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WATER RESOURCES PLANNING MODELING FOR EFFICIENT MANAGEMENT OF IRRIGATION CANAL

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Abstract
In the last years the spreadsheet-based models are widely applied for water resources planning and management. In this report, a model for planning water allocation from irrigation canal is presented. Algorithm based on the water balance which allows for allocation of available water resources of the source according to water requirements of crops in irrigated area, considering current technological constraints was developed and implemented in Excel environment. An existing canal was as a case study. The spreadsheet-based model provides support for efficient management of the irrigation canal.

Keywords: irrigation canal, water allocation, planning, spreadsheet-based model

Introduction

Planning of water allocation in irrigation canals is an important managerial activity aimed efficient use of water for irrigation, minimizing yield losses of the irrigated crops due to water deficit and water stress, also preventing over supply and the negative outcomes such as water logging and salinization agricultural land.
Using the optimization methods and computers, the operation of irrigation canals can be planned effectively. Last decades many models based of the integer linear programming and mixed integer linear programming techniques have been developed for solving the problem of optimal water allocation in irrigation canal (Anwar et al., 2001; Ramesh et al., 2009; Santhi et al., 2000). By reason of certain limitations in their formulation few of the developed models were used for water resources planning and management. For practical use, computer implementation of the planning algorithms is good to be done in an accessible manner for use of the engineering staff in charge of operational management of irrigation system (Steele et al., 2010). An alternative is the software application EXCEL, which as part of Microsoft Office is widespread and required basic computer knowledge.
In this paper a model for planning water allocation from run-of-the river irrigation canal is presented. Algorithm based on the water balance which allows for allocation of available water resources of the source according to water requirements of crops in irrigated area, considering current technological constraints was developed and implemented in Excel environment. The model was validated for an existing irrigation canal.

Material and methods

Water delivery network of the most of the existing irrigation systems consists of main canal, which is flowing all irrigation season and distributaries canals, which are controlled periodically for need of delivery of irrigation water to its command area. As water requirements of the agricultural crops are varied in the different growth stages, total of the days of the irrigation season is divided to the equal time intervals, a length of a week or a decade (10 days). Water distribution schedule is prepared on any day during the time interval that enables allocation of available water in terms of actual irrigation water requirements considering the technological constraints.

Mathematical formulation of the model
The planning model works on daily basis and 10-days irrigation period. As the main canal is feeding variable river discharge, the river flow is measured on any day of the time period. Available net water discharge (daily supply at

the head of main canal minus losses in main canal) is allocated to the distributary canals to fulfill their demands in terms of water for irrigation of the crops.

For proper execution of the plan of water supply of manually operated distributary canals, it is essential that the canal operation is to be simple. In the present operation scenario, distributary canals will be running at full, half or nil capacity on every day during the irrigation period. To keep daily water balance in the main canal one of the canals will be running in variable supply (Ramesh et al., 2009).

Objective function

The objective function is defined as maximization of the total supply to the distributary for the entire irrigation period. Mathematical representation of the objective is:

$$\text{Max} \sum_{k=1}^{10}\left(\sum_{\substack{i=1\\ i\neq l}}^{N} Q_{ik} + Q_{lk}\right)$$

where k = day number, N= distributary canals number, i = the distributary canal number, l = distributary canal with varied supply number, Q_{lk}= daily supply in the l^{th} distributary canal on k^{th} day (m^3/s), Q_{ik}= daily supply in the i^{th} distributary canal on k^{th} day(m^3/s).

$$Q_{ik} = \begin{cases} 0 & \text{when } i^{th} \text{ distributary is closed on } k^{th} \text{ day} \\ 0.5q_i & \text{when } i^{th} \text{ distributary is half open on } k^{th} \text{ day} \\ q_i & \text{when } i^{th} \text{ distributary is fully open on } k^{th} \text{ day.} \end{cases}$$

where q_i= capacity of i^{th} distributary canal (m^3/s).

In daily allocation of the net available irrigation water at the head of the main canal to the distributaries should be kept the following technological constraints.

Main Canal Supply Constraint

To ensure the balance of water amounts in the main canal the sum of supplies to distributary on any day should be less than or equal to net daily supply in the main canal:

$$\sum_{\substack{i=1\\ i\neq l}}^{N} Q_{ik} + Q_{lk} \le Q_{vk} \quad \text{k=1,2…….10}$$

where Q_{vk}=net supply in the main canal on k^{th} day.

Distributary canal demand constraint

The sum of daily supply of the distributaries for the irrigation period should be less than or equal to demand for 10– day period.

Mathematical representation of this constraint is:

$$\sum_{k=1}^{10} Q_{ik} \le D_i \quad \text{i =1,2,…….N}$$

And ≠l (3.1)

and for the distributary canal with variable supply:

$$\sum_{k=1}^{10} Q_{lk} \le D_l \qquad (3.2)$$

where D_i= demand for i^{th} distributary canal for 10–day period (m^3/s), D_l = demand for i^{th} distributary canal with varied supply for 10–day period (m^3/s).

Canal capacity constraint (1)

The water supplies to canals should not exceed the capacity of the canals on any day during the time period.

$$\begin{aligned} Q_{vk} &\le Q_{v\max} \\ q_i &\le q_{\max i} \end{aligned} \qquad (4)$$

where Q_{vmax}= design capacity of the main canal(m^3/s), q_{maxi}=design capacity of the i^{th} distributary canal (m^3/s).

In addition the distributary canal with variable supply should be supplied discharge at least equal to half design capacity to maintain sufficient flow depth in the canal. This limitation is expressed as follows:

$$\frac{q_{\max l}}{2} \le Q_{lk} \le q_{\max l} \quad \text{k=1,2,……..10 (5)}$$

These equations and constraints constitute a mathematical model of plan of supply and distribution of water in irrigation canal. Since an optimization problem is formulated the solution is an optimal water allocation plan which enables water supply of distributaries canals in accordance with the water requirements of the irrigated crops.

In this study an approach to be found in Excel environment an approximate solution for the optimization problem (1)-(5) is adopted. (2)

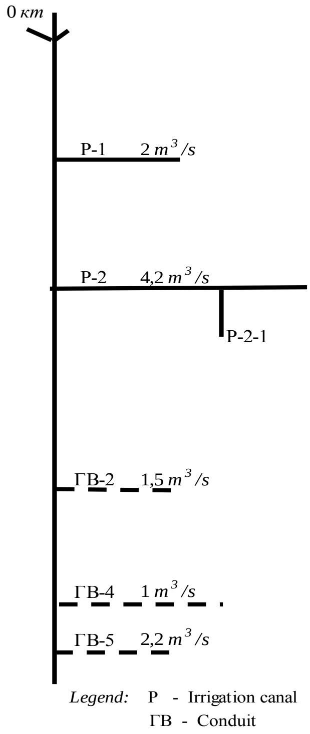

Figure 1. Layoutof the main canal of "Stryama-Chirpan" Irrigation system

Results and discussion

The spreadsheet model for operational planning of supply and distribution of water was developed and validated with data main canal "Stryama-Chirpan" irrigation system (Figure 1). The water source for this irrigation system is the Stryama River. The main canal works during the irrigation season from May to October and irrigates 1,843 *ha* agricultural area planted with rice, corn and vegetables. The canal has five distributaries. Water for rice fields is supplied by two open canals. Three conduits are located on the canal course. Details of the distributaries have been given in Figure 1.

The proposed algorithm based on the water balance was built in this table using Excel capabilities for consecutive estimates and available logic functions. No Visual Basic macros were used for the model development in Excel environment. The only macro was designed to reset the table before any new estimate thus provides an opportunity for repeated use of the table. The spreadsheet layout is shown on Figure 2.

A	B	C	E	K	L	M	N	O	P	Q

WATER ALLOCATION PLAN OF MAIN CANAL OF "STRYAMA- CHIRPAN" IRRIGATION SYSTEM

Day	River Discharge, m^3/s	Distributary №	1	2	3	4	5	Canal outflow, m3/s
		Net supply at the head of main canal , m^3/s	Distributary canal capacity, m3/s					
			2	4.2	1.5	1	2.2	
21-Jun	8.35	6.15	1.95	4.2	0.0	0.0	0.0	0.0
22-Jun	10.07	7.87	2.0	4.2	0.0	0.0	1.1	0.6
23-Jun	12.06	9.86	2.0	4.2	0.0	1.0	1.1	1.6
24-Jun	12.06	9.86	2.0	4.2	1.5	0.0	0.0	2.2
25-Jun	11.00	8.80	2.0	4.2	0.0	0.0	0.0	2.6
26-Jun	7.50	5.30	1.1	4.2	0.0	0.0	0.0	0.0
27-Jun	7.50	5.30	1.1	4.2	0.0	0.0	0.0	0.0
28-Jun	7.50	5.30	1.1	4.2	0.0	0.0	0.0	0.0
29-Jun	7.50	5.30	1.1	4.2	0.0	0.0	0.0	0.0
30-Jun	7.50	5.30	0.0	4.2	0.0	0.0	0.0	1.1
Min river discharge, m3/s		Total Supply, *m3/s*	14.35	42.0	1.5	1.0	2.2	RESET
	1.7	Demand, m^3/s	14.15	42.00	0.97	0.78	1.39	
Canal losses, m3/s	0.5	Deviation, %	1.4	0.0	53.9	28.6	58.4	

Figure 2.Spreadsheet layout for planning of water allocation from main canal of "Stryama-Chirpan" Irrigation system.

The input data needed to start the calculations are daily river discharge, minimum river flow rate, canal losses, demands of the distributaries canals for 10–day period (m^3/s), defined on the basis of net irrigated norms of irrigated crops. Input data are entered in the boxes from the table, colored in purple.

The net supply values at the head of the main canal for any days of the irrigation period are located in the third column of the table. In the next columns each of the distribution canals has a box in which the values of supply for each day of the interval are entered. The head cell of this box contains maximum capacity of the distributary.

Preparation of the water allocation plan

For each day of the period initially the daily measured value of river discharge is entered and on its basis the net daily supply at the head of the main canal is calculated as the difference of measured river discharge minus the sum of the amount of canal losses and the minimum river flow rate. Then selection of the operational discharges of distributary canals is made.

When entering a value of operational discharge of a distributary canal, the water balance in the main channel is monitored from the result in the cell in the last column of the table "Canal Outflow ". In obtaining a negative result, the supply to the canal should be reduced or stopped.

Based on the entries of distributary canals on any day of the period, water discharge value of the distributary canal P-1, which is assumed to operate at variable supply is automatically calculated from the water balance equation and in accordance with the restrictions (2) - (5). Implementation of the target (1) is monitored by calculating the deviation of water delivery to each distributary from the requested.

The model was tested with data for flow of the Stryama River for the lastten days of June. At the beginning of the period the flow rate of the river is high 8-10 m^3/s, but in the last days the main canal can be supplied less water discharge 5.3 m^3/s

The model shows how to manage distributaries in the 10-day period to fulfill the requests. Request of the canal P-2 is satisfied, when it runs at maximum capacity during the irrigation period. Request of conduits ГВ-2, ГВ-4 и ГВ-5 are met for 3consecutive days at work at half capacity. The obtained delivery schedule for the canal with a variable supply is shown on Figure 3. Its implementation does not require frequent changes of the regulating structure at its head. Total, the accuracy of meeting the requests of canals is relatively high - 4.9%. For the conduits the deviations are greater. This is due to the fact that the canals are oversized relative to the actual needs of the water for irrigation. Also, assuming that the distributaries work completely open or half capacity brings approach in determining the solution of the problem for optimal operational planning.

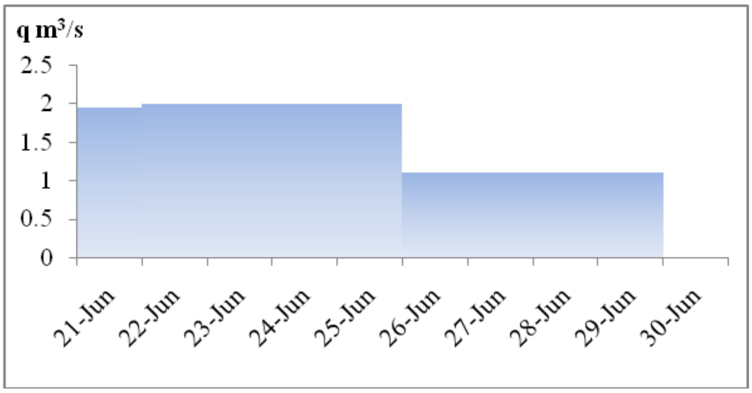

Figure 3. Delivery schedule for the canal with a variable supply

It is appropriate to choose the days that water will be delivered in the canals that do not work continuously close to the dates for watering the crops cultivated in the command area of the distributary. In order to minimize operational losses of the water is also appropriate to adopt operational sequence of distributaries canals "down-up" as the water supply to the canal up stream can immediately begin after stopping the supply of canal downstream.

Conclusions

The main objective of the modeling in this study is daily allocation of the net available irrigation water at the head of the main canal to the distributaries in accordance with water requirements and technological constraints. The model developed was validated for existing irrigation canal. Its use for preparation a schedule for distribution and supply of water in the irrigation canal does not create particular difficulties and satisfactory results were obtained. The spreadsheet-based model can provide support for efficient management of the irrigation canal.

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