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Performance Enhancement of Minor Irrigation System through Secondary Storage and Multiple Use Management

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PREFACE

In the process of irrigation development, minor irrigation systems have received equal importance with that of major and medium irrigation systems due to several advantages such as small capital investments, less gestation period, better flow control, farmers' friendly etc. In recent years, attention is being paid to rehabilitate the defunct minor irrigation systems to have better availability and distribution of irrigation water in the command. In the rehabilitated systems, it is expected that there will be better availability and distribution of irrigation water in the command both in the monsoon and dry season. In reality, in spite of increase in cropping intensity and irrigation intensity in the post rehabilitation period, there exists ample scope to enhance the crop coverage during dry season. Therefore, ways and means to augment the water resource scenario in the minor irrigation system is highly essential to bring the entire command area under crop coverage during dry season. Often, government assume that the transfer of management responsibility to farmer organizations will improve the accountability of the irrigation service to farmers, make the service more cost efficient, motivate farmers to invest more in maintaining irrigation systems and, ultimately, make irrigation systems and irrigated agriculture more sustainable. These expectations may not be always realistic. To address some of these problems, a study was conducted in a turned over minor irrigation system, results of which are documented here. The study envisaged in establishing the concept of secondary storage reservoir in the outlet command of flow based minor irrigation system to harvest rainwater during monsoon and store excess irrigation water, and utilizes the harvested water during the dry season most effectively. The technique of multiple use management of harvested water in the secondary storage reservoir though pisciculture and dry season crop cultivation was established. The effectiveness of WUA's functioning in creation, operation and maintenance of the system was also studied and ways and means to improve their effectiveness and sustainability were suggested. Hopefully, the outcome of the study will help policy planners, field engineers and farmers in formulating their strategies and preparing their plans for improving the irrigation and thereby the crop performance scenario in the irrigated command.

Authors

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1. INTRODUCTION

Over last few decades, rapid expansion of irrigation facilities has taken place globally as well as also in India. Due to small capital requirement, less execution time and better control over flow, minor irrigation (MI) schemes have received equal importance as that of major and medium irrigation projects. Number of MI schemes now lie derelict as the cost and resource required to operate and maintain them is simply too high for government departments. Water taxes have also been historically set too low to maintain the constructed systems. Therefore, it is considered late that these derelict schemes should be rehabilitated and handed over to the farmers for their future operation and maintenance.

Due to inadequate availability of irrigation water in the reservoir, most of the flow based minor irrigation projects suffer from poor irrigation intensity and cropping intensity. There is no proper crop planning especially during dry season taking into account the availability of irrigation water in the reservoir. Higher crop coverage sometimes leads to severe scarcity of irrigation water in the advanced crop growth stages thereby restricting the productivity of the crop significantly lower than the potential. Further, the Water Users Association which has been formed to look after the operation and maintenance of the system and collect water tax from the farmers still have several problems and its sustainability is questionable. Therefore, the challenges of food security in minor irrigation sector calls for immediate assessment of their performance to identify the gaps and development of suitable ways and means to bring improvement in the existing schemes performance level.

In the state of Orissa, it has been estimated that out of the total cultivable area of 65.59 lakh ha, about 59.00 lakh ha (39.49 from major and medium, 9.70 from minor flow, 8.87 from minor lift and 0.94 lakh ha from other sources) can be brought under irrigation through different sources. The irrigation potential by the end of year 2003-04 is estimated as 26.51 lakh ha (12.35 from major and medium, 4.97 from minor flow, 3.84 from minor lift and 5.35 lakh ha from other sources). Thus, about 19% of the total irrigated area in the state gets irrigation water from flow based minor irrigation projects (MIPs).

In the past, several researchers have studied different aspects of secondary storage reservoir concept in the command of major irrigation projects. Zimmerman (1966) stated "for effective and efficient use of water, it is essential for every farm entity to have a service reservoir so that the farmer can use his allocation at his convenience, both in regard to time of irrigation and size of the stream." Khanjani and Busch (1983) developed a method to specify the optimal sizes and locations of farm service reservoirs within an irrigation project. Mishra and Tyagi (1988) analyzed the performance of irrigation water delivery with introduction of secondary storage reservoir at the farm outlet level. Gowing *et al.* (2004) incorporated a large number of secondary reservoirs to reduce the management problems and enhance non-irrigation usage of water in a large scale irrigation project. The research outcome reported here is directed at investigating the scope and feasibility of introducing secondary storage reservoir in the outlets command of a flow based MI system to harvest rainwater during monsoon in addition to capturing the excess irrigation water supplied from the main reservoir through canal network and utilizing the harvested water during dry season in addition to the irrigation water available in the main reservoir. The intervention aims at augmenting the water resource scenario of the MI system thereby improving the cropping intensity, irrigation intensity and crop productivity of the command.

2. DESCRIPTION OF THE STUDY SYSTEM

Devijhar Minor Irrigation Project, located in the Ganjam district of Orissa state at 19^0 43′ 00" N latitude and 85^0 07′ 00" E longitude was chosen for this study. The CCA of the minor irrigation project is 500 ha. The catchment and command area of Devijhar Minor Irrigation Project is shown in Fig.1. The view of the reservoir of Devijhar MIP is shown in Plate 1. The reservoir has a live and dead storage of 85.41 ha m and 2.59 ha m respectively. The full reservoir level and dead storage level are 67.59 and 55.69 m from the mean sea level, respectively. The irrigation project has a main canal whose design discharge at its head regulator is 0.545 m^3/sec. It is 5.30 km long having 24 outlets. There is a minor canal, which off takes from the main canal at 932 m (Plate 2). The design discharge of the minor canal is 0.204 m^3/sec. The minor canal is 3.507 km long having 17 outlets. About half of the canal length is lined with cement concrete and the remaining half is unlined earthen channel. This minor irrigation project has been rehabilitated by the Government of Orissa with the assistance from European

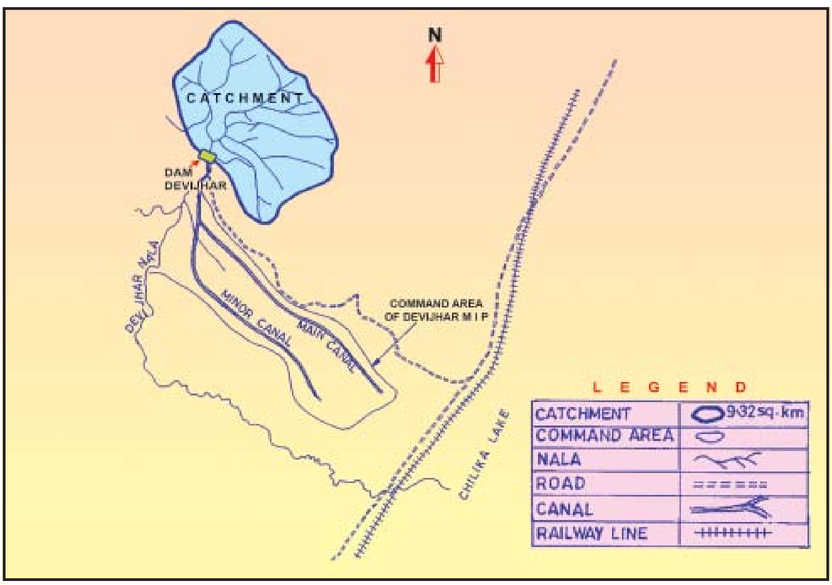

Fig. 1. Catchment and command area of the Devijhar Minor irrigation system

Commission and handed over to Water Users Association during July 2004 for its operation, maintenance and management. The project has a Water User Association (WUA) comprising of 934 members from 10 villages. The details of the MIP and its WUA are given in Table 1. The irrigation dates, irrigation intervals and water taxes for different crop are decided by the executive body of the WUA. WUA receives the requisition for irrigation water from outlet committees and then decide about the irrigation dates and intervals. Thus, the irrigation dates and intervals are decided by WUA as per the requirement of farmers/outlet committee, experience of the executive body of WUA and water availability in the main reservoir. Surface flooding and field to field irrigation is largely practiced due to existence of limited length of field channels below the outlet to convey irrigation water to farmer's field.

Table 1. Salient features of Devijhar minor irrigation project

Name of MI system	Name of WUA	Canals and Minors under WUA	Command Area (ha)	No. of member farmers	Total no. of villages
Devijhar MIP Dist. Ganjam Turned over on 05/07/04	Baba Sidheswar WUA	Main canal: 5300 m (24 outlets from main canal) Branch canal: 3507 m (17 outlets from branch canal	500	934	10

Agriculture and allied activities account for more than 65% of the total workforce indicating agriculture as the mainstay of the population. The marginal (<1 ha land holding) and small (1 to 2 ha land holding) farmers account for more than 85% of the total farming community. During rainy season paddy is the predominant crop. Further, during winter and summer season, crops like groundnut, black gram and green gram are grown in almost 2/3rd of the total command area. Sunflower and vegetables such

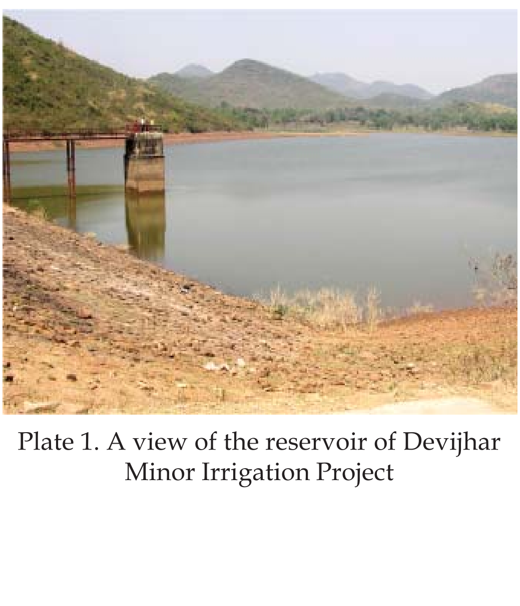

Plate 1. A view of the reservoir of Devijhar Minor Irrigation Project

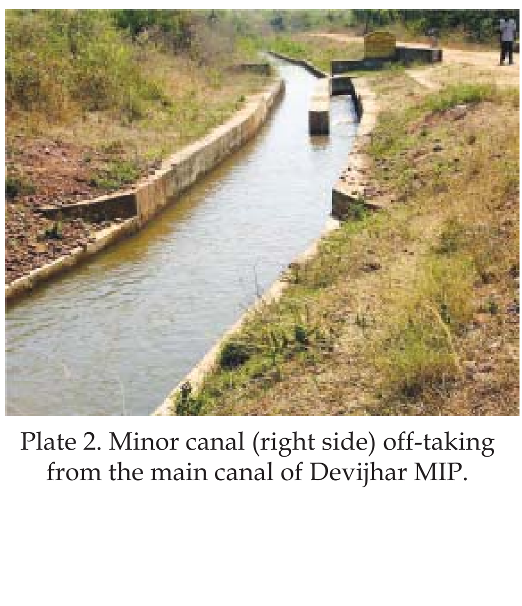

Plate 2. Minor canal (right side) off-taking from the main canal of Devijhar MIP.

as cabbage, cauliflower, tomato and brinjal are also grown in small patches. About 1/3rd of the command area remains fallow during winter and summer due to scarcity of irrigation water. The average annual rainfall of Devijhar MI project is about 1290 mm. The maximum and minimum temperature in summer is 38^{0}C and 29^{0}C and in winter is 27^{0}C and 15^{0}C, respectively. The predominant soil of the study area is sandy loam with the percentage of sand, silt and clay as 75.66%, 14.74% and 9.6%, respectively.

3. THE CONCEPT

The major objective of the research conducted here was to find out ways and means to augment the water resource scenario of a flow based minor irrigation project which suffers badly from inadequate irrigation water availability during dry season. The possibility of increasing the capacity of the main reservoir is very remote. Therefore, the concept of secondary storage reservoir in the command of each outlet is hypothesized. These reservoirs will harvest the rainwater during monsoon as well as capture excess irrigation water, if any, at the time of each irrigation. The harvested water in the secondary reservoir will be primarily utilized for raising crops in the dry season along with the water available in the main reservoir after meeting the requirement of *kharif* crops. The augmented water resource can be utilized in more effective and productive manner through multiple use management. The definition sketch of the proposed secondary storage reservoir is shown in Fig. 2.

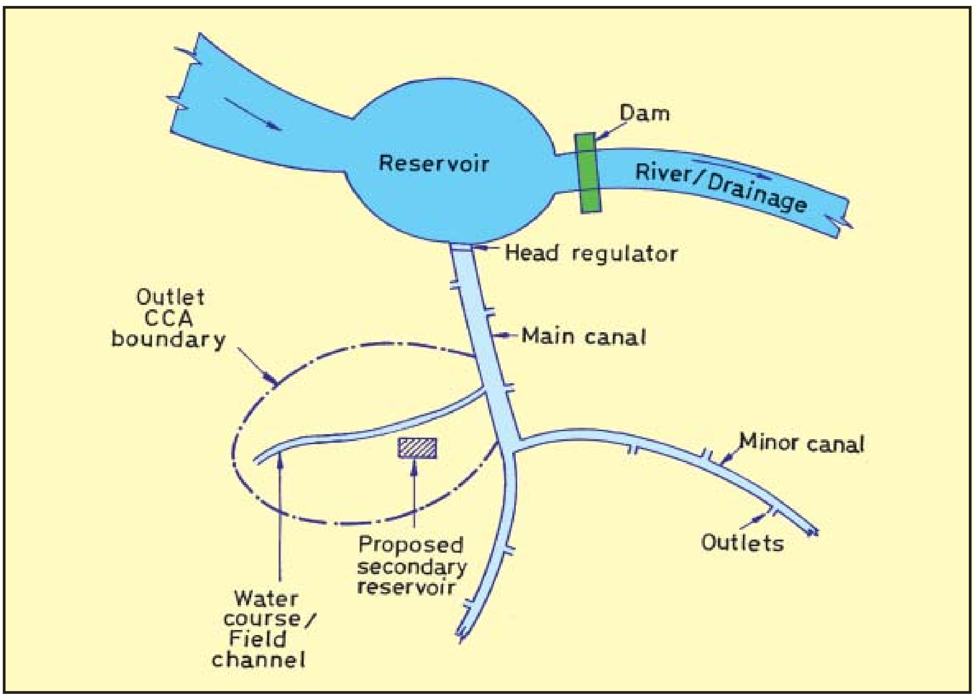

Fig. 2. Definition sketch of the proposed secondary reservoir in the Minor irrigation system

4. METHODOLOGY

The study involves the following steps:

i. Evaluating the hydraulic and agricultural performance of the minor irrigation project to have first hand information on how well the land and water resources are being utilized for agriculture, and to make strategic decision for improving the performance level.

ii. Also evaluating the institutional performance of the system (WUA's performance) to address the issues for its better performance and sustainability.

iii. Formulating a multi-objective optimization routine to determine the optimal size of the proposed secondary storage reservoir and the optimal cropping pattern for the dry season.

iv. Estimating the parameters required as input data set for the optimization model to run.

v. Assessing the improved performance of the project with the provision of secondary storage reservoir and comparing it with the existing project performance i.e., without secondary reservoir.

vi. Evaluating the economic feasibility of the proposed secondary storage reservoir and collecting information about existing water bodies in the command which can be used as secondary reservoirs with suitable modifications.

vii. Demonstrating the multiple use management of the stored water in the secondary reservoir in the outlet command of the study MIP and assessing its effect on improved crop production, productivity and net return.

viii. Understanding the Water Users Association's role in the operation and maintenance of secondary reservoir and suggesting measures for creation, operation, maintenance of such intervention.

4.1. Performance evaluation of the irrigation project

The hydraulic and agricultural performance evaluation helps in understanding that how well the irrigated agriculture is performing. It also helps in assessing how productively the land and water resources are being used for agriculture, and in making strategic decisions regarding irrigation.

4.1.1. *Hydraulic performance evaluation indicators*

In order to assess the performance of the irrigation water delivery, the hydraulic performance indicators such as adequacy, equity, relative water supply and relative irrigation supply were used.

(a) Adequacy

Adequacy of water delivery is dependent on water supply, specified delivery schedules, the capacity of the hydraulic structures to deliver water according to the schedules and the operation and maintenance of hydraulic structures. A measure of performance relative to this objective for a region or sub region R served by the system over the period T is given as follows.

$$P_A = \frac{1}{T}\sum_{T}\left(\frac{Q_{Dt}}{Q_{Rt}}\right) \quad \text{....(1)}$$

Where, Q_{Dt} = the actual amount of water delivered by the system in the period of time t^{th} and Q_{Rt} = the amount of water required for consumptive use, leaching requirement, land preparation, farm application and conveyance losses down stream of the delivery point in the period of time t^{th}. Sum total all these time periods is T. The delivery is considered adequate when Q_{Dt} is equal to $Q_{Rt.}$

(b) Equity

Equity is defined as spatial uniformity of the ratio of water delivered to the water required. An appropriate measure of the performance related to equity would be the average related spatial variability of the ratio of the amount delivered to the amount required over the time period of interest.

$$P_E = \frac{1}{T}\sum_{T} CV_R\left(\frac{Q_{Dt}}{Q_{Rt}}\right) \quad \text{...(2)}$$

Where, $CV_R\left(\frac{Q_{Dt}}{Q_{Rt}}\right)$ is the spatial coefficient of variation of ratio $\left(\frac{Q_{Dt}}{Q_{Rt}}\right)$ over the region R. This measure describes the degree of variability in relative water delivery from point to point over the region. The closer value of P_E to zero, the greater the degree of equity.

(c) Relative water supply (RWS)

Relative water supply is defined as the ratio of water supplied to an irrigation unit to the demand for water in that unit over a period of time. Relative water supply relates the water available for crops (including surface irrigation, ground water pumped and rainfall) to the amount that crops need (Bos *et al.*, 2005).

$$\text{RWS} = \frac{\text{Total water supply}}{\text{Crop demand}} = \frac{\text{Irrigation supply + rainfall}}{\text{Crop ET + seepage + percolation}} \quad \text{...(3)}$$

(d) Relative irrigation supply (RIS)

Relative irrigation supply relates the water available for crops (excluding rainfall) to the irrigation demand. This indicator shows how well irrigation supply and demand is matched. It is given as

$$\text{Relative irrigation supply} = \frac{\text{Irrigation supply}}{\text{Irrigation demand}} = \frac{\text{Irrigation supply}}{\text{CropET} - \text{Effective rainfall}} \qquad \ldots(4)$$

4.1.2. Agricultural performance evaluation indicators

It is expected that with the provision of irrigation, the agricultural scenario, such as production, productivity and cropping intensity will improve. Therefore, the following indicators such irrigation intensity, cropping intensity, standardized gross value of production (SGVP), output per cropped area, output per unit command, and output per irrigation supply were considered as the agricultural performance indicators.

(a) Irrigation intensity

Irrigation intensity is defined the ratio of total irrigated area in year to total command area. This is generally expressed in percentage. Thus,

$$\text{Irrigation intensity} = \frac{\text{Total irrigated area in a year}}{\text{Total command area}} \times 100 \qquad \ldots(5)$$

(b) Cropping intensity

Cropping intensity is defined the ratio of total cropped area in year to total command area. This is also expressed in percentage.

$$\text{Cropping intensity} = \frac{\text{Total cropped area in a year}}{\text{Total command area}} \times 100 \qquad \ldots(6)$$

(c) Standardized of gross value of production

SGVP was developed for conducting cross-system comparison mainly because there are differences in local prices at different locations throughout the world. To obtain SGVP, equivalent yield is calculated based on local prices of the crops grown and, compared to the local price of the predominant, locally grown, internationally-traded base crop. The second step is to value this equivalent production at world prices.

$$\text{SGVP} = \left(\sum_{j=1}^{N} A_j Y_j \frac{P_j}{P_b}\right) P_{world} \qquad \ldots(7)$$

Where A_j = Area under j^{th} crop; Y_j = Yield of the j^{th} crop; P_j = Local price of j^{th} crop; P_b = Local price of the base crop and P_{world} = World price of the base crop.

(d) Output per cropped area

It is the ratio of Standardized of gross value of production to irrigated cropped area.

$$\text{Output per cropped area} = \frac{\text{SGVP}}{\text{Irrigated cropped area}} \quad \ldots(8)$$

(e) Output per unit command

It is the ratio of Standardized of gross value of production to command area.

$$\text{Output per unit command} = \frac{\text{SGVP}}{\text{Command area}} \quad \ldots(9)$$

(f) Output per irrigation supply

It is the ratio of Standardized of gross value of production to diverted irrigation water supplied.

$$\text{Output per unit irrigation supply} = \frac{\text{SGVP}}{\text{Diverted irrigation water supplied}} \quad \ldots(10)$$

4.1.3 Economic feasibility test indicators

Most widely used discounted techniques such as Net Present Value (NPV), Benefit Cost ratio (B/C ratio) and Internal Rate of Return (IRR) were used here for the economic analysis of the secondary storage reservoir.

(a) Net present value

It is a single value representing the sum of discounted net benefits acquiring from any given project throughout its economic life (n). It is calculated as

$$\text{NPV} = \sum_{i}^{n} \frac{NR_i}{(1+r)^i} + \frac{SV}{(1+r)^n} \quad \ldots(11)$$

Where, NR_i = Net return or benefit in i^{th} year; r = Bank interest rate; i = Number of year, 1, 2, ……n; SV = salvage value.

The prevailing interest rate is considered here as 'r'. When NPV is positive (NPV>0), the project is viable. That is the project generates more returns over costs in totality. A negative value (NPV<0) implies that the project is not economically viable. When NPV=0, the measure is indifferent in its suggestion and the decision is left to the decision maker.

(b) Benefit cost ratio

This takes into account benefits and costs separately and is calculated as

$$\frac{B}{C} = \frac{\{\sum_{i}^{n} R_i/(1+r)^i + SV/(1+r)^n\}}{\{\sum_{i}^{n} C_i/(1+r)^i\}} \qquad \ldots(12)$$

Where C_i is the Costs incurred and R_i is the benefit realized each year end. B/C ratio summarizes the present discounted streams of costs and returns in terms of their ratio. When the ratio is equal to one, the measure is indifferent in its recommendation.

(c) Internal rate of return

It is the interest rate at which NPV is equal to zero. This measure tries to find out the return that the project is capable of generating over its economic life. Given the expression of NPV, IRR tries to find out 'r' that makes NPV expression equal to zero. When IRR is greater than bank rate or ones from alternative investment option, then project is viable.

$$\sum_{i}^{n} \frac{NR_i}{(1+r)^i} + \frac{SV}{(1+r)^n} = 0 \qquad \ldots(13)$$

4.1.4 Institutional performance assessment

Institutional intervention has taken place through formation of water user association (WUA) and handing over the irrigation system to WUA for operation and management of the system. The nature and functioning of the WUA, attitude of the farmers towards WUA, the extent of farmers' participation in irrigation management and group effectiveness of WUA were studied through focus group discussion, key informant interviews and interview schedule survey of selected farmers.

In order to analyze the attitude of farmers towards irrigation management transfer (IMT), a scale was developed that included 10 statements and response of each farmer was obtained for each statements on a 3-point continuum (2-agree, 1-undecided and 0-disagree for favourable statement and reverse for unfavourable statement). Therefore, maximum and minimum possible score of overall attitude was ranged from 20 to 0. Frequency, mean and standard deviation were calculated to aggregate the responses of farmers.

The extent of WUA member-farmers' participation in irrigation management was measured with the help of a Farmers' Participation Index (FPI).

$$FPI = \frac{\text{Mean participation score (P)}}{\text{Maximum participation score}} \times 100 \qquad \ldots(14)$$

Where, $P = S\, P_i / N$ and $P_i = S\, PP_j$

Where, PP_j = Total score of farmers' participation

$i = 1,2, \ldots\ldots\ldots, N$

$j = 1,2, \ldots\ldots\ldots, K$

N = total number of respondents

K = total number of statements (statements related to farmers' participation and score was assigned as 1 for 'yes' and 0 for 'no' response to each statement)

To understand the effectiveness of WUA, a Group Dynamic Effective Index (GDEI) was used that included 10 different parameters with different weightage (%) as indicated in Fig. 3. GDEI was studied on the basis of ten different parameters, which are participation (P), decision making procedures (D), operation, maintenance & management functions (O), interpersonal trust (T), fund generation (F), social support (S), group atmosphere (A), membership feelings (M), group norms (N) and empathy (E). To understand the effectiveness of WUA, GDEI was used that included above-mentioned 10 different parameters, which receive different weights in calculation of overall group effectiveness. Each parameter was assessed on the basis of 5 statements on which farmers' responses were taken on 3-point continuum ranging from 0 to 2. Mean and standard deviation values of each parameter were calculated at first step and thereafter, overall GDEI was calculated as follows:

$$GDEI = 0.20*P + 0.15*D + 0.12*O + 0.10*T + 0.10*F + 0.08*S + 0.08*A + 0.07*M + 0.05*N + 0.05*E \qquad \ldots(15)$$

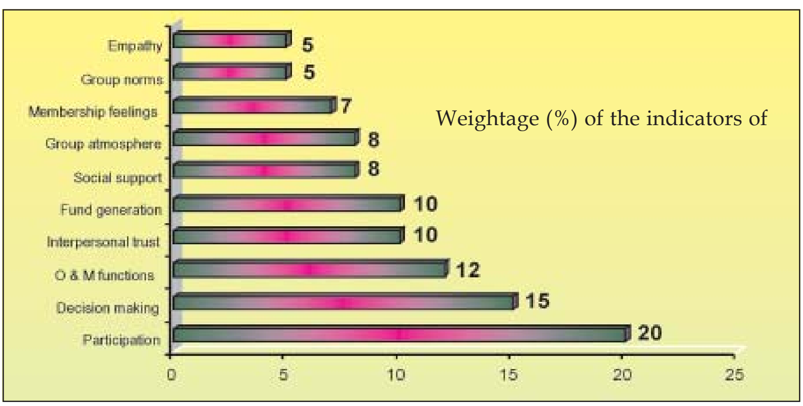

Fig. 3 Group dynamics effectiveness index (GDEI) with its indicators

5. FORMULATION OF THE OPTIMIZATION MODEL

Provision of secondary storage reservoir in each outlet command for rainwater harvesting in monsoon season is considered here to overcome the problem of irrigation water shortage for dry season crops in a minor irrigation project. The water stored in the secondary storage reservoir will cater the irrigation water requirement of dry season crops in addition with the left out water in the main reservoir. A multi-objective optimization routine is developed for determining the optimal size of the secondary storage reservoir and optimal cropping pattern for the chosen minor irrigation project (Adhikary, 2006). Short duration fish culture is suggested in the secondary storage reservoir to enhance the water productivity and make the proposition economically sound. Therefore, the depth of proposed reservoir is considered to be kept as 3.5 m. The following assumptions are made while formulating the multi-objective optimization routine.

i. The relationship between the variables in the objective functions and the constraints are linear.

ii. The soil characteristics of command area are considered to be homogenous.

iii. Each unit of land under consideration receives the same management practices for particular crop activity. Hence, the yield and benefit under a particular crop activity are constant.

iv. Timing and period of crop cultivation are constant and don't vary over years.

v. The cultivation cost per unit area of a crop is same irrespective of location within the project area.

vi. Each outlet command will have a similar cropping pattern irrespective of their location in the irrigation project.

5.1. Objective functions

Multi-objective optimization (Goal programming) technique is used to allocate optimal land area for different crops in dry season and to determine optimal size of secondary storage reservoir. Three objective functions are formulated which are as follows:

i. Maximization of net seasonal benefit,

ii. Maximization of cropped area, and

iii. Minimization of secondary storage reservoir construction and pumping costs.

i). Maximization of net seasonal benefit**:** The first objective function is to maximize the net seasonal benefit from the command area of the minor irrigation project i.e., to maximize the difference between gross seasonal return and the cost of production for the total cropped area during dry season.

$$Max\ Z_B = \sum_{j=1}^{N} B_j X_j \quad \ldots(16)$$

Where, N = Total number of crops grown; B_j = Net benefit of j^{th} crop per unit area excluding the cost of pumping and secondary storage reservoir construction (Rs/ha); X_j = Area of j^{th} crop (ha) (decision variable); and j = Index for crop, 1, 2 …….N.

ii). Maximization of cropped area: The second objective function is to maximize the total cropped area in the minor irrigation command. This aims at bringing more area under crop coverage.

$$Max\ Z_A = \sum_{j=1}^{N} X_j \quad \ldots(17)$$

iii). Minimization of secondary storage reservoir construction and pumping costs: The third objective function is to minimize the total cost involved in the construction of secondary storage reservoir and the cost of pumping of irrigation water from the secondary storage reservoir. It is assumed here that the secondary storage reservoir will be located in the outlet command in such a manner that at least 50% of the command will receive irrigation water from the secondary reservoir through gravity flow and the remaining 50% will receive water through pumping.

$$Min\ Z_{CP} = 10000\left[C_p \sum_{j=1}^{N} NIR_j (X_j/2) + \sum_{i=1}^{n} (C_i \times SA_i \times D)\right] \quad \ldots(18)$$

Where, C_p = Pumping cost for unit volume of irrigation water from secondary storage reservoir (Rs/m^3); NIR_j = Net irrigation depth required for the j^{th} crop (m); n = Total number of outlets; i = Index for outlet, 1, 2, ….n; C_i = Cost of construction of the i^{th} secondary storage reservoir (Rs/m^3); SA_i = Average surface area of the secondary storage reservoir under i^{th} outlet (ha) (decision variable); D = Depth of the secondary storage reservoir (m).

5.2. Constraints

The following constraints are considered.

i). Land area constraint: The total area under different crops in the command plus the total surface area of secondary storage reservoir of all outlets should be less than or equal to the total cultivable command area of the irrigation project.

$$\sum_{j=1}^{N} X_j + \sum_{i=1}^{n} SA_i \le A \quad \ldots(19)$$

Where, A = Total cultivable command area of the MI project (ha).

ii). Water allocation constraint:

(a). For the entire command area: The gross irrigation requirement of all the crops plus losses from the secondary storage reservoirs due to seepage and evaporation should be less than or equal to total volume of the secondary storage reservoirs plus water available in the main reservoir for dry season cultivation.

$$10000\left[\frac{\sum_{j=1}^{N} NIR_j\, X_j}{(\eta_a \times \eta_c)} + \sum_{i=1}^{n} SA_i \sum_{t=1}^{d} (S_t + E_t)\right] \le (p \times VM) + 10000\, D \sum_{i=1}^{n} SA_i \quad \ldots(20)$$

Or, $$10000\left[\frac{\sum_{j=1}^{N} NIR_j X_j}{(\eta_a \times \eta_c)} + \sum_{i=1}^{n} SA_i \sum_{t=1}^{d} (S_t + E_t) - D \sum_{i=1}^{n} SA_i\right] \le (p \times VM) \quad \ldots(21)$$

Where, η_a = Application efficiency (fraction); η_c = Conveyance efficiency (fraction); t = Index for day, 1, 2,.....d; S_t = Seepage and percolation losses on t^{th} day (m); E_t = Evaporation on t^{th} day (m); d = Total number of days in dry season; VM = Volume of main reservoir (m^3); p = Portion of the main reservoir volume indicating the availability of irrigation water for dry season (fraction).

(b). For the outlet command area: The gross irrigation requirement of each outlet command plus the losses from the secondary storage reservoirs due to seepage and evaporation should be less than or equal to the volume of secondary storage reservoir in their respective outlet command plus water available from the main reservoir to the command area of respective outlet. It is assumed here that the volume of water available in the main reservoir for dry season is proportionately distributed as per the command area of each outlet.

$$10000\left[\frac{O_i \sum_{j=1}^{N} NIR_j X_j}{(\eta_a \times \eta_c)} + SA_i \sum_{t=1}^{d} (S_t + E_t) - (SA_i \times D)\right] \le (O_i \times p \times VM) \text{ For all i} \quad \ldots(22)$$

Where, O_i = Portion of the total command area under i^{th} outlet (fraction).

iii) Maximum and minimum area constraint: Management considerations restrict some minimum and maximum value for irrigated areas under certain crops to meet the local food requirements.

$$A_{j\min} \leq X_j \leq A_{j\max} \qquad \text{For all j} \qquad \ldots(23)$$

Where, A_{jmin} = Minimum area of the j^{th} crops (ha); and A_{jmax} = Maximum area of the j^{th} crops (ha).

iv) Non-negativity constraint: In all circumstances the area under each crop and the area under each secondary storage reservoir are greater than or equal to zero.

$$X_j \geq 0 \text{ and } SA_i \geq 0 \qquad \ldots(24)$$

5.3. Model Simulation

The multi objective optimization routine mentioned above to decide the optimal size of the secondary storage reservoir and optimal cropping pattern was solved using QSB 3.0 software. This software runs in DOS environment and can solve various optimization problems. In case of goal programming problems, based on the prioritized objective function, the program uses a multiphase simplex method to solve the problem.

In the irrigation project, it is assumed that there will be secondary storage reservoir in each outlet's command to primarily cater the irrigation need of dry season crops. In total eight crops were considered for the dry season such as groundnut, sunflower, green gram, black gram, tomato, brinjal, cabbage and cauliflower. Four levels of water availability in the main reservoir i.e. 25, 50, 75 and 100 percent of its capacity was considered at the beginning of the dry season while making the simulation run of the optimization model through Goal programming technique. The priority level of the objective function was also changed as given below:

Case 1 : 1st priority - Maximization of net seasonal benefit

2nd priority -Maximization of cropped area

3rd priority - Minimization of secondary storage reservoir construction and pumping costs.

Case 2 : 1st priority - Maximization of cropped area

2nd priority -Maximization of net seasonal benefit

3rd priority - Minimization of secondary storage reservoir construction and pumping costs

Keeping in view the marketing and processing facilities, agricultural produce support price and needs of farmers, the minimum and maximum area under different crops were introduced as constraints in the optimization model to obtain more realistic optimal solution. While deciding the minimum and maximum area for crops, the prevalent cropping pattern of dry season of 2004-05 was used as the base data. In this season, the percentage of area under groundnut, sunflower, green gram, black gram, tomato, brinjal, cabbage and cauliflower were 37.00, 0.26, 18.00, 18.00, 0.06, 0.06, 0.06 and 0.06%, respectively. About 50% deviation was made for deciding maximum and minimum area for groundnut and pulses. Thus, maximum area for groundnut was kept 55% of the total area, as it is the most popular crop of the farmers of Devijhar minor irrigation project. Similarly, the maximum area limit for green gram and black gram were kept as 30% each. Sunflower is a newly introduced highly remunerative crop. Thus, the maximum area under sunflower was kept as 10% of the total command taking into account the handling, milling, processing facility and farmers ability to provide timely inputs. Due to perishable nature and lack of storage facility, maximum area for tomato, cauliflower, cabbage and brinjal was kept each at 2.5% of total command area. Minimum area for groundnut, green gram and black gram was kept as 18.5 %, 9% and 9%, respectively. The minimum area limit for sunflower and vegetables were kept as the actual area cropped during the dry season of 2004-05.

6. RESULTS AND DISCUSSION

The hydraulic and agricultural performance of the minor irrigation system was assessed to ascertain the scope for further improvement. The multi-objective optimization model was run to determine the optimal size of secondary storage reservoir and optimal cropping pattern for the dry season. The improved performance of the system due to provision of secondary storage reservoir was estimated. Analysis to test the economic feasibility of the secondary storage reservoir was also carried out. The extent of existing water bodies in the command of the study system was surveyed. Benefits accrued through use of irrigation water from the secondary reservoir in addition to the water available in the main reservoir and multiple use of the harvested water through pisciculture was determined through field demonstration. Institutional aspects of creation, maintainance, management and sustainance of the proposed intervention was discussed from the experience gathered during experimental study.

6.1 Performance evaluation of the minor irrigation system

In the study system, operation of canal head regulator and allocation of irrigation water to a specific outlet/ group of outlets depending on crop water requirement is decided by the Management Committee (MC) of Water User Association (WUA). During the dry season of 2005-06, the WUA decided to supply irrigation water up to 17th outlet in the main canal and 15th outlet in Badakheta minor due to limited water availability in the main reservoir. Two irrigations were given during this season, the first irrigation during 28th December 2005 to 4th January 2006 and the second irrigation during 25th February to 2nd March, 2006.

6.1.1. Hydraulic performance evaluation

The hydraulic performance indicators such as equity, adequacy, relative water supply and relative irrigation supply were computed to assess the hydraulic performance of the study system. Total flow volume per cropped area for each outlet (in terms of cm depth) was determined for 2nd irrigation. Figs.4 and 5 present the outlet wise average depth of water applied for the Main canal and Badakheta minor, respectively. In the main canal, the flow volume per cropped area value ranged from 3.5 cm (outlet No. 17) to 12.3 cm (outlet No. 14). The mean and standard deviation of these values were obtained as 7.61 cm and 2.45 cm, respectively. The equity value (coefficient of variation) for the main canal system was computed as 0.32. Similarly, for the Badakheta minor the flow volume per cropped area value ranged from 1.27 cm (outlet No.15) to 12.6 cm (outlet No. 4). The mean and standard deviation of these values were obtained as 5.00 cm and 2.73 cm, respectively. The equity value (coefficient of variation) for the Badakheta minor canal was computed as 0.55. The water delivery in the main canal is thus observed to be more equitably distributed in comparison to Badakheta minor.

Though the irrigation water was supplied in the main canal up to 17th outlet and in the Badakheta minor up to 15th outlet, the command areas in the remaining outlets were also cropped. Taking in to account all the outlets and considering zero depth of water application for the outlets in which irrigation water was not supplied, the mean, standard deviation and equity value were calculated. The mean, standard deviation and equity value for main canal were obtained as 5.17 cm, 4.14 cm and 0.80, respectively. Similarly, the mean, standard deviation and equity value for Badakheta minor were obtained as 4.17 cm, 3.13 cm and 0.75, respectively. Thus, in both the canals there is scope to improve the equity of irrigation water distribution. Proper fixing of the outlets sill level, outlet diameter and lining of the canal system to minimize conveyance losses can possibly improve this situation.

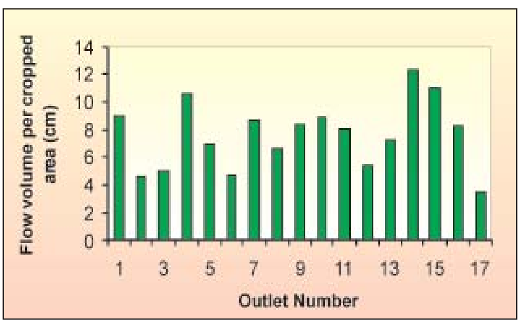

Fig. 4 Flow volume per cropped area in different outlets command of the Main canal during 2005-06 dry season's 2nd irrigation

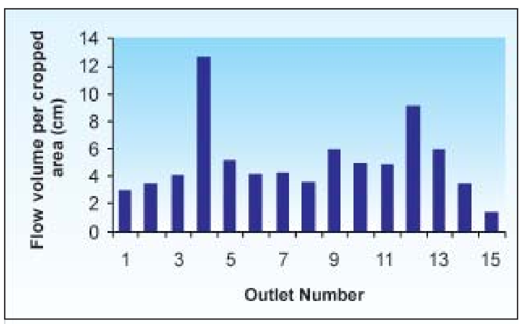

Fig. 5 Flow volume per cropped area in different outlets command of the Badakheta minor during 2005-06 dry season's 2nd irrigation

The adequacy of water delivery was determined at the head regulator of the main canal during 2nd irrigation supply. The water requirement of the total cropped area in the command between 1st and 2nd irrigation period was estimated and compared with the total volume of irrigation water supplied during the 2nd irrigation (Table 2). In the dry season of 2005-06, about 331.57 ha was cultivated. The adequacy value for the system for 2nd irrigation was obtained as 0.396. Ideally it should have been one. Thus, the system greatly suffers from inadequate irrigation water supply due to non-availability of water in the main reservoir emphasizing ample scope for creation of additional water resources. It is also observed that the farmers don't take into account the availability of water in the main reservoir while making their crop planning. Due to this, they don't get adequate amount of water to irrigate their crops. In this process, the tail end farmers of the both the canal systems have suffered maximum.

Table 2. Adequacy of water delivery during 2nd irrigation for Devijhar MIP

Total volume of irrigation water supplied during 2nd irrigation(m^3)	Crops grown	AreaUnder different crops(ha)	Crop water requirem-ent (m)	Flow volume required at the head regulator of the main canal (m^3)	Adequacy
180014.4	Groundnut	242.71	0.11	259694.35	0.396
	Sunflower	0.07	0.11	74.90	
	Green gram	86.30	0.22	188131.82	
	Brinjal	1.00	0.27	2690.00	
	Cabbage	1.00	0.25	2450.00	
	Cauliflower	0.50	0.25	1225.00	
Total				**454266.07**	

The value of relative water supply (RWS) and relative irrigation supply was computed for the entire dry season. Here, relative water supply relates the irrigation water available for crops from surface water and rainwater to the amount of water the crop needs (Table 3). The value of RWS was determined as 0.687 indicating that about two third of the crop water demand is met from irrigation and rainfall. Similarly, the relative irrigation supply which indicates about the crops getting enough water or too much was determined as 0.641 (Table 4). The value of less than one indicates that there is no wastage of water through over irrigation.

Table 3. Relative water supply during the dry season, 2005-06 in Devijhar MIP

Total volume of irrigation water supplied during dry season, 2005-06 (m^3)	Total rainfall volume during the dry season (m^3)	Crops grown	Area Under different crops(ha)	Total crop water requirement, (PET + seepage + percolation losses)(m)	Total volume of water required by the crops(m^3)	Relative water supply
A	B		C	D	C´D	(A+B)/ Σ(C´D)
500040	436400	Groundnut Sunflower Green gram Brinjal Cabbage Cauliflower	242.71 0.07 86.30 1.00 1.00 0.50	0.47 0.36 0.24 0.57 0.53 0.45	1143140.55 254.80 204528.63 5740.00 5320.00 2230.00	0.687
		Total			**1361213.98**	

Table 4. Relative irrigation supply during the dry season, 2005-06 in Devijhar MIP

Total volume of irrigation water supplied during the dry season, 2005-06(m^3)	Crops grown	Areaunder different crops(ha)	Irrigation demand, (PET – effective rainfall)(m)	Volume of irrigation water demand(m^3)	Relative irrigation supply
500040	Groundnut Sunflower Green gram Brinjal Cabbage Cauliflower	242.71 0.07 86.30 1.00 1.00 0.50	0.278 0.202 0.113 0.349 0.320 0.259	674719.9 141.4 97517.9 3490 3200 1295	0.641
	Total			**780364.2**	

6.1.2. Agricultural performance evaluation

The cropping pattern of study area during the dry season of 2005-06 is shown in Fig. 6. Groundnut is the predominant crop of the area covering about 48.54% of the command. About 33.69% area of the command remained fallow. Pulses, vegetables and sunflower covered remaining 17.77% of the command area. Limited availability of irrigation water in the main reservoir has restricted the farmers to go for crop cultivation in the entire command during the dry season. Further, to increase the area under crop coverage during the dry season and to derive maximum benefit from the system, harvesting of rainwater in the command and determination of an optimal cropping pattern taking into account the availability of irrigation water are essential.

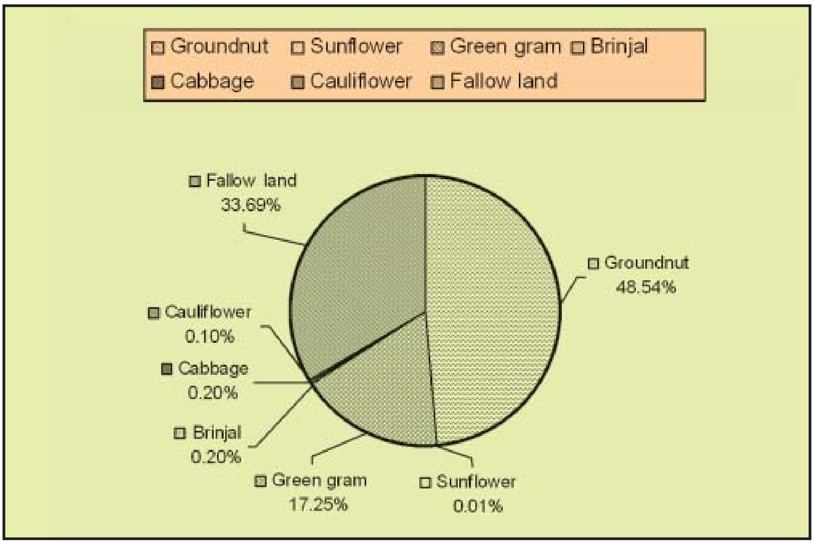

Fig. 6 Cropping pattern as percentage of command area during dry season, 2005-06 in Devijhar minor irrigation system.

The agricultural performance of system was assessed using irrigation intensity, cropping intensity, standardized gross value of production, output per cropped area, output per unit command and output per unit irrigation supply as indicators. The total crop coverage during the rainy and dry season of 2005-06 was 498.13 and 331.57 ha, respectively. The cropping intensity of the command was determined as 165.94 %. During the dry season, irrigation water was supplied up to 17th outlet in the Main canal and up to 15th outlet in the Minor canal even though the remaining outlets command had also some crop coverage. The actual area received irrigation was during this season was 268.45 ha out of total cropped area of 331.57 ha. Thus, the irrigation intensity value worked out as 153.32 %. Therefore, about half of the total command area was deprived of irrigation water during the dry season.

The standardized gross value of production from the entire command during the dry season was computed as Rs. 46,40,236.87. Here paddy was considered as the base crop. The local price and global price of paddy was considered as Rs.4.6/kg and Rs.5.8/kg respectively (Table 5). Using the SGVP value, output per cropped area, output per unit command and the output per unit irrigation supply were computed as 17,284.97 (Rs./ha), 9,280.47 (Rs./ha) and 9.27 (Rs./m^3) respectively (Table 6). These values were found to be lower than the potential values. Inadequate amount of irrigation water coupled with less investment on agricultural inputs are possibly some of the reasons responsible for the lower values of agricultural performance indicators.

Table 5. Standardization of gross value of production (SGVP)

Type of crop	Area under crop (A_i) (ha)	Yield(Y_i) (kg/ha)	Local price of the crops (P_i) (Rs/kg)	Local price of the base crop (P_b) (Rs/kg)	World) price of the base cropP_{world} (Rs/kg)	A_iY_i (P_i/P_b)	SGVP (Rs)
Groundnut	242.705	1000	14.00	4.6	5.8	738667.39	4640236.87
Sunflower	0.07	1000	16.36			248.95	
Greengram	86.299	150	15			42211.47	
Brinjal	1.0	10500	4			9130.43	
Cabbage	1.0	15000	2			6521.74	
Cauliflower	0.5	10000	3			3260.86	
Total						**800040.84**	

Table 6. Agricultural performance of Devijhar MIP

Sl. No.	Agricultural performance indicator	Value
1	Irrigation intensity (%)	153.32
2	Cropping intensity (%)	165.94
3	Standardized gross value of production (Rs.)	4640236.87
4	Output per cropped area (Rs./ha)	17284.97
5	Output per unit command (Rs./ha)	9280.47
6	Output per unit irrigation supply (Rs./m^3)	9.27

6.1.3. Institutional performance evaluation

Institutional intervention through formation of water user association (WUA) and handing over the irrigation system to WUA/ farmers for operation and management took place during July 2004. The institutional performance indicators such as the nature and functioning of the WUA, attitude of the member-farmers towards WUA, the extent of their participation and group effectiveness of WUA were studied through focus group discussion, key informant interviews and interview schedule survey of selected farmers.

Attitude of the farmers towards WUA

An analysis of the attitude of the farmers is made on the basis of their agreement or disagreement on following 10 statements. The detail response of farmers is given in the Table 7. It is heartening to find that all the selected member-farmers of WUA under Devijhar MI project showed positive attitude being agreed most of the issues mentioned in the Table. However, almost all of them were undecided about WUA's role in judicious management of water and few of them were not fully convinced that WUA establishes financial self-sufficiency. This kind of non-convincing attitude may be due to the experience of the farmers in the year 2004-05, while many farmers grew groundnut crop during dry season and faced dearth of irrigation water towards later part of the crop growth period. This sought for proper crop planning taking into account type of crop, area under them, their crop water requirement and availability of water in main reservoir for providing irrigation.

Table 7. Attitudes of the member-farmers of WUA under Devijhar MI system

Statements	Response of farmers (N=91)		
	Agree	Undecided	Disagree
	F (%)	F (%)	F (%)
WUA has made significant improvement in the farming condition of farmers	91 (100.0)	0	0
WUA promotes mutual co-operation among farmers	91 (100.0)	0	0
WUA does solve water related problems of farmers	91 (100.0)	0	0
WUA fails to maintain economy and equitability in distribution of water among the farmers	0	2 (2.2)	89 (97.8)
Irrigation system performs excellently since the responsibility of operation and maintenance shifted to farmers group/WUA	91 (100.0)	0	0
WUA also ensure regular maintenance of all the watercourses and other structures in its jurisdiction	91 (100.0)	0	0
WUA establishes financial self-sufficiency	76 (83.5)	8 (8.8)	7 (7.7)
WUA does not have any impact in increasing the income of member farmers	0	9 (9.9)	82 (90.1)
WUA intends for judicious management of water and in reality nothing is done so far	0	90 (98.9)	1 (1.1)
Formation of WUA has increased conflicts in village	2 (2.2)	3 (3.3)	86 (94.5)

F means frequency of farmer-respondents and figures in the parenthesis indicate percentage

Extent of WUA member-farmers' participation in irrigation management

The responses of selected member-farmers were recorded with help of developed schedule that included statements on different issues related to farmers' participation. Score was assigned as 1 for 'yes' and 0 for 'no' response to each statement and farmers participation index (FPI) was calculated. A detail account of the farmers' response on each issue is given in the Table 8. It is interesting to note that member-farmers of WUA at Devijhar do not participate in fund generation activity other than water tax collection and they are also not involved in deciding cropping pattern and training for mobilization of the farmers towards participatory irrigation management. In earlier section of attitude analysis it is found that farmers were undecided in their response towards WUA's role in judicious management of water and financial self-sufficiency of WUA. It is worth concluding here that lack of participation as revealed above has influenced their attitude.

Table 8. Farmers' opinions with respect to their participation in irrigation management activities of WUA at Devijhar

Statements under issues related to participation	No. of farmers with positive response	Mean score (N=91)	Standard deviation
Farmers involve in internal water distributions	91	1.0	0.00
Farmers fix water rates for different crops	91	1.0	0.00
Farmers participate in the collection of water rates	91	1.0	0.00
Farmers follow water sharing for irrigating crops	87	0.96	0.20
Farmers select specific crop pattern to be adopted by all member farmers	1	0.01	0.12
Farmers take care of maintenance of outlets, channels and distribution systems	87	0.96	0.20
Farmers aware about law /rule /act, which support farmers' participation in irrigation management	87	0.96	0.20
Farmers raise their own fund other than water rates	0	0	0.00
Farmers have got mobilized for participatory irrigation management through training	4	0.04	0.20
Farmers understand problems related to irrigation service controlled by outsiders, therefore, adopt participatory methods to solve such problems	91	1.0	0.00
All member-farmers participate in periodical meetings of WUA	87	0.96	0.20
Farmers' group/ WUA arrange financial support for participatory agricultural activities time to time	3	0.03	0.17
			FPI value = 65.92

Group effectiveness of WUAs

Group dynamics effectiveness (GDE) was studied on the basis of ten different parameters in GDEI, which receive different weights in calculation of overall group effectiveness. Levels of parameters of group dynamic effectiveness in different WUAs are presented in the Table 9. It is evident that parameters like participation, group atmosphere and membership feeling were perceived relatively high by the member-farmers of WUA. Lower value for the parameter empathy indicates the lack of understanding of each others situation among the members of the WUA.

Table 9. Group dynamics effectiveness index of WUA in Devijhar MIP

Parameters of GDEI	WUA at Devijhar (N=91)	
	Mean	**SD**
Participation	7.99	0.10
Decision making	5.37	1.55
O & M functions	6.84	0.58
Fund generation	6.93	0.74
Group atmosphere	9.20	1.29
Membership feeling	7.88	0.47
Norms	6.45	0.85
Empathy	3.32	0.73
Interpersonal trust	6.02	0.30
Social support	6.01	0.10
Overall GDE	6.82	0.26

Maximum and minimum possible mean score is 10 and 0, respectively

It is interesting to note that inspite of largeness of the WUA at Devijhar MIP, member-farmers perceived most of the parameters favourably. Prevalence of village water user groups at each village and their representation in the management committee (MC) of WUA may have cater the need of the farmers better thereby influenced the perceptions of the respondent-farmers at Devijhar. Relatively lower values of the parameters viz. empathy and decision making indicate the disatisfaction of the members on WUAs understanding of indivdual member's need and process of making decision regarding crop planning, water control and delivery, revenue generation etc.

During the discussion with officials, MC members of WUA and farmers it was agreed by the majority that success and achievement of WUA depend on the extent to which nature and functioning of the programme/project address the problems and needs of the farmers in irrigation management, the extent to which the farmers have been organized in group with participation and empowerment culture for group action, and the extent to which the improvements can be made in the strategies for effective group mobilization and sustainability.

6.1.4. *Performance assessment of irrigation water supply and distribution from farmers' perspective*

Framers' dissatisfaction with the water delivery services in the command prompted to undertake further study to understand the condition and water delivery at the outlet level. Farmers' responses on irrigation water supply and distribution was studied through a questionnaire survey (Table 10). The survey covered a sample of farmers whose fields fall under commands of two selected outlets each at head, middle and tail reach of the Devijhar MIP. Accordingly, six outlets (6R and 7R at head, 11R and 12R at middle, 21R and 22R at tail reach) were selected and total sample of 100 farmers were covered.

The outlet command area is varied between 52.89 ha in 6R and 7.3 ha in 22R. Average area of the farmers fall under a given outlet command varied from 0.78 to 1.13 ha. During *kharif* season, duration of irrigation water supply in the head, middle and tail reach outlet is observed as 14 days, 12 days, and 9 days respectively. Similarly, in *rabi* season there is hardly any supply of irrigation water in tail reach. Head and middle reach receives water for 9 and 6 days duration, respectively. This clearly indicates the inequitable water distribution over the length of the canal system. Interval between two irrigations is about two weeks in head and middle reach and 17-19 days in tail reach during *kharif*; however, it is about four weeks in head and middle reach and five weeks in tail reach during *rabi* season. Field to field by flooding method of irrigation is dominant followed by irrigation through filed channels. About one-fourth of the sample farmers get irrigation partially by field channel and flooding. Three to four farmers irrigate at a time from the stream coming from an outlet. Farmers' perception towards outlet condition, sufficiency of irrigation water, stream size, irrigation water availability during crop's need, equity of irrigation water distribution and irrigation system performance below outlet level was assessed on a 5-point continuum scale (1-very poor to 5 - excellent). There is not much difference in the perceptions of farmers regarding sufficiency of irrigation water received during *kharif*; however, it is not sufficient during *rabi* season; tail end farmers being the worst affected. Same is the fact for the stream size of irrigation water. It is surprising to find that availability of water during crops' need is perceived lowly by the farmers even in *kharif* season while it is poor during *rabi* season. Farmers have opined that equity of irrigation water availability to farmers is poor except for the farmers under 11R outlet's command during *kharif*. Overall half of the sampled farmers mentioned about irrigating crops even when not needed, which is more at the tail end of MIP. Farmers perceived the functioning of irrigation system at outlet level as above average during *kharif* and below average during *rabi* season.

Table 10. Farmers' perceptions towards irrigation water distribution below the outlet level in Devijhar MIP, Ganjam

Particulars		Perceptions of the farmers under different outlets of Devijhar MIP					
		6R (n=21)	7R (n=22)	11R (n=16)	12R (n=17)	21R (n=13)	22R (n=11)
Outlet command area (ha)		52.89	20.43	15.57	15.96	11.55	7.30
Outlet diameter (cm)		15	15	12	12	15	12
Avg. area of the farmers in outlet command (ha)		0.78	1.13	0.81	0.86	0.82	0.88
No. of farmers' fields location in outlet command	Near (within 1000m) Middle (>1000 to 2000m) End (>2000m)	7 8 6	7 7 8	4 4 8	7 5 5	4 4 5	3 4 4
Avg. duration of irrigation supply in an outlet (days)	*Kharif* *Rabi*	14 9	14 9	12 6	12 6	9 Not enough supply	9 Not enough supply

Interval between two irrigations (days)	*Kharif* *Rabi*	14 31	15 31	13 28	14 28	17 35	19 36
No. of farmers' mode of irrigation to field	Field channels Field to field by flooding Partially by field channel and flooding	9 8 4	5 10 7	2 8 6	6 9 2	4 5 4	4 5 2
No. of farmers irrigate at a time from the stream coming through same outlet		4	4	4	4	4	3
Outlet condition*	*Kharif* *Rabi*	3.43 2.76	3.59 2.67	4.19 2.38	3.71 2.94	3.15 1.15	3.36 1.09
Sufficiency of amount of irrigation water received*	*Kharif* *Rabi*	3.16 2.47	3.27 2.27	3.63 2.13	3.12 2.29	2.92 1.31	3.09 1.00
Stream size of irrigation water*	*Kharif* *Rabi*	3.05 2.37	3.00 2.14	3.69 2.13	3.18 2.35	2.77 1.15	3.00 1.09
Irrigation availability at the time of crop's need*	*Kharif* *Rabi*	2.79 1.47	2.82 1.41	3.44 1.88	3.06 1.35	2.31 1.00	2.82 1.00
Equity of irrigation water availability to farmers*	*Kharif* *Rabi*	1.42 1.11	1.68 1.18	3.00 1.75	1.00 1.00	1.23 1.00	1.00 1.00
No. of farmers irrigating crops even when not needed	Yes No	6 15	12 10	7 9	5 12	11 2	9 2
Functioning of irrigation system below outlet*	*Kharif* *Rabi*	3.00 2.05	3.05 1.95	3.75 2.00	2.94 2.29	2.92 1.08	3.45 1.00

* Farmers' perceptions through linguistic expressions were quantified, where minimum and maximum possible mean score is 1 and 5, respectively.

6.2. Optimal size of secondary storage reservoir and optimal cropping pattern

Initially, the optimization model was run without incorporating the maximum and minimum area constraints of different crops. For Case I, the model considered only brinjal being the highest remunerative crop and neglected all other crops. Similarly, for Case II, the model considered only green gram being the lowest water requiring crop and neglected all other crops. Thus, the optimal solution found to be an unacceptable proposition to farmers. Therefore, inclusion of maximum and minimum area constraints for different crops became inevitable to obtain a realistic and acceptable optimal solution.

Table 11 presents the optimal cropping pattern and optimal surface area of secondary storage reservoir for Case 1 at different water availability levels in the main reservoir. In this scenario, the total cropped area at 25, 50, 75 and 100% main reservoir water availability levels were 404.97, 412.99, 421.35 and 429.89 ha, respectively. As the 1st priority here is to maximize the net seasonal benefit, the optimization model considered the maximum limit of some highly remunerative crops (tomato, cabbage, brinjal and cauli flower) as the optimal solution. Similarly, model considered here the minimum area limit of greengram and blackgram (45 ha) as the optimal solution (for all four levels of water availability) since the net return from these two crops is lowest than the other crops. Further, the area under groundnut was obtained as 263.67, 271.69, 275, and 275 ha for 25, 50, 75 and 100 % of main reservoir water availability, respectively. The area for sunflower was obtained as 1.3, 1.3, 6.35 and 14.89 ha for 25, 50, 75 and 100 % of main reservoir water availability, respectively. These values indicate that with availability of more water the area under oilseed crop is found increasing.

The last row of Table 11 presents the total surface area of secondary storage reservoirs. The optimal surface area of secondary storage reservoir as the percentage of the command area was obtained as 19.00, 17.40, 15.73, and 14.00% for 25, 50, 75 and 100% of water availability in the main reservoir, respectively. As expected, with the increase in water availability in the main reservoir, the surface area requirement of the secondary reservoir decreased. Considering that on an average by the end of monsoon season about 50% of the main reservoir capacity will have irrigation water for the dry season crops, the optimal surface area of the secondary storage reservoir was obtained as 17.40% of the command area.

Table 11. Optimal cropping pattern and secondary storage reservoir area (for Case 1) considering minimum and maximum area constraint

Crop/secondary storage	Area under various crops and area of secondary storage reservoir (ha) at different water availability levels in the main reservoir			
	at 25%	at 50%	at 75%	at100%
Groundnut	263.67	271.69	275	275
Sunflower	1.30	1.30	6.35	14.89
Green gram	45.00	45.00	45.00	45.00
Black gram	45.00	45.00	45.00	45.00
Tomato	12.50	12.50	12.50	12.50
Brinjal	12.50	12.50	12.50	12.50
Cabbage	12.50	12.50	12.50	12.50
Cauliflower	12.50	12.50	12.50	12.50
Secondary reservoir area	95.03 (19.00%)	87.01 (17.40%)	78.65 (15.73%)	70.11 (14.00%)

Note: Figures in the parenthesis indicate the percentage of command area

6.3. Improved system's performance due to secondary storage reservoir

The performance of the existing system is compared with the improved performance of the system with provision of secondary storage reservoir at 50% water availability in the main reservoir. As the entire cropped area is expected to get sufficient irrigation water, the cropping intensity and irrigation intensity value will be the same after construction of secondary reservoir. Thus, increase in irrigation intensity and cropping intensity was obtained as 7.74 and -0.45 percent respectively for Case 1 and 16.2 and 7.36 percent, respectively, for Case 2 (Tables 13 & 14). The increase in SGVP, output per cropped area, output per unit command for Case 1 were obtained as 171.66, 76.5 and 171.66 percent, respectively. Similarly, the increase in SGVP, output per cropped area, output per unit command for Case 2 was 84.5, 11.20 and 84.5 percent, respectively. Thus marginal increase is observed for cropping intensity and irrigation intensity values and substantial increase is noticed for SGVP, output per cropped area and output per unit command. This is due to fact that presently more area is put under crops during dry season without adequate irrigation water supply. With the provision of secondary storage reservoir, in addition to bringing more area under cultivation, the irrigated area which is presently getting less amount of irrigation water will receive full. Thus, there will be jump in the productivity level of different crops leading to higher SGVP, output per cropped area and output per unit command values.

Table 13. Comparison of performance of the MI system with and without secondary storage reservoir (for Case 1)

Performance indicator	Existing system	Systems with secondary storage reservoir	Percentage change(%)
Irrigation intensity (%)	153. 32	165.19	7.74
Cropping intensity (%)	165.94	165.19	-0.45
SGVP (Rs.)	4640236.87	12605848.30	171.66
Output per cropped area (Rs./ha)	17284.97	30523.37	76.50
Output per unit command (Rs./ha)	9280.47	25211.69	171.66

Table 14. Comparison of performance of the MI system with and without secondary storage reservoir (for Case 2)

Performance indicator	Existing system	Systems with secondary storage reservoir	Percentage change(%)
Irrigation intensity (%)	153. 32	178.16	16.20
Cropping intensity (%)	165.94	178.16	7.36
SGVP (Rs.)	4640236.87	8561743.37	84.50
Output per cropped area (Rs./ha)	17284.97	19222.16	11.20
Output per unit command (Rs./ha)	9280.47	17123.49	84.50

6.4. Economic analysis

Economic analysis of the optimal solution was calculated at 50 % water availability in the main reservoir. The initial investments, annual costs and annual returns from irrigation were calculated for the total command for 25 years as because the life span for the secondary storage reservoir was considered here as 25 years (Panigraghi and Panda, 2003). The initial investment is associated to first year of the project. The yearly maintenance cost for the secondary reservoir and pump set was taken as 1% and 2.5% of the initial cost, respectively (Mishra and Tyagi, 1988). Cultivation cost and return from fish and crops are variable. The percentage change in cultivation cost for groundnut, sunflower, green gram, black gram and vegetables were taken as 3.12, 6.37, 3.43, 3 and 3.12 respectively. The percentage change in returns for groundnut, sunflower, green gram, black gram and vegetables were as 9.058, 15.108, 9.304, 9.612 and 9.058 respectively (Sen and Bhatia, 2004). For calculating the Net Present Value (NPV) and Benefit Cost ratio, discount rate at 9% was considered.

The present worth value of the annual costs and returns were calculated for all 25 years of simulation. The benefit cost ratio for Case 1 and Case 2 were obtained as 1.68 and 1.86, respectively. The net present value (NPV) and internal rate of returns (IRR) for Case 1 were Rs.162701247 and 22.52 %, respectively. Similarly for Case 2, the NPV and IRR were Rs. 135865000 and 24.43 %, respectively. In both the cases (Case 1 & 2), the benefit cost ratio of more than one, positive value of NPV and higher value of IRR than the bank interest rate indicate that the proposition of secondary storage reservoir in the command of the MI system is economically viable. Economic feasibility of the intervention reinforces the proposal. Thus, to increase the productivity, cropping intensity and overall production in a minor flow irrigation system there is a need for creation of additional water resource through rainwater harvesting in secondary storage reservoir that is located in the command of each outlet.

6.5 Assessment of area under existing water bodies

After developing the methodology and determining the optimal area required for secondary reservoir, the immediate question which comes to the mind is from where and how the area required for the secondary reservoir will be met. To partially answer this query, the area under the existing water bodies in the command of Devijhar MIP was assessed. In total there are 10 villages which come in the command of this MIP. Table 15 indicates the village-wise area and number of water bodies (both individually owned and community owned) present in the command area of the Devijhar MIP. In total, there are about 54 water bodies present occupying approximately about 55 ha which when works out comes around 11% of the command area. This figure may vary from system to system. However, it is certain that major portion of the area required for secondary reservoir can be met through use of existing water bodies with suitable modifications such as providing inlet, outlet, pumping unit etc. The remaining area can be obtained either from community owned land or from individual owned land with development suitable institutional mechanism.

Table 15. Area and number of existing water bodies in the command of Devijhar MIP

Sl No.	Village name	Area under existing water bodies (ha)		
		Community owned	Individual owned	Total
1	Aitipur	3.28 (2)	0.11 (2)	3.39 (4)
2	Tentulia Palli	1.13 (4)	1.04 (6)	2.17 (10)
3	Biripur	1.81 (2)	0.07 (1)	1.88 (3)
4	Parinuagaon	18.12 (6)	0.93 (3)	19.05 (9)
5	B K Saranpur	0.64 (2)	0.04 (1)	0.68 (3)
6	Ustapada	14.86 (3)	0.00 (0)	14.86 (3)
7	Laxmanpur	7.91 (5)	1.47 (4)	9.38 (9)
8	Bagalpur	2.56 (9)	0.00 (0)	2.56 (9)
9	Kamarsingh	0.14 (1)	0.00 (0)	0.14 (1)
10	Kaithapada	0.83 (1)	0.12 (2)	0.95 (3)
	Total	**51.28 (35)**	**3.78 (19)**	**55.06 (54)**

Figures within the parenthesis indicate number of water bodies

6.6 Multiple use management of harvested water in secondary reservoir - field study

Due to limited irrigation water availability in the main reservoir during the dry season 2006-07, farmers restricted area for growing the second crop. The farmers located only in the head and middle reaches of the canal system grew light duty *rabi*/ summer crops. The crop coverage was severely restricted in the tail reach. In order to explore the possibility of growing *rabi*/ summer crops using the irrigation water from a secondary reservoir, an existing community owned water body located in the Kamarsingh village in the command of outlet 8R of the main canal system was chosen for this study. The outlet 8R off-takes at 2.17 km RD from the main canal. It has a design discharge of 19.6 lit/sec and command area of 17.98 ha with 34 beneficiaries. The area of chosen secondary reservoir is about 700 m^2 (Plate 3). The depth of the reservoir is about 3.6 m. The farmers having their lands in the vicinity of the secondary reservoir were

Plate 3. Secondary reservoir in the Kamarsingh village

encouraged to grow vegetables and oilseed crops in the dry season utilizing the water from it through a 3.5 HP pump set. The secondary reservoir stores excess irrigation water supplied through the canal system from the main reservoir besides harvesting rainwater during rainy season. The depth of water in the reservoir fluctuated between 1.5 m (in the month of May) to 2.8 m (in the month of November) in the dry season of the experimental year.

Sunflower, ladies finger, brinjal and tomato were grown in *rabi* season (Plates 4 & 5). The establishment of sunflower and brinjal was observed to be quite good in terms of plant population, stem circumference, seed or fruit number and fruit /grain yield (Table 16) due to timely irrigations at critical crop growth stages. The economics of crops cultivated using water from the main reservoir and water from main + secondary reservoir has been computed and given in Table 17. In all the cropping patterns, crops receiving water from both the reservoirs have yielded more and resulted in higher net return. Among the cropping pattern considered, rice tomato cropping pattern has

Plate 4. Sunflower crop grown in the Kamarsingh village using the water from secondary reservoir.

Plate 5. Brinjal grown in the Kamarsingh village using the water from secondary reservoir

Table 16. Growth and yield of crops during *rabi* 2006-07, receiving irrigation water from main reservoir (MR) and main reservoir + secondary reservoir (MR+SR)

Crop growth parameter	Sunflower		Brinjal		Tomato		Groundnut	
Plant height (cm)	MR	MR+SR	MR	MR+SR	MR	MR+SR	MR	MR+SR
Stem circumference (cm)	126	132	38	40	34	36	39	41
Number of leaves /plant	4.03	4.18	2.91	2.98	2.62	2.74	–-	–-
Head diameter (cm)	16.2	17.4	10.1	10.4	–-	–-	–-	–-
Number of seeds /head	11.5	12.2	–-	–-	–-	–-	–-	–-
Number of pods/plant	239.4	265.8	–-	–-	–-	–-	–-	–-
Yield (q/ha)	8.4	9.6	72.2	83.5	79.6	91.5	8.1	9.3

resulted in highest net return of Rs. 29,457/ha followed by rice brinjal cropping pattern (Rs.26,757/ha). The benefit cost ratio of 2.07 was computed for rice tomato cropping pattern followed by 1.99 for rice brinjal.

Table 17. Economics of different cropping systems receiving irrigation water from main reservoir (MR) and main reservoir + secondary reservoir (MR+SR) for *rabi* 2006-07.

Cropping system	Gross return (Rs/ha)		Cost of cultivation (Rs/ha)		Net return (Rs/ha)		Benefit cost ratio	
	MR	MR+SR	MR	MR+SR	MR	MR+SR	MR	MR+SR
Rice-groundnut	38,202	40,842	21,175	21,875	17,027	18,967	1.80	1.87
Rice-sunflower	36,982	39,582	18,175	18,875	18,807	20,707	2.03	2.09
Rice-brinjal	49,262	53,782	25,975	27,025	23,287	26,757	1.90	1.99
Rice-tomato	52,222	56,982	26,475	27,525	25,747	29,457	1.97	2.07

Price of crop produce: Rice grain @ Rs. 6.50/kg, rice straw @ Rs. 0.3/kg, groundnut pods @ Rs. 23/kg and brinjal fruits @ Rs. 5/kg.

The experiment on multiple use management of harvested water from secondary reservoir continued also during the dry season of 2007-08. Rice, groundnut, brinjal etc. were grown in the experimental site in the command of the secondary reservoir. During the crop growing period, the water level in the secondary reservoir fluctuated between 2.85 m to 1.9 m. In total, two irrigations were given from the main reservoir during *rabi* season. The 1st irrigation was supplied on 6th January for a period of 8 days and the second irrigation on14th March for a period of 10 days. In addition to irrigation water from main reservoir, water from secondary reservoir was also used for irrigating different crops. The crops grown in secondary reservoir command were supplied with additional 2-3 irrigations compared to that of crops grown in the main reservoir. The crop growth performance of rice, groundnut and brinjal in the command of the secondary reservoir was found quite impressive in comparison to the crop grown only with irrigation water from main reservoir (Table 18). The economics of the crops cultivated using water from the main reservoir and water from main + secondary reservoir has been computed and given in Table 19. Among the cropping pattern

Table 18. Growth and yield of crops during *rabi* 2007-08, receiving irrigation water from main reservoir (MR) and main reservoir + secondary reservoir (MR+SR)

Crop growth parameter	Rice		Groundnut		Brinjal	
Irrigation water source	MR	MR+SR	MR	MR+SR	MR	MR+SR
Plant height (cm)	84	1.02	37	44	36	42
Plant population /m^2	38	43	23	25	7	8
Grain/ kernel/ fruit yield (q/ha)	28	37	9.4	11.7	43	51
Straw/ haulm yield (q/ha)	34	45	19.8	23.5	-	-

Table 19. Economics of different cropping systems receiving irrigation water from main reservoir (MR) and main reservoir + secondary reservoir (MR+SR) for *rabi* 2007-08

Cropping system	Gross return (Rs/ha)		Cost of cultivation (Rs/ha)		Net return (Rs/ha)		Benefit cost ratio	
	MR	MR+SR	MR	MR+SR	MR	MR+SR	MR	MR+SR
Rice-rice	41,370	47,550	24,635	25,685	16,735	21,865	1.68	1.85
Rice-groundnut	43,770	49,060	23,265	23,965	20,505	25,095	1.88	2.05
Rice-brinjal	43,650	47,700	28,545	29,595	15,105	18,105	1.53	1.61

Price of crop produce: Rice grain @ Rs. 6.50/kg, rice straw @ Rs. 0.3/kg, groundnut pods @ Rs. 23/kg and brinjal fruits @ Rs. 5/kg.

considered, rice groundnut has resulted in highest net return of Rs.25,095/ha followed by rice rice cropping pattern (Rs.21,865/ha). The benefit cost ratio of 2.05 was computed for rice groundnut cropping pattern followed by 1.85 for rice rice cropping pattern.

Aquaculture in the secondary reservoir

Low input-based scientific fish culture was carried out for two consecutive years (2006-08) in the secondary reservoir by the User group. Fish seed of Indian Major Carps (IMCs) (*Catla catla, Labeo rohita* and *C. mrigala*) and exotic carp *C. carpio* were stocked after proper acclimatization @ 15,000 early fingerlings/ha {Mean body weight (MBW)3.2 $\pm$ 0.7 gm}. Stocking composition was 20:40:35:5. Supplemental feeding was provided with a ratio of 55:35:10 (rice bran: mustard oil cake: fish meal) @ 5%, 4%, 3% and 2.5% of MBW, twice a day, during 1st, 2nd, 3rd and 4th month to harvesting, respectively. Periodic manuring with raw cattle dung (RCD) @ 500 kg/ha and liming @ 50 kg/ha were carried out at every 15 days interval to maintain plankton population in the eco-system.

The recorded mean minimum and maximum values of various water quality parameters in the secondary reservoirs during the ongoing experimental period were: water temperature 27.1 - 33.7 ^{0}C; water pH 6.9 – 8.1; dissolved oxygen 4.3 - 6.9 ppm; total alkalinity 87 - 133 ppm; dissolved organic matter 2.9 - 6.6 ppm; nitrite –N 0.006 - 0.07 ppm; nitrate-N 0.06 - 0.5 ppm; ammonia 0.01 - 0.33 ppm; transparency 34$\pm$4; and total suspended solid 177 - 372 ppm. TSS and DO concentration showed a decreasing trend with the advancement of rearing period while, gradual increase in nitrite, nitrate, ammonia were attributed by increased level of metabolites and organic matter. At any given point of time, other water quality parameters did not register any specific trend.

After 226 days of rearing, the 1st crop harvesting was carried out in the month of April, 2007 (Plate 6). The average MBW was 1246.5 gm, 219 gm, 243.4 gm and 379.3 gm for *Catla, Rohu, Mrigal* and *C. carpio* respectively (Table 20). Total yield was 186 kg and productivity was 2.65 t/ha/226days as against the previous year yield of 60 kg

(0.85 t/ha/year) i.e., farmer's practice. The apparent feed conversion ratio was 1.34. Biomass contribution was maximum by *C. catla* (88.5 kg) followed by *C. mrigala* (46 kg). Higher and lower PI was recorded incase of *C. catla* (185.9) and *L. rohita* (41.8) respectively, while higher and lower PSI was recorded incase of *C. catla* (1575.9) and *C. carpio* (59.6) respectively. Similarly, after 273 days of rearing, the 2nd crop harvesting was carried out in the month of May, 2008. In the 2nd crop, the average MBW was 1050 gm, 269 gm, 252 gm and 302 gm for *Catla*, *Rohu*, *Mrigal* and *C. carpio* respectively (Table 21). Total yield was 191.8 kg and productivity was 2.74 t/ha/273days. The apparent feed conversion ratio was 1.48. Biomass contribution was maximum by *C. catla* (84.5 kg) followed by *L. rohita* (49.2 kg). Higher and lower PI was recorded incase of *C. catla* (116.3) and *L. rohita* (26.7) respectively, while higher and lower PSI was recorded incase of *C. catla* (1267.5) and *C. carpio* (104.5) respectively.

Plate 6. User group busy in harvesting the fish in Kamarsingh village

Higher PI, PSI and PDI in case of surface feeder was probably due to the stocking composition and minimal inter specific competition with column feeders, while moderate growth performance of both column and bottom feeders were due to stronger competition for food and space among each other. The low input-based scientific intervention has enhanced the overall yield by three fold (up by 210% during the 1st year and 220% during the 2nd year) in comparison to yield before intervention i.e., farmer's practice.

Table 20. Species-wise production characteristics of IMCs in secondary reservoir (2006-07)

Species	*C. catla*	*L. rohita*	*C. mrigala*	*C. carpio*
SR%	33.8	44.0	51.0	58.0
Biomass (kg)	88.5	40.5	46.0	11.0
PDI (g)	5.5	0.95	1.06	1.66
Performance index (PI)	185.9	41.8	54.06	96.28
Production-Size Index (PSI)	1575.9	126.7	159.9	59.6

Table 21. Species-wise production characteristics of IMCs in secondary reservoir (2007-08)

Species	*C. catla*	*L. rohita*	*C. mrigala*	*C. carpio*
SR%	30.3	27.2	73.0	33.0
Biomass (kg)	84.5	49.2	34.5	23.6
PDI (g)	3.84	0.98	0.92	1.10
Performance index (PI)	116.3	26.7	67.2	36.3
Production-Size Index (PSI)	1267.5	189.8	125.6	104.5

Users group was formed for maintenance and management of the secondary reservoir and their group leaders (two persons) was unanimously chosen by the user group. The crop diversification activities, irrigation application schedule, fish culture in the secondary reservoir, selling of fish, operation of bank account etc. were carried out by the group leaders. Group meetings were often held during evening hours to take decision on above mentioned activities. The group opened its saving account at State Bank of India, Langaleshwar branch, Khalikote, Ganjam. The account was opened by depositing Rs.5000/- which was obtained from sale produce of harvested fish in the year 2007. Subsequently, the revolving fund was utilized for procurement of inputs like fish seeds, feed, fuel for the pump set etc.

6.7. Institutional mechanism for improved performance of WUA in creation and utilization of water resource

Secondary reservoirs in the command of each outlet have been found to have significant potential in augmenting the irrigation water resource and overall production of the command. The productivity of stored water can be increased through multiple use management by way of fish culture in the reservoir, horticulture in the reservoir's embankment, application of irrigation to *rabi* crops etc. In this context, participatory creation, utilization and maintenance of secondary reservoir with a micro-level institutional arrangement is important which has been described below based on the experience gained through this study.

6.7.1. Creation of secondary reservoir

- Place of creation: It is ideal to have it on community land in the command of a given outlet. If common land is not available, individual farmer is to be motivated to construct the reservoir on his land and accordingly benefit will be shared among the users.
- Users' group formation: The farmers having land in command area of a given outlet as well as getting water through secondary reservoir would be members of users group. The formation of users group would be on the basis of utilization of water by the farmers from specific secondary reservoir. The number of users groups

depends on number of secondary reservoirs created under a given outlet of the canal system. Thus, each secondary reservoir will have a user group.

- Process of creation: The construction of secondary reservoir may be under taken following participatory approach in which users will bear the expenditure. This may be realized through self or hired labour or proportionate contribution of the fund required for construction.

6.7.2. Utilization of secondary reservoir

- Mode of utilization: The utilization of secondary reservoir includes irrigation to the crops raised in its command, on-dyke horticultural crops cultivation, fish farming, duckery in the reservoir etc. The user group needs to decide on cropping pattern, irrigation schedule and intricacies of fish and duck farming.
- Fund generation: User group need to decide the water rates and collect from each users depending upon the types of crop grown and number of irrigations received from the reservoir. Similarly, a percentage of accrued income from fish farming and / or duckery as decided by the group would be saved in group's account.
- Method of benefit sharing: Benefit sharing becomes simple and easy, if the secondary reservoir is located on the common land. When the reservoir is constructed in individual's land benefit sharing needs to be worked out through agreement between the individual farmer on whose land the reservoir is created and the other user members. A percentage of accrued income from fish farming and / or crop cultivation may be given to the farmer who has provided the land for reservoir. It may also happen that individual farmer given land may enjoy entire right of fish farming in the reservoir while others get water for irrigation to the crops by paying water tax.

6.7.3. Maintenance of secondary reservoir

Major shortcomings of any operation research project are speedy withdrawal of technology and poor maintenance of resources created after completion of the project. This makes the project unsustainable after withdrawal of the project functionaries. Therefore, maintenance of secondary reservoirs by the users is of paramount importance. The important aspects in this regard are as follows:

- Responsibility of maintenance of resource should be taken care by the users group.
- Financial support to manage and maintain the resources by farmers' groups would be through group's own generated fund.
- Contribution of own labour and resource for repair and maintenance of reservoir.
- Irrigation and line department officials should act as facilitator and supportive to farmers' participation in water management.

◆ Follow up action through farmers training on scientific water management and providing technical guidance, advice and support to properly maintain the created water resource for effective utilization would ensure sustainability of technological intervention.

It is essential to develop a sustainable water management strategy compatible to the socio-economic conditions and aspiration of the people. Concerted efforts by the user group for achieving common goals and sharing benefits are essential.

7. TECHNOLOGY DISSEMINATION AND CAPACITY BUILDING THROUGH FARMERS TRAINING PROGRAM

In order to disseminate the techniques of improving performance of the minor irrigation system, a farmers' training program was organized at Badakheta village in the command of Devijhar MIP, Ganjam district during 17th to 23rd February 2009 (seven days period). About 64 farmers including 10 women farmers from 10 villages under three gram panchayats (Aditipur, Tentuliapada and Langaleswar) of Khalikote, Ganjam participated in this training program (Plates 7 & 8). This includes 12 schedule caste farmers. The training module was developed based on the location-specific problems. The major problems identified were lack of adequate water for irrigation, problems associated with groundnut cultivation, poor rainwater utilization, and lack of community or participatory approach amongst farmers. To address these problems a total of 28 sessions were conducted in which farmers were trained on several technologies / practices / issues by the resource persons. Besides the scientific faculty of DWM, experts from different organizations like OUAT, Bhubaneswar; DDA office, Khalikote, Executive engineer, MI division, Berhampur, Veterinary office, Khalikote, SBI, Khalikote, retired officials from Irrigation and other line departments provided the training. Prospects of secondary reservoirs in the minor irrigation command, success stories on various irrigation and agriculture related issues, problems relating

Plate 7. Technology dissemination through farmers training in Devijhar MI command

Plate 8. Women farmers participating in the technology dissemination process

to water user associations etc. were presented and discussed in detail. Thorough discussion was also made on groundnut cultivation, which happens to be their most remunerative crop.

8. CONCLUSIONS

The hydraulic and agricultural performance of the recently rehabilitated and turned over minor irrigation system indicated that there is further scope for increasing the performance of the system through creation of additional water resources within the command. The multi objective optimization routine successfully optimized the size of the secondary storage reservoir and the cropping pattern considering various constraints. The performance of the system significantly increased due to provision of the secondary storage reservoir. The economic analysis reveals that the intervention is economically feasible. Thus, the limited water availability in a flow based minor irrigation system can be overcome through provision of secondary reservoirs in the command of each outlet. These reservoirs will harvest rainwater during monsoon in addition to collecting the unutilized irrigation water. The harvested water is utilized for irrigation in the dry season, short duration fish culture etc. Survey revealed existence of large number of poorly maintained water bodies in the command which can be utilized as secondary reservoirs with suitable modifications and maintenance. Therefore, the importance of rainwater conservation in the irrigated command needs to be given emphasis. Harvesting of rainwater and its use in the existing water bodies in the command of the study system has been demonstrated successfully to the farmers. Substantial increase in dry season's crop yield and fish yield has also been recorded. The outcome of the study alongwith other location specific agriculture and irrigation related issues were discussed with the farmers through a seven days training programm. Encourging response of farmers in this dissemination process was highly satisfying.

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Table 12 presents the optimal cropping pattern and optimal surface area of secondary storage reservoir for Case 2 at different water availability levels in the main reservoir. By changing the priority level (for Case 2), total cropped area at 25, 50, 75 and 100% of water availability in the main reservoir was obtained as 436.85, 445.41, 453.99 and 462.52 ha, respectively. In this case, the maximum area limit of green gram and black gram was obtained as the optimal solution for all levels of water availability in the main reservoir. This is because green gram and black gram require the least amount of water amongst all the crops considered. So in a water scarce situation, more area can be brought under cultivation by growing low water requiring crops. Minimum area limit was assigned for vegetables due to their high requirement of water. Area under tomato, brinjal, cabbage and cauliflower at all levels of water availability in main reservoir was 0.3 ha. Similarly minimum area (92.5 ha) was also assigned to groundnut at all levels of water availability in the main reservoir. Area under sunflower was 43.15, 51.71, 60.29 and 68.82 ha at 25, 50, 75 and 100% of water availability in the main reservoir, respectively, as return from sunflower was higher having less water requirement in comparison to other crops. The optimal surface area of secondary storage reservoir as the percentage of the command area was obtained as 12.63, 10.92, 9.20 and 7.49% for 25, 50, 75 and 100% of water availability in the main reservoir, respectively. Inter comparison of model outputs for case 1 & 2 reveals that the total cropped area has increased and the secondary storage reservoir area has decreased in Case 2 as was expected. Further, it may also be concluded that by keeping the 1st priority as maximization of net benefit and maximization of cropped area the optimal surface area for secondary storage reservoir as the percentage of the command area was obtained as 17.40 % and 10.92 % respectively at 50% water availability in the main reservoir.

Table 12.: Optimal cropping pattern and secondary storage reservoir area (for Case 2) considering minimum and maximum area constraint

Crop/secondary storage	Area under various crops and area of secondary storage reservoir (ha) at different water availability levels in the main reservoir			
	at 25%	at 50%	at 75%	at100%
Groundnut	92.50	92.50	92.50	92.50
Sunflower	43.15	51.71	60.29	68.82
Green gram	150.00	150.00	150.00	150.00
Black gram	150.00	150.00	150.00	150.00
Tomato	0.30	0.30	0.30	0.30
Brinjal	0.30	0.30	0.30	0.30
Cabbage	0.30	0.30	0.30	0.30
Cauliflower	0.30	0.30	0.30	0.30
Secondary reservoir area	63.15 (12.63%)	54.59 (10.92%)	46.01 (9.20%)	37.48 (7.49%)

Note: Figures in the parenthesis indicate the percentage of command area