Optimum Water Allocation in a Diversion Type Irrigation Scheme: Gampolawela Rajaela Diversion Scheme

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ABSTRACT: The use of optimization techniques for supplying irrigation water can significantly improve the water use efficiency. The paper presents a methodology developed to optimize water allocations in a diversion type irrigation scheme. The methodology, which is in two stages develops potential release policies during its first stage. The second stage, which is based on Dynamic Programming technique, selects the optimum release pattern from the above potential policies. The application of the model to the Gampolawela Rajaela Diversion Scheme revealed the effectiveness of the decisions made by the model over the actual release pattern.

INTRODUCTION

Central region of Sri Lanka has a large number of diversion type irrigation schemes. The availability of a considerable amount of rain in this area, for the provision of crop water requirement reduces the irrigation demand and makes such schemes viable. The limitation of the irrigable lands due to the terrain that consist of many streams located close to each other is another factor that favours diversion schemes. Further, the topography may not favour construction of reservoirs in this area most of the time.

The main problem that a diversion scheme faces is the insufficiency of water during dry periods due to increase in crop water requirement and the decrease in main stream flow. This makes the distribution and management of irrigation water in diversion schemes a difficult task during such periods. Design and operation of diversion schemes could be handled efficiently if the available water and the rainfalls are incorporated into the decision making process. Incorporating these aspects to estimate an optimal irrigation requirement can be achieved through operations research techniques,

Application of operations research techniques for allocation of irrigation water is limited. Complicated models due to the large number of variables such as irrigation requirements, releases, canal discharges together with number of plots and time periods necessary to describe irrigation systems may be the reason. To overcome such difficulties, this model separates the modeling process in to two stages. First stage derives number of alternatives for supplying the irrigation demand within a given time period and the other stage applies operations research techniques to find their best combination for optimal operation.

Linear programming (LP) was used by Holzapfel *et al* (1986) for optimization of a furrow and border irrigation design. The objective function and the constraints were non-linear and they were linearized to use LP technique. Such simplifications may not 'represent the real system. Boman and Hill (1989) developed a model for making daily operating decisions required for operation of an irrigation water delivery system. The model determines optimum releases for each gate in the system based on time interval between gate changes, the demands for the downstream use and the demand for water withdrawals within each reach. The LP optimization model minimizes the differencesbetween the demands and the gate releases.

The objective functions of irrigation system operations are mostly non-linear and Dynamic Programming (DP) technique (Bellmann, 1957) can solve them without any simplification. This paper presents a model developed based on DP technique for the optimal allocation of irrigation water in a diversion type scheme.

MODEL DESCRIPTION

Dynamic Programming was selected as the optimization technique mainly due to its ability to incorporate non-linear objective functions and constraints without simplifications. The model optimally allocates irrigation water to different plots along a main canal. This spatial distribution is limited to a single time step and the optimum results are sequentially integrated in time to form the final policy. The present model assumes that the irrigation requirement in a period is independent of the amount of irrigation water supplied previously. Physical canal properties of the system such as reach length, maximum canal capacities, area of plots, evapotranpiration and rainfall are the initial inputs required for the model. Weekly total irrigation requirements of each plot were estimated and various different patterns of daily releases during the week were derived to supply these requirements. These patterns were the alternatives used in the model. Output of the model was the set of alternatives, which provide a flow with a least amount of deviations within a period.

Objective function

The objective of the model is to keep the diversion into the main irrigation canal at a constant value. This is achieved in the objective function by minimizing the squared sum of the hourly deviation between the diverted flow and the available flow over a week in each canal reach. The release patterns during a week is pre-determined and given to the model as a set of different alternatives. The final result will select the best alternative from this set.

$$z = \min_{j} \sum_{p=1,np} (Q_i - r_{ijp})^2 h_{ijp}$$

where,

- Q_i - Discharge available at the diversion in week i,
- h_{ijp} - Duration of release 'r_{ijp}' in hours,
- r_{ijp} - Rate of release of alternative j of irrigation plot p during week i,
- np - Total number of irrigation plots,
- i - Index of weeks,
- j - Index of release alternative, and
- p - Index of irrigation plots.

Constraint on canal capacity

The releases made to any irrigation plot at any given time should not exceed the maximum carrying capacity of the canal.

$$r_{ijp} \leq C_p$$

where,

C_p - Capacity of the canal of plot p.

Constraint on duration of the release

The releases to an irrigation plot should be determined so that the supply can be made within a week (168 hrs). The duration of each release is upwardly round off to the nearest hour.

$$h_{ijp} \leq 168$$

Constraint on irrigation water supply

The irrigation water supply should cater to the demand to meet the crop water requirement and associated losses from irrigation fields and canals.

$$r_{ijp} h_{ijp} \geq D_{ip}$$

where,

D_{jp} - Irrigation duty for plot p for the week i.

Evaluation of irrigation demand

The irrigation demand in a week is calculated in the daily basis and sum up for the week. Daily evapotranspiration of the reference crop is calculated using the Penmann Method. Standard crop coefficients are used in the calculations. The field losses are considered in two different components. The losses at the application level is considered as an application efficiency and the continuing loss from the fields due to deep percolation are considered as a percentage loss from irrigation water. The losses from irrigation canals are considered as a constant loss per unit length of the canal, which depends only on the wetted area.

$$D_{jp} = \sum_{d=1,7} \left[\frac{(K_c ET_0 - I)_d}{E_a (1 - L_{prc})} + L_{cnv} l_p \right]$$

where

K_c - Crop coefficient,

E_a - Application efficiency,

ET_0 - Reference crop evapotranspiration,

I - Rainfall during the day,

L_{prc} - Deep percolation loss as a percentage of irrigation water,

L_{cnv} - Conveyance loss as the loss from canal per unit length per day,

l_p - Length of canal up to plot p, and

d - Index of a day in a week.

Recursive Equation

Above model is solved using the deterministic dynamic programming and the following recursive equation is used in evaluating the objective function.

$$f_{ip}\left(r_{ip}\right) = \min_{j}\left[(Q - r_{ijp})^2 h_{ijp} + f_{i(p-1)}\left(r_{i(p-1)}\right)\right]$$

Decision variable and release alternatives

Decision of the model is the release pattern during a week. **A** set of patterns, called here the release alternatives, are derived separately and input to the optimization model. The constraints on minimum release, duration of release and the constraint on canal capacity are considered during the formulation of the release alternatives.

PROJECT AREA

The Gampolawela Rajaela Diversion Scheme is a medium scale irrigation scheme located in the Kandy district of the Central Province of Sri Lanka. The scheme irrigates its command area by diverting water from Ulapone Oya, a tributary of the Mahaweli river. The main canal, which starts from the diversion weir across Ulapane Oya is about 17.4 km long. The total irrigated area of 162 ha is divided into several sub-areas as shown in Figure 1.

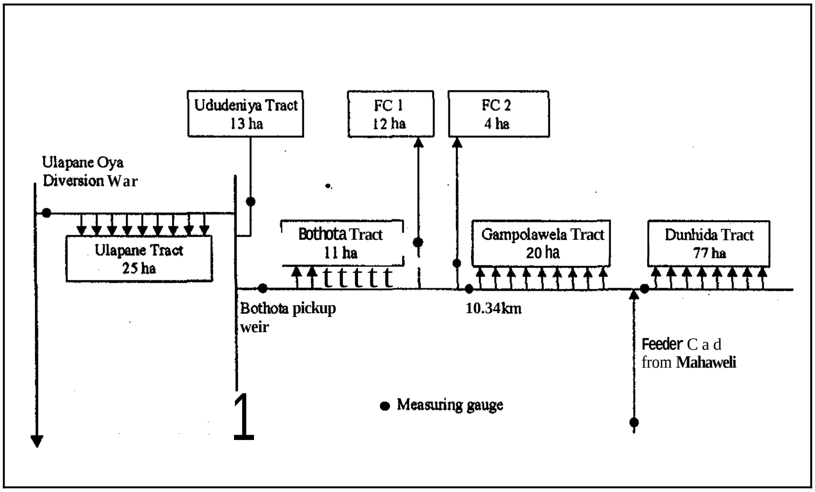

Figure 1 Schematic diagram of the Gampolawela Rajaela Scheme

From the Ulapone headworks, water is distributed to its first tract at Ulapone having 25 ha and the main canal beyond this point takes its course in natural stream. Water is picked up by Ududeniya anicut from this natural stream for a tract extending to 13 ha. The natural stream is intercepted by Bothota pickup weir, and the main canal, which originates from Bothota anicut, supplies water to Bothota tract extending to **11** ha. The next area is fed from FC1 and FC2, which take off from the main canal. The main canal continues and supplies water to Gampola tract of 20 ha before encountering the feeder canal from Dunhinda in Mahaweli river, which brings in diversion water from the Mahaweli river to feed the last tract of the Gampolawela Rajaela scheme in Dunhinda of 77 ha.

APPLICATION

The Gampolawela Rajaela Scheme served as the source of test data for the model. Release data and climatological data were collected for the Yala season 1997. The irrigation demands of the area were estimated based on the evapotranspirations calculated from the Penmann Equation for the same period. The equation according to Doorenbos and Pruitt (1984) is,

$$ET_0 = c[W.Rn + (1 - W).f(u).(ea - ed)]$$

Where,

- W - Weighting factor,
- Rn - Net radiation,
- f(u) - Wind function,
- ea - Saturated vapour pressure,
- ed - actual vapour pressure, and
- c - adjustment factor.

The parameters were estimated using climatological data and the relevant tables given in Doorenbos and Pruitt (1984). The required climatological data were gathered from a station near Peradeniya. The historical rainfalls were considered at this stage to calculate the net crop water requirements. The application efficiency and deep percolation were taken as 60% and 20% respectively (Doneen and Westcot, 1988). The conveyance losses were estimated based on the infiltration rate per unit area of the wetted surface of the canal and its value is 5 mm/hr.

In the first stage, the model develops alternative release patterns for each plot based on above irrigation requirement for each week. This weekly requirement is supplied in seven days in equal amounts in the fist alternative. The same is supplied in five days in the second alternative. Third alternate supplied. the requirement at the canal capacity, but the time of supply was round off to nearest day and the rate of supply was reduced accordingly. Fourth and fifth alternatives consider a supply a day and two days longer than the third alternative respectively. Table 1 presents the alternatives derived for a plot for a week as an example.

TABLE 1 – Alternative releases for plot-1 in week-2 in m^3/s

Day		1	2	3	4	5	6	7
Discharge	Alt. I	0.0169	0.0169	0.0169	0.0169	0.0169	0.0169	0.0169
	Alt. II	0.0237	0.0237	0.0237	0.0237	0.0237	0	0
	Alt. III	0.1185	0	0	0	0	0	0
	Alt. IV	0.0592	0.0592	0	0	0	0	0
	Alt. V	0.0395	0.0395	0.0395	0	0	0	0

In its second stage, the model selects the optimum release pattern for a week for each plot from the candidate release policies. Thus the optimum releases are derived for the whole irrigation season by sequencing the weekly policies. Table **2** presents the optimum release pattern for the system in a week.

TABLE 2 – Optimum releases during week–2 in m^3/s

Plot	Day 1	day 2	day 3	day 4	day 5	day 6	day 7
1	0.0237	0.0237	0.0237	0.0237	0.0237	0	0
2	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
3	0.0174	0.0174	0.0174	0	0	0	0
4	0.0114	0.0114	0.0114	0.0114	0.0114	0	0
5	0.0038	0.0038	0.0038	0.0038	0.0038	0	0
6	0.0190	0.0190	0.0190	0.0190	0.0190	0	0
7	0.0521	0.0521	0.0521	0.0521	0.0521	0.0521	0.0521
Tot. rel.	0.1362	0.1362	0.1362	0.1188	0.1188	0.0609	0.0609

As seen in Table 2 the total releases have daily deviations, which is not the most desirable operational pattern. This deviation is due to the limitation of the number of alternatives considered in this application.

The actual releases during the Yala season 1997 were collected from the Department of Irrigation. The optimal releases and the actual releases in the canal, at Ulapane and at the head end of Gampola tract, are compared in Figure 2 and Figure 3, respectively.

The optimal releases required at Ulapane in Figure 2, increase during early mid season and decrease towards the end. This change is mainly due to rainfall compensating part of crop water requirement, which reduces the irrigation demand. The actual releases do not reflect this trend as the controls at the head end of the canal are not functioning presently due to vandalism. This lack of control may be one of the reasons for optimal releases to be always less than the actual releases at Ulapane. Also, the flow measurements were found to be doubtful in certain cases as the measuring fumes near gauges were found to be silted, giving increased water depths. Besides, the results fi-om the model may be on the lower side. One reason for this may be the values assumed for losses, viz, application efficiency, conveyance losses and deep percolation are less than the actual values. It is necessary to check these values for their validity for the field conditions. The model calculates the irrigation demands using a perfect foresight for the rainfall.

In contrast to the above, the comparison of releases in the canal at 10.34 km in Figure 3 shows lesser deviations. The control of the canal originating from Bothota pickup weir is functioning properly. Optimal release pattern at this point has less fluctuation than the observed releases.

CONCLUSIONS

Conventionally the irrigation systems operations are scheduled to handle a given release pattern to irrigation plots. A rotational system with fixed releases and duration are commonly used as these release patterns. The model presented in the paper can consider several such release patterns to a plot and, it determines the optimum one. The optimum releases minimize fluctuations in the canal discharge. Such a policy will be simple enough to allow easy implementation in diversion irrigation schemes with minimum gate operations. Reductions in fluctuation in canal discharge allow supply from a constant flow as available in a diversion type irrigation scheme.

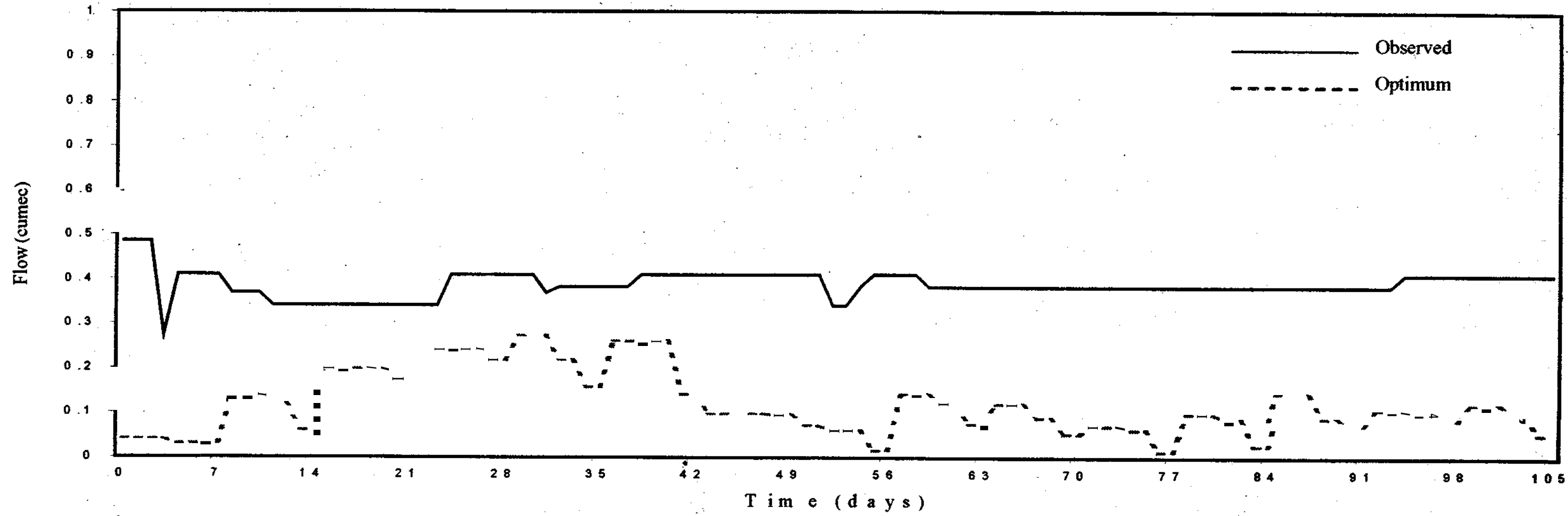

Figure 2. Comparison of observed and computed releases in the canal at Ulapane – Yala 1997

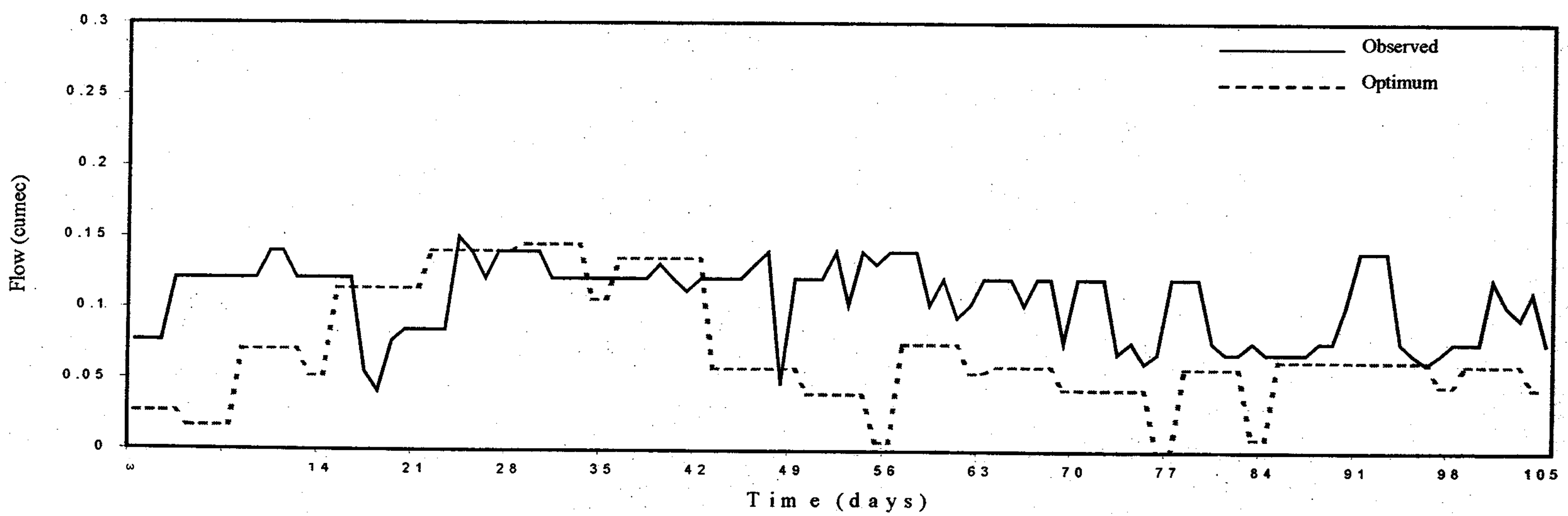

Figure 3 Comparison of observed and computed releases in the canal at 10.34 km. – Yala 1997

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