THEME-VI

WATER RESOURCES SYSTEMS

GENERALIZED HEADWORKS SIMULATION MODELLING: THE AUSTRALIAN EXPERIENCE

George Kuczera

University of Newcastle, NSW, Australia

Recent work in Australia on the modelling of complex headworks systems is considered. This work has focussed on the development of computer software implementing the concept of a generalized objective-driven simulation model. Two models, REALM and WATHNET, are described with emphasis on their practical implementation. At the heart of both models is a network linear program (NetLP) guided by a hierarchy of objectives and constrained by physical and institutional constraints. To use of iterative convergence techniques has greatly enhanced the power of the NetLP. These NetLPs required complex input data and can produce voluminous output. The realize the potential of these models considerable effort needs to be expended on the design of the user interface. Both REALM and WATHNET are supported by user interfaces that port easily across different computer systems, yet simplify the task of complex data entry and, most importantly, communicate complex results through extensive use of graphics. Experience with a range of Australian headworks systems ranging from urban to complex irrigation-urban networks suggests that the concept of a generalized simulation model based on network linear programming is sound and provides a powerful tool for simulating complex headworks systems.

OPTIMAL OPERATION OF A RESERVOIR FOR MULTIPLE CROPS — THE CASE OF SOMASILA RESERVOIR

B.R.K. Murthy & P. Venkatraman***

* K.S.R.M. College of Engineering, Cuddapah, India

** S.V.U. College of Engineering, Tirupati, India

The study deals with optimal operation of a single reservoir in the context of multiple crops. An LP model is formulated on monthly water requirements to find optimum cropping patterns subjected to land and water constraints and applied to Somasila Reservoir on Pennar River. Two objectives maximizing the returns from agriculture and maximizing irrigated cropped area considered in the model are analysed in the context of multi objective planning and trade offs discussed.

OPTIMAL OPERATING RULE FOR RESERVOIR WITH HYDRO POWER GENERATION AND IRRIGATION

U. Ratnayake & R. Harboe

Asian Institute of Technology, Bangkok, Thailand

Many methods have been suggested to optimize hydropower generation systems while satisfying downstream water requirements for irrigation, water supply, navigation, salinity intrusion control, etc. Most of the models consider these downstream demands only as constraints to the model.

Annual firm power optimization models require input of monthly energy generation distribution pattern. A new objective function which maximizes the minimum moving summation of energy generation in twelve month period is developed. The reservoir is optimized subjected to downstream demand constraints to arrive at the optimal annual energy generation pattern. This pattern is then used in stochastic optimization of the reservoir to find the optimal firm power amount that can be used as a target in standard operating rule. The results showed a considerable improvement in the amount of firm power generation.

OPTIMAL IRRIGATION PLANNING : A CASE STUDY

V. Ravikumar & K. Venugopal

Anna University, Madras, India

To help assess the optimal expansion of Irrigation area a Steady state probabilistic dynamic programming model is adopted. The model considers two state variables namely Reservoir storage and streamflow. The optimal planning of Irrigation area is based on the concept of Reservoir yield. The Reservoir yield depends on the streamflow variability, capacity of the reservoir and operating policy. This work relates to the application of the model in the system namely Krishnagiri Reservoir Project across river Ponnaiyar in Tamilnadu, India. The correlation between seasonal streamflows were found to be insignificant and so considered as probabilistic. The operation policy is based on minimizing the sum of squared deviations of actual releases from the demand. In this Irrigation system two paddy crops

are grown in two seasons such as kharif and rabi respectively and certain area is allocated for annual crops. The model solution gives operating policy with respect to the status of the storage, season and the streamflow. The model also gives the probability distribution of reservoir states for each season and the reliability of reservoir releases for a given crop area in each season. The paddy area in the kharif is obtained for a dependability of 75%. The model can be used to study the effect of increasing the area in any season on the reliability of supply to all the seasons.

IRRIGATION SYSTEM PERFORMANCE : CONCEPTS, INDICATORS, STANDARDS AND APPLICATION

N.K. Tyagi

CSSRI, Karnal, Haryana, India

A state of the art review of the irrigation system performance concepts, measures and specifications of performance is presented. On the basis of critical review, suitable indicators for evaluating performance at different hydraulic levels of irrigation system are identified. The equity, adequacy (relative water supply, RWS) and reliability (timeliness) at watercourse level and the application, storage and distribution efficiencies at the farm level were selected as the performance indicators. Using the established indicators, the performance was evaluated in part of Bhakra Canal Command in Haryana. The efficiencies of the on-farm system were influenced most by the stream size. Though application efficiencies were quite high, the storage efficiency representing adequacy and distribution uniformity were low. In irrigation with fixed frequency schedules, the inadequate application are likely to affect crop yields adversely.

The equity in water distribution decreased with size of the watercourse (flow rate) and the average value of interquartile ratio (water supplied in the most favoured quarter/water supplied in the least favoured quarter) was 1.85. There were locational an intraseasonal variations in adequacy which improved from tail to head and was higher during rainy season as compared to winter season. With average value of RWS at 0.64 across watercourses and seasons, the system had a highly deficient water supply. Water productivity which reflects both adequacy and timeliness had an average value of only 0.51 across watercourses and seasons. Lower values of water productivity as compared to seasonal adequacy reflect time mismatch between supply and demand.

The major drawbacks of the system seem to be volumetric inequity, time mismatch between demand and supply and non-uniform water application. Improvement in performance is possible through provision of proper unit command areas, variable warabandi time, auxiliary storage and adjustment in water delivery schedules.

OPTIMUM RESERVOIR SYSTEMS OPERATIONS, REVIEW OF STOCHASTIC MODELS

Taha B.M.J. Ouarda & Fahim Ashkar

University of Moncton, Moncton, Canada

Optimal planning and operation of large multi-reservoir systems is a complex problem, with difficulties compounded by the presence of diverse and conflicting beneficial uses, such as water supply for domestic and industrial needs, irrigation, hydroelectric production, navigation, flood control, water quality control, fish and wild life maintenance, and recreation. The basic technical difficulties associated with this optimization problem are represented by the characteristics of high dimensionality, stochasticity, nonconvexity and nonlinearity. These characteristics pose serious difficulties to existing optimization techniques. A great deal of approximation and simplification has been used by researchers to fit this problem in the general structure of existing algorithms. Other resarchers attempted various improvements and adaptations to available procedures to allow them to effectively handle the optimization of complex multi-reservoir systems. Recent improvements in modeling techniques, synthetic hydrology, and computational ability spurred also the development of an overwhelming number of new models and solution procedures. Although a great deal of research has been accomplished, only a few of the developed techniques have been adopted for implementation in real-world systems, and the gap between theory and practice remains pronounced in the field of water

resources systems analysis. This gap in enhanced by the lack of confidence by practitioners in the capabilities of developed techniques to assess real problems, as well as by previous failures of some of these models. More effort must be directed towards narrowing this gap and overcoming communication problems between researchers and practitioners. The purpose of this research is to provide an updated review, classification and evaluation of the state-of-the-art of optimization of large-scale multi-reservoir systems. This research is oriented toward the stochastic environment and focuses on solution methods that account explicitly for the uncertainties related to the water system. Several models and solution procedures incorporating the stochasticity factor have been followed for the operation of reservoir systems. Such formulations include stochastic simulation, explicit and implict stochastic optimization (Monte Carlo analysis), linear decision rules, chance constrained models, reliability programming, stochastic dynamic programming, stochastic control algorithms, or different techniques using Markov processes. Some of the models mentioned offer the advantage of keeping the "risk probability" under control, or provide the capability to assess the trade-off between risk and benefits, and hence might be more attractive. These different approaches and concepts are more detailed in this work.

The water resources planning and operation community is certain today that it is possible to achieve significant benefits from an improved and more efficient operation of reservoir systems through the use of modern systems analysis techniques. It is hoped that this research will help strengthen the partnership between water resources management and systems analysis, and contribute towards closing the gap between theory and practice by narrowing the large literature available, and by providing the necessary comparison of solution techniques falling under completely different theories.

A DECISION SUPPORT MODEL FOR COMPLEX WATER RESOURCES SYSTEMS

Joaquim Andreu*, Pierluigi Claps**, Mauro Fiorentino** & Maria Rosaria Margiotta*

** Universidad Politecnica de Valencia, Valencia, Spain

* Universita della Basilicata, Potenza, Italy

A decision support model — and the related computer program for complex water resources system planning and management has been developed at the University of Valencia (J. Andreu, J. Capilla and E. Sanchis, *III Simposio Sobre el gua en Andalucia, 1991).* The model is based on the monthly scale and is thought to be used on personal computer. Three sub-models are included: 1) optimization model, 2) simulation model, 3) groundwater model to take into account distributed aquifers into the simulation model. The computer program permits input/output operations in a graphic mode, it runs under the environment WINDOWS and can exchange data with most of the commercial electronic sheets. The water resources system is represented as a conservative network. The objective function is based upon the minimization of weighted sums of demand deficits. The weights can be chosen by the operator.

In this paper a fourth sub-model, for generating synthetic runoff series is proposed and an application of the full model, is presented. The proposed sub-model is helpful for planning purposes. The model is based upon the identification of the streamflow process as an ARMA type stochastic process, consistent with the hypothesis that the persistence characterstics of the monthly runoff series are mainly due to the effect of: i) large and deep groundwater reservoirs, which produce spring discharges and decay on a multi-annual time scale, and ii) smaller groundwater reservoirs which are effective on a seasonal basis. Estimation of model parameters is carried out at the significant aggregation time scale. The model is presented with regard to the real case of the *Basento* water supply system (Southern Itlay) which includes three large surface reservoirs located on different rivers and exploits surface water of four rivers and spring water of two main spring groups.

USE OF NEURAL NETWORK THEORY IN THE STOCHASTIC OPTIMISATION OF RESERVOIR OPERATION

F. Bouchart & I. Goulter

University of Central Queensland, Queensland, Australia

True interpretation of risk in the operation of any system, including reservoir, should ideally consider the complete risk curve rather than one or two parameters, e.g., mean and standard deviation of the curve. Neural network theory is proposed as a means of efficiency considering the complete risk curve in the determination of optimal reservoir operating policies.

Two classes of neural networks are examined. In the first class the neural network must 'decide' which of the candidate categories of 'desirability' a particular risk curve falls. In other words it must decide on a single category. The second class of neural network can 'distribute' its decision choice as to which category the risk curve falls among the candidate categories with varying levels of support. The second methods is preferable because, if a particular risk curve does not clearly fit into a single category the neural network in able to indicate which of the two or more categories it sees the risk curve fitting. The first class of network would simply assign the network to a single compromise or 'average' category without any indication of the two (or more) categories to which the risk curve might actually belong.

The design (number of input and output nodes and number of layers of nodes) of the neural network is described and its use in the determination of policies for optimal operation of reservoirs demonstrated by application to the operation of the Fairbairn Reservoir in Central Queensland, Australia.

SAMPLING STOCHASTIC DYNAMIC PROGRAMMING APPLIED TO THE OPERATION OF RESERVOIRS

Jerson Kelman

CEPEL, Rio de Janeiro, Brazil

It is described an optimization algorithm for reservoir operation, called Sampling Stochastic Dynamic Programming (SSDP), that is well suited to "soft" constraints. These are constraints that the operator of the reservoir system always tries to meet, given that water is available, before making any kind of economical evaluation. SSDP describes the complex spatial and temporal correlation structure of streamflows by the empirical distribution represented by sample streamflow sequences, called "streamflow scenarios". Each streamflow scenario is a multivariate time series, one year long, historical or forecasted, of river flows in the basin. The algorithm calculates the future benefit (or cost) for each streamflow scenario, conditioned to decisions that do not lead to future violations of the soft constraints, whenever possible. Deterministic optimization couldn't be used in this calculation because the result would be artificially optimistic. Rather, future benefits (or costs) for each streamflow scenario are calculated taking into account the uncertainty about future flows.

OPTIMAL OPERATION OF THE MAHANADI RIVER PROJECT RESERVOIR SYSTEM

S. Narulkar & P.P. Mujumdar***

* Indian Institute of Technology, Bombay, India

** Indian Institute of Science, Bangalore, India

The Mahandi River Project (MRP), located in the upper reaches of the Mahanadi River basin is a multipurpose, multiple reservoir system. The objective of the project is to meet the municipal and industrial water demands besides supplying water for irrigation in the region. The project consists of six reservoirs and three inter basin transfer links on two major river basins, namely, the Pairi and the Upper Mahandi. As the total annual flow in the two rivers is inadequate to meet the full demands, the Government of Madhya Pradesh, India, has set up the following order of priorities for utilisation of water from the MRP system.

1. Industrial and Municipal Supply.
2. Kharif Irrigation, with allocation being made for maturing late kharif paddy if monsoon ends early and for early plantation of paddy, if monsoon commences late.
3. Rabi irrigation, to the extent possible, with the remaining storage in the reservoirs.

In the present paper, a multi objective model developed for the optimal integrated operation of the MRP reservoirs is discussed. The model is formulated using Linear Programming. The objective of the model is to provide a monthly operating policy for each of the six reservoirs such that the irrigated area in the Rabi season is maximised. A high penalty is levied for not meeting the other demands. An attempt is being made to incorporate the inflow and demand forecasts in a meaningful way into the model so that strategies for real time operation of the system may be obtained. A brief discussion on the previous work done by others on the operation of the MRP system is also presented.

APPLICATION OF STOCHASTIC DYNAMIC PROGRAMMING— A CASE STUDY

K. Venugopal & M.S.V. Subhakar

Anna University, Madras, India

With continuous increase in demand for water, the available water needs to be utilised optimally. Linear and dynamic programming approaches are used for optimal allocation of available resources. This work relates to application of stochastic dynamic programming to Narmadasagar reservoir across river Narmada to be taken up in Madhya Pradesh to assess the maximum firm power generation. Even though Narmadasagar reservoir is meant to meet both irrigation and firm power requirements, as the irrigation requirement is very low, only firm power generation is taken up for this study. Thirty two years of inflow data are used for modelling. Water year is taken as July to June of the ensuing year. The water year is split into three periods, July-September, October-December and January-June for arriving at the steady state transitional probability matrix. The inflows are grouped into five states and the reservoir storage (dead storage of 1357 Mm^3 and full capacity of 12212 Mm^3) is divided into 20 states. Stochastic dynamic programming package namely 'CSUDP' is used in this study. For each run, trial value of firm power target is assumed. Benefits and penalties for shortfall are given. Optimal operation policy is arrived at and results are discussed.

OPTIMAL INTERSEASONAL MULTICROP IRRIGATION SCHEDULING WITH DIFFERENT RELEASE LEVELS AND THEIR PERFORMANCE IN AN UNCERTAIN ENVIRONMENT

P.P. Mujumdar, Y. Ellamraj** & B.V. Rao***

* Indian Institute of Science, Bangalore, India

** Indian Institute of Technology, Bombay, India

An important problem in the planning and operation of irrigation schemes is the determination of optimal irrigation scheduling in an uncertain environment given limited water resources and increasing concern about productivity. The specific problem dealt with in this study is how best to allocate a finite quantity of water released from the reservoir for a given release level during a time period and to study the performance measures viz., Reliability and Resiliency given a specific irrigation policy.

The method uses two models viz., a soil moisture simulation model and a water allocation model. The simulation model determines, for known initial soil moistures of the crops, the irrigation requirement, the actual evapotranspiration and the final soil moisture of each crop for a given irrigation application.

The water allocation model determines the irrigation application by taking into consideration the competition for water among the crops during a time period when there is a deficit release from the reservoir serving the crops. The water allocation model is solved by dynamic programming (DP).

The release from the reservoir for irrigation during each period is specified by the standard operating policy (SOP). The method is applied to a case study of Malaprabha reservoir in Karnataka, India.

AN OPTIMIZATION MODEL FOR MULTIPURPOSE MULTIRESERVOIR, SCREENING, WITH EXPLICIT SYSTEM YIELD RELIABILITY CONSIDERATION

Amit Kumar Sinha & B.V. Rao

Indian Institute of Technology, Bombay, India

An optimization algorithm is presented extending the work of *Lall* and *Miller* model (1988) for selecting among and sizing potential reservoir located at sites spread over basins located in Maharashtra and Gujarat, in India. The basic objective of the model is to aid the state and country water planners to develop plans to meet projected water demand. Hence the decision variables are constructed to be physically interpretable and meaningful to the decision maker. The provision of water to meet the irrigation and hydropower demands are considered. A hybrid simulation-optimization strategy is used to consider the monthly operation of the reservoir in an annual yield framework. The model has a feel of simulation model with the usual parametric simulations replaced by a powerful optimization algorithm. Reservoir storage capacities are computed functionally using a sequent trough algorithm, this scheme is compared with *Lall* and *Miller's* (1988) and *Lall's* (1993) modified sequent peak algorithm and shown that the sequent trough algorithm performs better in terms of efficiency and computational time. Optimal generator capacity is also determined using the implicit simulation model. Applications of the model developed with data from sites on the Par, Ambica. Auranga and Purna basins are presented.

HYDROLOGICAL MODELLING OF WATER RESOURCES FOR WATERSHED RESERVOIR — COMMAND AREA CONTINUUM

K.A. Rao & R. Subbaiah***

* Indian Institute of Technology, Kharagpur, W.B., India

** Agricultural University, Junagadh, Gujarat, India

Efficient utilization of water resources requires the knowledge of various parameters related to the watershed-reservoir-command area-environment-continuum. The important information needed of this integrated system are: i) the characteristics of rainfall and runoff for forecasting the availability of water from the natural resource to the reservoir, ii) optimal reservoir scheduling policies to supplement the irrigation demands for effective production, iii) knowledge of crop response to varying levels of water applications and iv) optimizing the allocation of scarce water among crops or competing unit of the same crop for maximizing or minimizing certain objective. This paper is concerned with critical assessment of state of art of various models developed at each ensuing stage of the integrated system and their adoption to different agro-climatological zones of India.

MODELLING FOR RESERVOIR OPERATION FOR IRRIGATION

S. Vedula & P.P. Mujumdar

Indian Institute of Science, Bangalore, India

An overview of the developments in modelling for reservoir operation for irrigation is given. The models developed in this field progressively improved from time to time to take into account more and more aspects in the complex decision making mechanism with uncertainty in such factors as water supply, rainfall and crop water demands. Stochastic considerations of the inputs and multiple crops and the need to integrate the decision making mechanisms at the reservoir and the field levels brought additional complexity into the model formulation. Recent works in this area have promised a great hope for meaningful real time applications of the developed models.

INTEGRATED RIVER BASIN PLANNING AND DEVELOPMENT — SOME CASE STUDIES

S.K. Sinha

Central Water Commission, New Delhi, India

Water has been recognised as a basic and crucial natural resources for economic development. However, the availability of water does not match with the demand in terms of quantity, quality, time and place. Further, it is replensible natural resources that is often scarce. The conservation and optimum utilisation of this scarce resources is extremely important for national economic development. This essentially calls for integrated river basin planning and development for short and long range conservation, utilisation, development and management of basin's water and related land resources in optimum ways. In this paper, an attempt has been made to bring out the various aspects of integrated river basin planning and present some case studies.

RESERVOIR ALLOCATION STUDIES OF A FIVE RESERVOIR SYSTEM — A CASE STUDY

G. Lakshmikandam

Krishna Water Supply Project, Madras, India

The Parambikulam — Aliyar Project (PAP) is located in the Anamalai Ranges of the Western ghats in the southern peninsular India covering a basin area of 773.73 square kilometres with 6 Nos of sub-basins lying at 10° latitude North and between 76° and 77° longitudes East. It serves the twin Governments of states of Tamilnadu and Kerala through sharing the waters for irrigation uses and by generation of power. The creation of the multi-reservoir system is still in advanced stages

of construction. The allocation study and the operational studies following the planning were carried out to evolve the operating criteria for a partial recent scenario considering the initial 12 years period for a series-parallel multi-objective five reservoir (FIVRES) system consisting of the reservoirs of Sholayar, Parambikulam, Kerala Sholayar, Tunacadavu and Peruvaripallam reservoirs.

An attempt is made in this paper to describe the multi-reservoir system in brief indicating the areas of scope for improvement among the various uses. A brief outline of the state of art of literature together with studies carried out and the description of the data base available is presented. The development of the Allocation model for deriving rule curves is fully described.

The allocation model was formulated as a Twelve Season Linear Programming Model. It included the system equations, water right inequality on Nirar, agreement diversion equation on Sholayar, target energy equation for 2 power houses and uniform release equations for irrigation tunnels over each irrigating season. The outlet discharge inequalities, head constraints and capacity of each reservoir, outlet and power house were included in the formulation of the linear programming problem with a bounded (overall) matrix of size 258x332. This was solved using MPS 360 in IBM 370/155 computer and required a cpu execution time of 44.10 sec. for each run. 224 of such runs were made using the 12 years of historic monthly net inflow data and 100 years of synthetic data derived during HEC4 package adjusted for extremes for developing the rule curves.

The generation of the matrix coefficients were carried out by 'FIVRES' program developed during the study and the generated data files were concartenated to the parameter files to make the input and this was interfaced with the main program. This overall processing using 'FIVRES' occupied a virtual memory of 786K bytes. The analysis of the results were carried out in 3 different ways and the rule curves were derived. The rule curves were later validated through a short term daily model for improvements over historic operation. The rule curves with sample results are discussed.

USEFULNESS OF IMD VALUES OF POTENTIAL EVAPOTRANSPIRATION TO COMPUTE CROP WATER REQUIREMENT IN WATER RESOURCES PLANNING

A.K. Sharda, K. Arumugam & Anita Lalchandani

National Water Development Agency, New Delhi, India

An efficient planning is an integral component of any water resources development programme. Water resources planning is a multidisciplinary one encompassing numerous fields such as hydrology, climatology, agriculture, economics and ecology. Estimation of various inputs like availability of water, status of utilisation, water requirement and cost economics have to be precise and realistic so that a planned project becomes feasible and sustainable. Besides, the approach and assessment of project should also have national perspective in mind in order to maintain its applicability and acceptability.

Irrigation occupies predominant place in the water resources development sector. Proper water management becomes an essential aspect of any irrigation project in order to make an economic and efficient use of water for crop production and to protect the soils against the lurking hazards of waterlogging, soils salinity and alkalinity etc. The projection of precise crop water requirement is a must for successful operation and maintenance of any irrigation project. In recent years, the climatological approach obtained wider acceptability all over the world to compute the crop water requirement. It has been observed that use of different methods based on climatological approach often yield variable results.

India Meteorological Department has over three hundred stations spread all over India to collect relevant climatological data required for the purpose of computing potential evapotranspiration values. In this paper, an attempt has been made to highlight the significance of use of published IMD values of potential evapotranspiration in projecting irrigation water requirements in various sub basins of Mahanadi, Godavari and Krishna river basins. The results also indicate the effect of varying cropping patterns on irrigation deltas and the corresponding changes in the crop water requirement for planning purposes in these river basins. For the sake of maintaining uniformity and accuracy, it has been recommended that IMD values of potential evapotranspiration may be employed all over the country to compute crop water requirement for any irrigation project.

RIVER FLOW PREDICTION: A NEURAL NETWORKS APPROACH

L.K. Mishra & G.K. Pradhan

University College of Engineering, Burla, Orissa, India

River flow prediction is important in view of effective management of water resources, water pollution control, etc. There is much hydrologic research in this area, and rapid progress has been made especially in the field of low-flow prediction. In order to apply hydrologic models to actual river flow prediction, many data, sophisticated computations, and a special knowledge of hydrology is required. On the other hand, from the view point of practical and operational use, a prediction algorithm is needed having the following features: simplicity of the algorithm, short computation time, and applicability to small amount of data. In the last few years, layered feed-forward neural networks learning by error back propagation has been applied to an impressive number of scientific problems. Here we investigate the effectiveness of such architectures for predicting the future behaviour of river flow systems. We focus on constructing the nonlinear river flow prediction model from the available data such as river flow and areal mean precipitation. Our algorithm, an improved version of the back propagation algorithm first proposed by Rumelhart, Hinton and Williams (1986), is useful for the prediction of complex nonlinear systems with a small number of input-output data. It is quite a new approach, one which can determine the input-output relationship of a river system from only a small amount of the time series of the previously measured flows and rainfall data. Numerical comparisons are performed between the prediction models: by our variant of the back propagation and by the elaborate hydrologic methods, and we show that there are improvements in the introduced prediction algorithm for real — time computation.
