP, 44(3), 51-58, 1987.

Mohan,S., and D.M. Raipure, "Multiobjective river basin planning - a case study", Journal of Institution of Engineers, Vol. 72, pp. 161-167, 1991.

Mohanty,R.P., and N. Patnaik, "Towards a policy framework for management of a multipurpose reservoir system", Journal of the Institution of Engineers(I), Civil Engg. Div., 57(CI6), 1977.

Mohanty,R.P., and N. Patnaik, "Flood control heuristics for a multipurpose reservoir system", Journal of the Institution of Engineers (India), Vol. 62, Pt. CI4, 1982.

Mohanty,R.P., K.C. Sahu and B.S. Rama Rao, "Optimization studies on operational aspects of a multiple purpose reservoir system- A case study", Journal of Irrigation and Power, CBIP, Vol. 33 No. 4, 1976.

Mohile,A.D., and E.V. Jagannathan, "Analysis of integrated water power system through linear programming", Proceedings of National Symposium of Planning and Design of Water Resources Systems, Vol. I, Bihar College of Engineering, Patna, 1983.

Mohile,A.D., and E.V. Jagannathan, Water Resources System Engineering - Status and Indian Perspective, Status Report No. 8, Central Board of Irrigation and Power, New Delhi, 1984.

Mohile,A.D., "Hydrologic review of dam safety", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988.

Murthy,C.V.R., "Reservoir operation and dam safety with special reference to Sriramsagar dam in Andhra Pradesh", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988a.

Murthy,C.V.R., "A critical review of the operation of spillway gates in the multi-purpose reservoirs in Andhra pradesh", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988b.

Murthy,Y.K., & M.S. Reddy, "Sizing of spillways for large dams in India", Journal of Irrigation & Power, Vol. 47(2), CBIP, 121-150, 1990.

Padhi,G.N., and S.K. Dhruva, "Value of water for multipurpose use", Proceedings of International Symposium on Real Time Operation of Hydrosystems, Vol. I, University of Waterloo, Ontario, Canada, 1981.

Patel,C.C., "Storage reservoirs in India", Journal of Irrigation & Power, CBIP, Vol. 36(4), pp. 345-350, 1979.

Pattanik,A.B., "A system dynamic operation procedure for Hirakud reservoir" Workshop on Designing on Dams for Hydrologic Safety, CBIP, Nagpur, 1988.

Pattegar,B.G., "Dependability criteria in the planning of storage reservoirs for irrigation and hydroelectric projects", Journal of Irrigation & Power, CBIP, Vol. 36(4), pp. 425-434, 1979.

Pendse,Y.D., A. Sekhar, and R.N.P. Singh, "Multiobjective analysis for water resources development", Journal of Institution of Engineers, Vol. 69, pp. 174-177, 1988.

Prasad,M., "Simulation-optimization technique for firm yield in optimal conjunctive water resources management", Journal of Institution of Engineers, Vol. 69, pp. 178-185, 1988.

Purohit,M.U., "Reservoir operation with reference to dam safety", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur 1988.

Puroshottam,J., "Optimum benefits by integrated operation of multipurpose reservoirs." Proceedings of the XIX IAHR Congress, Vol. IV, Subject-C, New Delhi, 1981.

Radhey Shyam, H.S. Chauhan, and Sewa Ram, "Integrated use of surface and ground waters in Nainital bhabar (U.P.)", Proceedings of Seminar on Assessment, Developments and Management of Ground Water Resources, Vol. II, Central Ground Water Board, New Delhi, 1983.

Raman,H., S. Vasudevan and K. Gupta, "Multiobjective planning in small watersheds", Journal of Institution of Engineers(India), Vol. 70, pp. 193-196, 1990.

Raman,H., and S. Vasudevan, "Reservoir operation optimization - A computer aided application", Proceedings of National Seminar on Use of Computers in Hydrology & Water Resources, Vol. II, Central Water Commission, New Delhi, 1991.

Raman,H., S. Mohan, K. Raju, and S. Malhotra, "An integrated model for multi reservoir operation", Proceedings of National Seminar on Use of Computers in Hydrology & Water Resources, Vol. II, Central Water Commission, New Delhi, 1991.

Raman,H., S. Mohan and N.C.V. Rangacharya, "Expert system for drought management", Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Ramanmurthy,K.V., P.K. Gupta, M.M.K. Shirsagar, and S.A. Tongonkar, "Electronic analogue computer for flood forecasting for Tapi basin", Journal of Institution of Engineers, Vol. 70, 5-15, 1989.

Ramamurthy,K., and J. Joseph, "Optimal firm power from a multireservoir system", Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Ramaseshan,S., "Multiobjective Analysis: A case study", Lecture Notes on the International Workshop on Systems Analysis of Problems in Irrigation Drainage and Flood Control, Central Board of Irrigation and Power, New Delhi, 1981a.

Ramaseshan,S., "Operation policy for multipurpose reservoirs through simulation A case study", Lecture Notes on the International Workshop on Systems Analysis of Problems in Irrigation, Drainage and Flood Control, Central Board of Irrigation and Power, New Delhi, 1981b.

Ramaseshan,S., "Expert systems for issues in water resources engineering", Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Ranganathan,C.L., A.D. Mohile, R.K. Sharma, and R.M. Patel, "Decision theory approach to storage planning", Proceedings of the 46th Annual R & D Session. CBIP, Trivendrum, 1976.

Rao,B.V., and S.B. Shah, "Optimal operation of Girna reservoir", Proceedings of the International Symposium on Water Resources Systems, Water Resources Development Training Centre, Roorkee, 1980.

Rao,B.V., and V.V. Kumar, "Inter-basin transfer of water among peninsular Indian rivers- A study of Godavari-Cauvery river links", Proceedings of National Seminar on Use of Computers in Hydrology & Water Resources Vol. II, Central Water Commission, New Delhi, 1991.

Reddy,D.V., and S. Vedula, "Optimal operation of a serially linked reservoir systems", Journal of the Institution of Engineers(India), Civil Engg. Div., Vol. 61, Pt. CI 5, 1981.

Reddy,P.J., R. Raghavendran, and P.V.R. Krishna Rao, "Optimal reservoir capacity and operation policy through linear decision rule, a case study", Proceedings of the 48th Research & Development Session of CBIP, Vol. I, Hyderabad, 1980.

Reddy,M.S., "Spillway design with reference to downstream channel capacity", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988.

Rema Devi and Arun Kumar, "Stochastic Reservoir Yield Analysis, using TPM method", Proceedings of National Symposium on Planning and Design of Water Resources System, Vol. II, Bihar College of Engineering, Patna, 1983.

Senthilkumar,A.R., and K. Venugopal, "Real time operation of a typical distributory of an irrigation system through Lotus 1-2-3", Proceedings of Fourth National Symposium on Hydrology, Madras, 1991.

Seth,S.M., and S.K. Jain, Flood Control Regulation of Machhu II Reservoir, National Institute of Hydrology, Roorkee, 1900.

SEU, "System engineering for integrated development of water resources in India", System Engineering Unit, C.W.C., New Delhi, 1987.

Singh,N., "Improving operational efficiency of spillway gates", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988.

Singh,N., "Operation of spillway by using a microprocessor", Journal of Irrigation and Power, CBIP, 47(2), 121-150, 1990.

Singh,R., and G. Chauhan, "System design for multibasin planning", Proceedings of International Symposium on Water Resources Systems, W.R.D.T.C., Roorkee, 1990.

Sinha,C.P., and P.G. Charyulu, "Optimal crop planning for Gomti Kalyani doab", Proceedings of International Symposium on Water Resources Systems, Water Resources Development Training Centre, University of Roorkee, 1980.

Srinivasan,K., and B.S. Thandeswara, "Flood management in the Adyar river basin", Proceedings of the XIX IAHR Congress, Vol. IV, Subject-C, New Delhi, 1981.

Srivastava,D.K., and Z.A. Bhandary, "Operation study of flood detention basins in river Jhelum, Kashmir valley", Journal of the Institution of Engineers (India), Civil Engineering Division, 61(CI2), 1980.

Srivastava,D.K., and M.C. Chaturvedi, "A study of Narmada water resources utilization, A pragmatic solution", Journal of the Institution of Engineers(India), Civil Engg. Div., Vol. 59, Pt. CI3, 1978.

Srivastava,D.K., and M.C. Chaturvedi, "Study of Four Reservoirs in Narmada river basin by simulation", Proceedings of International Symposium on Water Resources Systems, Water Resources Development Training Centre, Roorkee, 1980.

Sud,S.C., and M. Sivadas, "System studies of Vellar basin", Proceedings of Fourth National Symposium on Hydrology, Madras, 1991.

Sud,S.C., and L. Kumar, "Multipurpose multireservoir simulation-Acres reservoir simulation program", Proceedings of National Seminar on Use of Computers in Hydrology & Water Resources, Vol. II, Central Water Commission, New Delhi, 1991.

Sudaryaiya,E., and N. Subramanyam, "Operation of D.V.C. reservoirs", Workshop on Designing of Dams for Hydrologic Safety, CBIP, Nagpur, 1988.

Thangaraj,C., "Multiobjective analysis in river basin operation", Journal of Institution of Engineers, Vol. 72, pp. 156-160, 1991.

Tirupati,B., and S. Ramaseshan, "Spreadsheet applications in water resources", Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Tyagi,N.K., and V.V. Dhruvanarayana, "Chance constrained programming for optimum water use in Karnal region", Proceedings of International Symposium on Water Resources Systems, Water Resources Development Training Centre, Roorkee, 1980.

Varma,M., and P.S. Kardia, "Optimum utilization of irrigation water through system designs", 45th Annual R and D Session, CBIP, Vol. I - Hydraulics, Hyderabad, 1976.

Vedula,S., and P. Rogers, "Multiobjective analysis of irrigation planning in river basin development", Water Resources Research, 17(5), 1304-1310, 1981.

Vedula,S., ''Systems analysis in water resources planning and management'', Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Venugopal,K., and C. Prasad, ''Assessing the performance of Narmadasagar complex through simulation using critical period analysis'', Proceedings of National Workshop on Water Resources Project Management, IIT, Madras, 1990.

Venugopal,K., et al, ''Simulation of Periyar Vaigai irrigation system'', Proceedings of National Seminar on Use of Computers in Hydrology & Water Resources, Vol. I, Central Water Commission, New Delhi, 1991.

WAPCOS, Reservoir Operation Manual - Damanganga Project, Water and Power Consultancy Services(India) Ltd., 1988.

Yoganarasimhan,G.N., and J.P. Chand, ''Integrated planning of surface and ground water'', Proceedings of the Workshop on Conjunctive Use of Surface and Ground Water, Vol. I, Water Resources Development Training Centre, Roorkee, 1976.