# OPTIMISATION MODELS FOR REDUCTION OF EFFLUENT LOAD FROM PADDY FIELD BY RECYCLING USE OF WATER

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## ABSTRACT

This paper develops two generalised optimisation models for paddy fields which can be used for quantitative and qualitative management of water resources in paddy field. Optimisation model-1 is used to minimise the cost of irrigation and drainage which is applied in actual practice by the farmers based on their own schedule and local weather conditions. Optimisation model-2 is used to minimise the cost of effluent (N) removal from paddy fields, regulating reservoirs and canals. In both the models objective function to be minimised is formed by summing the products of the decision variables multiplied by their corresponding cost coefficients. The constraints for the models include quantity of water for irrigation and drainage (if excess pounding depth), area of paddy field land, regulating reservoir and canal and mass of effluent load to be removed in these three systems. The results obtained indicate that if there is higher quantity of load to be removed then it is advisable to keep more area for regulating reservoir and drainage canal. The models can also be used to optimise the selection of best management practices on a field by field basis for entire water shed. In b+81-298-38-7702oth the models solution achieved are global optimal solution which can be effectively applied for water , land and agricultural effluent management and can serve as a powerful tool for decision and policy makers. The results of optimisation model have been achieved by standard optimisation software of LINDO Systems, Inc. USA.

**KEYWORDS : Water Resources Management; Optimisation Model; Paddy Field; Water supply System; Reservoir Storage; Effluent Load.**

## INTRODUCTION

Agricultural nonpoint source (NPS) pollution continues to be a major concern to our degrading surface and subsurface water quality (Chatterjee, A., 1997). With limited resource available, that control/ recycle/ implementation programs adequately consider the impacts of alternative management, land use and conservation approaches (e.g. recycling effluents, fertiliser management and different cropping practices etc.) on NPS pollution. Evaluating each alternative management, land use and conservation practice through experiments and monitoring programs is not feasible because of enormous cost, time and labour involvement. Optimisation modelling studies combined with monitoring programs are often the only efficient means of providing timely inputs to facilitate management decision at a reasonable cost. So at present there is a need to develop the optimisation models which can be used to study management strategies on a field by field basis and provide an optimal solution that minimises NPS pollution and maximises net farm return. The work reported here is the effort in this direction.

Various investigators have developed linear programming models for water resources systems (Singh, R. K., 1997, 2000), (B.B. Lal Pande et al. 2001). These models have application in the areas of multiobjective water resources management of river stretch, microlevel water resource management in the irrigation and the sustainable development of water resources. Other researchers (Trapanese and Smolen, 1982; Storm etal., 1985) have also tried to evaluate the cost effectiveness of alternative pollutant loss reduction plans and to optimise best management practices (BMP) implementation strategies. The work reported by (Duane, Q., et-al. 1992), (Gan, T.Y., et-al.1996), (Young, R.A., et.al, 1989) give similar efforts in this direction. To the best of our knowledge development of optimisation models for reduction of effluent load from paddy field by recycling use of water is first in itself.

In present study model area and its irrigation drainage system (Shiratani et al., 2002) is hypothetically considered as a typical area of paddy fields where a modern land consolidation project was implemented. The system as a whole consists of four blocks (100 hectare for each block) of paddy fields, irrigation canals, drainage canals and regulating reservoirs with pump station to recycle the run off from the blocks. During the irrigation period, river water is diverted in to the main canal by a headwork and then flows to two branch canals according to the irrigation plan of the land consolidation project. Drainage from the paddy fields and leftover irrigation water are gathered into lateral drainage canals and then connected to main drainage canal. Then this run-off is fed into regulating reservoir for recycling and then pumped back into the main canal this reduces water out take from river. The results of this model are used as an input in the optimisation model developed here.

## GENERAL FORMULATION OF OPTIMISATION MODELS

***Model-1 (Irrigation water management to keep optimum depth of pounding for field management and rice harvesting)***

Objective function is set up to optimise the cost of irrigation and drainage. This objective function is set-up based on the actual practice by the farmers to cultivate their own paddy fields according to their own schedule and local weather conditions (Shiratani et.al. ,2002). The cost function used are $C_1$ and $C_3$ in which $C_1$ is the cost of irrigation per unit depth (in mm) and per unit area (in hectare) of paddy field land and $C_3$ is the cost of drainage per unit depth per unit area of paddy field land. The variables used in the optimisation models are $X_{1i}$, $X_{2i}$ and $X_{3i}$ in which the $X_{1i}$ is the irrigation required at $i$th day to the paddy field for per unit area of the land if there is rainfall on $i$th day, $X_{2i}$ is the overall irrigation required at $i$th day per unit area of the paddy field and $X_{3i}$ is the overall drainage required per unit area of the paddy field land on $i$th day. The cost function is defined as $F$ which minimises the cost of irrigation and drainage from the paddy field. With this statement objective function can be written as follows:

$$MinimiseF = \sum_{s=1}^{m} \sum_{j=1}^{n} = C_s X_{ji} \forall s, j \quad (1)$$

$$MinimiseF = C_1 X_{1i} + C_3 X_{3i} \quad (2)$$

Constant parameters

The constant parameters taken in the optimisation model is lot management water requirement $m$ = 3.5 mm and evapo-transpiration, $b$ = 5.0 mm.

Constraints on overall irrigation

The following are the constraints set-up for the overall irrigation required by paddy field on $ith$ day for per unit area of the land. New parameters which are to be defined are $C_i$ optimum pounding water depth in mm at the $i$th day, $h_{i-1}$ is actual pounding water depth in mm at ($i$-1)th day and $P_i$ is the amount of percolation in mm and other parameters are defined as above. With this the constraint can be written as follows.

$$P_i = 15 \ mm \ when \ h_{i-1} > 15mm \ and \ P_i = h_{i-1} \leq 15mm \quad (3)$$

$$X_{2i} = (C_i - h_{i-1} + P_i + b + m) \ when \ C_i > 0mm \ and \ (C_i - h_{i-1} + P_i + b) > 0mm \quad (4)$$

or

$$X_{2i} - (C_i - h_{i-1} + P_i + b + m) > 0 \quad (5)$$

and

$$X_{2i} = m \ when \ C_i = 0mm \ or \ (C_i - h_{i-1} + P_i + b) < 0mm \quad (6)$$

or

$$X_{2i} - m = 0 \quad (7)$$

Constraints on irrigation water to be supplied

The following are the constraints setup for irrigation water to be supplied to the paddy field if there is rainfall on $i$th day. So that it will give the optimum pounding depth required. New parameters which is to be defined is $R_i$ is the rainfall on $i$th day in mm, this will reduce the depth of irrigation required on $ith$ day. With this the constraints can be written as:

$$X_{1i} = X_{2i} - R_i when( X_{2i} - R_i ) > m \quad (8)$$

and

$$X_{1i} - m = 0 when (X_{2i} - R_i) > m \quad (9)$$

Constraints on surface drainage

The following are the constraint set-up for surface drainage required for the paddy field in order to keep the optimum depth of pounding. All the parameters are defined as above. The constraints are written as follows.

$$X_{3i} = ( h_{i-1} + X_{1i} + R_i - P_i - b - 80 ) mm when ( h_{i-1} + X_{1i} + R_i - P_i - b - 80 ) mm > 0mm \quad (10)$$

or

$$X_{3i} - (h_{i-1} + X_{1i} + R_i - P_i - b - 80) > 0 \quad (11)$$

or

$$X_{3i} - X_{1i} - (h_{i-1} + R_i - P_i - b - 80) > 0 \quad (12)$$

or

$$X_{1i} - X_{3i} + (h_{i-1} + R_i - P_i - b - 80) < 0 \quad (13)$$

and

$$X_{3i} = m when (h_{i-1} + X_{1i} + R_i - P_i - b - 80) < 0 \quad (14)$$

or

$$X_{3i} - m = 0 \quad (15)$$

Non negativity constraints

The following are the non negativity constraint which indicates that in no situation the value of $X_{1i}$, $X_{2i}$ and $X_{3i}$ will be less than zero. So the constraint can be written as $X_{1i}$, $X_{2i}$ and $X_{3i} \geq 0$.

Actual pounding depth

The actual pounding water depth can be calculated as follows in which the $h_i$ is actual pounding water depth at $i$th day.

$$h_i = h_{i-1} + R_i + X_{1i} - P_i - b - S_i \quad (16)$$

and

$$h_i = 0mm if h_i < 0mm \quad (17)$$

So for known value of $X_{1i}$ from optimisation model the value of $h_i$ can be computed which will be optimum value corresponding to minimum cost of irrigation and drainage, here $S_i$ is discharged to water depth of 10 mm when the day is for the transplantation.

***Model-2 (N balances in paddy fields, regulating reservoirs and canals during irrigation period)***

Typically, in a N balances in paddy fields, regulating reservoirs and canals during the specified irrigation period of 148 days, the following information is available: the area of the paddy field, regulating reservoir and canal in hectares, the total amount of in flowing load, out flowing load and removed load in kg of N from these three systems. The mean removal rate of N per unit area per unit time from paddy field, regulating reservoir and canal is 53.6 g per hectare per day, 222.6 g per hectare per day and 394.53 g per hectare per day respectively. The cost of N removal from paddy field, regulating reservoir and canal is assumed as a unit cost. Given the above information objective function is to prepare the optimisation model which will minimise the cost of N removal from all these three systems. The decision variables are the hectares of paddy field crops, regulating reservoir and the canals. The constraints are set-up for total available land for paddy field, regulating reservoir and canals in hectares, the constraints are also set-up for total amount of nutrients to be removed from these three system and finally the non negativity constraints for all three decision variables and depending upon the original situations in the field the general model of the problem can be written as follows.

Since the objective is to minimise the cost associated with the three decision variables specified above the objective function mathematically stated as follows:

Objective function

$$Minimise F = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{o} C_i R_j X_k T, \forall i, j and k \quad (18)$$

In which $F$ is the value of the objective function , $C_i$ is the associated cost of N removal from paddy field, regulating reservoir and canal per unit mass $R_i$ is the mean removal rate of N from paddy field, regulating reservoir and canal per unit area per unit time, $X_k$ is the decision variable associated with the land area of paddy field, regulating reservoir and canal and $T$ is the total irrigation period which is crop period of paddy in Japan of 148 days in which the total load removal is done. In achieving the above objective constraints for total available land for paddy field, regulating reservoir and drainage canal mathematically stated as follows:

Constraints for total available land

$$\sum_{k=1}^{o} X_k \leq \sum_{l=1}^{p} A_{l,} \forall k, l(\ ) \quad (19)$$

In which $A$ represents the total available land for all three purposes. In order to avoid the excess removal of N load a constraint should be set-up to net mass of N load to be removed from the water from all three systems to be considered for this purpose mathematically can be stated as follows:

Constraint on net effluent load

$$\sum_{j=1}^{n} \sum_{k=1}^{o} R_j X_k T \geq \sum_{q=1}^{r} M_q, \forall i, j and q \quad (20)$$

In which $M_q$ represents the mass of total N load to be removed from all three system i.e. paddy field, regulating reservoir and canal. Since all the decision variable stated in the problem are desired to be positive, hence finally non-negativity constraints can be written as follows:

Nonnegative constraint

$$\sum_{k=1}^{o} X_k \geq 0, \forall k(\ ) \quad (21)$$

So the above optimisation model is a general model which can be used to minimise the cost of N load removal from paddy field, regulating reservoir under the stated constraints. The model will be a useful tool in the land resource management problems will give different options to decision or policy makers for the land resource use.

## INPUT DATA

The in put data required by the models are rainfall in mm during Paddy crop period of 148 days from April to Septemb er and N balances in Paddy Field, regulating reservoir and canal for the crop period of 148 days [1]. Other constant parameters used in the models are defined in the text. The cost of irrigation, drainage and nutrients loads removal are assumed as a unit cost.

## DISCUSSION

The models were developed for optimising the cost of irrigation, drainage and effluent load removal. The decisions variables were defined as the amount of irrigation and drainage required under the defined set of constraints in the first model and in the second model the decisions variables were defined as the area of land should be put for paddy field, regulating reservoir and drainage canal to optimise the cost of N load removal from all these three regulating systems. The results of the models are depicted in Fig.1-3. Both the models were solved using standard optimisation software of Lindo System, Inc. USA. The values of the decisions variables for five different cases are reported in these Figures. Interpretations of these results are done as follows.

Referring Fig.1 given below. It is assumed that the minimum pounding depth should be 10 mm. So in order to achieve this pounding depth minimum 18.5 mm of water should be provided by irrigation and if there is rainfall of 5.0 mm on that day then the irrigation required will be only 13.5mm and corresponding minimum cost of irrigation will be 1080 thousands unit cost for the chosen cost function since there is no drainage required corresponding cost will be zero. Similarly if we refer case-2 for net irrigation of 50.0 mm if surplus of 31.5 mm is allowed for drainage then for required irrigation of 18.5 mm then corresponding minimum cost of drainage will be 1260.00 thousands unit cost. If we refer case-3 for net irrigation of 150.0 mm if surplus of 131.5 mm is allowed for drainage then the corresponding minimum cost will be 5260.00 thousands unit cost. In case-4 for net irrigation of 45.0 mm if surplus drainage required is 26.5 mm then the corresponding minimum cost will be 1060.00 thousands unit cost. Finally in case-5 for net irrigation of 18.5 mm the irrigation required will be 8.5 mm since there is rainfall of 10.00 mm that day so corresponding minimum cost of irrigation will be 680.00 thousands unit cost. So we have seen here this model is accurately able to compute the amount of irrigation, drainage and corresponding optimum cost. If the cost functions, various constant parameters and amount of rainfall on that day is known.

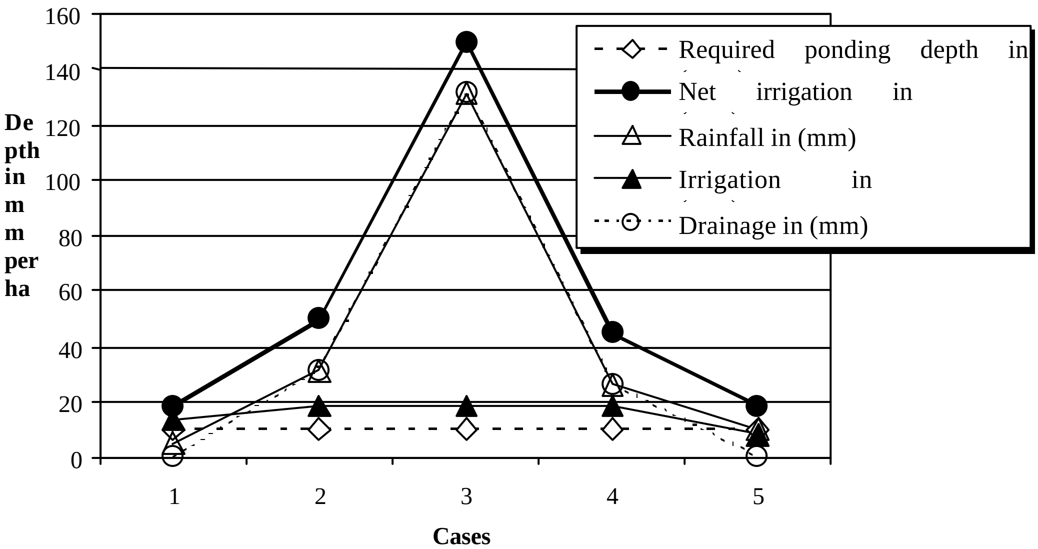


Figure.1: Results of the optimisation model-1,depicting irrigation and drainage fixed optimum ponding

Referring Figures.2 & 3 given below. If we take the net land area 2000 hectares or less and net N removal of 8000 Kg or more with the constant rate of removal and chosen cost function, 1008.6 hectares of land should be kept under paddy field cultivation and surplus of 991.6 hectares can be utilised for regulating reservoir and canal in order to have the minimum value of objective function equal to15.99960 thousands unit cost. If we see the model-2 case-2 and taking the net land area of 409.335 hectares or less for paddy field regulating reservoir and canal and net N removal of 3492.1Kg or more with constant rate of removal for all three systems. Then for chosen cost function the objective value to be minimum of 17.46039 thousands unit cost. If the area for regulating reservoir should be kept as105.9979 hectares and surplus of 303.3371 hectares can be fixed for paddy field and canal. Similarly in model-2, case-3, for net area of 1000 hectares or less and net N removal of 5000 kg or more, the area under paddy field should be 630.3 hectares and surplus area of 369.7 hectares can be used for regulating reservoir and canal for the minimum value of objective function to be 24.99937 thousands unit cost. Model-2, Case-4, for net area of 1500 hectares or less and net N removal of 7000 kg or more the area under paddy field should be 882.39 hectares and surplus area of 617.6 hectares can be utilised for regulating reservoir and canal and corresponding optimum cost will be20.99947 thousands unit cost finally model-2, case-5 for the net area of 5000 hectares or less and net load to be removed 10,00 kg or more the area under paddy field cultivation should be kept as1260.6 hectares rest of the surplus area can be used for regulating reservoir and canal for the minimum objective value of 29.99924 thousands unit cost.

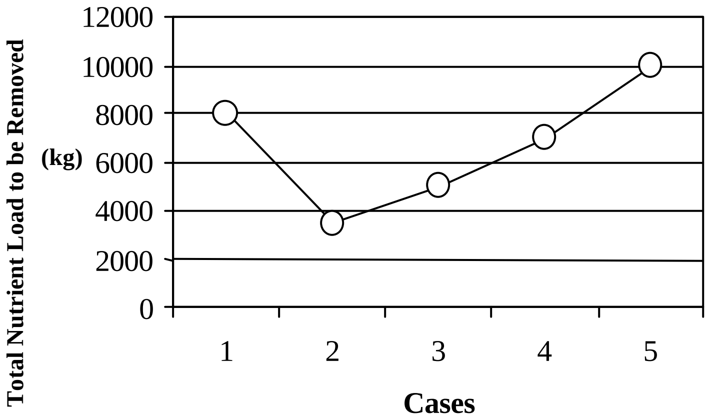


Figure.2: Input nutrient load to be removed in Kg in model-

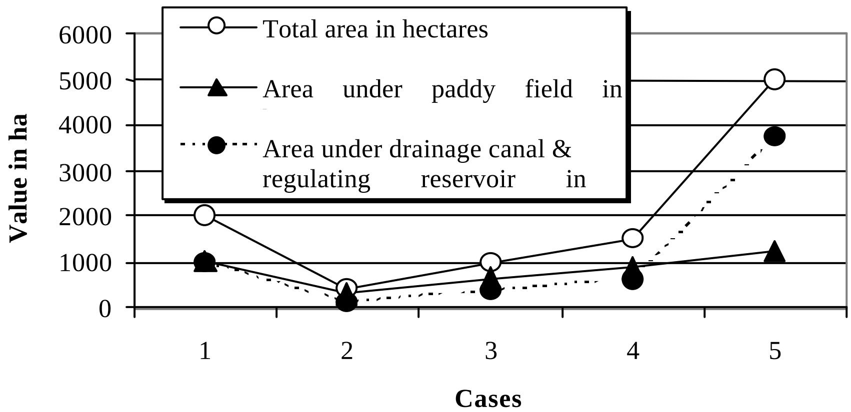


Figure 3: Results of model- 2 for the area under paddy field regulating reservoir & canal (clay type) in hectares

The results found in the model-2 suggests that If there is high quantity of N load to be removed then it is advisable to keep more area for regulating reservoir and drainage canal this is because of high rate of N removal from these systems as reported by (Shiratani et.al. 2002). So for available realistic information's at field the model is capable of suggesting good land resource management policy for the nutrients removal from paddy field, regulating reservoir and canal.

## CONCLUSIONS

The linear optimisation model developed here in is an effective tool for water, land and agricultural effluent management and can serve as a powerful tool for decision and policy makers. The results obtained indicate that if there is higher quantity of load to be removed then it is advisable to keep more area for regulating reservoir and drainage canal. The models can also be used to optimise the selection of best management practices on a field by field basis for entire water shed. In both the models solution achieved are global optimal solutions. In future work the model can be extended as a reliability-based optimisation model and inclusions of other potentially important variables can be considered. The concept of fuzzy linear programming can be included to make the model work in fuzzy environment. The concept of certain better search technique can be included such as Genetic Algorithm (GA) to make the models more versatile.

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