NATURAL RESOURCES SYSTEMS PROGRAMME

***PROJECT REPORT*[1]**

DFID Project Number

R7830 and R7839

Report Title

A simple water balance tool for participatory evaluation of water management options in the canal command.

Annex Bvi of the Final Technical Report of projects R7830 and R7839.

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Organisation

Rothamsted Research and ICAR Research Complex for Eastern Region

Date

2004

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[1] This document is an output from projects funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

CONTENTS

Summary

In a canal command, assessment of different components of the water released from the canal offtakes is very important to ensure optimum water utilization in the canal command. A MS Excel spreadsheet based model has been developed to provide a tool for appropriate water management in the canal command. Although the model has been developed keeping specific conditions of a distributary (RPC V) of Patna Main Canal (PMC) under the Sone canal system in Bihar, yet it can conveniently be developed for the other systems also. During kharif season, conventionall the distributary has a 15 day cycle with 10 days on and 5 days off. Hence, canal needs to be operated such that water is delivered to all the fields in the entire command. The canal operation involves the decisions at the canal operators levels which are: 1) how much water has to be diverted to the distributary at the offtake from the PMC ?, 2) what proportion of the water reaching the minor offtake, be diverted to minor and feed Reach II simultaneously?, and 3) when the outlets need to be closed?. Apart from the water application to the fields for the crop production (including deep percolation), the other components of the water are seepage loss (in distributary / minor and water courses) and surplus water flow from end of Reach II and Tangrila and excess water delivery from the outlets. The main objective of the canal operation scheduling is to maximize the water allocation to the fields while minimizing the unproductive losses through surplus or excess flow from outlets especially during water scarcity periods. The model computes all the components of the water delivered with options to rectify the decisions for the canal operations. During certain periods of water scarcity or non-availability, the model also provides enough information on spatial (outlet command wise) and temporal (daily basis) water demand that needs to be fulfilled using other sources. Conventionally, the rice transplanting is staggered in the command to minimize the gap between water need and water availability. The model also considers these important aspects and estimates the temporal crop water demand. Offline linkage of the spreadsheet output with GIS environment was made to present the results spatially. Results have been analysed under various scenarios and presented graphically as well as on GIS based maps. Feedback on water balance tool suggests that it is helpful in decision making about adequate release of water with a view to minimize its wastage. This decision support tool is considered a dialogic tool as it facilitates more democratic dialogue with field functionaries and the farmers. It has value, not only in awareness and knowledge sharing to support on farm water management (OFWM) decisions at the distributary level, but also in providing essential information to assist canal management decisions.

1.0 Introduction

Improper canal operation and mismanagement of water in command mostly results in high water losses either through surplus flow or water deficit. The uncontrolled flow of water from outlets further aggravates the conditions as it delivers excess water in head reaches while middle and tail reach fields remain water starved. Such conditions lead to several drawbacks e.g. reduced yield and quality of produce, creation of water logged conditions in the low land areas, increased water related disputes in the society, etc. As a result, the poor farmers and labourers suffer the most in particular, while whole society including landless directly or indirectly associated with agriculture and resource rich farmers, suffer in general. Water management at the lower level e.g. Water Users Association (WUA) becomes difficult and may often lead to failure of participatory irrigation management (PIM). Hence, it is important that canal operation and water release, allocation and distribution should be equitable and based on actual water requirement in order to realise maximum benefits to the society.

Under the DFID funded project (NRSP R-7830), such issues were raised during dialogue with the participating farming communities, WUA and canal managers related to the project site – the command of RP Channel V, a distributary of Patna main canal under Sone canal system.

In the course of dialogue with the water users (farmers and sharecroppers), WUA and canal managers, the water regulation at each outlet level and delivery of water in the distributary were found important issues. The water delivery in the distributary from main canal was not as per requirement of the water in the distributary command, but fluctuated widely The outlets were not being regulated as per the need, as there was no provision for gates to control flow of water. However, the outlets were being closed using mud and straw with substantial seepage. The problems related to water management, which directly or indirectly affect poor farmers, are:

1. Inequitable water distribution across the command: Due to higher water intake at the head and middle reaches (by putting obstructions across the flow), the tail reach farmers rarely get water during peak water demand periods.
2. Waterlogging: Indiscriminate release of water from the outlets results in overflow from the outlets, which creates waterlogging in the lower reaches of most of the outlet command.
3. Low production level: The overall production level is low all over the command owing to excess water application (in upper reaches) and deficit water application (in lower reaches).
4. Water related disputes: Such conditions create several disputes and unrest in the community leading to poor productivity of land and water resources.

Resource rich farmers supplement water demand from groundwater lifting, but the resource poor farmers suffer the most due to water scarcity, and they depend on outside income generating opportunities to improve livelihood. Hence, to improve the conditions, it is important to have controlled water flow from outlets and delivery of water in distributary as per demand in the command. But, if the outlets are to be controlled, what should be the policy? During the discussion with the WUA and canal managers, necessity of a simple operational tool was felt to provide sufficient information on operation of outlets and canal flow regulation for implementation of efficient on farm water management technologies/strategies. In view of this, efforts were initiated to devise a simple tool to help in decision making for improved water management at different levels of management such as farmers, WUA, canal managers, politicians and bureaucrats as shown in Fig 1.

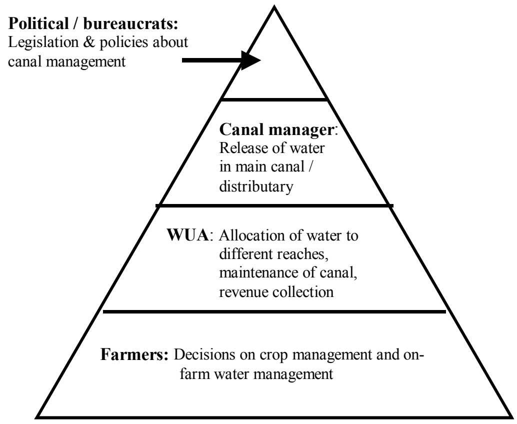


Fig. 1 Pyramid of flow of decisions under PIM.

Based on the capacity building by the IWMI, Colombo, MS Excel spreadsheet was considered as one of the suitable media to develop such tool, because it was easy to demonstrate the effect of various decisions on emerging water distribution scenarios. The tool helps in interactive presentation of results (numerically as well as graphically) of any change in the decision. Further, it is easy to transfer the information and database in GIS environment to present information with spatial significance, i.e. on map of the command in order to study spatial variations.

This working paper highlights and elaborates the process involved in the development of such working tool and its utility.

1.1. Identification of essential features of desired tool

In order to evolve appropriate water management strategies in the command area, it is important to have enough information on the following

- Spatial and temporal water requirement in the canal command.
- Actual water delivered to the fields in different outlet commands after seepage loss.
- Water to be released in the canal (distributary or minor) keeping in view the availability such that gap in availability and requirement is minimized resulting in minimum surplus flow as well as water logging conditions.
- Schedule of outlets flow regulation for meeting water demand in all the fields under the outlet command with a view to minimize surplus flow as well as seepage.

In order to have above information, the water managers need to carry out long calculations with temporal variation because the temporal water requirement varies with the rainfall occurrence, staggering of crop planting, changes in cropping pattern, etc. Practically, the water in the canal command is never released in accordance with the water requirement, which mostly leads to a large portion of the command either water congested or water deficit. On the other hand, the outlets are not regulated as per the water requirement of the outlet command area. This also results in more water withdrawal by the outlets located in the head reaches, and the tail enders remain water starved. Hence, the tool sought to be developed, should have capability to generate real time information based on the prevailing climatic conditions and land utilisation pattern of the area. During dialogue with canal managers, it was pointed out that water availability in the canal varies with rainfall occurrence and it is not always possible to release water in the distributary as per the demand. This further complicated the development of tool, and required to generate information under deficit or excess water release from main canal. Bifurcation of discharge available at offtake of minor (point B in Fig. 3) is another important decision for distribution of water in the command of Tangrila and Reach II.

Based on the identified features as above, development of tool was initiated under the Excel Spreadsheet environment.

1.2 Description of the target area

The decision support tool was developed for the command of RPC V, a distributary of Patna main canal under Sone Canal System. In this section, a brief description of the project area is presented.

Patna Main Canal System

Sone canal system is one of the oldest irrigation systems operating since 1874. The Eastern link canal originates from a barrage located at Indarpuri (in Aurangabad district, Bihar) and Patna Main Canal (PMC) emanated from the Main eastern canal at Barun (8 km from the barrage). It is 78 miles (124.8 Km) long and has 12 reaches (portion between two consecutive locks) and 12 falls (Table 1). The total culturable command area is 164,443 ha, out of which 74% is irrigated during Kharif season only. The other features of the PMC e.g. reach-wise relative distance (RD), GCA, CCA, and hydraulic data are given in Table-1.

Table 1: Details of the Patna Main Canal

Fall / Reaches	Location (miles)	Existing Fall (ft)	RD miles		GCA (ha)	GCA (ha)	Discharge (cusec)	Bed width (ft)	FSD (ft)	Bed slope
			From	To						
1. Barun	0.00	0.00	0.00	11.75	10782	8846	2960	134	7.5	1/5533
2. Dehra	11.75	8.09	11.75	14.50	17532	14383	2452	128	7.5	1/7500
3. Tejpura	14.50	13.46	14.50	20.95	25426	20860	2110	112	7.5	1/7500
4. Sipaha	20.95	10.56	20.95	26.03	16124	13230	1817	104	7.5	1/8000
5. Agnoor	26.03	10.00	26.03	30.00	664	546	1650	84	7.5	1/6654
6. Belsar	30.00	10.25	30.00	36.00	11206	9194	1400	80	7.3	1/7500
7. Walidad	36.00	12.77	36.00	42.26	12384	10159	1191	72	7.0	1/7500
8. Arwal	42.26	10.50	42.56	48.26	15328	12575	905	60	6.5	1/7500
9. Mahabalipur	48.26	9.20	48.26	54.00	38446	31541	695	50	6.3	1/ 7000
10. Rani Talab	54.00	8.24	54.00	61.75	10025	8224	500	38	6.0	1/6500
11. Bikram	61.75	10.00	61.75	68.50	18010	14776	250	20	6.0	1/7000
12. Naubatpur	68.26	12.15	68.50	78.00	10513	8626	60	20	6.0	1/7000
13. Khagaul	78.00	NA	NA	NA	NA	NA	NA	20	Surplus to Ganges	

GCA – Gross command area; CCA – Culturable Command Area; FSD – Full Supply Depth

Fig.2 presents the line sketch of PMC and its distribution network between 36 and 78 miles and location of RPC-V, the project area.

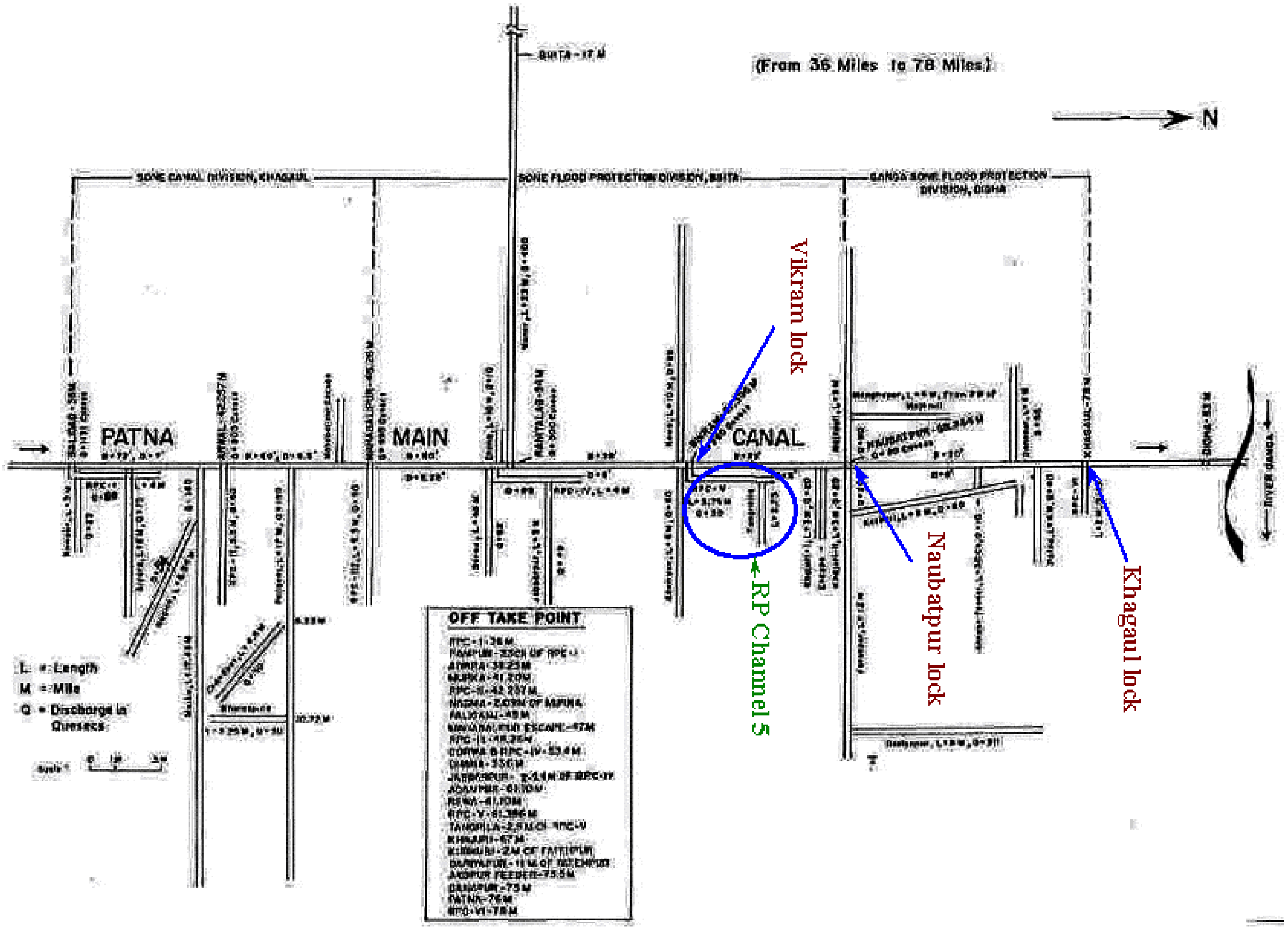


Fig. 2. Line Sketch of Patna Main Canal (from RD 36 to 78 miles) and location of RP Channel V command

Right Parallel Channel – V (RPC V)

The distributary RPC-V originates from the gated diversion at 61.396 miles (RD) on PMC about 0.78 km before Bikram lock (fall). The command area (25°25’40” - 25°27’40” N, 84°52’40” – 84°56’45” E) covers about 21 villages, some of which lie partially in the command (Fig. 3). RPC V is 6.1 km long, runs parallel to PMC on right side and again meets PMC to discharge the surplus flow (points A-B-C in Fig.3). At 5.133 km from the offtake (at B), a minor Tangrila offtakes from the RPC V which has 3.8 km length. Hence, it has three parts, each with distinct hydraulic characteristics (Fig. 3):

- ✓ AB – Main reach or Reach I;
- ✓ BC – Reach II; and
- ✓ BD – Tangrila Minor.

The hydraulic features of the three parts are given in Table 2.

Table 2: Hydraulic features of Right Parallel Channel V distributary.

Reach	Command area (ha)		No. of outlets	Length (Km)	Design Dischrg (Cusec)	Depth (ft)	Bed Width (ft)	Bed Slope	Side Slopes	Free Board (ft)
	Kharif	Rabi								
Reach I	549.32	303.71	29	5.133	50	3.50	6.00	1:2500	1:1	1.50
Reach II	38.65	24.77	5	0.914	20	2.50	4.00	1:2500	1:1	1.50
Tegrila	246.40	139.22	24	3.813	22	2.75	6.00	1:2500	1:1	1.50
Total	834.37	467.70	58	9.860						

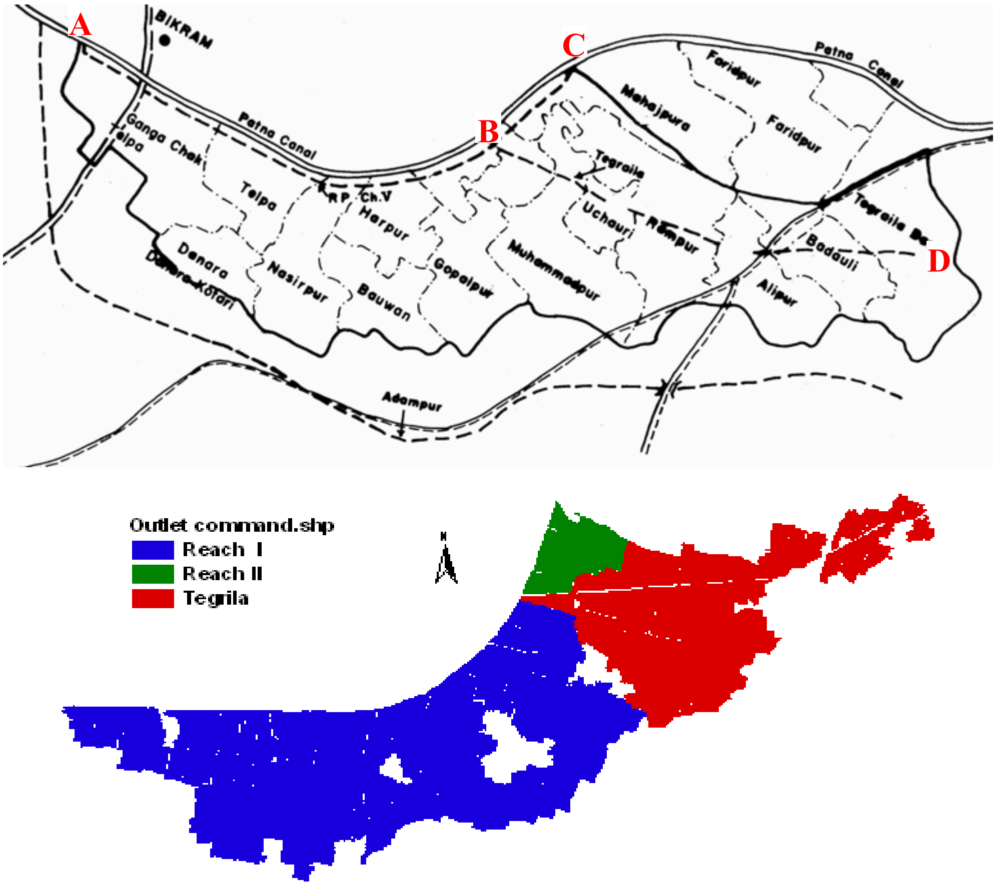


Fig. 3. Map of the command area of RPC V distributary: (a) Location of offtake (A), Tegrila offtake (B), end of RPC V (C) and end of Tegrila (D) and village boundaries; (b) GIS mapped

command area of three reaches

2.0 Materials and Methods (Spreadsheet Model Development)

Excel spreadsheet based modelling tool was developed using water balance approach. The command of RP Channel V was divided into three sections i.e command fed by Reach I, Reach II and Tangrila minor. Command of each outlet was considered as a unit for assessing the water demand, water release and deficit. The water released in the distributary has three major components: (i) water delivered to fields; (ii) water lost into seepage; and (iii) water flown out of command as surplus flow. Other components e.g. evaporation from the water surface, etc. were neglected. However, further division of total water delivered to the field (including rainfall) into its components e.g. deep percolation, evapo-transpiration, runoff (due to excess rainfall), etc. has been considered while estimating the water requirement at the outlet command level.

In the present model, only kharif season with rice cultivation in the entire command is considered. The major assumptions in model development are:

- The Kharif season starts on 1st June with sowing of nursery.
- Nursery is sown only in 10% of total rice area.
- The period of transplanting is 25th June to 26th August, which was grouped as per standard meteorological weeks (26th to 34th). However, it was assumed that harvesting of all crops takes place in the month of November and no irrigation is required after end of October.
- Depth of irrigation applied such that the total ponding depth becomes 75 mm;
- Height of bunds around rice field is150 mm.
- ET values are used irrespective of crop stage while accounting for staggering of transplanting.
- Weekly irrigation (two irrigations per irrigation cycle of 15 days) is followed during entire season.
- Although the sowing period is varying, but the maturity is similar for whole of the command area. This is a reasonable assumption with growing of varieties of short duration for late transplanted crop and to minimise the effect of temperature lowering on grain filling.

2.1 Collection of Input Data

Information on canal and command area

Hydraulic design parameters (Table 2) of the distributary and its outlets were collected from the Irrigation Department. There are 58 outlets on the three parts of the distributary. Features of the outlets are given in Table 3. The outlets are provided on the distributary in the form of pipes of 3", 6" or 9" diameter made up of pre-casted cement concrete. These pipes are approximately 5 m long, laid across the right side embankment of the RPC V distributary and on both sides of Tangrila. In RPC V distributary pipe outlets are located at elevations varying between 0.12 and 0.76 m above the bed level of the distributary (Table 3). The water-courses carry water from the outlets to the fields and are of varying lengths with minimum of 115 m to 3615 m. In general, shorter watercourses have command area nearer to the distributary, while longer have command area at some distance and no water is taken from these for nearer fields. Similarly, the command of the watercourses is ranging between 0.91 and 53.25 ha.

Table 3. Hydraulic data of different outlets in three parts of the RP Channel V distributary

Reach	Outlet No.	Height above bed (m)	Size (inches)	RD (m)	Length of the water courses (m)	Command area (ha)
Reach I	OL1	0.76	6	17	338	15.65
Reach I	OL2	0.46	9	179	441	7.49
Reach I	OL3	0.30	6	300	175	4.19
Reach I	OL4	0.30	9	629	859	23.65
Reach I	OL5	0.37	6	1036	550	8.68
Reach I	OL6	0.46	6	1264	714	21.65
Reach I	OL7	0.37	6	1560	500	9.92
Reach I	OL8	0.30	6	1728	2690	1.15
Reach I	OL9	0.26	6	1731	665	28.65
Reach I	OL10	0.30	6	1794	813	14.41
Reach I	OL11	0.37	6	1949	458	8.40
Reach I	OL12	0.26	9	1971	3388	48.77
Reach I	OL13	0.30	6	1975	1400	18.28
Reach I	OL14	0.46	6	2306	1400	12.22
Reach I	OL15	0.46	9	2562	800	14.79
Reach I	OL16	0.37	6	2933	1785	34.07
Reach I	OL17	0.30	6	3297	450	7.46
Reach I	OL18	0.26	9	3417	1288	45.27
Reach I	OL19	0.30	6	3530	115	1.34
Reach I	OL20	0.26	9	3708	2525	53.25
Reach I	OL21	0.30	6	3909	600	32.46
Reach I	OL22	0.46	6	4046	430	32.54
Reach I	OL23	0.26	6	4100	1125	30.47
Reach I	OL24	0.24	6	4108	1435	18.82
Reach I	OL25	0.49	6	4387	159	4.35
Reach I	OL26	0.26	6	4451	1025	20.12
Reach I	OL27	0.23	6	4707	162	14.41
Reach I	OL28	0.26	6	4923	375	10.28
Reach I	OL29	0.21	6	4988	385	6.58
Reach II	OL30	0.15	6	5142	306	9.59
Reach II	OL31	0.18	6	5258	129	6.64
Reach II	OL32	0.21	6	5371	205	5.42
Reach II	OL33	0.18	6	5633	1025	13.52
Reach II	OL34	0.15	6	5827	128	3.48
Tegrila	TOL-1	0.30	6	5649	175	2.61
Tegrila	TOL-2	0.26	9	5713	3615	48.06
Tegrila	TOL-3	0.30	3	5714	175	2.69
Tegrila	TOL-4	0.33	6	5715	175	15.58
Tegrila	TOL-5	0.27	6	5715	1005	25.70
Tegrila	TOL6	0.23	6	6443	267	13.92
Tegrila	TOL7	0.18	6	6594	810	12.38
Tegrila	TOL8	0.26	6	6612	379	11.45
Tegrila	TOL9	0.20	6	6612	352	9.83
Tegrila	TOL10	0.23	6	6629	513	10.72
Tegrila	TOL11	0.26	6	7106	275	18.45
Tegrila	TOL12	0.20	6	7108	186	12.38
Tegrila	TOL13	0.15	6	7771	262	10.28
Tegrila	TOL14	0.20	6	7903	195	12.71
Tegrila	TOL15	0.18	6	8109	308	16.43
Tegrila	TOL16	0.15	6	8215	375	2.95
Tegrila	TOL17	0.18	6	8217	500	3.36
Tegrila	TOL18	0.15	6	8409	240	1.62
Tegrila	TOL19	0.14	6	8437	525	5.52
Tegrila	TOL20	0.15	3	8548	245	1.25
Tegrila	TOL21	0.12	6	8598	242	1.47
Tegrila	TOL22	0.14	3	8760	185	4.70
Tegrila	TOL23	0.12	6	8835	166	1.40
Tegrila	TOL24	0.12	3	8946	148	0.91

	Outlet No.	Height above bed (m)	Size (inches)	RD (m)	Length of the water courses (m)	Command area (ha)

During kharif (monsoon) season, 15 days cycle is followed in water release in the distributary with 10 days on and 5 days off. However, the actual release varies with time and discharge. Fig.4. illustrates the water release pattern during kharif 2001.

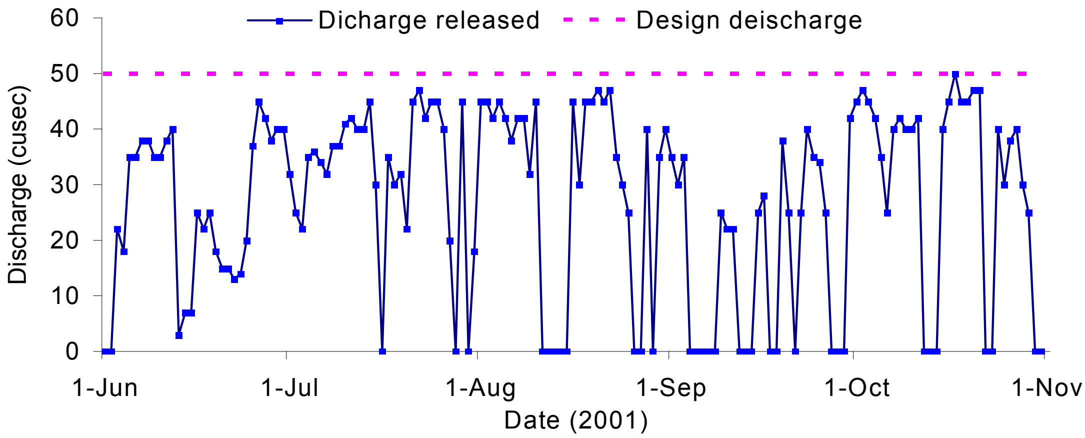


Fig. 4. Actual water release pattern in RPC-V from PMC during kharif 2001

Installation of the lysimeters

Lysimeters in the field

Irrigation Water Requirement

In order to estimate the irrigation water requirement, the information on water balance components at the field levels is needed. Since paddy is cultivated in submerged condition, the major components of water balance at the field level are: rainfall, evapo-transpiration (ET), deep percolation (DP) and runoff due to overtopping of the field bunds. Rainfall occurred in the command area was measured using rainguage installed in the command areas itself or measured at the meteorological laboratory at ICAR RCER Experimental farm, WLAMI Complex, Patna. For determining ET and DP, lysimetric studies have been carried out in the canal command area at three locations: (i) Aspura (head reach); (ii) Nisarpura (mid reach); and (iii) Bedauli (tail reach).

Three lysimeters were installed at each location as shown in Fig. 5. The water lost from the lysimeter of type A is the ET consumed for crop production. The water lost from lysimeter of type B is ET+DP, while the water released from the opening of type C is the ET+DP+runoff generated due to excess rainfall. The effective rainfall used for the crop production is the difference between actual rainfall and runoff. The rainfall was measured at the three locations using ordinary raingauge.

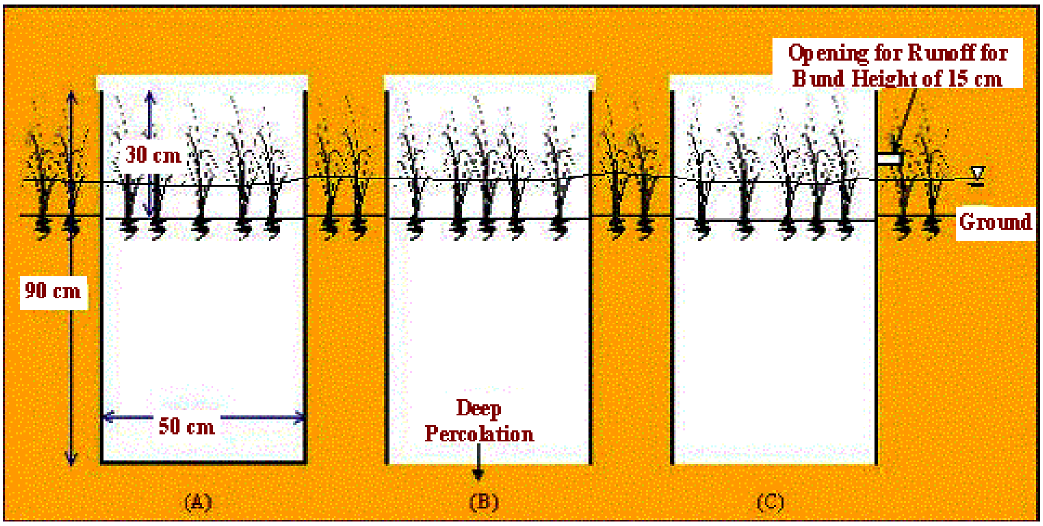


Fig.5 Set up of lysimeters in the rice field, (a) closed bottom; (b) open bottom; (c) open bottom with outlet at bund height (15 cm).

Figs. 6 shows the different components of field water balance. Using this information, the daily irrigation water requirement in each of the outlet command was estimated.

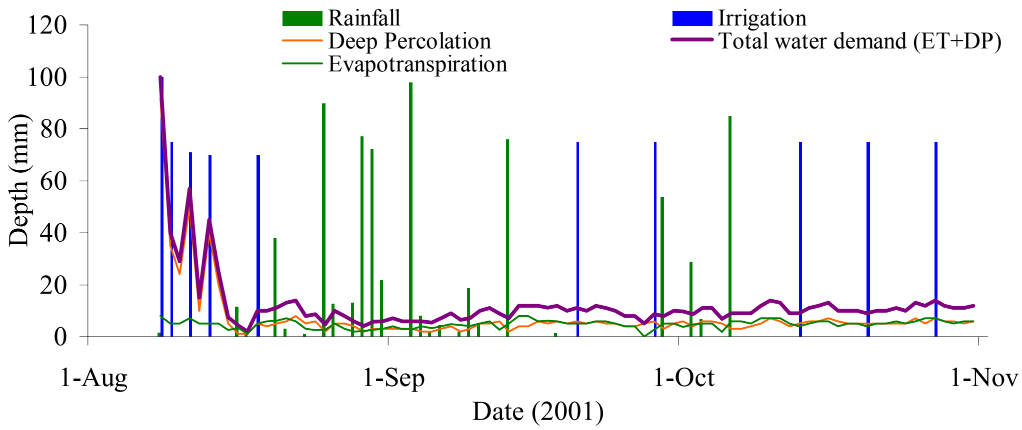


Fig. 6 Components of field water balance from lysimeters (Aspura)

Irrigation efficiency and Seepage

As no appropriate value of the water application efficiency is available, a value of 50% is assumed. WAPCOS (1988) reported the seepage rate of 0.005 m^3/day per m^2 of wetted perimeter. This value has been adopted to estimate the seepage loss in distributary and watercourses.

Rice crop calender

The earlier studies in the area show that normally the transplanting occurs in 26th to 34th standard meteorological weeks (Singh *et al.*, 2002) i.e. 25th June to 26th August (Fig. 7).

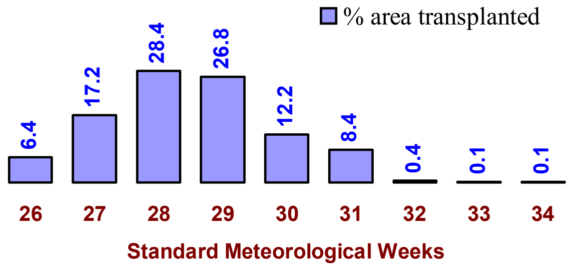


Fig. 7. Percentage of command area transplanted in the week

Hence, provisions are made in the model to stagger the transplanting of rice among the outlet commands, and the crop water requirement is calculated accordingly. Nursery has been considered in 10% of the total sown area in a particular week. Normally, 25-35 days seedlings are transplanted; hence, the nursery calendar with staggering is followed as given in Table 4. However, the week considered in the model is different from that of the standard meteorological week. For the modelling, 15 days cycle was considered which has been divided into two weeks (first of 7 days and second of 8 days). Accordingly, different activities (related to irrigation) in the crop season was divided with period of each activity in multiples of 15 days (Table 5).

Table 4: Staggered nursery and transplanting periods.

Met. Week No.	Transplanting Period	Nursery sowing Period
26	25-Jun -01-Jul	01-Jun - 07-Jun
27	02-Jul -08-Jul	
28	09-Jul -15-Jul	
29	16-Jul -22-Jul	08-Jun -15-Jun
30	23-Jul -29-Jul	16-Jun -22-Jun
31	30-Jul -05-Aug	23-Jun -30-Jun
32	06-Aug -12-Aug	01-Jul -07-Jul
33	13-Aug -19-Aug	08-Jul -15-Jul
34	20-Aug -26-Aug	16-Jul -22-Jul

Table 5 Crop calender

Crop Activity	Period	Days
Nursery	1-30 June	30
Land preparation	15-30 June	15
Transplanting	1-15 July	15
Development stage	16 Jul -14 Aug	30
Mid season	15 Aug - 28 Sep	45
Late season	29 Sep - 28 Oct	30
Total days in season		165

2.2 Procedures

The procedures used in estimation of water balance components and then linking it with spatial GIS data are described in this section.

Estimation of water balance

The water balance in the command area was worked out simply as

Inflow = *Outflow* + *Change in storage* (Difference in final and initial soil moisture content)

The change in soil moisture storage is supposed to be insignificant from the point of view of macro level water management analysis of the canal command, hence it is neglected.

The inflow can be given as

$$Infow = V_d + R \quad \ldots(1)$$

and outflow can be given as

$$Outflow = V_f + V_s + V_{sf} \quad \ldots(2)$$

where V_d is volume of water released in distributary; R is the rainfall occurred; V_f is water diverted to fields; V_s is water lost in seepage and V_{sf} is water in surplus flow. V_{sf} may further be given as

$$V_{sf} = V_{sf-d} + V_{sf-T} + V_{sf-wc} \quad \text{…(3)}$$

where d in subscript denotes seepage flow from end of the distributary, T for end of ***Tangrila***, and wc for end of all water courses.

At field level, the water balance is computed as

$$V_f + R = ET_c + DP + R_{off} \quad \text{…(4)}$$

where ET_c is evapotranspiration of crop; DP is deep percolation; and R_{off} is runoff due to overtopping of bunds of given height.

Estimation of hydraulic components of canal

The flow in the distributary was estimated using simple engineering expressions. Manning's equation was used to estimate flow (Q_d) in the distributary as

$$V = \frac{R^{2/3} S^{1/2}}{n} \quad \text{…(5)}$$

$$Q = V \, x \, A_d \quad \text{…(6)}$$

where V is the flow velocity in distributary, R is the hydraulic radius, S is bed slope and A_d is cross sectional area of the distributary flow. The value of 'n' was estimated from back calculation using the design values of hydraulic parameters. The values obtained are 0.0323 for main section, 0.0312 for Reach II, and 0.0471 for Tangrila minor, which are reasonably well under the conditions of unlined and less maintained channels.
Using the values of hydraulic parameters, discharges (Q) were calculated for different values of water depth (H). Power function was fitted to the data as

$$H = a.Q^b \quad \text{…(7)}$$

The function was used to determine H values for given values of Q. The coefficients a, and b were different for the three sections.
The outlets were made up of concrete pipes having diameters of 3", 6" or 9" and the friction loss in the pipe outlet (hs) can be given as

$$hs = \frac{4 f l v^2}{2 g d} \quad \text{…(8)}$$

where the values for friction coefficient f are approximated to 0.008 for 6" pipe and 0.007 for 9" pipe, Length l is 5 m, and flow velocity, v is given by

$$v = Cd\sqrt{2gh} \quad \text{…(9)}$$

Here Cd is a coefficient of discharge, g is acceleration due to gravity and h is the depth of water above centre of the pipe outlet. Eq. (9) subjected to condition: $H < h_o$ then hs=0, where H is total depth of water above bed of the canal, h_o is height of centre of outlet above bed of the canal.

The discharge from the outlets (Qo) having diameter d, and water head (h) at the entry point, was estimated using orifice formula as

$$Qo = Cd.\left[\frac{\pi}{4}d^2\right]\sqrt[2]{2.g.(h-hs)} \quad \ldots(10)$$

The value of coefficient Cd was taken as 0.60. Eq (10) is with the assumption – 1) always full pipe flow for all the heads (h>0). It can fail (actual discharge will be less) at the time when h<d/2 (radius of pipe). However, there will be pipe flow when h > (h-d/2) > 0 which is neglected. It is expected that the error will be minimised due to effect of one over another. Eq.10 is used with the condition h < 0 then Qo = 0

Seepage rate from the canal for a segment between two outlets (i^{th} and $i\text{-}1^{th}$)

$$Qs_i = s.WP_i.L_i \quad \ldots(11)$$

The bed width was assumed to be constant for each section of the distributary / water courses. For canal, the wetted perimeter (WP) varies with head of water (H) available at the i^{th} outlet that remains constant between segment (i-1) and i. For watercourse, it is simplified by taking average of WP at starting point and at end point with h=0 (i.e. WP=bed width). For distributary, $L_i=RD_i-RD_{i-1}$, where RD is relative distance from offtake of the distributary. While it full length of the watercourse. Condition: if no water flowing $Qd_i=0$ then $WP_i=0$.

Estimation of irrigation requirement

The total irrigation requirement (TIR) on i^{th} day for the crop was estimated as

$$TIR_i = ET_i + DP_i - R_i + R_{off},_i \quad \ldots(12)$$

The nursery is grown on 10% of the total area under outlet command, which requires two weekly irrigations during the first fortnight. From the second fortnight and onwards, full irrigation to meet the 15 days water demand was applied and estimated as

$$IR_i^{15} = \frac{A_i\left[\sum_{n=1}^{15} TIR_n\right]}{\eta} \quad \ldots(13)$$

where η = irrigation efficiency (assumed to be uniform throughout the command and was 50%), and A is the area of outlet command.

Matching water demand and supply

The Outlet operation was considered to be on daily basis i.e. for opening or closing of outlets, operator would visit once in a day only.

Discharge in the distributary (Qd) available at i^{th} outlet is

$$Qd_i = Qd_{i-1} - Qo_{i-1} - Qs_{i-1} \quad \ldots(14)$$

Volume of water delivered to the outlet command (after deduction of water course seepage, Qsw)

$V_i = (Qo_i - Qsw_i) * t$, where t = 86400 sec. …(15)

Balance of water to be delivered (Vb_i) in the subsequent days of the fortnight is

$$Vb_i^n = IR_i^{15} - V_i \quad \ldots(16)$$

The outlet is closed (Qo = 0) on the $(n+1)^{th}$ day when $Vb_i^n \leq 0$. However, the negative value of Vb_i^n is considered to be surplus flow from the outlets. The water flow in distributary after feeding last outlet in Reach II and Tangrila was considered as surplus flow from the respective points.

2.3 Linking with GIS

Efforts were made to establish interactive linkages of the results obtained from water balance model with the GIS maps to generate spatial scenarios of water management. However, within the stipulated time of the project, an offline linkage was developed with the GIS to display the effects of different decisions on the maps of the command. The GIS outputs in the form of plot attributes within the outlet commands were used as input for computation of water balance components. The procedure involved conversion of excel file to database file, which was directly linked with spatial data in a GIS environment using ArcView software (ANNEX- B-vii, Section 3.18).

2.4 Presentation of interactive results

The spreadsheet tool consists of twelve worksheets related to different steps involved in estimation of water balance and other aspects of scenario development, while two summary sheets present the results on 15 days cycle basis and daily basis. However, the detailed information, spatial and temporal, on different water balance components was available in corresponding sheet, which may be used for taking any decision. It occupies nearly 10 MB of memory space.

Interactive features include change in values related to various canal water management decisions. The effect is shown instantaneously when values of various parameters are changed, e.g if option of controlled outlet flow is changed to uncontrolled one, the results appear on the screen instantaneously in the form of changed values related to different parameters, or changed graphs (if presented graphically). Though the information may be extracted on daily basis, but to generate summarised scenarios, water balance components have been presented under the headings:

- ✓ Climatic parameters
- ✓ Irrigation management parameters
- ✓ Water balance at distributary level
- ✓ Water balance at outlet level
- ✓ Components of water balance

The decisions related to water flow bifurcation between Tangrella and Reach II can be fed directly from the daily summary sheet, while irrigation factor (portion of water demand to be met out from canal water in a particular cycle) can be changed in cyclic summary sheet.

The information may conveniently be presented in graphical form (bar chart, pie diagram or line diagram) utilising the facilities available in Excel Spreadsheet.

3.0 Results and Discussion

The spreadsheet based mathematical tool can be used for evaluation of effect of most canal management decisions on water availability scenarios in the canal command. It provides information on

- Outlet-wise Percentage area irrigated

- Water lost through seepage in distributary and water courses
- Surplus flow from - end of RP Channel V (at C in map), end of Tangrila minor (at D), and outlets
- Spatial (outlet command wise) and temporal (daily) water need considering amount of crop water requirement and water already released in a particular cycle.
- Outlet-wise area irrigated as well as area remained unirrigated at the end of each cycle. This also helps in decision on conjunctive use of ground water with canal water.

It has capability to generate scenarios for different decisions in respect of

- Discharge offtake from main canal
- Bifurcation of discharge between Reach II and Tangrella minor.
  - Manually operated
  - Uncontrolled without gate
- Controlled water flow from outlets
- Irrigation scheduling
- Staggering of dates in rice transplanting
- Any other aspect to be explored by use of the tool.

All the above results are certainly useful in

- Analyzing scenarios emerging from variation in decisions of water management
- Day to day monitoring of the water release pattern in accordance with the water need

Assessment of temporal and spatial level of water availability in comparison to water need will help in visualizing need of conjunctive use in different outlet command as well as need for change in cropping pattern.

3.1 Various scenarios generated using the tool

Using the tool various scenarios were generated to observe the effect of certain decisions. The results of such scenarios are given below.

Conditions		Percent area remained unirrigated	Surplus flow (% of water released)	Seepage loss (% of water released)	Water applied to fields (% of water released)	Remarks
1. Controlled outlet flow vs uncontrolled flow	a. Controlled	50.30	25.99	30.49	43.52	By controlling the flow, 9.3 % more area can be irrigated and surplus flow can be reduced by 6.2% as compared to uncontrolled flow.
	b. Uncontrolled	59.60	32.19	32.44	35.38	
2. Follow up of cyclic flow strictly with	Exact cyclic flow (uncontrolled flow)	66.89	34.05	32.61	33.34	By following true cyclic flow with 35 cusec reduced the irrigation status, while the

uniform discharge of 35 cusec for 10 days and off for 5 days as compared to actual release pattern during kharif 2002.	Actual release (Uncontrolled flow)	59.60	32.19	32.44	35.38	irrigation was more with actual cycle when there was more flow for some of the period .

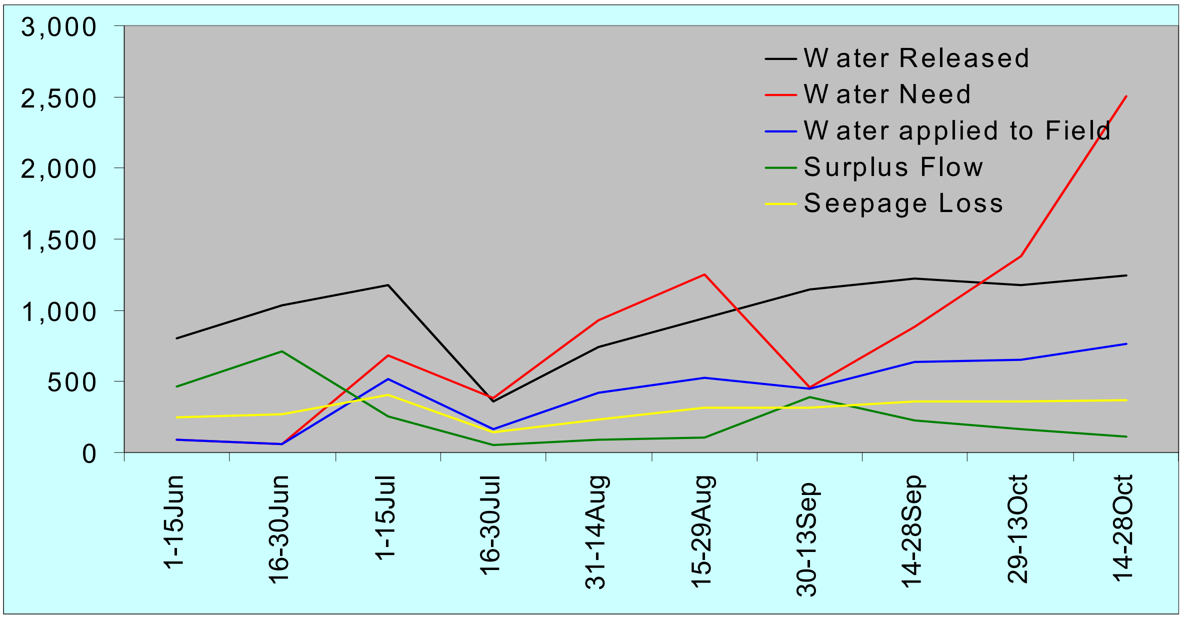
The above results are also presented graphically as well as geo-graphically as below:

For Controlled flow

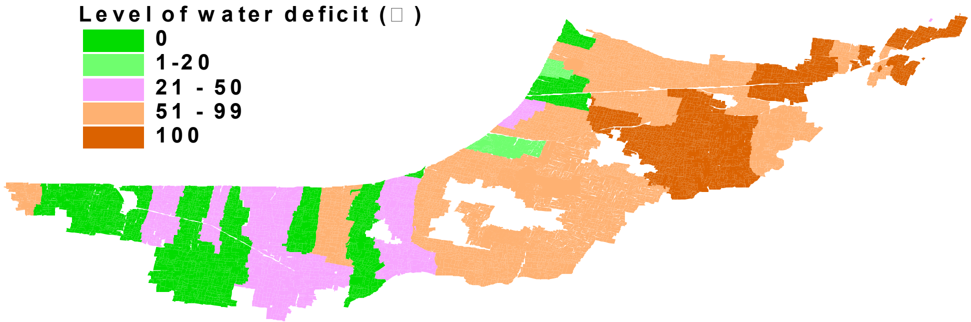
=IF(CP13>0,CP14/CP13*100,0)

	Water Management Summary of RPC-V Distributary of Patna Main Canal (Sone Canal System) In South Bihar											
2	Total command	-	834.36 ha		I Reach=	549.32 ha		II Reach=	38.66 ha		Tang.=	246.40 ha.
3		Unit	1-15Jun	16-30Jun	1-15Jul	16-30Jul	31-14Aug	15-29Aug	30-13Sep	14-28Sep	29-13Oct	14-28Oct	Total
5	**CLIMATIC PARAMETERS**												
6	Rainfall	mm	354.86	42.24	43.42	165.52	17.37	66.31	55.26	135.39	0.00	0.00	900.37
7	Evap	mm	63.98	48.13	40.93	43.13	42.88	58.66	31.83	63.70	63.29	59.67	516.20
8	ET (actual)	mm	79.50	79.50	72.00	72.00	78 40	57.33	59.26	76.87	77 39	82.00	734.25
9	Deep Percolation	mm	75.00	75.00	75.00	75.00	75.00	64.00	49.00	76.00	72.00	85.00	721.00
11	**IRRIGATION MANAGEMENT**												
12	Irrigation factor		1.00	1.00	0.50	0.50	1.00	1.00	0.50	1.00	1.00	1.00	
13	Irrigation Need	cum	92,309	56,723	680,841	382,788	930,580	1,251,543	459,063	884,345	1,382,828	2,503,086	8,624,104
14	Vol. Of water deficit	cum	0	0	166,788	215,827	508,306	723,906	9,664	246,882	730,957	1,735,405	4,337,736
15	Deficit (Overall)	%	0.00	0.00	24.50	56.38	54.62	57.84	2.11	27.92	52.86	69.33	50.30
16	Deficit (I Reach)	%	0.00	0.00	12.04	41.85	42.13	44.85	1.16	15.32	39.92	59.99	39.11
17	Deficit (II Reach)	%	0.00	0.00	4.53	28.29	22.46	31.82	0.00	4.50	24.49	50.48	28.00
18	Deficit (Tang.)	%	0.00	0.00	59.34	91.60	87.51	90.89	4.53	59.67	86.15	93.12	79.14
20	**WATER BUDGET AT DISTRIBUTARY LEVEL**												
21	Total water Release	cum	800.119	1,032,570	1,176,934	362,134	743,842	942,036	1,147,572	1,220,977	1,174,487	1,247,892	9,848,563
22	Seepage In Dist.	cum	181.865	232,693	219,064	78,488	118,015	158,388	195,689	187,744	160,267	179,309	1,731,424
23	Diverted through Outlets	cum	286,564	141,619	770,159	251,395	552,620	701,299	615,998	844,343	876,507	967,832	6,008,335
24	Sur[illegible] II Reach	[illegible]	220,514	374,216	164,539	27,413	62,445	65,538	267,438	169,259	99,160	83,480	[illegible]
25	Surplus flow by Tang.	[illegible]	111,176	284,214	23,172	4,909	10,832	16,812	68,447	19,632	18,553	17,272	575,01[illegible]
27	**WATER BUDGET AT OUTLETS LEVEL**												
28	Seep.In water course	cum	63,297	33,805	185,980	63,942	114,321	153,216	116,213	172,539	181,073	186,961	1,271,347
29	Surplus flow of outlets	cum	130,958	51,091	70,126	20,492	16,025	20,445	50,386	34,341	43,563	13,190	450,61[illegible]
30	Applied to fields	cum	92,309	56,723	514,053	166,961	422,274	527,637	449,399	637,463	651,870	767,681	4,286,369
32	**COMPONENTS OF WATER BALANCE**												
33	Surplus flown out	%	57.82%	68.71%	21.91%	14.58%	12.01%	10.91%	33.66%	18.28%	13.73%	9.13%	25.99%
34	Seepage Loss	%	30.64%	25.80%	34.42%	39.33%	31.23%	33.08%	27.18%	29.51%	30.77%	29.35%	30.49%
35	Applied to Field	%	11.54%	5.49%	43.68%	46.10%	56.77%	55.01%	39.16%	52.21%	55.50%	61.52%	43.52%

Summary sheet for various water cycles under controlled flow



Graphical presentation of water balance components under controlled flow

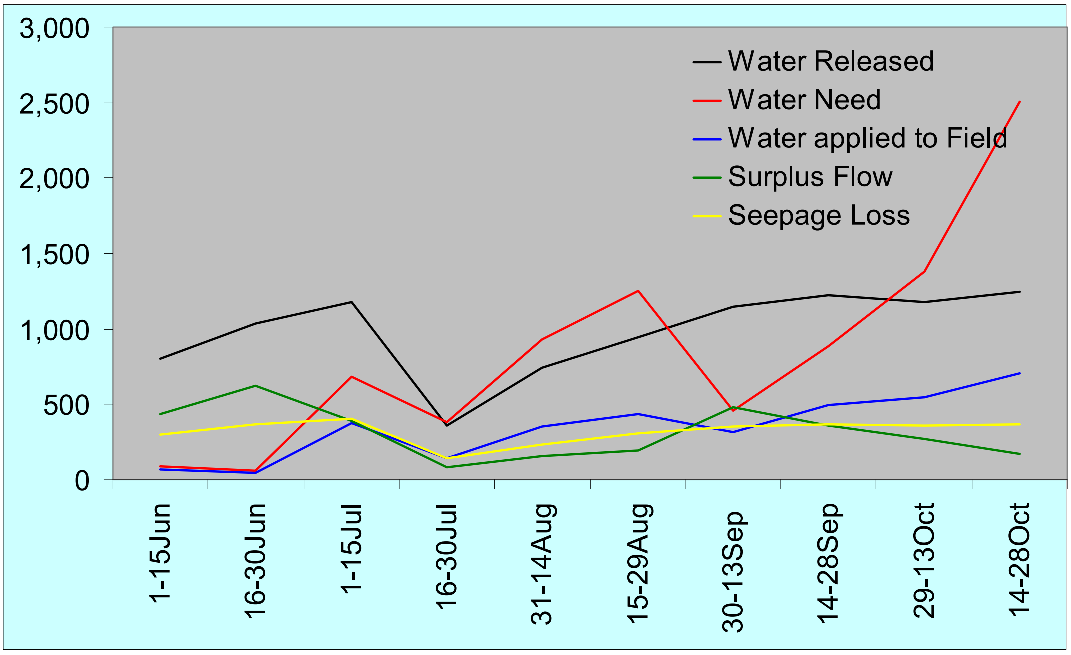


GIS map for 30th July 2002 under controlled flow

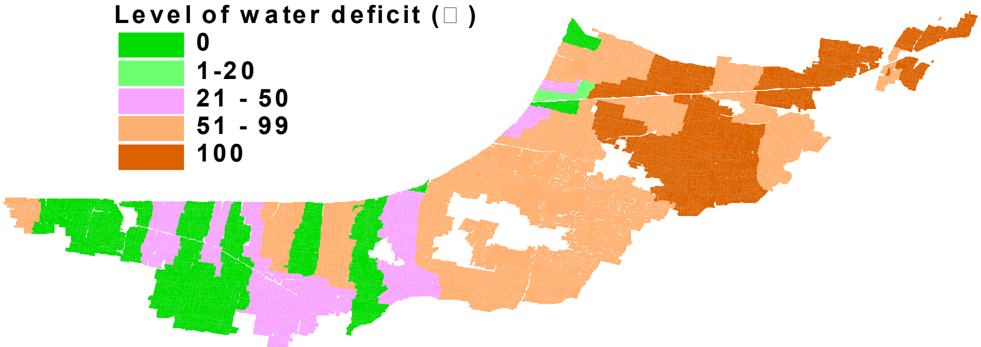
For Uncontrolled flow

	B	C	D	S	AH	AW	BL	CA	CP	DE	DT	EI	EX
1	Water Management Summary of RPC-V Distributary of Patna Main Canal (Sone Canal System) in South Bihar												
2	Total command	=	834.36 ha		I Reach=	549.32 ha		II Reach=	38.65 ha		Tang.=	246.40 ha.	
3		Unit	1-15Jun	16-30Jun	1-15Jul	16-30Jul	31-14Aug	15-29Aug	30-13Sep	14-28Sep	29-13Oct	14-28Oct	Total
5	CLIMATIC PARAMETERS												
6	Rainfall	mm	354.86	42.24	43.42	185.52	17.37	66.31	55.26	135.39	0.00	0.00	900.37
7	Evap	mm	63.98	48.13	40.93	43.13	42.88	58.66	31.83	63.70	63.29	59.67	516.20
8	ET (actual)	mm	79.50	79.50	72.00	72.00	78.40	57.33	59.26	76.87	77.39	82.00	734.25
9	Deep Percolation	mm	75.00	75.00	75.00	75.00	75.00	64.00	49.00	76.00	72.00	85.00	721.00
11	IRRIGATION MANAGEMENT												
12	Irrigation factor		1.00	1.00	0.50	0.50	1.00	1.00	0.50	1.00	1.00	1.00	
13	Irrigation Need	cum	92,309	56,723	680,841	382,788	930,580	1,251,543	459,063	884,345	1,382,828	2,503,086	8,624,104
14	Vol. Of water deficit	cum	23,385	10,051	303,884	242,573	575,429	818,515	142,543	389,826	834,479	1,799,320	5,140,006
15	Deficit (Overall)	%	25.33	17.72	44.63	63.37	61.84	65.40	31.05	44.08	60.35	71.88	59.60
16	Deficit (I Reach)	%	6.75	6.13	25.27	49.00	48.65	51.86	9.29	25.27	46.32	62.34	45.49
17	Deficit (II Reach)	%	12.62	0.00	35.67	42.77	37.04	52.12	11.27	22.12	40.24	56.24	42.29
18	Deficit (Tang.)	%	83.44	80.57	95.35	97.07	95.11	97.67	82.66	89.46	94.77	95.62	94.28
20	WATER BUDGET AT DISTRIBUTARY LEVEL												
21	Total water Release	cum	800,119	1,032,570	1,176,934	362,134	743,842	942,036	1,147,572	1,220,977	1,174,487	1,247,892	9,848,563
22	Seepage in Dist.	cum	155,445	185,782	202,051	76,382	113,157	151,681	171,081	174,172	172,146	175,400	1,577,297
23	Diverted through Outlets	cum	593,395	782,370	902,793	260,847	583,333	733,008	898,517	965,010	929,008	989,080	7,637,362
24	*Surplus flow by II Reach*	cum	39,361	47,427	52,633	20,529	36,665	41,353	62,610	64,822	54,957	66,326	486,684
25	*Surplus flow by Tang.*	cum	11,999	17,062	19,457	4,517	10,757	15,994	15,441	16,974	18,375	17,086	147,663
27	WATER BUDGET AT OUTLETS LEVEL												
28	Seep.in water course	cum	140,899	180,835	204,724	64,957	118,712	158,707	180,046	190,187	185,699	192,951	1,617,716
29	*Surplus flow of outlets*	cum	383,572	554,864	321,113	55,676	109,469	141,273	401,951	280,305	194,961	92,364	2,535,548
30	Applied to fields	cum	68,924	46,671	376,956	140,215	355,152	433,027	316,520	494,518	548,349	703,766	3,484,098
32	COMPONENTS OF WATER BALANCE												
33	Surplus flown out	%	54.36%	59.98%	33.41%	22.29%	21.09%	21.08%	41.83%	29.66%	22.84%	14.09%	32.19%
34	Seepage Loss	%	37.04%	35.51%	34.56%	39.03%	31.17%	32.95%	30.60%	29.84%	30.47%	29.52%	32.44%
35	Applied to Field	%	8.61%	4.52%	32.03%	38.72%	47.75%	45.97%	27.58%	40.50%	46.69%	56.40%	35.38%
36	Surplus Flow	cum	434932	619353	393203	80722	156892	198621	480007	362100	268293	175776	3,169,894

Summary sheet for various water cycles under uncontrolled flow



Graphical presentation of water balance components under uncontrolled flow



GIS maps for 30th July 2002 under uncontrolled flow

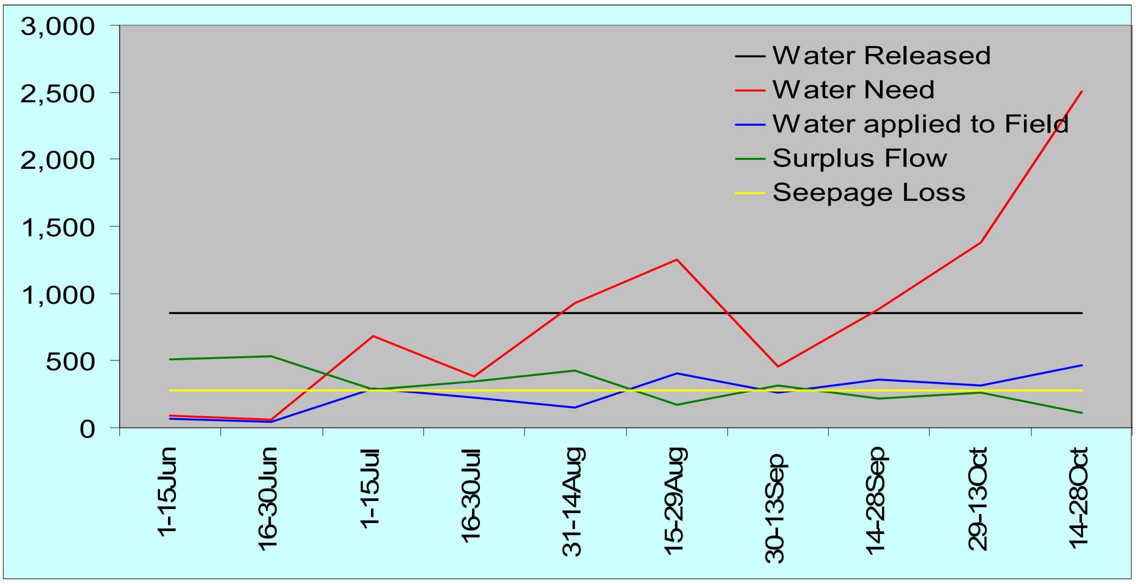
For cyclic water flow

Water Management Summary of RPC-V Distributory of Patna Main Canal (Sone Canal System) in South Bihar

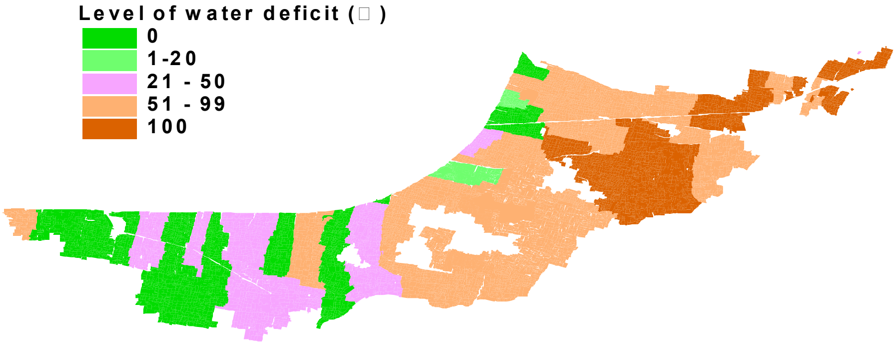
Total command - 834.36 ha I Reach= 549.32 ha II Reach= 38.65 ha Tang.= 246.40 ha.

	Unit	1-15Jun	16-30Jun	1-15Jul	16-30Jul	31-14Aug	15-29Aug	30-13Sep	14-28Sep	29-13Oct	14-28Oct	Total
CLIMATIC PARAMETERS												
Rainfall	mm	354.86	42.24	43.42	165.62	17.37	66.31	55.26	135.39	0.00	0.00	900.37
Evap	mm	63.98	48.13	40.93	43.13	42.88	58.66	31.83	63.70	63.29	59.67	516.20
ET (actual)	mm	79.50	79.50	72.00	72.00	78 40	67.33	59.26	76.87	77 39	82.00	734.25
Deep Percolation	mm	75.00	75.00	75.00	75.00	75.00	64.00	49.00	76.00	72.00	85.00	721.00
IRRIGATION MANAGEMENT												
Irrigation factor		1.00	1.00	0.50	0.50	1.00	1.00	0.50	1.00	1.00	1.00	
Irrigation Need	cum	92,309	56,723	680,841	382,788	930.580	1,251,543	459,063	884,345	1,382,828	2,503,086	8,624,104
Vol. Of water deficit	cum	23,269	10.448	346,922	154.047	665.096	843,594	196,376	521,287	974,183	2,033,516	5,768,737
Deficit (Overall)	%	25.21	16.42	50.95	40.24	71.47	67.40	42.78	58.95	70.45	81.24	66.89
Deficit (I Reach)	%	6.75	6.76	34.03	15.60	59.95	54.42	20.10	42.93	58.49	73.50	53.56
Deficit (II Reach)	%	16.55	7.66	43.66	40.58	66.21	59.33	41.76	46.38	65.83	79.33	62.14
Deficit (Tang.)	%	82.30	80.57	95.20	92.44	97.99	97.61	93.49	96.62	97.84	98.81	97.10
WATER BUDGET AT DISTRIBUTARY LEVEL												
Total water Release	cum	856,397	856,397	856,397	856,397	856,397	856,397	856,397	856,397	856,397	856,397	8,563,968
Seepage In Dist.	cum	138,081	138,081	138,081	138.081	138.081	138,081	138,081	138,081	138,081	138,081	1,380,810
Diverted through Outlets	cum	667,203	667,203	667,203	667,203	667,203	667,203	667,203	667,203	667,203	667.203	6,672,027
Surplus flow by II Reach	cum	35.835	35.835	35.835	35.835	35.835	35.835	35.835	35.835	35.835	35.835	358,351
Surplus flow by Tang.	cum	15,278	15,278	15,278	15,278	15,278	15,278	15,278	15,278	15,278	15,278	152,780
WATER BUDGET AT OUTLETS LEVEL												
Seep.In water course	cum	141.150	141,150	141,150	141,150	141,150	141,150	141,150	141,150	141,150	141,150	1,411,499
Surplus flow of outlets	cum	457.013	479,779	192.134	297.312	260,568	118,104	263,365	162,996	117.408	56.483	2,405,161
Applied to fields	cum	69,040	46,274	333,919	228,741	265,484	407,949	262,688	363,057	408,644	469.570	2,855,367
COMPONENTS OF WATER BALANCE												
Surplus flown out	%	59.33%	61.99%	28.40%	40.69%	36.39%	19.76%	36.72%	25.00%	19.68%	12.56%	34.05%
Seepage Loss	%	32.61%	32.61%	32.61%	32.61%	32.61%	32.61%	32.61%	32.61%	32.61%	32.61%	32.61%
Applied to Field	%	8.06%	5.40%	38.99%	26.71%	31.00%	47.64%	30.67%	42.39%	47.72%	54.83%	33.34%
Surplus Flow	cum	508126	530882	243247	349425	311681	169717	314478	214109	168522	107596	2,916,[illegible]

Summary sheet for various water cycles under cyclic water flow



Graphical presentation of water balance components under cyclic water flow



GIS map for 30th July 2002 under cyclic water flow

4.0 Feedback

The modeling tool with few scenarios was demonstrated to the members of WUA and canal managers through an interaction meeting held on 10th March 2004. The feedback suggested that

- The tool has significant potential value in helping communities to demonstrate the implications of their decisions to those responsible for main canal management
- State-level agencies responsible for main canal management find such information useful in decision making
- GIS-based spatial representation enabled a number of possible strategies to be evaluated:
  - ➢ The implications of controlling bifurcation of discharge between Reach II and Tangrila minor using a gate
  - ➢ The effect of controlling of water flow from outlets
  - ➢ Irrigation scheduling
  - ➢ Staggering of rice transplanting dates
- It has significant potential to be used as a dialogic tool in creating awareness and in knowledge sharing to support OFWM decisions at the distributary level.
- A tool to provide essential information to assist canal management decisions and support linkage between OFWM and canal management.
- The tool needs to be made more versatile by adding features on related aspects of water management e.g. effect of delay or advancement of sowing.
- Such tools are to be developed for other crops also.

□.0 Conclusions

A simple mathematical tool has been developed in Excel Spreadsheet and linked with GIS. The tool has its important use for analyzing scenarios emerging from different canal operation and water management in the command. It presents information not only in the form of numerical values, but also graphically as well as on maps, which enables decision makers to take appropriate decisions based on spatial and temporal data. It will certainly be useful in reducing the conflicts mostly emerging from spatial disparity in water availability. However, the time available within the project duration was very limited and only a beginning to find such solutions could be done. Efforts have to be made to make such tool more versatile and capable of providing enough information for canal manager to take decision on canal operation and to decide crop and cropping pattern along with package of practices by the farmers under varying conditions of water availability. Such tools could be used as dialogic tools to facilitate more democratic dialogue with stakeholders.

□.1 Strategies for up scaling

- Sensitization workshop meetings and consultative workshops, supported by such dialogic tools to facilitate better understanding and improved linkages between the main canal and OFWM issues for disseminating these ideas for scaling up.
- Develop easy to understand training module for field functionaries for scaling up.

□.0 References:

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