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Development and Application of an Integrated Reservoir-Based Canal Irrigation Model (IRCIM)

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ABSTRACT: Most of the irrigation literatures mainly focus on the demand and distribution aspects only. Irrigation projects, which receive water from reservoir, can be challenging to manage since annual fluctuations in runoff from the reservoir's catchment can have considerable impact on the irrigation management strategy. Several independent models have already been developed for runoff prediction, reservoir operation, crop water demand calculation and canal flow simulation. However, these individual models may not meet the objectives of the irrigation departments dealing with the whole scheme. This paper presents the development and application of an Integrated Reservoir-based Canal Irrigation Model (IRCIM) which can take into account the impact of rainfall on reservoir inflow through catchment hydrologic modelling, the irrigation water availability through reservoir water balance, the irrigation demand through command hydrologic modelling, and decide on a rotational delivery schedule that minimizes the gap between demand and supply through proper canal irrigation management. Developed model was tested for Kangsabati Irrigation Project, West Bengal, India. Saturated hydraulic conductivity value (K_S) was determined as 4.31 mm d^{-1} for Kangsabati reservoir. A year-independent alternative delivery schedule: transplanting date as July 24, number of irrigation as 3 and type of rule curve as MRC (minimum rule curve), was also proposed which can be followed mechanically without manager's expertise. Thus, it was recommended to adopt the alternative delivery schedule which produced quite comparable performance with the existing delivery schedule for all the simulation years.

INTRODUCTION

Steering the overall growth of the economy, agriculture sector contributes to 22% of the Gross Domestic Product (GDP) (AIC, 2006). Irrigation has acquired increasing importance in agriculture the world over. During the last two decades, irrigation's steady boom has begun to wane. The gradual expansion in irrigation development has played a significant role in strengthening the Indian economy. Irrigation, the single largest user of the water resources, accounts for about 84% of all withdrawals in India (Planning Commission, 2002). However, with increasing municipal and industrial needs, its share of water is likely to go down. Thus, in future, irrigation has to become efficient and produce more with less water. India has made considerable progress as far as creation of irrigation potential is concerned. The total irrigation potential has increased from 22.6 Mha in 1951 to 93.95 Mha in 2001, out of which 80.06 Mha has been utilized at the end of the ninth five year plan (Jeyaseelan, 2004). The gap between irrigation potential created and utilized is a matter of concern. The success of irrigation system operation and planning depends on the quantification of supply and demand and equitable distribution of supply to meet the demand if possible, or, to minimize the gap between the supply and demand.

The mathematical models of canal operation and automation (Malaterre, 1995, U.S. Army Corps of Engineers, 2002; Islam, 2005) developed over the years exclusively concentrate on hydraulic aspects of canal system and do not take the hydrology of reservoir

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catchment and irrigated command into account. On the other hand, a few attempts have been made to develop irrigation system management or decision support systems to assist water managers in taking appropriate decisions, e.g., CADSM (Prajamwong, 1994), OPDM (USU, 1996), OMIS (Delft Hydraulics and DHV Consultants, 1989), INCA (Makin, 1995), SIMIS (Mateos *et al.*, 2002), etc. These models mainly focus on the demand and distribution aspects only.

Most of the rainfall-runoff models work best when data on the physical characteristics of the watershed are available at the model grid scale (Colby, 2001 and Miller *et al.*, 2002). This kind of data is rarely available, even in heavily instrumented research watersheds. Now Remote Sensing (RS) and Geographic Information System (GIS) make it easier to extract land surface properties at spatial and temporal scales. One of the most widely used techniques for estimating direct runoff depths from storm rainfall is the United States Department of Agriculture (USDA), Soil Conservation Service's (SCS) and Curve Number (CN) method (NRCS, 2003). Many researchers used information derived from satellite data and integrated them with GIS to estimate SCS CNs and runoff. Routing of runoff in river network may be undertaken using a variety of modelling procedures. The Muskingum method (Nash, 1959; Overton, 1966) continues to be popular for flood routing. Muskingum routing parameters related to physical and hydraulic characteristics of channel can also be obtained using GIS technique. The complexity and non-linearity involved in rainfall-runoff process and routing of runoff downstream through a channel make it attractive to try the Artificial Neural Network (ANN) approach, which is inherently suited to problems that are mathematically difficult to describe. The Levenberg-Marquardt optimization technique (Levenberg, 1944; Marquardt, 1963) can be incorporated into back propagation algorithm to make training faster and efficient to find better optima for a variety of problems.

In real-world situations, the reservoir operating rules guide the operators in making the actual release decisions. Yeh (1985) and Wurbs (1993) reviewed various models reported in the literature and provided a state-of-the-art summary of the applications of reservoir operation models. The HEC-3 (HEC, 1971) and HEC-5 (HEC, 1979) models are considered to be the best documented among the general reservoir simulation models. However, they do not perform any rainfall-runoff computations and thus, inflow to the reservoir must be input to these models.

For field crops, SWACROP (Feddes *et al.*, 1984), CROPWAT (Smith, 1992), SWSSM (Lamacq and Wallender, 1994), etc., are examples of widely used models that are based on semi-empirical and physical approaches. Several studies have focused on paddy water balance. Many scientists have used numerical and analogue models, e.g., PADIWATER (Bolton and Zandstra, 1981), SAWAH (ten Berge *et al.*, 1992), ORYZA2000 (Bouman *et al.*, 2001), etc., to study the specific aspects of water movement through and below the root zone of paddy basins.

Hydraulic models can simulate the changes in the water surface profiles in canals with respect to time and space. The conveyance losses can be assessed for specified surface and subsurface conditions using such models if the seepage rate is known. Many complicated simulation models of the hydraulics of flow in irrigation canals are available. Some, like MIKE-11 (DHI, 1992), HEC-RAS (U.S. Army Corps of Engineers, 2002), CanalMod (Islam, 2005), etc., can simulate flow under complex canal flow conditions (operation of gates, presence of control and drop structures, etc.). These models were developed for steady and gradually varied flow. They are highly data intensive and cannot adequately account for some actual flow conditions, like frequent canal filling and dewatering (as required for the rotational irrigation practiced in many schemes in India) which involve rapid flow changes. Several attempts at using such models in India have not proved successful. Mandavia and Acharya (1995), after a review of the applications of such models under Indian conditions, recommended that simple models that use available data be used.

Recently a couple of attempts have been made to combine the hydraulic-hydrologic simulations of canal-command for efficient irrigation water management, one in Mahanadi Reservoir Irrigation Scheme (Singh *et al.*, 1997) and the other in Right Bank Main Canal (RBMC) of Kangsabati Irrigation Project, West Bengal (Mishra *et al.*, 2005). Both the above studies, however, did not take into account reservoir component. Hajilal *et al.* (1998a and 1998b) though incorporated a reservoir component in a similar study in Jayakwadi Irrigation Project, Maharashtra, they did not consider reservoir catchment hydrology. Thus, there was need to develop an Integrated Reservoir-based Canal Irrigation Model (IRCIM). Keeping the above mentioned facts in view, the present study was taken up with the following objectives:

1. To develop catchment, reservoir and crop water demand modules for an Integrated Reservoir-based Canal Irrigation Model (IRCIM).

2. To seamlessly link different modules through a rotational canal irrigation management system for generating a delivery schedule that minimizes the gap between water availability and demand.
3. To test the developed modules using data of an existing reservoir-based canal irrigation project.

MODEL DEVELOPMENT

Developed IRCIM consists of three modules, viz., catchment, reservoir and crop water demand modules.

The "*catchment module*" predicts daily runoff from the catchment that inflows to the reservoir. This module is provided with the flexibility of selecting between SCS CN method combined with Muskingum routing technique and ANN based model. SCS CN method combined with Muskingum routing technique can be used if information on land use, soil and river network are available; otherwise, ANN based model can be used for relating rainfall with daily runoff. In ANN based technique, daily runoff values are predicted by network trained through the Levenberg-Marquardt algorithm.

The "*reservoir module*" is based on conservation of mass approach, and results in daily reservoir storage. Total storage in the reservoir is the storage corresponding to stage of the reservoir obtained from the stage-storage curve. Release from the reservoir can be obtained from rule curve of that particular reservoir. Evaporation from the reservoir can be estimated either by pan evaporation method or by Penman method. Seepage from the reservoir can be estimated using the saturated hydraulic conductivity (K_s) of soil at the reservoir bottom, which is a calibration parameter of the reservoir module.

The "*crop water demand module*" comprises of water-balance models for both paddy and field crops. This module is provided with the choice of calculating reference evapotranspiration (ETo) by FAO-24 (Doorenbos and Pruitt, 1977) pan evaporation method, Hargreaves (Hargreaves and Samani, 1985) method and FAO-56 (Allen *et al.*, 1998) modified Penman Monteith (PM) method. The part of the precipitation, that infiltrates into the soil and is available for crop use, can be calculated either by the fixed percentage of rainfall method or USDA SCS method (SCS, 1967). If crop is in ponding phase, deep percolation can be estimated either by one dimensional Laplace equation or by an empirical equation developed by Mishra *et al.* (1998). In case of saturation phase (between saturation and field capacity), deep percolation can be calculated either by using a process developed by Khepar *et al.* (2000) in combination with van Genuchten-Mualem (Mualem, 1976; van Genuchten, 1980) model or by using simple water balance. In case of depletion phase, deep percolation loss is negligible. Crop evapotranspiration (ET_c) can be calculated using either of the FAO-56 single crop coefficient or dual crop coefficient approaches.

The irrigation management system is the core of the model and runs the required module when needed. It also controls and steers the data flow among different modules and decides optimum allocation of water at distributary head by a rotational distribution system. Flowchart of the developed irrigation management system is shown in Figure 1. Canal flow model of Vyas and Sarma (1992) was modified and used in IRCIM to estimate the wetted area in canals as well as seepage losses and the irrigation release requirement at the headwork of main canal. For each group, procedure starts at the downstream end distributary of the group and progresses sequentially upstream up to the first distributary of that particular group. Then, total irrigation requirement of that group is translated up to the reservoir through main canal. Release through direct outlet points of canal is estimated using orifice formula. The front end of the IRCIM model has been developed in Visual Basic 6.0 and the back end coding is done in C language. The Graphical User Interface (GUI) is the most important feature of the model as it provides a better interaction between the model and its user. This user-friendly integrated model has been developed with an aim to provide the irrigation departments a tool for planning the canal releases on scientific basis.

STUDY AREA

The Kangsabati Irrigation Project, situated in the western part of West Bengal, India was selected as the study area. Total catchment area and gross command area of the Kangsabati reservoir are about 3428 sq. km and 5568 sq. km, respectively. The present study considered the whole catchment of Kangsabati reservoir for inflow prediction and also modelled the Kangsabati reservoir for predicting daily reservoir release. However, for irrigation management system modelling, only the Left Bank Feeder Canal (LBFC) and Khatra Main Canal (KMC) (upper) have been considered (Figure 2). Total area of the selected command is about 104 sq. km with sandy loam as predominant soil and paddy as dominant crop. Kharif paddy is sown by mid-June to early-July and transplanted between mid-July and end-July with November being the harvesting month.

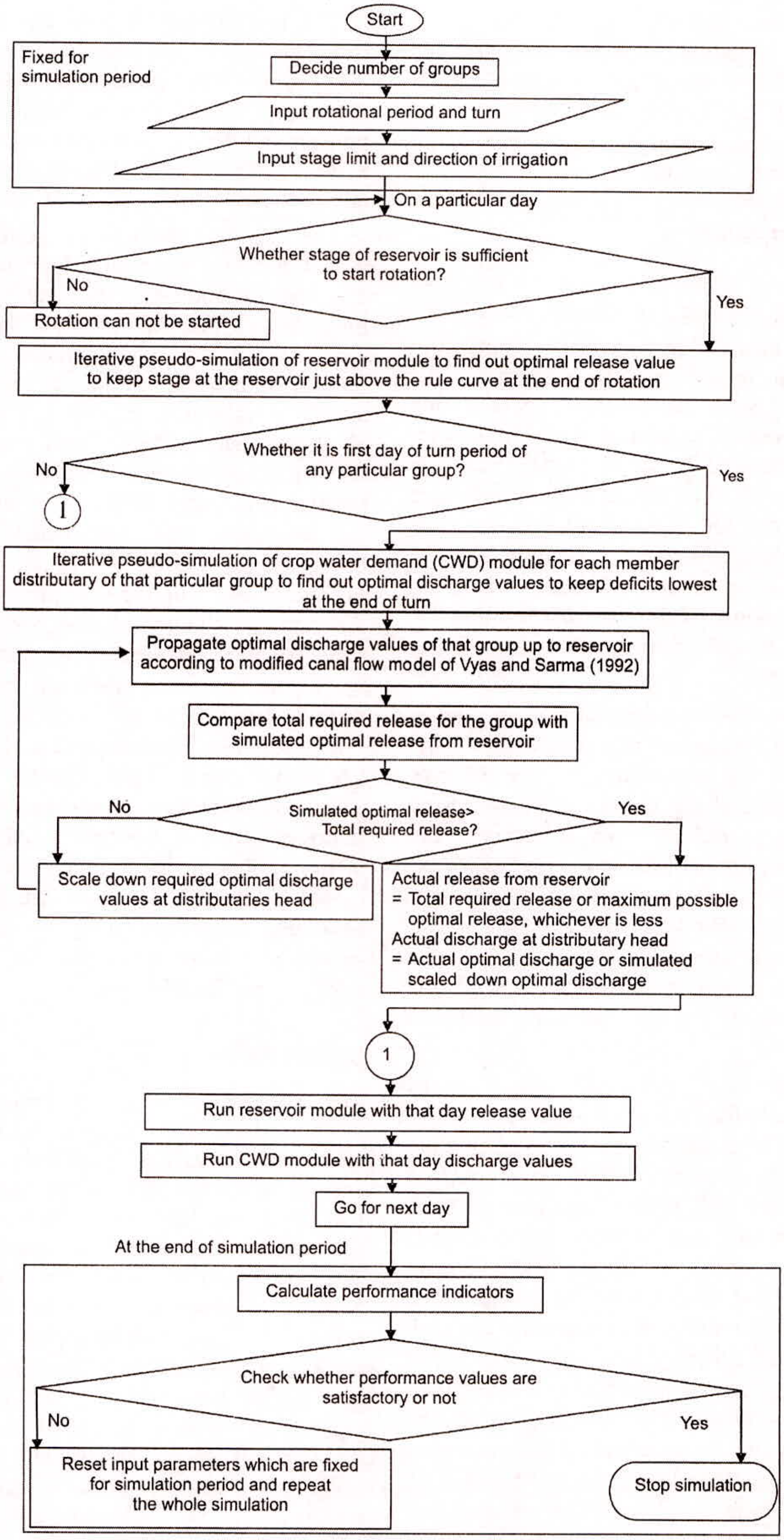


Fig. 1: Flowchart of irrigation management system

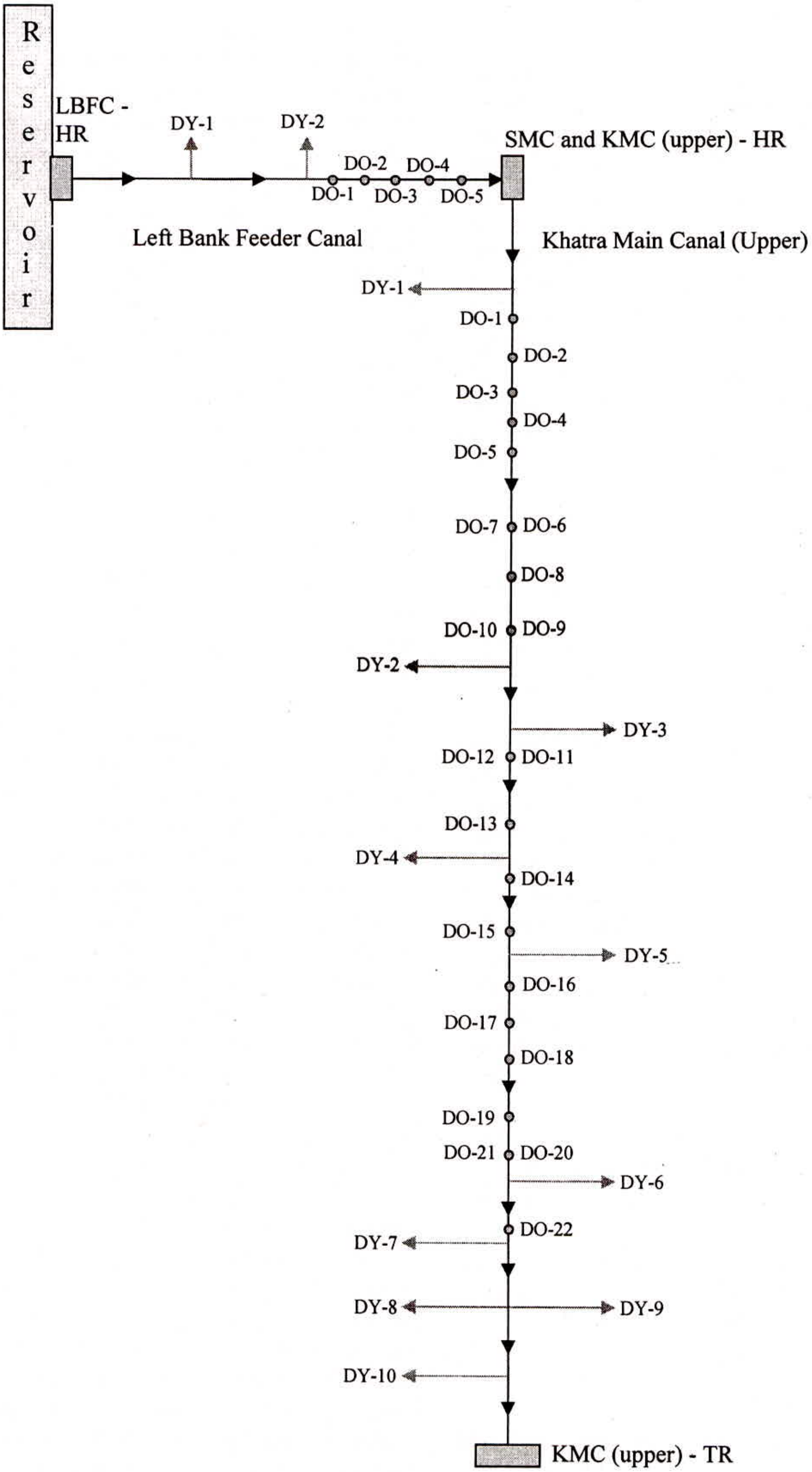


Fig. 2: Schematic diagram of LBFC and KMC (upper)

ACQUISITION OF DATA

Daily rainfall data of 17 years (1987–2003) measured at five rain-guage stations in Kangsabati reservoir catchment, namely, Kangsabati Dam, Rangagora, Kharidu̱ar, Tusama and Simulia were collected from Central Water Commission, Asansol, Ministry of Water Resources, Govt. of India. The toposheet of Kangsabati catchment, land use classification map and soil map were available in the Agricultural and Food Engineering Department, IIT Kharagpur. General characteristic curves, such as stage-area and stage-volume curves of the Kangsabati reservoir; dead storage level; full storage level; daily flow releases at head regulator of RBMC and LBFC; spillway discharges as downstream flow from reservoir and daily inflow to the reservoir from the catchment were collected for the period of 17 years (1987–2003) from Office of the Superintending Engineer, Irrigation and Waterways Department, Bankura, Govt. of West Bengal. Daily flow releases at head regulator of Silabati Main Canal (SMC) and tail regulator of KMC (upper) for the 16 years period (1988–2003); channel dimensions and Manning's n values of LBFC and KMC (upper); design discharge and command area for each distributary of LBFC and KMC (upper) and information about direct outlet points of canal were collected from the office of the Executive Engineer, Irrigation and Waterways Department, Khatra, Bankura. Seepage loss rate in the canal and value of field application efficiency (80%) were taken from the Water and Power Consultancy Services (India) Ltd. report (WAPCOS, 2003). The soil survey map of the command area, prepared by National Bureau of Soil Survey and Land Use Planning, was available in the Agricultural and Food Engineering Department, IIT Kharagpur. Daily rainfall, pan evaporation, maximum temperature, minimum temperature, average relative humidity, sunshine hour and wind speed data of Susunia farm of Bankura were collected for the same 16 years period (1988–2003) from the Department of Agriculture, Govt. of West Bengal. Kharif crop data were obtained from the Water and Power Consultancy Services (India) Ltd. report (WAPCOS, 2003).

METHODOLOGY

The stream network of the Kangsabati catchment was generated from its DEM using AVSWAT 2000. The basin and reach parameters, extracted by analyzing the DEM, were input to IRCIM to predict the runoff of the watershed using distributed curve numbers. The whole catchment was divided into Thiessen polygons corresponding to the existing five rain-gauge stations. The number of sub-basins under each rain-gauge was determined by overlaying the Thiessen polygon map over the delineated watershed map using ArcView 3.1. Land use and soil type of each land cover of every sub-basin were determined using ArcView 3.1 by overlaying the land use classification map and the soil map over the delineated watershed map. To determine the runoff using CN values, the model needs to find out the correct combination of seven calibration parameters, viz., Manning's n for longest path and overland flow in sub-basin; Manning's n for reach; initial abstraction coefficient; weighting factor, X, for Muskingum routing; and Muskingum routing coefficients, $coef_1$ and $coef_2$. For calibration, rainfall-runoff data of four successive years (1996–1999) were used.

Using the Levenberg-Marquardt algorithm, different neural networks were trained for daily rainfall-runoff data of same four years (1996–1999). The training data has to be large enough to contain the characteristics of the catchment and to accommodate the requirements of the ANN architecture. In this study, minimum number of neurons in input layer was taken as five considering daily rainfall data from five different rain-gauge stations in the catchment. The networks were trained with varying number of input neurons (5, 10, 15, 20, 25 and 30) considering not only present but also up to past five days rainfall data of gauging stations for taking into account the effect of antecedent moisture content. No specific method was available in the literature to determine the number of neurons in the hidden layers. So, the networks were trained with different number of neurons (5, 10, 15, 20, 25 and 30) in hidden layers, as well as for different number (1 and 2) of hidden layers. Number of neuron in the output layer was always taken as one, representing outflow at the outlet point of the catchment (at Kangsabati reservoir site). The training process was terminated when one of the two criteria was fulfilled, i.e., either the error reduced below a given error tolerance or the number of training cycles reached maximum limit. All the possible combinations with varying number of neurons in input and hidden layers as well as number of hidden layers as mentioned above were tried for selecting the best network architecture for 5 training cycles. Subsequently, this best network was trained for different number (5, 10, 15 and 20) of training cycles to find out the optimum number of training cycles. The daily data used for training and testing the networks were normalized such that, the data lie between 0 and 1, as the sigmoid activation function used for training the network has lower and upper limits of 0 and 1, respectively.

Two rule curves for Kangsabati reservoir were generated by taking average (ARC) as well as minimum (MRC) of stage values on daily basis for 16 years period (1988–2003). Actual stage of the reservoir at any day should never be lower than the stage at dead storage level (in this case 120.4 m). Thus, maintaining minimum stage at 120.4 m throughout the year was taken as another rule (120.4_RC) for deciding release using this model. The saturated hydraulic conductivity (K_s) value was calibrated for daily stage data of 1988 to 1997 using the trial and error method. Finally, the arithmetic average of all the year-wise calibrated K_s was taken as the K_s of Kangsabati reservoir.

Analysis of the 16 years (1988–2003) canal release data of the LBFC system revealed that on an average canal was operational for 62 days and provided two to four irrigations of varying duration and frequency during the kharif season. Daily releases from reservoir for the monsoon period of 11 years, 1988 to 2001 (except the years 1990, 1994 and 1998, having only two irrigations), were predicted by the developed IRCIM. To account for the variations in the transplanting dates and the number of irrigation during the cropping season, a total of six modified schedules were considered. To keep these modified schedules within the framework of existing scheduling pattern, the total supply days in all the modified schedules were kept as 62 days. The starting date for kharif irrigation supply should match with the usual transplanting date, i.e., July 24. However, to account for the variations in the transplanting date, the irrigation starting dates were shifted by 5 days on either side of July 24. The number of irrigation was also varied from three to four, with almost fixed duration of supply, followed by equal duration of canal closure. Four simulation scenarios were considered in the study. These were (i) actual canal scheduling with original transplanting date (S1), (ii) IRCIM scheduling for usual transplanting date (S2), (iii) IRCIM scheduling for 5 days advanced transplanting date (S3) and (iv) IRCIM scheduling for 5 days lagged transplanting date (S4). The three IRCIM scheduling simulations (S2, S3 and S4) were carried out both for three irrigations as well as for four irrigations. In the first scenario (S1), actual canal release data were input to the model. However, for second (S2), third (S3) and fourth (S4) scenarios, all the three different rule curves were tried to decide on canal releases. Simulations for above four scenarios were performed for the kharif irrigation period. An attempt was made to develop an improved year-independent alternative delivery schedule based on the analysis of 11 years (1988 to 2001, excluding 1990, 1994 and 1998) simulation results with all the above scenarios. This fixed schedule does not need any prior experience on the Kangsabati irrigation project and can be followed by the managers mechanically without considering the climatic characteristics of that particular year.

After successful execution of each module of IRCIM independently, it was intended to simulate the complete system in an integrated way for two relatively current years 2002 and 2003. In these simulations, it was decided to use the method that performed better between the SCS CN and ANN for reservoir inflow prediction. For reservoir water balance, the K_s calibrated for Kangsabati reservoir was used. The whole system was also simulated using the observed reservoir inflows and the performance indicators were compared with that obtained using ANN predicted inflows for both the years. To evaluate the performance of IRCIM simulation results, predicted values were compared with the observed ones. Two dimensionless statistical performance criteria, viz., Modelling Efficiency (ME) and Coefficient of Residual Mass (CRM) were used for these comparisons. For water delivery system performance evaluation, four performance indicators, viz., adequacy, efficiency, dependability and equity, as prescribed by Molden and Gates (1990), were used in the present study.

RESULTS AND DISCUSSION

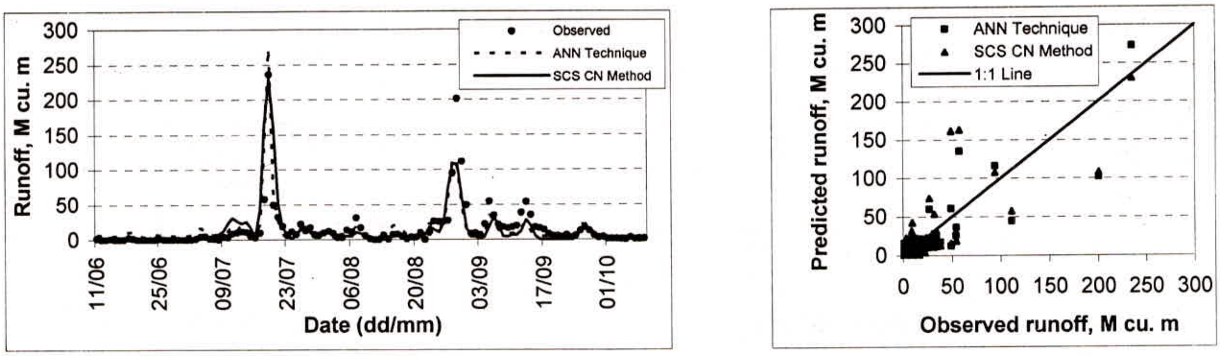
In case of SCS CN method, for all four calibration years, best results were obtained for Manning's n for longest path and overland flow in sub-basin, and Manning's n for reach as 0.075, 0.01 and 0.05, respectively; and initial abstraction, I_a, as 0.2 S. These calibrated Manning's n values satisfactorily represented the existing characteristics of sub-basins and reaches of the study area. Weighting factor, X was determined to be 0.2 in 1996 as well as in 1998. However, its value was found to be 0.0 in 1997 and 0.3 in 1999. Value of Muskingum routing coefficient, $coef_1$, varied from 0.5 to 1.1, whereas, that of $coef_2$ varied from 0.4 to 1.1. ME for all the calibration years were greater than 0.6. In addition, CRMs were less than 0.2 for all calibration years except the year 1999. ME value was obtained as high as 0.9 (in 1999) and CRM value as low as 0.14 (in 1996 and 1997). So, it could be concluded that SCS curve number module was satisfactorily calibrated. Using average calibrated values of all seven parameters, model was validated for the monsoon season of 1987, 1989, 1990 and 1993. During validation, ME was obtained as high as 0.76 and CRM as low as 0.06, which were quite acceptable. In case of runoff prediction using ANN technique, it was found that the network 20–20–1 (20 input neurons to consider past three days rainfall data in addition to present day rainfall data of five rain-gauge stations, and 20 hidden neurons in a single hidden layer) performed the best. To avoid over training, number of cycles was restricted to 10. Using weight file of the selected network (20–20–1) trained for 10 cycles, ANN module was validated for the same years as SCS CN module. In the validation years, ME ranged from 0.67 to 0.80 and CRM from 0.03 to 0.20. From the above ME and CRM values, it was observed that daily runoff was predicted more accurately by ANN technique compared to SCS CN method (Figure 3).

In reservoir module, calibration parameter, K_S, varied from 2.50 to 6.57 mm d^{-1} for all the 10 calibration years with an average value of 4.31 mm d^{-1}. Annual total seepage loss was also calculated from annual reservoir water balance components. The K_S, computed from this annual total seepage loss, varied from 2.12 to 7.72 mm d^{-1} with an average of 4.69 mm d^{-1} which was quite comparable with the K_S calibrated from daily basis simulations. High values of ME and low values of CRM for all the calibration years indicated good calibration of K_S for reservoir water balance. Using average of calibrated saturated hydraulic conductivity values i.e. 4.31 mm d^{-1}, reservoir module was validated for sequential years of 1998 to 2001. In validation, ME and CRM varied from 0.93 to 0.94 and from 0.003 to 0.006, respectively. Such high ME and low CRM values and Figure 4 show very good validation of the reservoir module with the average K_S, 4.31 mm d^{-1}.

For evaluating the performance of the irrigation management system of the developed model, predicted daily releases from reservoir were compared with the observed ones. For this comparison, actual irrigation scheduling as practiced in any particular year was adopted. To ensure maximum possible release from the reservoir, 120.4_RC was considered while predicting daily release. ME for these comparisons ranged from 0.950 to 0.996 and CRM from 0.04 to 0.13. Thus, it can be said that model performed satisfactorily in predicting daily releases. However, positive CRM values in all years implied that the model under-predicted the release values. On an average, total predicted release was 9.86% less than the total observed release.

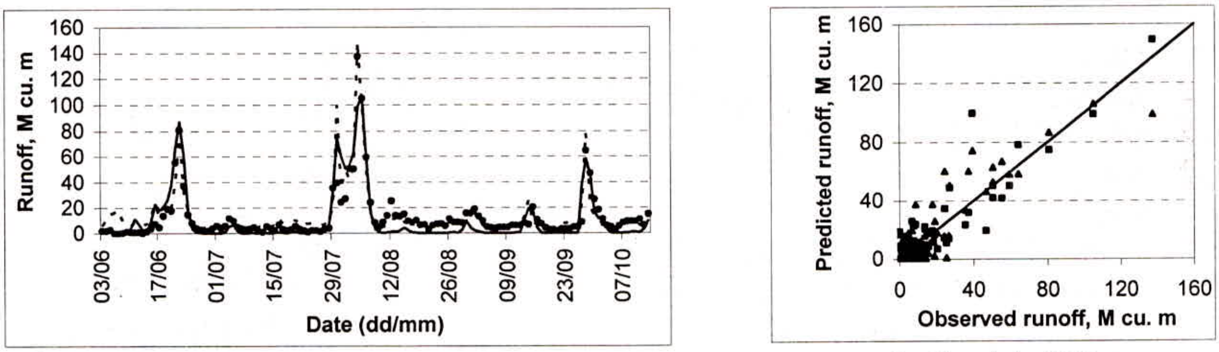
This may be because of existence of ponds adjacent to the canal and some unrecorded field channels from canal as reported by the Irrigation and Waterways Department, Khatra, Bankura.

The overall performance indicators, Adequacy, Efficiency, Dependability and Equity for canal irrigation system corresponding to different scenarios for all the 11 simulation years were determined. The performance of the model determined best delivery schedule was better than the actual delivery schedule in six of the 11 years (1989, 1993, 1995, 1997, 1999, and 2000). For 1988, the model determined delivery schedule performed at par with the actual delivery schedule. For the remaining four years (1991, 1992, 1994 and 2001), the actual delivery schedule performed better than the model determined delivery schedule. However, on an average, the model determined best delivery schedules were found to improve the adequacy, dependability and equity by 11.96%, 51.38% and 61.11%, respectively over the actual delivery schedules. The other performance indicator Efficiency was always found 1.00 as the model never applied irrigation exceeding the requirement. For maximum number of simulation years, model performance was better for transplanting date as July 24, number of irrigation as 3 and type of release as MRC. Hence, it was proposed as the year-independent alternative delivery schedule. Now, for all 11 simulation years, performances of irrigation management system were compared between respective actual delivery schedule and the alternative delivery schedule. The performance of the alternative delivery schedule was better than the actual delivery schedule in six of the 11 years (1989, 1993, 1995, 1997, 1999 and 2000). For 1988, the alternative delivery schedule performed at par with the actual delivery schedule. For the remaining four years (1991, 1992, 1996 and 2001), the actual delivery schedule performed better than the alternative delivery schedule. However, on an average, the alternative delivery schedule was found to improve the adequacy, dependability and equity by 7.61%, 18.78% and 45.24%, respectively over the actual delivery schedules. Figure 5 presents the seasonal irrigation water applied by actual and alternative delivery schedules. It can be noticed that except for 1991 and 1995, irrigation water applied by alternative delivery schedule was less than the actual schedules for remaining nine years. On an average, the alternative delivery schedule saved 18.36% irrigation water over actual schedules, but increased the crop evapotranspiration by 0.61%. This indicated that, with the alternative delivery schedule, the paddy was under less water-stressed condition and was expected to give more yield.



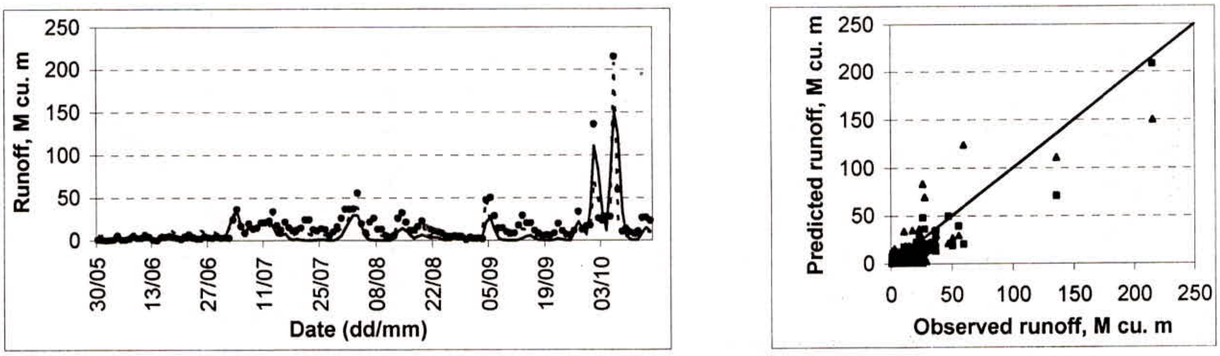
Time series plot—1987

Scatter plot—1987



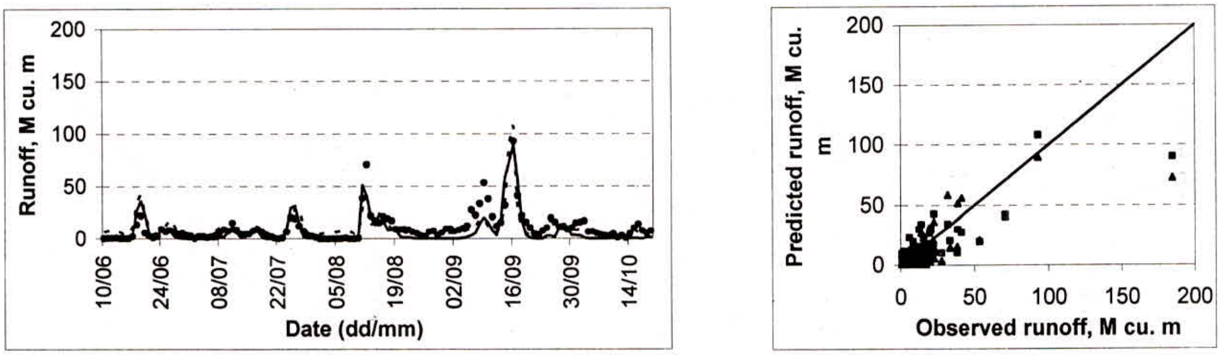
Time series plot—1989

Scatter plot—1989



Time series plot—1990

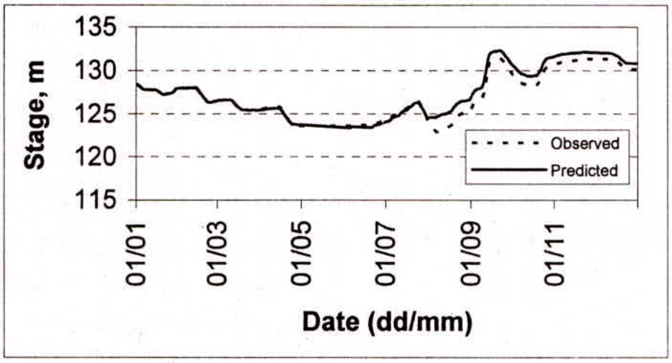
Scatter plot—1990



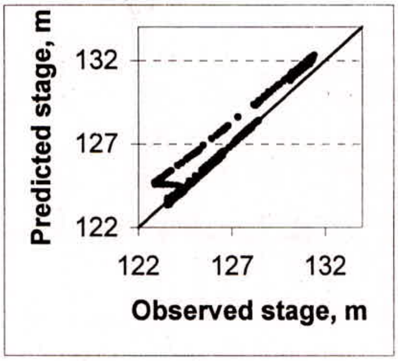
Time series plot—1993

Scatter plot—1993

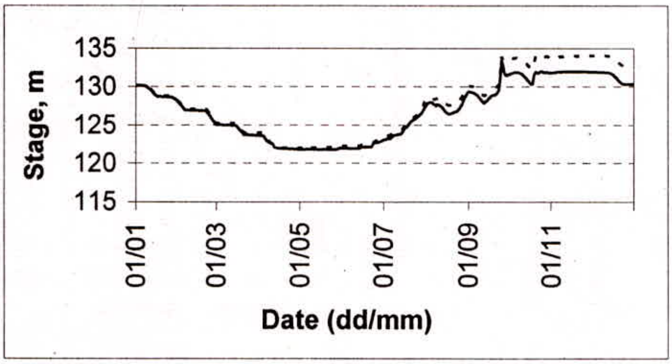
Fig. 3: Comparative time series and scatter plots for SCS CN method and ANN technique (validation years)



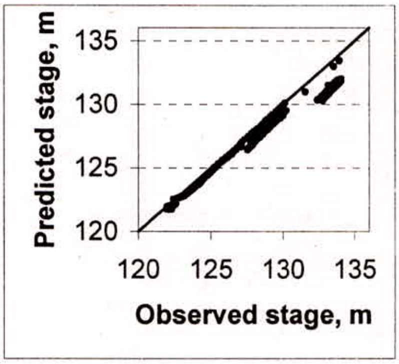
Time series plot—1998



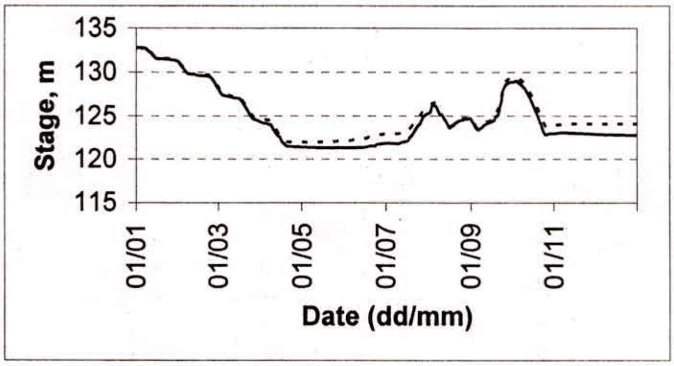
Scatter plot—1998



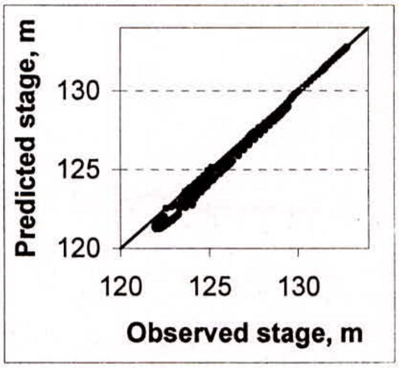
Time series plot—1999



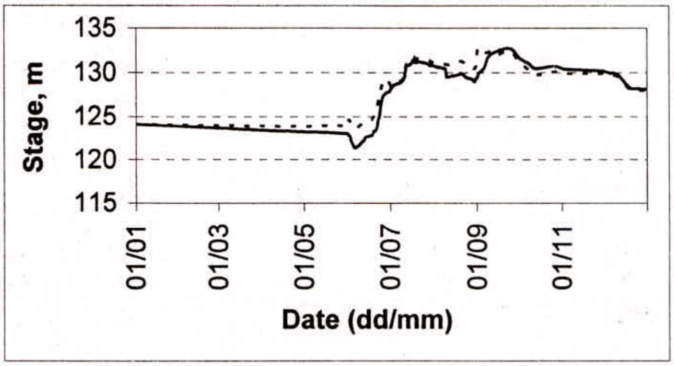
Scatter plot—1999



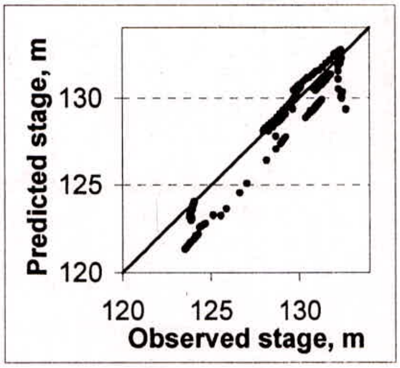
Time series plot—2000



Scatter plot—2000



Time series plot—2001



Scatter plot—2001

Fig. 4: Time series and scatter plot for reservoir water balance (validation years)

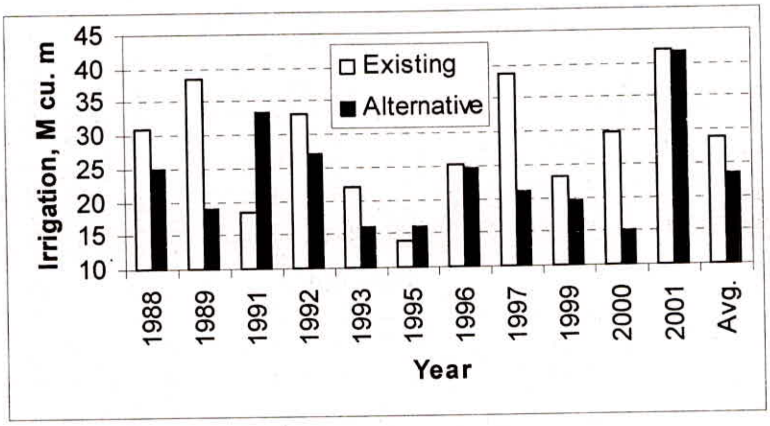


Fig. 5: Seasonal irrigation water applied by existing and alternative schedules

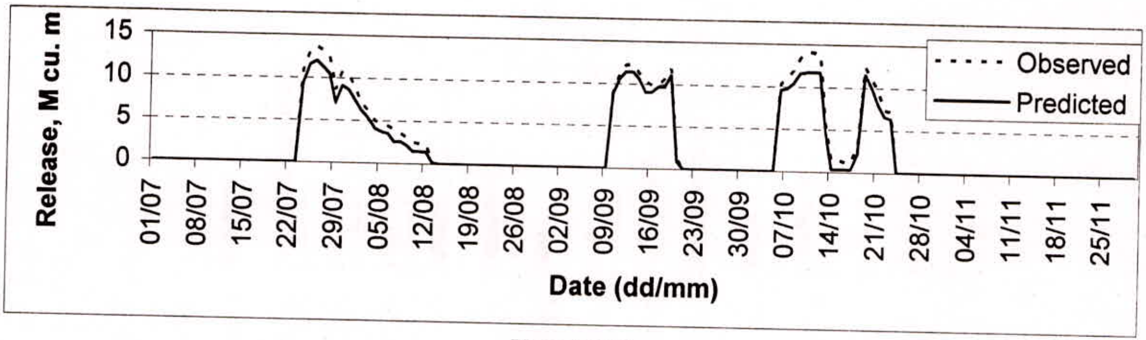
For the command area of LBFC and KMC (upper), performance of actual delivery schedule was quite good for most of the simulation years. However, such a varied actual delivery schedule involved lot of experience of the manager, whereas, the year-independent alternative delivery schedule could be followed mechanically without manager's expertise. In spite of that, the performance of alternative delivery schedule was quite comparable for all the simulation years with that of the actual delivery schedule while saving sizable amount of water. Thus, it was recommended to adopt the alternative delivery schedule instead of existing delivery schedule.

Being better in prediction of runoff from catchment of Kangsabati reservoir, ANN was chosen over SCS CN method for simulation of the complete integrated system. Using the weight file of ANN training, inflow to the reservoir was predicted for the simulation years 2002 and 2003. ME and CRM values were 0.74 and –0.17 for 2002 and 0.82 and –0.07 for 2003, respectively. Using observed inflows to the reservoir and calibrated saturated hydraulic conductivity (4.31 mm d^{-1}), reservoir module was validated for both the simulation years. ME and CRM values were 0.99 and 0.002 for 2002 and 0.95 and –0.005 for 2003, respectively. Again, using saturated hydraulic conductivity as 4.31 mm d^{-1}, reservoir module was validated for ANN predicted reservoir inflow, where ME and CRM were obtained as 0.82 and –0.01 for 2002 and 0.70 and –0.01 for 2003, respectively. Results indicated an acceptable agreement between observed and predicted stages. From the obtained ME and CRM values (0.73 and –0.01 for 2002 and 0.87 and –0.01 for 2003), it was inferred that reservoir stage predicted using ANN predicted inflow was quite comparable with stage predicted using observed inflow. Using the ANN predicted inflow, reservoir module was simulated in conjunction with crop water demand module as well as irrigation management system. Comparing maximum possible release, as decided by IRCIM, with observed release, ME and CRM were 0.98 and 0.14 for 2002 and 0.98 and 0.12 for 2003, respectively, which indicated satisfactory performance of the model in predicting daily release (Figure 6(a)&(b)). In both the simulation years, the performance of the model determined best delivery schedule was better than the actual delivery schedule. However, the performance of the alternative delivery schedule was better than the actual delivery schedule in 2002; but, in 2003 the alternative delivery schedule performed at par with the actual delivery schedule. Simulation of the whole system using the observed reservoir inflow also yielded exactly the same performance indicators, as were obtained by ANN predicted inflow for both the years.

SUMMARY

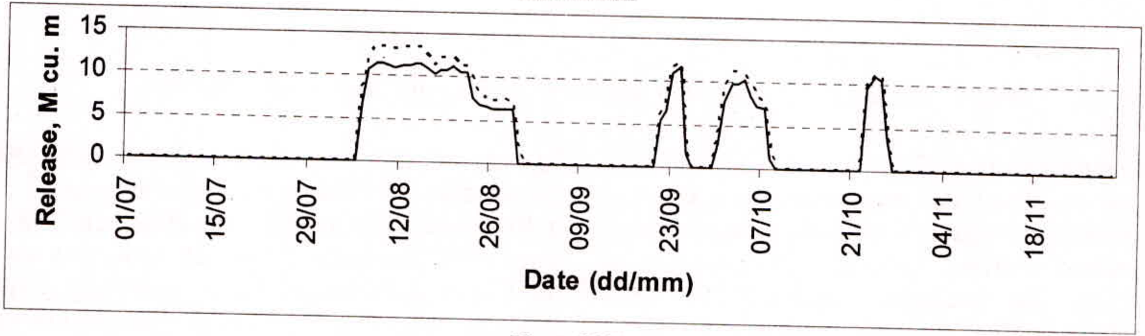
An Integrated Reservoir-based Canal Irrigation Model (IRCIM) was developed which could take into account the impact of catchment rainfall on reservoir inflow, assess irrigation water availability from reservoir, estimate the irrigation demand of command, and subsequently decide on a rotational delivery schedule to minimize the gap between demand and supply. The model has a user-friendly interface for entering and editing river as well as canal network description, catchment, reservoir and command information, and for viewing the results. The developed model was applied to Kangsabati Irrigation Project, situated in the western part of West Bengal, India. The application results were satisfactory for both module wise and integrated simulations. The test results suggested that IRCIM could help in pre-season planning of the allocation schedules based on hydraulic and hydrologic simulations, and post-season evaluation of the system performance. It could be used as a tool by irrigation departments for planning the canal releases on scientific basis.

(a)



Year: 2002

(b)



Year: 2003

Fig. 6(a)&(b): Comparison between predicted and observed reservoir releases

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