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A GIS based model for integrated water resources Management in an irrigation system

M.K. GOEL AND S.K. JAIN
National Institute of Hydrology, India

U.C. CHAUBE
Indian Institute of Technology Roorkee, India

Abstract Irrigation accounts for around 83% of the total freshwater demands in India. With limited availability of water as compared to demands, considerable improvement in efficiency of water use by different sectors, especially irrigation, is urgently required. Some of the major non-structural causes of low water use efficiency in irrigation systems include wasteful use of water by head-reach farmers, inequity and indiscipline in the irrigation system operation, lack of involvement of beneficiaries, and absence of meaningful co-ordination of multidisciplinary departments at various levels. This paper reports the development of a spatially distributed simulation model for analyzing the real-time allocation of surface water and groundwater in an irrigation command. The model is linked to GIS for considering the spatial characteristics of important agriculture-related variables and for effective presentation of results. Based on the irrigation demands, canal water availability and groundwater conditions during a week, the model optimally allocates the surface water and groundwater while maintaining the environment. Application of the model requires real-time flow of multi-disciplinary data at the control centre. Presentation of results in map form can make the general public more informed and can involve them in decision-making process. The effect of adopting various efficiency enhancement measures or other system modifications on the overall system performance can be analyzed by the model. The model application is demonstrated for the Lakhaoti branch command area under the Madhya Ganga Canal System in U.P. State, India.

Keywords : Irrigation water management, simulation model, spatially distributed model, GIS, conjunctive use, soil water balance, canal network simulation.

INTRODUCTION

Total water use in agriculture in India is around 525 billion cubic meter (BCM) and with this water use, the country is able to produce sufficient food grain (212 million tons) for meeting the present requirements. However, the National Commission for Integrated Water Resources Development Plan (NCIWRDP, 1999) has estimated that by the year 2050, the irrigation demands would raise to around 628 BCM (as per low demand scenario) or 807 BCM (as per high demand scenario) and 16% of the population in India would be under water scarcity conditions. One solution to the problem lies in making integrated and efficient utilisation of the available water resources. Government of India has estimated that water use efficiency in canal command areas in India lies between 38-40% (GoI, 1999, Vol. II). Being the largest consumer, there is a need to enhance the water use efficiency in irrigation sector. On a rough basis, it is estimated that 10% increase in present level of water use efficiency can bring 14 million hectare of additional land under irrigation from the existing irrigation capacities.

National Water Policy (2002), vide para 9.1, has also advocated for adoption of appropriate techniques for optimizing efficiency.

Introduction of canal irrigation facilities in a command area sets in new hydrological regime with revised conditions of groundwater recharge and withdrawal. If the water is not utilized as per the developed plan or if there is significant difference in the actual and design values of demands and supply, an imbalance is created in the ecosystem that can lead to deterioration of the system. In the head and middle reaches of a canal command, often more water is delivered to crops, which rarely corresponds in amount and timing to the crop requirements. Over-utilization of surface water gives rise to deleterious effects like waterlogging and salinity. At the tail-end of irrigation networks, unreliable water deliveries force the farmers to use groundwater where over-exploitation of groundwater results into mining of groundwater reservoir and lowering of the water table regime, thereby damaging the environment. Some of the major inadequacies in management of irrigation systems in developing countries include under-utilization of created irrigation potential; unreliable, inadequate, and inequitable water distribution; problems of waterlogging, salinity and alkalinity; over-exploitation of groundwater resulting in excessive lowering of water table; and low main system and on-farm efficiencies.

Integrated and rational management of surface water and groundwater resources in an irrigation system can provide an effective antidote to some of these problems. Efficient use of available water resources requires mathematical models to simulate the dynamics of water distribution in an irrigation system. A number of computer-based models have been reported in the literature (such as SIMIS, CAMSIS, INCA, OMIS, IMSOP etc.) to help irrigation manager in operation of a canal system. Lenselink and Jurriens (1992) and Mujumdar (2002) have reviewed and summarized mathematical models for irrigation water management. More than 100 irrigation and hydrology related software have been cited at the internet site – IRRISOFT (http://www.wiz.uni-kassel.de/kww/irrisoft/irrisoft_i.html) which contains a database of software and corresponding links. Majority of the developed models analyze the system operation in terms of water demands and supply and optimize the water allocation to meet some performance-based criteria/objectives.

Once an irrigation project is planned and designed, it needs to be efficiently operated to derive maximum benefits and to maintain the sustainability of environment. This requires drawing up a schedule of canal network operation and consequent surface water irrigation, as well as a schedule of operation of tube wells, in space and time, over the entire command for every crop season and for all crop seasons. This can be best facilitated with the help of a simulation model incorporating surface water-groundwater interaction, consumptive use and soil moisture accounting. The model should be used both for prescriptive as well as predictive purposes with on-line observations and corrections. ICID-CIID (2000) has brought out a catalogue of various canal operation simulation models developed in the past. ASCE Task Committee (1993) has observed that in the absence of application of any scientific decision support system for the management of large-scale irrigation systems in Asian region, water allocations generally ignore crop water demands with respect to time and quantity leading to poor performance of irrigation projects. With this need in view and to help in the scientific and rational management of irrigation water, a model has been developed for real-time conjunctive operation of a canal network. The model is linked to GIS database for utilizing the spatially distributed data of different variables (rainfall, soil type, crop type, groundwater depth etc.) and provides the results in GIS environment for easy visualization and interpretation. However, the field application of such a strategy requires not only close coordination among various related departments such as Irrigation Department, Groundwater Department, Agriculture Department, Remote Sensing Centres, Meteorological Department etc. but also establishment of an extensive geo-referenced system database and the network for real-time data collection. This paper presents a brief description of model. Its application is cited for a command area under Madhya Ganga Canal System in UP State, India.

GIS BASED CONJUNCTIVE OPERATION SIMULATION MODEL

Large amount of spatial and temporal information (cropping pattern, soil properties, rainfall, topography, groundwater conditions, canal system characteristics, water use efficiencies etc.) is involved in irrigation water management in a command area. The decision-making process for irrigation management in developing countries has been handicapped with the non-availability of geographic information on real-time basis and/or the inability to process and analyze vast quantity of geographic data. To help in the scientific and rational conjunctive management of irrigation water, a spatially distributed simulation model has been developed that can integrate various processes of irrigation management from micro-scale (field level) to macro-scale (overall command) and provide a comprehensive analysis of the total system (Goel 2003). Objective of the developed geo-simulation (GIS based simulation) model is to integrate the spatial information on different variables related to irrigation water demand and supply for real-time conjunctive operation of a canal network. The model uses the remote sensing observations for ascertaining the prevailing cropping pattern in the command and is linked to GIS database for utilizing the spatially distributed data of different variables. GIS is also used to depict the model results in map form for easy comprehension and visualization.

Modelling Strategy Adopted

The model uses spatially distributed data of various features of the command area, attribute data related to crops and soils and the dynamic data related to rainfall, evapo-transpiration and canal network operation. The spatial data includes crop map, soil map, Thiessen polygon map of rainfall stations, digital elevation map, flow direction map, canal layout map, canal irrigable area map, and groundwater depth map. The model operates at weekly time step and consists of two major distributed sub-models [Soil Water Balance Model (SWBM) and Canal Network Simulation Model (CNSM)] and a number of minor sub-models for database generation and linkage. The purpose of SWBM is to simulate the moisture variation in root zone of crops for finding spatially distributed irrigation demands, groundwater recharge, water stress conditions in crops, and soil moisture content at the end of each week. CNSM is used to analyze various scenarios of canal network operation on the basis of water demands, supply, and system characteristics. For generating revised groundwater conditions corresponding to the different canal operation scenarios, an existing groundwater model (Visual MODFLOW) has been linked with the modeling scheme. The model is also linked to the ILWIS GIS system for preparation of spatial input maps and for presentation of outputs in map form.

After developing the database for the canal command, the model run is started for a specified week. If it is the starting week of model execution, then suitable initial soil moisture conditions in the command are assumed. Otherwise, the moisture content in the crop root zone in various grids at the end of previous week becomes the initial moisture content for the present week. Next, the probable rainfall and evapo-transpiration estimates in the command at various stations are obtained (either from forecast information or statistical analysis) and the soil water balance model (SWBM) is run to find the grid-wise irrigation demands.

After calculating the spatial irrigation demands, CNSM is used to simulate the canal network operation and find the best configuration of canal water delivery depending on the canal water availability during the week and the prevailing groundwater conditions in the command. At the end of week, knowing the actual meteorological conditions and the actual canal network operation, SWBM is run again to estimate the spatial distribution of soil moisture, groundwater recharge and the extent of groundwater pumping requirement. Spatial estimates of pumping and recharge are then linked with a groundwater simulation model to find the groundwater table for the subsequent week. CNSM can be used to examine the consequences of different canal water allocation policies. If, as a result of the particular policy, the developed groundwater conditions are unacceptable, the canal operation policy can be revised and CNSM runs can be taken again. CNSM is run for each week of crop season to manage the available surface water and groundwater conjunctively in real-time. The flow chart of the overall modelling approach is presented in Fig. 1.

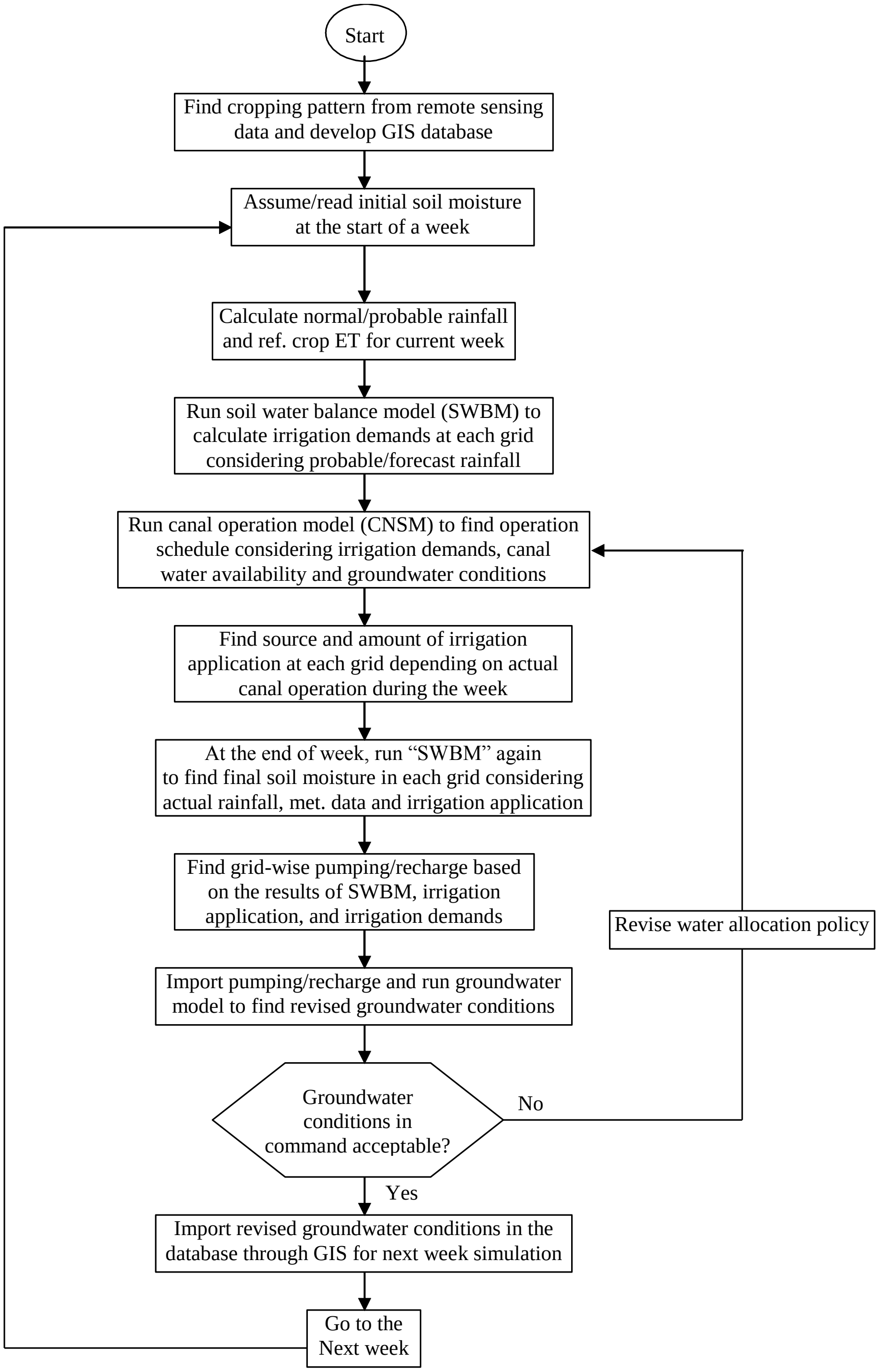


Fig. 1 Flow chart of modelling scheme

Soil Water Balance Model (SWBM)

Soil water balance of cropped area is a dynamic process influenced by crop and soil properties, climatological variables and topography. In this overall modeling scheme, moisture variation in the root zone is simulated to find the irrigation demands, groundwater recharge, and crop water stress in the command area. SWBM simulates the dynamics of soil-water-plant interaction and makes grid-wise computations using the raster as well as attribute data. Raster data includes crop type, soil type, Thiessen polygon of rainfall stations, surface elevation, flow direction, groundwater depth, and actual irrigation application. Attribute data includes crop properties (such as maximum root depth, time to reach the maximum root depth, starting week of the crop, total time period, weekly crop coefficients etc.) and soil properties (such as specific gravity, porosity, field capacity, permanent wilting point, and hydraulic conductivity). In addition, dynamic data needs to be provided every day/week such as rainfall at different gauging stations in/around the command area, reference crop evapo-transpiration, and the irrigation water delivery.

Two time steps are possible in this sub-model: daily or weekly. In weekly time step, the various inputs and outputs of the system are assumed to be lumped over the whole week while in daily time step, the water balance computation is performed for each day of the week considering daily rainfall and daily reference crop evapo-transpiration. The calculations are performed for all the days of the week and the soil moisture status at the end of the last day of the week is given as output (final moisture content at the end of the week).

Four spatial maps (grid-wise output) are generated by the SWBM: (a) final moisture content at the end of the week, (b) irrigation water demand, (c) crop water stress, and (d) groundwater recharge. The maps can be displayed in a GIS system for easier interpretation and decision making. A view of the irrigation demand map and groundwater recharge map generated by the SWBM is shown in Figs. 2 and 3 respectively.

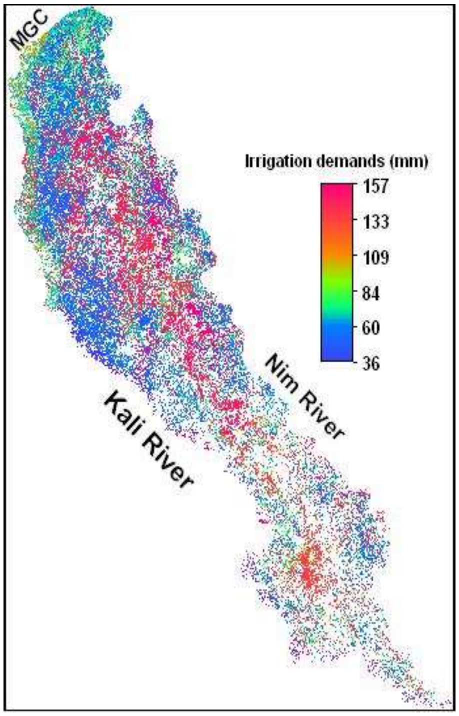


Fig. 2 Irrigation demand map during a week as obtained from SWBM

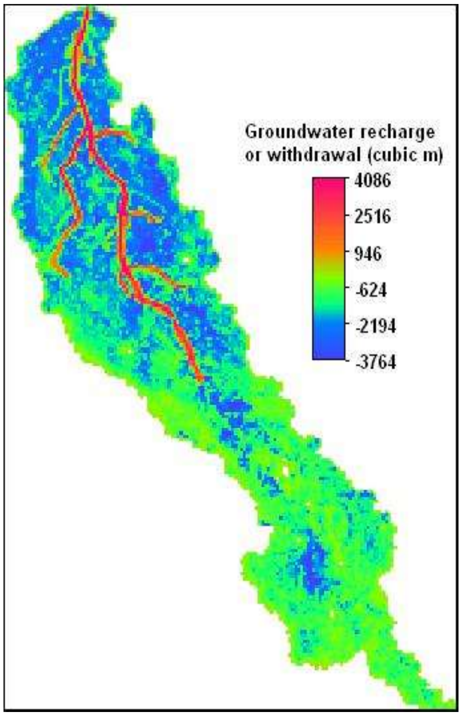


Fig. 3 Groundwater recharge/withdrawal map during a week as obtained from SWBM

In the overall modelling scheme, SWBM is utilized in two steps for each week. First, it is used to forecast the irrigation demands for the forthcoming week corresponding to the normal/probable rainfall and evapo-transpiration. Based on these demands, the operation of the irrigation system is simulated. After the week has passed and the actual rainfall, evapo-transpiration, and actual canal operation during the week become known, the SWBM is run again to find the final moisture content at the end of the week based on the actual input to the system. This information is used to forecast the irrigation demands for the subsequent week.

Canal Network Simulation Model (CNSM)

The objective of this sub-model is to simulate the weekly operation of canal network for satisfying the irrigation demands. CNSM can be used to simulate different canal operation scenarios and evaluate system performance. The operation approach in the CNSM model is governed by the irrigation demands (estimated by the SWBM), surface water availability in the canal system and the prevailing groundwater conditions in the command area during a week. The approach utilizes the surface water to the extent possible provided that groundwater conditions permit. This results in least power requirement for extracting groundwater and simultaneous recharging of the groundwater aquifer.

CNSM model also accounts for the spatial and attribute information of the command area. Spatially distributed information used by the CNSM include crop type, layout of canal network, layout of irrigable areas of different canal segments, irrigation demands, and the depth of groundwater table. Attribute information used by the CNSM relates to the characteristics of different canal segments (discharge capacity, section details, irrigable area, conveyance efficiency, application efficiency and field channel efficiency in the local command, canal seepage rate, priority of segment demand etc. CNSM model also requires information about those canal segments, which are running at the end of the previous week for calculating fill-time of different segments.

The irrigation demands (obtained from the SWBM) at all grids that lie within the irrigable command of each canal segment (from canal irrigable area map) are accumulated after accounting for the water application efficiency and the field channel efficiency and the total irrigation demands in different canal segments of the entire canal network are worked out. Next, calculations are started from the tail end of the system in the upstream direction. Knowing the discharge capacity of canal segments, the required run-time and seepage loss in each segment is worked out. Canal seepage is then added to the water demands of a segment and the final run-time is computed iteratively. The water requirements are accumulated in the upstream direction after giving due consideration to canal capacity. If the canal capacity at a segment is not sufficient, then the amount of groundwater required (because of capacity constraint) in the segment is found out. The groundwater demands of intermediate segments are settled first by curtailing irrigation demands of some downstream canal segments (based on the groundwater conditions). Calculations are carried up to the head of the canal system by satisfying the capacity constraint of all intermediate segments and the total water requirement at the head is estimated. This is the canal water requirement in the command (including seepage losses) that can be satisfied from the existing canal system. Now, this requirement is compared with the available water at the system head. If the water availability is more than or equal to the required demand, then the system is operated according to the discharge requirement as calculated earlier for different segment. However, if the availability is less than the demands, then, some allocation criteria needs to be evolved to find the segments of canal water supply and groundwater supply.

Five different distribution/allocation policies have been included in the model and the operator can select any one policy for the operation of the canal system. The results of different policies can be analyzed before the implementation of any particular approach. For finding the water allocation to different canal segments, calculations proceed from the head of canal system towards the tail end. Different allocation policies that have been included in the simulation model are:

Policy 1:Head-reach priority

Under this policy, the segments in the head reach are given priority and their demands are met in full. The remaining water left at a system node is sent to the downstream segments. This policy is mainly applicable to a system with no control on the canal flow and the canal water is utilized as far as and as long as it is available.

Policy 2: Based on conjunctive use of water

Under this policy, curtailing the irrigation demands of some downstream canal segments compensates the deficit at the head of the canal system. The demands of such affected canal segments are met through groundwater withdrawal. The groundwater depth under each canal segment governs the identification of affected segments. The segment of least depth of groundwater is selected iteratively and the calculations are repeated for finding revised water requirement at head under changed demand scenario till the water demands match with the water availability.

Policy 3: Proportionate supply

Under this policy, water available at a system node is distributed proportionately among different segments (bifurcating from a node) in proportion to their total demands. Thus, this policy tries to equitably distribute the deficit among different canal segments.

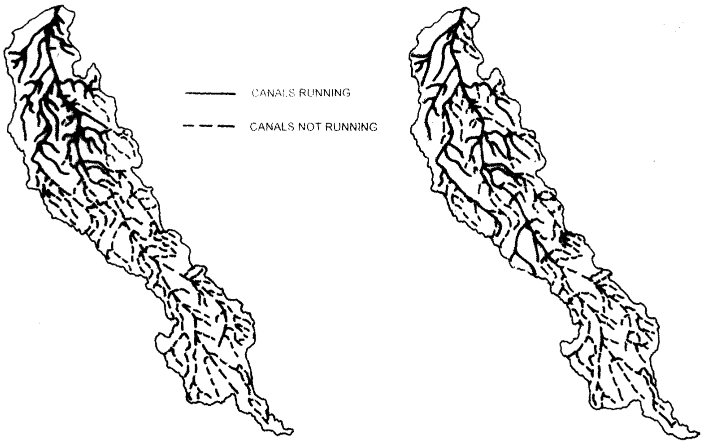
Policy 4: Tail-reach priority

Under this policy, the allocation is started from the tail end of the system and it advances in the upstream direction as the demands of the tail-end canals are satisfied. Using this policy, the operator can visualize the total extent of the downstream canal system that can be satisfied for the available water. Since the groundwater depth in the tail-end is generally high as compared to the head reaches and canal water is given priority in tail-end, this policy also tries to equalize the groundwater regime in the command area.

Policy 5: Conjunctive use with minimum energy demand

Under this policy, the canal-run configuration corresponding to the least energy requirement in the irrigation system for pumping groundwater is identified. After finding the canal-run configuration corresponding to Policy-2, the canal-run segments are moved in the upstream direction one-by-one and the corresponding energy requirement in the system for pumping groundwater is calculated. The configuration that results in least energy requirement is recommended.

Canal network simulation can be analysed with any of the available allocation policies. The output of simulation analysis indicates the discharge, run-time, and seepage loss of various canal segments for the week under consideration. Output results of the simulation model are presented in the form of maps and table. Different results of CNSM model can be instantly visualized in GIS. Various maps that can be generated include: whether a canal segment is supplied water or not, cause of not running the canal segment, required discharge, run-time, seepage loss, groundwater usage etc. A view of the canal operation map corresponding to the policy of head reach priority (Policy-1) and policy of conjunctive use with minimum energy demand (Policy-5) are shown in Fig. 4 (a) and (b) respectively.



(a) **(b)**

Fig. 4 Canal operation [Canals running (Red), Canals not running (Blue)] for a week with (a) Policy of head-reach priority, (b) Policy of CU with minimum energy demand

MODEL APPLICATION TO A CANAL COMMAND AREA

The model application is demonstrated for the Lakhaoti branch canal command area under the Madhya Ganga Canal Project (MGCP) in UP State, India. The MGCP envisages utilization of surplus water of Ganga River during the monsoon period. The Lakhaoti branch commands an area of 1930 sq km that lies between latitude 27°45′ to 28°45′ N and longitude 77°45′ to 78°35′ E. c The area is bounded by the Kali river in the west and the Nim river in the east. The area experiences moderate type of sub-tropical and monsoon climate with average annual rainfall of 653.7 mm. Principal crops in the area during the Kharif season (June to October) are paddy, sugarcane, maize, arhar (pulse crop), and guar (fodder crop). A schematic map of the study area is shown in Fig. 5.

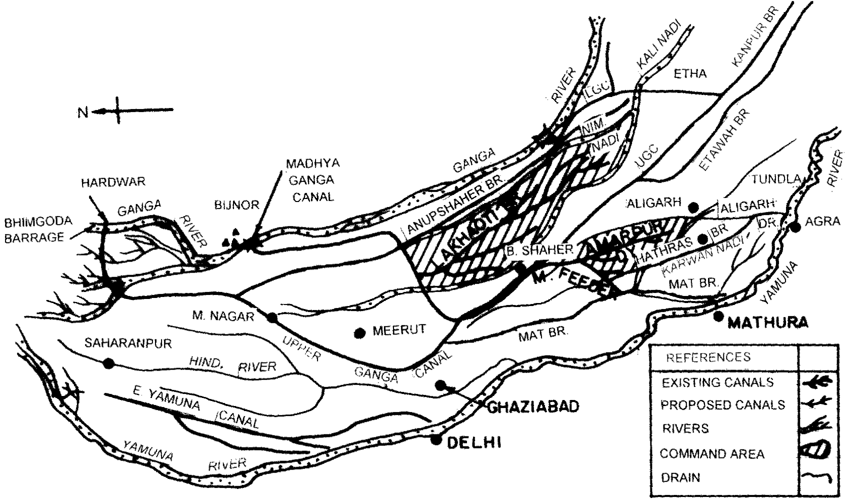


Fig. 5 Schematic map of MGC system

Database Development for Lakhaoti Command

The model has been run with the data of Lakhaoti command area at weekly time step covering the full Kharif season of the year 1998. To apply SWBM, eight data layers have been prepared in image form: (a) crops in the command [from remote sensing analysis], (b) soil type variation [from digitization of soil map], (c) rainfall variation [from Thiessen polygon map of rainfall stations], (d) digital elevation map [from GIS analysis of topographic information], (e) flow direction map [from DEM], (f) groundwater depth map [from water level data in observation wells], (g) irrigation application map [depending on the canal network layout and canal water supply], and h) initial moisture map. For the application of the CNSM, three additional images have been used: (a) canal network layout map, (b) irrigable command areas of different canal systems, and (c) irrigation demand map [which is one of the outputs of SWBM]. For the application of groundwater simulation model, two additional images specifying the properties of the aquifer medium have been used: (a) specific yield map, and (b) transmissivity map. The raster images have been converted in ASCII format using GIS software for input to the SWBM and CNSM.

Identification of Crops

Remote sensing data of LISS-III sensor of IRS-1C/1D satellite (spatial resolution 23.5 m) have been analysed in the ERDAS IMAGINE system to prepare crop map of the study area for the Kharif season of year 1998. Images of four different dates (June 2, July 23, October 9, and October 31) have been acquired and multi-spectral and multi-temporal attributes of remote sensing have been used in conjunction with the crop calendar to identify various crops. For example, images of June, July and October 9 have been used for sugarcane identification. Sugarcane is the only major crop in the image of June, which remained in the command till the end of October. Similarly, rice crop in the command has been identified by analyzing the images of July 23 and October 9. Rice fields appeared with water signatures in July 23 image and as clear vegetation signatures in October 9 image. The acreage of various crops identified using remote sensing has been found to be close to the proposed acreage in command. After the identification of individual crops, a composite image of Kharif season crops has been formed and used as the crop map of the command. Results of remote sensing analysis have been verified from the ground-truth survey with an overall accuracy of 80.7%.

The soil map has been obtained from the National Bureau of Soil Survey and Land Use Planning, New Delhi. The canal network map and the characteristics of different canal segments have been obtained from the Irrigation Department. Groundwater levels in various observation wells at the beginning and end of Kharif season have been obtained from the Groundwater Department. Aquifer properties in the command area (specific yield and transmissivity maps) have been obtained from an earlier groundwater modeling study carried out for the same area (Nayak et al. 1990). The crops in Lakhaoti command in the Kharif season of year 1998 are shown in Fig. 6. The irrigable areas of different canal segments are shown in Fig. 7.

Attribute data relates to the properties of different crops and soils, and canal system characteristics. Root depth characteristics and the fraction of available water for different crops have been obtained from FAO (1977). Crop factors and other characteristics of different crops have been taken from the Irrigation/Agriculture Department. Soil samples have been collected from many locations in Lakhaoti command and soil characteristics of different soil types in the command have been determined by laboratory analysis. Various characteristics that are specified for each canal segment and are used by the CNSM include: discharge capacity, length, bed width, water depth, side slope (V:H::1:z), irrigable area, conveyance efficiency, application efficiency in irrigable command, field channel efficiency in the irrigable command, seepage rate per unit wetted area, number of tube

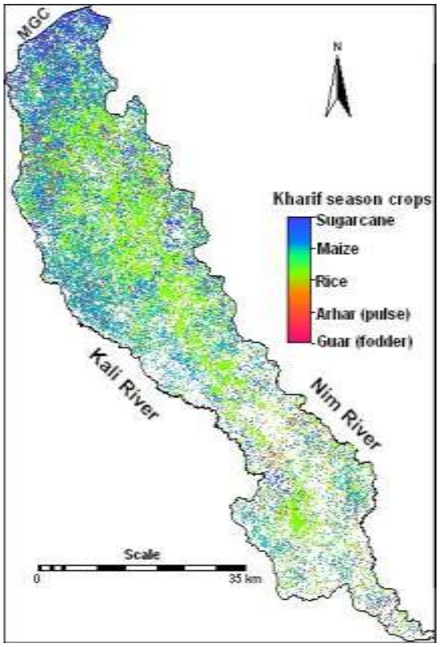


Fig. 6 Kharif crop map in year 1998 in Lakhaoti command

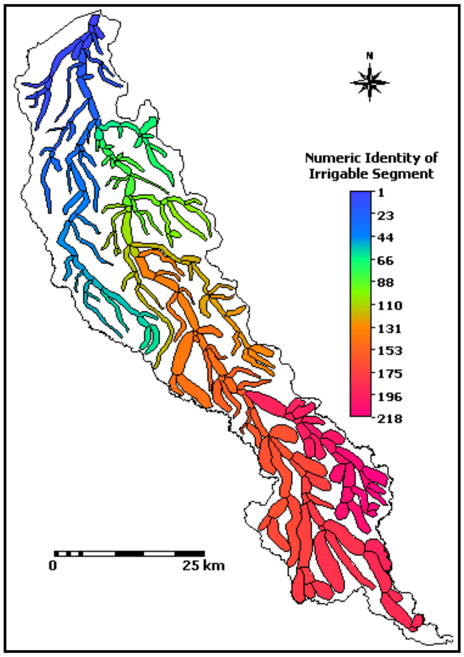


Fig. 7 Irrigable areas of different canal segments in Lakhaoti command

wells operating in the irrigable command, average power of pumping plants, number of hours for which power supply is generally available in the irrigable command, and linkage of various canals. Dynamic information (rainfall data at five raingauge stations, evapo-transpiration, and canal water supply) in the Lakhaoti command during the year 1998 has been obtained from the concerned departments.

Model Execution and Discussion of Results

The SWBM and CNSM models have been run at weekly time step from June 11, 1998 to October 15, 1998 while the groundwater model (Visual MODFLOW) has been run at monthly time step to determine revised groundwater surface in subsequent months. The SWBM has been run considering actual rainfall and evapo-transpiration data as input and grid-wise irrigation demands, recharge, and final water content during each week have been worked out. Using the irrigation demands and actual supply of canal water at the system head, the CNSM has been run to find the grid-wise canal water application and groundwater withdrawal. Based on the irrigation demands worked out by the SWBM, total water requirements at the head of the canal system have been estimated by the CNSM. The estimated water requirements at the canal head have been found to be very close to the canal capacity at the head (64 cumec), which suggests that estimation of irrigation demands by the SWBM lie quite close to reality.

In addition to comparing the estimated and envisaged canal water demands, model results have been verified by comparing the observed and simulated groundwater levels in different observation wells in the command area. Knowing the grid-wise groundwater recharge and pumping, net recharge or pumping at each grid has been worked out. For use in groundwater model, pumping/recharge values have been aggregated from a grid-size of 24 m to a grid-size of 480 m. The pumping/recharge values of different weeks during a month have been accumulated and then imported in Visual MODFLOW. The revised groundwater surface is used by the SWBM and CNSM for different weeks in the subsequent month. The models have been run in sequence covering for full Kharif crop season and groundwater levels in different observation wells at the end of Kharif season (October 15, 1998) have been estimated. Observed water levels in October in different observation wells are also available from field records and the same have been compared with simulated water levels. The graph depicting the simulated and observed levels in October is shown in Fig. 8.

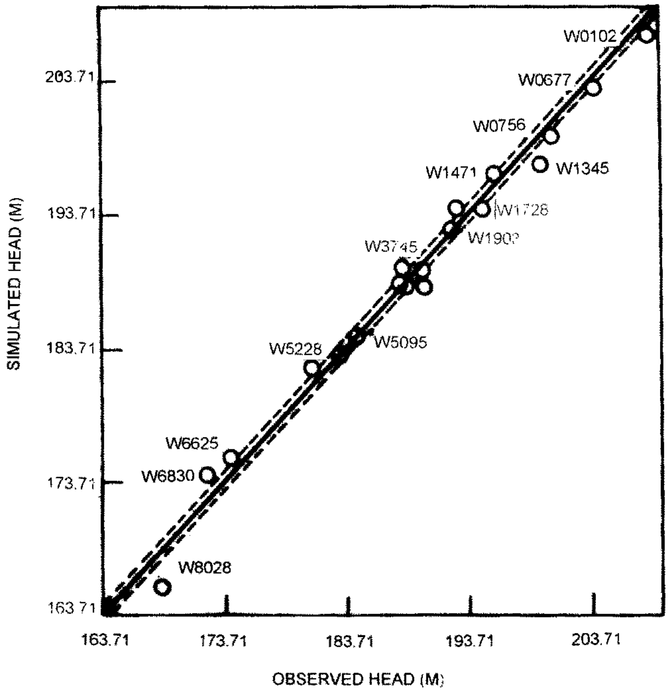


Fig. 8 Observed and simulated groundwater levels in Lakhaoti command in October, 98

It is observed from the graph that for most of the wells, the observed and computed levels match to a considerable extent. The residual mean of the observed and simulated levels comes out to be around -0.3 m with standard error of estimate as 0.314. The close match between observed and simulated water levels suggests that the spatial pumping and recharge estimates provided by the model application give true representation of the actual pumping/recharge in the command area. Since the grid-wise pumping and recharge values are directly related to the various components of the irrigation system such as soil water content estimation, canal water use, canal seepage losses, groundwater withdrawal etc., it can be concluded that various components of irrigation system evaluated by the SWBM represent the true picture of the command during a week.

Analysis of Different Scenarios of Irrigation Water Distribution

The year 1998 was a wet year with monsoon rainfall exceeding the normal rainfall by about 20% resulting in reduced irrigation demands in most part of the Kharif season (when canal water is supplied to the command). In CNSM, different allocation policies are invoked only when there is water deficit condition in the command and the irrigation demand at head exceeds the water availability. Otherwise, canal water is allocated as per the calculated demands in various segments. For this reason, a hypothetical case of water deficit condition has been assumed so that different allocation policies could be analyzed. For creating deficit conditions, the weekly rainfall in the year 1998 has been taken to be 60% of the actual weekly rainfall and the water availability at canal head is reduced to 75% of the planned supply in the canal system. Under these conditions, water scarcity in the command occurred in 12 out of 18 weeks (July 11 to October 15, 1998). The model has been run for the Lakhaoti system for 18 weeks (the period for which the canal system is planned to be run) starting from June 11, 1998. The model has been run for five times adopting a specific allocation policy for each run. Under each run with a particular allocation policy, the groundwater surface has been generated for each month using pumping/recharge estimations with Visual MODFLOW.

It has been observed that the head priority policy (Policy-1) results in maximum utilization of water for meeting irrigation demands as the canal seepage losses are minimum. However, since this policy does not consider the groundwater scenario in the command and allocates water in the head reaches, the total energy requirement (for groundwater withdrawal) for meeting full irrigation demands in the total command comes out to be 2596.10 million Kilowatt-hour (MkWh). On the other hand, policy of tail-priority (Policy-4) results in least use of canal water and most of the water is lost to canal seepage. Total energy requirement (for groundwater withdrawal) for meeting full irrigation demands in total command under Policy-4 comes out to be 2659.67 MkWh. Policy of conjunctive use (Policy-2) allocates the water in areas of deeper water depth and thus results in energy conservation, though seepage losses under this policy remain high. Under this policy, energy demand in total command comes out to be 2593.07 MkWh. Policy of proportionate supply (Policy-3) results in relatively higher amount of canal water utilization for meeting irrigation demands (as compared to Policy-2 and Policy-4) and lesser canal seepage. However, since no consideration is given to the groundwater scenario in the command, this policy requires higher energy for withdrawing groundwater (2607.02 MkWh in total command) for meeting full irrigation demands. In comparison to the results with four conventional policies, the results with policy of minimum energy demand (Policy-5) indicate that by judiciously selecting the canal network for operation during a week, it is possible to achieve a relatively higher utilization of canal water for irrigation with higher canal seepage and with least energy demand for withdrawing groundwater for meeting irrigation demands. Fig. 9 presents the canal seepage losses and Fig. 10 shows the energy demand in the total command under different operation policies.

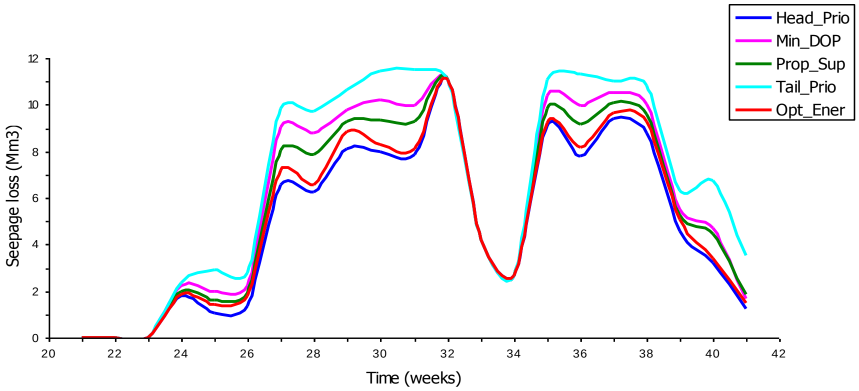


Fig. 9 Canal seepage losses under different allocation policies

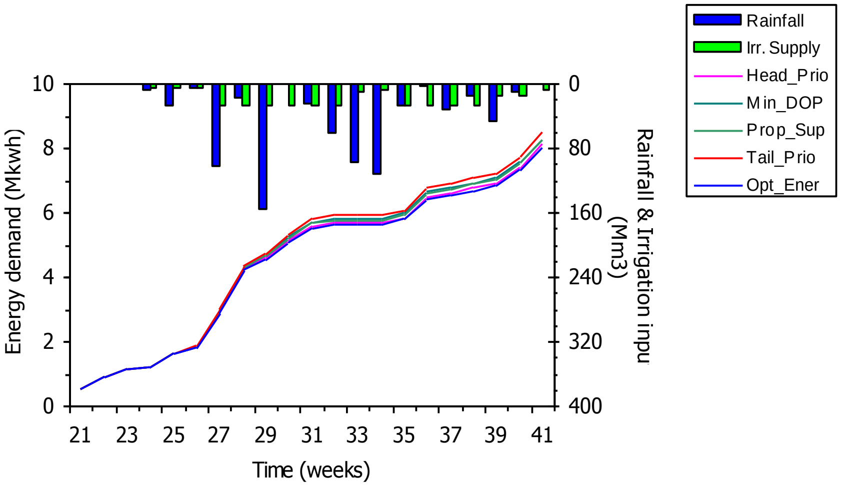


Fig. 10 Cumulative energy demand under different allocation policies

From Fig. 9, it is seen that canal seepage is higher with Policy-5 as compared to Policy-1 thus recharging higher amount of water in aquifer system. Still, energy requirement under Policy-5 is least (Fig. 10). By adopting Policy-5, energy demand in total command comes out to be 2568.82 Mkwh which is 27.28 Mkwh less than that for Policy-1. The reason for this large saving in energy is that Policy-5 supplies judiciously allocates the canal water taking in to consideration the depth of groundwater and the seepage losses in conveying canal water to larger distances. Policy-5 recharges the aquifer in areas which have relatively deeper groundwater table. It needs to be mentioned here that the amount of energy saving for total command area under policy-5 is case specific and depends on a number of factors such as irrigation demands, water deficit at head, cropping pattern, aquifer characteristics etc.

CONCLUSION

Integrated and judicious use of surface water and groundwater resources could play an important role in solving some major water-related problems (waterlogging and salinity) in irrigation commands. Further, the capability to acquire digital geographic data through remote sensing and handle large volumes of data using GIS has opened vast opportunities in developing realistic simulation models for irrigation water management. A conceptual continuous spatially distributed model for real-time conjunctive operation of an irrigation system has been developed and presented. The model integrates spatial variables related to water balance of cropped areas (crop type, soil type, rainfall, physiographic characteristics, groundwater conditions, canal network layout etc.) with the attribute details of existing crops, soils, and canal system and dynamic details of rainfall, reference crop evapo-transpiration, and actual canal network operation to rationally allocate the surface water and groundwater in canal command areas. The simulation model can be employed by the irrigation manager for real-time operation of canal network. The model can also be used to evaluate the long-term impact of adopting a specific water allocation policy or adopting a specific cropping pattern on the system performance and sustainability. The presentation of results in map form makes it easy for the users to visualize and comprehend the integrated situation in the command area.

REFERENCES

ASCE Task Committee on Irrigation Canal System Hydraulic Modelling. (1993). “Unsteady flow modelling of irrigation canals”, Journal of Irrigation and Drainage Engineering, ASCE, 119(4): 615-630.

Burton, M.A. and Farrier, D.R., (1986). “An introduction to CAMSIS, Computer aided engagement and simulation of irrigation systems”, University of Southampton, UK.

FAO. (1977). “Crop water requirements”, In: Doorenbos, J. and Pruitt, W.O. (Eds.), Irrigation and Drainage Paper 24, FAO, Rome, Italy.

Goel, M.K. (2003). “Spatially distributed simulation of an irrigation system”, Ph.D. thesis submitted to WRDTC, Indian Institute of Technology, Roorkee.

Government of India. (1999). “Ninth five-year plan 1997-2002 Vol. I and II”, Planning Commission, New Delhi.

Government of India. (1999). Reports of the National Commission for Integrated Water Resources Development Plan, New Delhi, 1999.

ICID-CIID. (2000). “Canal operation simulation models”, Compiled by J. Goussard, September 2000.

IRRISOFT. (2003). “Database on irrigation and hydrology software”, Internet site http://www.wiz.uni-kassel.de/kww/irrisoft/irrisoft_i.html run by Stein, T.M.

Krogt, W.N.M. van der. (1994). “OMIS: a model package for irrigation system management”, In: Irrigation Water Delivery Models, Proceedings FAO Expert Consultation, October 1993, Rome. Water Report 2, FAO, Rome.

Lenselink, K.J. and Jurriens, M. (1992). “An inventory of irrigation software for microcomputers”, ILRI, Wageningen, The Netherlands.

Makin, I.W. and Skutsch, J.C. (1994). “Software of management of irrigation systems”, In: Irrigation Water Delivery Models, Proceedings FAO Expert Consultation, October 1993, Rome. Water Report 2, FAO, Rome.

Malano, H.M. (1994). “Irrigation main system operation model (IMSOP): Case study and integrated computerization framework”, In: Irrigation Water Delivery Models, Proceedings FAO Expert Consultation, October 1993, Rome. Water Report 2, FAO, Rome.

Mateos, L., Lopez-Cortijo, I. and Sagardoy, J.A. (2002). “SIMIS: the FAO decision support system for irrigation scheme management”, Agricultural water management, 56: 193-206.

Ministry of Water Resources, Govt. of India, 2002. National water policy. April, 2002.

Mujumdar, P.P. (2002). “Mathematical tools for irrigation water management: An overview”, Water International, 27(1): 47-57.

Nayak, B.B. (1990). “Groundwater modeling for Lakhaoti branch command area”, unpublished dissertation for M.E. (WRD), University of Roorkee, Roorkee.

AUTHORS’ BIODATA

M.K. Goel is currently working as Scientist “E1” at the National Institute of Hydrology, Roorkee, Uttaranchal, India [Email: mkg@nih.ernet.in]. While working in the Water Resources Systems Division of the Institute, his area of interest include analysis of water resources systems, water management in command areas, reservoir sedimentation, and remote sensing and GIS applications in water resources.

S.K. Jain is currently working as Scientist F and Head, Water Resources Systems Division at National Institute of Hydrology, Roorkee, Uttaranchal, India. [Email: skj@nih.ernet.in]. He is involved in R and D activities related to surface water, water resources systems, etc. He has more than 23 years of experience in these fields. He has published 105 papers and has co-authored two text books.

U.C. Chaube is presently working as Professor in Water Resources Development and Management, Indian Institute of Technology - Roorkee, Roorkee 247667, Uttaranchal, India [email: umeshfce@iitr.ernet.in]. His areas of interest mainly include analysis of water resources systems and irrigation water management.