Policy Alternatives for the Management of Minor and Medium Irrigation Schemes to Develop Groundwater Systems in Restricted Catchments for the Improvement in Food Productivity in the Dry Zone of Sri Lanka

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Introduction

Agriculture continues to be one of the largest sectors in the economy of Sri Lanka, accounting for 18 % of the gross domestic product (GDP), 35 % of total employment and more than 20 % of exports. It is the main source of livelihoods for the rural population, which accounts for 70 % of the population. Past agricultural policies of the country were directed towards self-sufficiency in rice, and presently production exceeds the requirement and is expected to increase from 2.6 million metric tonnes to about 3.33 million metric tonnes in the next 25 years with the increase of the population (Sivakumar 2002b).

Status of the Agriculture Sector

The important factor to consider in the agriculture sector is the low farm incomes due to low productivity, especially in irrigation schemes. Recent studies reveal that in some irrigation systems, less than 50 % of the family income is derived from irrigated agriculture and a greater part of the family income is derived out of non-agricultural activities. Furthermore, it was revealed that, 10 acres of irrigated agriculture has to ensure at least 250 person-days of employment to be the major source of income of farmers. In order to overcome this situation it is required to improve irrigation water availability economically (Sivakumar 2002a).

Probably the most profound challenge facing world agriculture today and in the foreseeable future is how to produce more food with less water. The primary challenge in the water sector of developing countries is, and will be, how to cope with rising competition for water among multiple stakeholders in ways which are equitable, efficient and sustainable. Recent research in Sri Lanka (Shanmuganathan 2004) has shown that most of the dry-zone districts are also facing serious water scarcity, which will worsen over time. Sri Lanka is already the fourth driest Asian country on a per capita basis, and has very high rainfall variability. Therefore, the global concerns about water scarcity do apply to this country also.

Status of Food Production and Water Resources

Food scarcity is a pressing problem in many countries. The problem, however, is particularly serious in less developed countries with low agricultural production combined with a fast growing population. To meet food requirements, efforts should be made to increase food production at least several times over the present supply. This can be done by the use of better viable and vigorous seeds, development and cultivation of new improved crop varieties, use of proper fertilizers, pesticides, and herbicides, better on-farm water management, better use of agricultural implements, provision of extension services, strengthening of the existing institutions and introduction of new socioeconomic, legal and organizational support to improve productivity. Proper economic management of water, however, is of overriding importance in the production of food. The success and efficiency of most other measures are dependent on the quantity, quality and timing of the irrigation water supply, the way it is used, and the degree of control over it (Sivakumar 2001a). Water is critical to the web of life, but at the same time, it is a limited resource in many areas of the world. Proper economic management of this scarce resource is essential for the improvement and sustainability of food production.

Water Scarcity

The human race through the ages has striven to locate and develop fresh water, being one of the basic necessities for subsistence of life. Over 90 % of liquid fresh water available at any given moment on the earth lies beneath the land surface. Groundwater, unlike surface water, is available in some quantity almost everywhere that man can settle in; is more dependable in periods of drought; and has many other advantages such as the fact that it is directly consumable; that it requires less investment than surface water; and that it has a readily absorbable high nutrition content for crop production.

The need to stabilize agricultural production in Asia, where over 40 % of the area is drought-prone, translates to the need to promote the speedy development of groundwater resources. Even in areas where there are surface water supplies available through major, medium and minor irrigation projects, groundwater is playing an increasingly vital role in supplementing surface water (Nagaraj and Dewan 1972). The importance of the role of groundwater to meet water supply requirements for domestic, rural, urban, industrial and agricultural use needs no emphasis. The increasing demand placed on it has stimulated investigations directed towards the quantification of the resource, which is basic for the formulation of plans for its exploitation, management and conservation (Sivakumar 2001b).

Irrigation holds a special place in the water scarcity debate, as it uses more than 70 % of the world's total water supply, while in Sri Lanka about 96 % of annual freshwater withdrawal is used for agriculture. Sri Lanka is the world's second highest user in terms of percentage of population, among others in utilizing fresh water withdrawals for agriculture (Ilampooranan 1993).

The Need for Research

The much-needed water for agriculture sectors in dry and intermediate zones, which covers about two-thirds of Sri Lanka, has to come from water available for irrigation, while meeting the challenge of increasing food production. Opportunities available for further expansion of irrigated lands in the country are very slim (Sivakumar 2009). Introduction of other food crops (OFCs) is economically feasible to overcome this problem. There is a wide gap between OFCs planned and accomplished in completed projects. Where paddy and OFCs are cultivated, the availability is always tied to paddy cultivation and this compels OFC growers to produce to the glut created by rain-fed cultivators thus reducing profits (Sivakumar 2008). The absence of a proper mechanism to compensate those who switch to OFCs compels others to grow paddy. Hence, clear scientific justification is needed to address the problem through an in-depth research supported change of policy to reduce the pumping cost of OFC cultivation by raising the water table. The water table can be raised by foregoing a certain percentage of paddy cultivation and keeping some percentage of water in irrigation schemes exclusively for recharging groundwater.

Research Objective

Research was carried out to address the acute problem of water scarcity and to spell out an operational policy for conserving surface water. The objective was to reduce the use of surface water for paddy cultivation under minor and medium irrigation schemes and to increase the extent of OFC cultivation using groundwater. Also, to create an artificial boundary to lift the water table and reduce the pumping cost of irrigation so that OFC could achieve the optimum crop yield.

Research Methodology

The methodology of this research uses a complete water balance study in a restricted catchment area incorporating a few medium irrigation schemes, several minor irrigation schemes and a large number of dug wells to illustrate the:

a) Development of a model to represent all the relevant variables connected with the movement and utilization of surface and groundwater

b) Usage of the above model to study the viability of conserving surface water by storing groundwater; and reducing the extent of paddy cultivation that relies on surface water; and increasing the extent of OFC cultivation using groundwater to achieve optimum crop yield

c) Economic viability of achieving optimum crop yield as in (b)

d) Creation of an artificial aquifer boundary to optimize the effectiveness of groundwater use to achieve optimum crop yield

e) Economic viability of the creation of a artificial boundary in terms of productivity

f) Increased crop production by combining both (b) and (d)

g) Economic viability of achieving optimum crop yield as in (f)

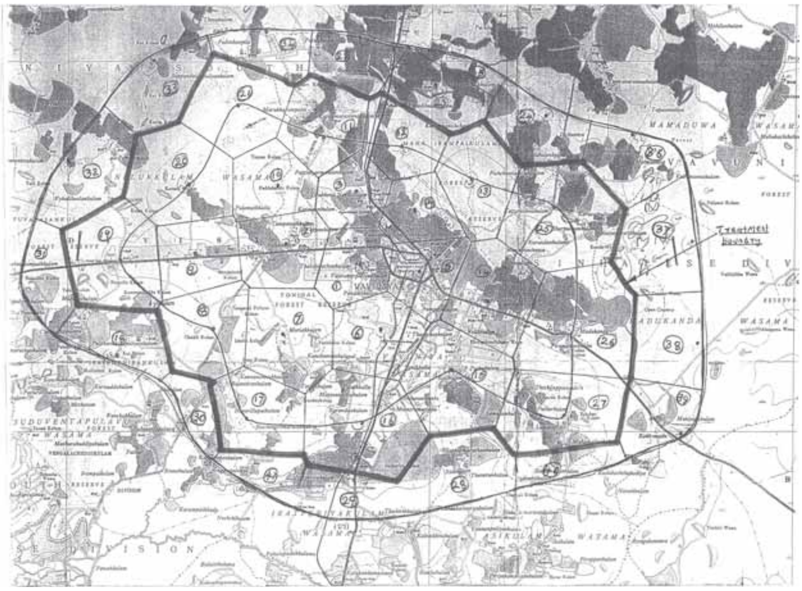
Many field experiments conducted by agronomists reveal that the increase in the yield of a crop depends (in addition to other factors) on dissolved nitrogen in the irrigation water that is supplied (Ferreira and Goncalvesn 2007). More frequent and less intense irrigation tends to give a better crop yield due to reduced moisture stress, requires less water to fill the root zone to field capacity and reduces solute movement. The general relationship between crop yield and water applied to the crop tends to increase linearly up to about 50 % of full irrigation, and then moving in a convex curvature to the optimum yield, followed by a reduced yield with further increases in applied water (Jeffrey and Russel 2003).

Farmers whose sole objective is to get optimum net income tend to irrigate their crop by incurring the minimum cost for their irrigation water and getting optimum productivity for their crop. Hence, the main methodology adopted in this research regarding the optimum crop yield is economizing the cost of the irrigation water and increasing the extent of cultivation per unit of irrigation water.

Study Area Characteristics

The study area as in Figure 1 is located in the northern part of Sri Lanka between 9° 22' and 9° 52' north latitude and between 79° 52' and 80° 49' east longitude. The area covers 6 medium irrigation schemes, 40 minor irrigation schemes, around 2,000 shallow wells, including 41 observation wells in a polygonal network formed by connecting the perpendicular bisectors of adjoining observation wells, covering 185.23 km^2 in both the Vavuniya and Vavuniya South Divisional Secretary's Divisions in the Vavuniya District.

Figure 1. Study area with polygonal network.



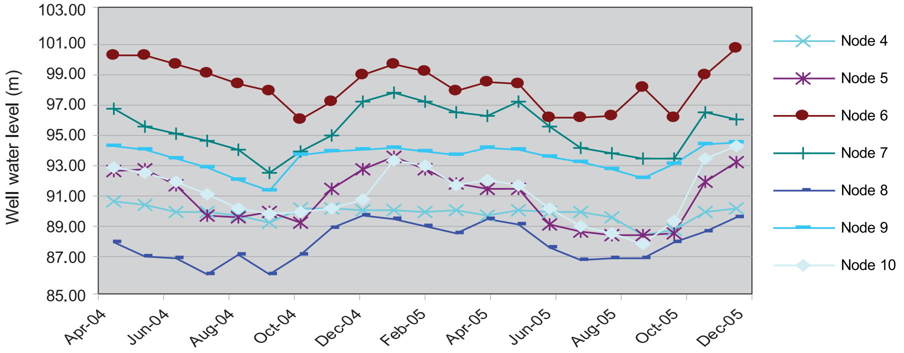
This area falls within the dry zone of Sri Lanka and in the Agro-ecological region of DLI (Ponrajah 1984). The average annual rainfall of the district is around 1,400 mm. The monthly average temperature is around 27.5° C, although it falls below this level during October to January. The main rainy season extends from early October to late January and the sub-rainy season extends from late March to late May.

Soil and Groundwater of the Study Area

The general landscape of this area, with 3 % to 4 % slopes, contains minor and medium watersheds and catchment basins. Reddish brown earth, low humid clays and alluvial soil are the main soil groups, which occupy the concave valleys and bottom lands. Shallowly weathered and rarely fractured crystalline rock with a thin soil mantle and limited groundwater potential determines the substrata of the study area (Cooray 1984).

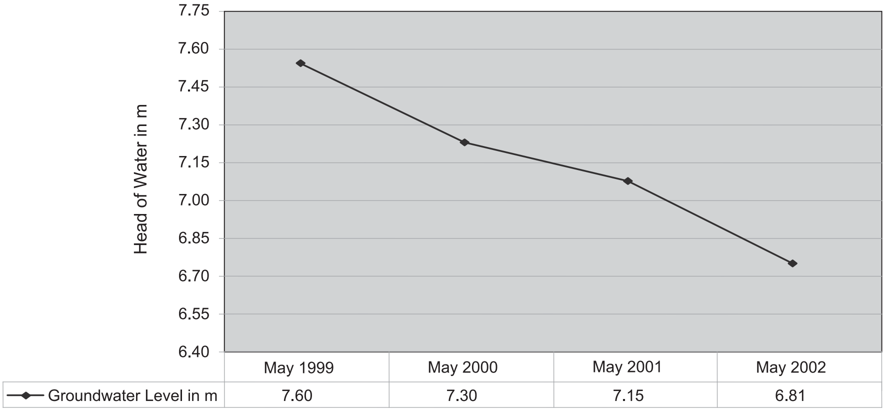
The cultivation of subsidiary food crops of about 0.2 to 1.0 hectare lots derives the needed water mostly from shallow dug wells, which have been constructed with a 4 m to 6 m diameter and a depth of about 9 m (DOA administration report, 1999 to 2003). Water levels of observation wells collected from 1997 to 2004 are given in Figure 2.

Figure 2. Monthly groundwater level fluctuation.



The collected water levels reveal that there is a substantial decline in the groundwater table in this region. Figure 3 clearly illustrates that the groundwater table did not reach its previous year (1991) maximum level during 1992 to 2002. This may be due to the excessive exploitation of groundwater; or due to the reduction in recharge of the aquifer by the speedy filling of minor

Figure 3. Average groundwater level at the end of recharging periods.



tanks for domestic consumption; or the combination of both influenced by the influx of displaced populations in this area given the conflict situation that prevailed in the country.

Groundwater Model Formulation

A groundwater model is a system which represents the flow of groundwater in a given aquifer. In general, there are two idealized uses of simulation in groundwater hydrology. The first use is in the prediction of future events based on a calibrated and validated model (Loague et al. 1995); the second use is in the development of concepts for the design of future experiments to improve the understanding of processes (Chawla 1990).

Data Required for Developing a Groundwater Model

All groundwater resource studies are iterative because perfect data are not available and circumstances change over time. Improved assessment becomes possible once more and data are available (Issar and Passchier 1990). The first phase of a study of a groundwater model consists of collecting all existing geological and hydrological data of the groundwater basin in question. This will include information on surface and subsurface geology, water tables, precipitation, evapotranspiration, pumped abstractions, stream flows, soils, land use, vegetation, irrigation, aquifer characteristics and boundaries. Developing and testing the numerical model requires a set of quantitative hydrogeological data that fall into two categories: 1) physical framework such as topography, geology, types of aquifers, aquifer thickness and lateral extent, aquifer boundaries, lithological variations within the aquifer, and aquifer characteristics; and 2) hydrological stress parameters such as water-table elevation, type and extent of recharge areas, rate of recharge, type and extent of discharge areas and rate of discharge.

Model Calibration

Generally, calibration is defined as the adjustment of parameter values within known ranges to simulate the measured state of the flow system (Bair and Roadcap 1992). However, because of the complexity of calibration, most practitioners still rely on ‘trial and error’ methods throughout the world (Olsthoon 1995).

The longer the period used for calibration, the better results such a system will yield. This is particularly so for unconfined aquifers, which have a long natural response time (Chawla 1990). As long-term records are seldom available, the model usually has to be calibrated using data covering only a relatively short period, and the time periods, if possible, should be selected according to where extremes of water table behavior have occurred. The absolute minimum period, however, is data spanning for two full years, the first year being used to adjust the input data and the second year serving as a check to see whether the adjustments were adequate. If not, the process is repeated (Boonstra and Ridder 1981).

Source of Errors

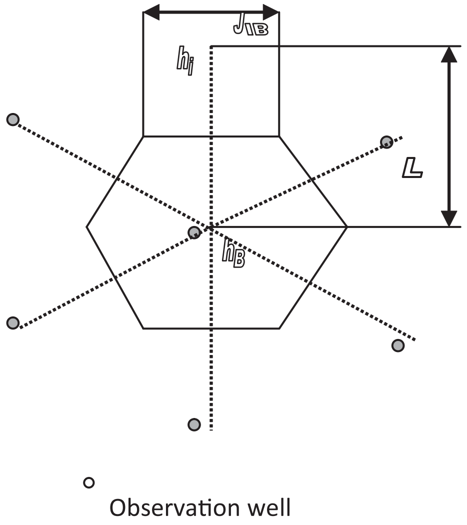
The list below demonstrates that almost all input data are subject to error. The deviation between the calculated and observed water levels will often be the result of a combination of these errors. Of course, errors can also be made in feeding the data in the computer and it is advisable to first check whether any such error had been made. Errors in input data can arise from two categories of sources.

- Errors in the physical properties of the aquifer
    - Transmissibility ‘T’
    - Specific yield ‘Sy’
    - Water table elevation
    - Type of aquifer
- Errors in the hydrological stress exerted on the aquifer
    - Recharge from precipitation
    - Recharge due to seepage in the conveyance and distribution system and application of irrigation water in fields
    - Lateral groundwater flow through boundaries
    - Groundwater abstraction

Calibration Procedure

As deviations between calculated and observed water tables are due to either error in individual input parameters or due to a combination of such errors, and the problem one faces in changing the values, which are not known exactly, is that it can cause errors as well. Values of these parameters lead to residue in the equation. The values of the parameters can be determined so as to minimize the residue. This process is called a ‘calibration process’. Figure 4 shows one typical node within the polygonal network to illustrate the water balance of any polygon in the study area.

Figure 4. Typical polygon for node B.



Subsurface flow + vertical flow will be equal to change in storage as given below.

$$\sum_{i=1}^{M}(h_i^{j+1} - h_B^{j+1})Y_{iB}T_{iB} = \frac{S_B}{\Delta t}(h_B^{j+1} - h_B^{j})A_B + A_BQ_B^{j+1}$$

For the calibration periods, the values of h_i^{j+1}, h_B^{j+1}, h_o^{b} and Δt are known. In case the values of T_{ab}, S_B and AQ_B^{j+1} are known, the equation should be exactly satisfied. In case the values of these parameters are not known accurately and due to the error in the assumed values of transmissibility, storage coefficients and recharge coefficients, the equation will not balance. Hence, there will be an error or residue RES_B^{j+1}.

$$RES_B^{j+1} = \sum_{i=1}^{M}(h_i^{j+1} - h_B^{j+1})Y_{iB}T_{iB} - \frac{S_B}{\Delta t}(h_B^{j+1} - h_B^{j})A_B + A_BQ_B^{j+1}$$

The objective of the calibration process is to determine the values of T_{ab}, S_B and recharge coefficients so as to minimize the square of this residue. Squaring is done to avoid the cancellation of positive and negative errors. In each of the error optimization models, four variables for polygonal inputs, one variable for that particular polygonal specific yield, and five to seven variables for transmissibility for every polygonal connection, were formulated with constraints. Constraints were given as practicable ranges for the recharge coefficients, specific yield, and transmissibilities. The objective function together with constraints below, are used as error optimization models for each node.

$$Min\sum_{i=1}^{N}\left[\sum_{i=1}^{M}(h_i^{j+1} - h_B^{j+1})Y_{iB}T_{iB} - \frac{S_B}{\Delta t}(h_B^{j+1} - h_B^{j})A_B + A_BQ_B^{j+1}\right]^2$$

Where,
M - Number of wells surrounding node B, N - Number of seasons for calibration
Subject to:$-0.06 < S_{B} <$ 0.15, $15 < T_{iB} < 25$, $0.075<a<0.15$, $0.05<b<0.1$, $0.15<c<0.25$, $0.9<d<1.5$. Where a, b, c are the recharge coefficients of tank storage, field input, and rainfall respectively and d is the withdrawal factor.

For the entire study area, altogether 164 variables for polygonal recharge coefficients, 41 variables for specific yield and 100 variables for transmissibility and 17 variables for the boundary lateral flow were found by error minimization using the non-linear optimizer such as GINO or MATCAD 2000.

First, for each node, models for minimization of the residue can be formulated. Using one of the non-linear optimization packages, all the models can be minimized separately and the values of stress parameters and recharge coefficients can be found. Taking these values of stress parameters and recharge coefficients as initial values to the groundwater model, residue in each node has to be found. Whenever the residue is not within the tolerance level, stress parameters and recharge coefficients have to be adjusted slightly and systematically, so that the residue for the first iteration can be found. By observing the trend of change in residue, within the third or fourth iterations, the residues in all the nodes can be brought to the tolerance level.

This is a trial and error method. However, 'MATCAD2000' (a user-friendly package requiring less computing time), which is superior to GINO, was used in this study to minimize the iteration time. All the 41 polygons were individually minimized using MATCAD2000 and the values of S_B, T_{iB}, a, b, c and d were found. While doing the second node minimization, if it is connected to the first node, the corresponding T_{iB} found from previous minimization was used and that particular constraint was removed from the second optimization model. By this method the entire 41 polygons were optimized and the hydro-geological parameters for each polygon were found.

Prediction of Model

All the work of collecting data, preparing the data and calibrating the model allows us to reconstruct the measured water table elevation. But the true purpose of a model is to indicate what the long-term behavior of the water table would be if certain plans for the use of water are implemented. 'Prediction run' is the term used when the model simulates the future behavior of the groundwater system when a certain development plan is implemented. It also allows us to study the consequences of a number of alternatives within the development plan. Possible situations to consider may include:

- Identifying effective recharge locations
- Whether a change in the cultivation pattern is necessary
- Changing the operational policy
- Whether irrigation canals have to be lined or not
- What the best site for a pumping station is
- What the effect of changes in the relative contribution of surface water and groundwater are
- Whether there is any possibility of raising the water table by reducing the permeability of the peripheral area of a restricted catchment

By simulating such alternatives, one can provide the decision-makers with a sound basis to select the most appropriate plan.

The period over which the model can simulate future conditions in prediction runs depends on several factors, which includes periods for which the model had been calibrated and the pattern of development activities during the calibration as well as during the prediction period. One should not predict for more than about twice the period used for calibration (Boonstra and Ridder 1981). The important data for prediction runs are:

- Data on initial water table elevation
- Data on recharge and abstraction rates
- Data on boundary condition

Prediction Model in Spreadsheet

For prediction, the water balance equation has been re-arranged to have h_B^{j+1} in LHS with RHS as function of h_B^{j+1} as below.

$$h_i^{j+1} = h_B^{j} + \left[. A_B Q_B^{j+1} + \sum_{i=1}^{M} (h_i^{j+1} - h_B^{j+1}) Y_{iB} T_{iB} . \right] \Delta t / S_B A_B$$

As h_B^{j+1} is connected to M surrounding nodes, while finding the h_B^{j+1} the already found h_B^{j+1} will slightly vary. Hence, after completing the first iteration process for all the 41 nodes, the same process has to be repeated five to six times to get accurate results. The function of GOALSEEK in spreadsheet with a small micro was used in this prediction run, and all the iterations were performed in a few key strokes to predict the water level with zero error. Even though the model is formulated season-wise, prediction is possible monthly or even weekly by changing a few cell formulae and adding a few more cell formulae.

Model Validation

Validation efforts are simply a comparison of modeling results against field data. Since the goal of model validation is to ensure that the modeling results provide a good representation of the actual processes in the real system, validation should be applied to every step of the modeling process (Chawla 1990).Validation is the simulation of a different measured state of the flow system using the final parameter values from model calibration (Chawla 1990).There have been a number of definitions of model validation. The International Atomic Energy Agency defines validation as follows: “A conceptual model and the computer code derived from it are validated when it is confirmed that the conceptual model and the computer code provide a good representation of the actual processes occurring in the real system.”

To test the validity of the model using the calibrated parameters and using the eighth season (September 2001), water level as initial water level and the rest of the inputs, the ninth season (May 2002) water level was predicted using the prediction model. Wherever the predicted values were not matching with the observed values, the stress parameters were systematically and slightly adjusted to get a good match. In the same way, using the ninth season (May 2002) water level as the initial water level and the rest of the inputs, the tenth season (Sept. 2002) water level was predicted using the prediction model. In the same way, the water levels of May 2003, September 2003, May 2004 and September 2004 were predicted and compared with observed water levels.

This led to an observed error in depth of the water table in the order of the magnitude ranging from -0.08 % to +2.1 %. For a groundwater simulation model in the integrated finite difference method, an error of this magnitude may be regarded as acceptable depending on the scope and purpose of the project.

Operational Research

Using the calibrated model, several prediction runs were carried out to determine the behavior of water levels to illustrate:

1) The possibility of reducing the extent of cultivation using surface water and increasing the storage of groundwater for economic cultivation

2) The possibility of creating an artificial aquifer boundary to reduce the lateral flow and raise the water table for economic pumping that would reduce the cost of irrigation water and increase productivity

3) The possibility of combining both 1 and 2 to raise the water table by improving the groundwater storage capacity to increase the crop yield and by increasing the extent of economic cultivation per unit of irrigation water

To achieve these, the following steps were carried out;

1. The behavior of the water table of this catchment was analyzed by keeping 10 %, 20 %, 30 %, 40 % and 50 % of the full capacity of the irrigation schemes during the season of June to September. This was done by assuming that, to keep 10 % of the full capacity of a medium and minor irrigation scheme, 12 % of cultivation has to be foregone.
2. The first interior boundary of the study area was selected for the creation of an artificial boundary by using boundary treatment. To create the artificial boundary, the transmissibility values (actually the permeability) were reduced in steps and the behavior of the water table was observed. The 'T' values between 17 very extreme peripheral nodes (18, 30, 41, 29, 28, 40, 39, 38, 37, 36, 24, 35, 22, 34, 33, 32, 31) and 14 interior adjoining nodes (8, 17, 16, 15, 27, 26, 25, 13, 23, 12, 11, 21, 20, 19) were reduced in steps of 2 – 3 m^2 /day and the water levels were predicted. There are 30 nodal connectivities. Hence, all the 'T' values were changed in five steps.
3. During this analysis, every step of paragraph 1 was carried out for all five steps of paragraph 2. Accordingly 25 trials were carried out. Even though this was a very cumbersome exercise, the outcome produced an interesting shift.

The summary of results of the operational research considering the above three different options are given below.

- Changing the operational policy of minor and medium irrigation schemes by foregoing cultivation by 25 % to 35 % to conserve surface water by storage as groundwater, is giving water table gains in almost all nodes except nodes 37 and 38 by 0.533 m to 0.914 m during discharging season, and by 0.762 m to 1.143 m during recharging season. This is a reduction of almost 45 % to 65 % of water table loss in between two consecutive seasons in 80 % of the area of the catchment under study.

- Creating an artificial aquifer boundary to optimize the effectiveness of groundwater in an elevated water table using peripheral boundary treatment, causes a reduction of 35 % to 45 % in permeability and increases the nodes in the water table to be closer to the treated boundary by 0.457 m to 0.838 m during recharging season.
- Combining peripheral reduction in permeability by 35 % to 45 % and foregoing the cultivation of minor and medium irrigation schemes by 45 % to 55 % result in an average gain of water table during discharging season (June – Sept) by 1,067 m to 1,448 m excluding node 37 and 38. The same trend is observed in recharging season although to a lesser degree. This is a reduction of almost 60 % to 70 % of water table loss in between two consecutive seasons in 95 % of the area of the catchment under study.

Economic Analysis of the Operational Research

Detailed cost benefit analysis for all the three options of the operational research were carried out taking into account the farmers' sole objective of getting maximum net income, and their tendency to irrigate their crop by spending the minimum for their irrigation water and getting the maximum productivity of their crop. Hence, one of the main assumptions adopted in this economic analysis regarding the optimum crop yield is economizing the cost of the irrigation water and increasing the extent of cultivation for every unit of irrigation water, leaving out the physiology of the crop. Foregoing cultivation will be a loss to Gross Domestic Product (GDP) and lead to a loss in Gross National Product (GNP) too. The gain in water table will reduce the cost of energy by way of fuel and electricity. This reduces the cost of irrigation and in turn increases the extent of cultivation per unit of irrigation water and leads to increases in the crop yield. This will indirectly contribute to GDP and GNP.

Economic Analysis for the Change in Operational Policy of Irrigation Schemes

The change in operational policy will reduce the extent of paddy cultivation. This could be taken as the indirect cost and will occur yearly. The return was calculated based on savings in electricity by raising the water table on an average in steps of 0.63 ft., 1.75 ft., 2.41 ft., 2.93 ft. and 3.12 ft. for 1,680,030 m^3 of domestic pumping, 2,281,220 m^3 of agricultural pumping and 160,910 m^3 of production well pumping in season 13; and in steps of 0.96 ft., 2.29 ft., 3.46 ft., 3.92 ft. and 4.05 ft. for the pumping of 1,679,190 m^3 of domestic pumping, 2,149,900 m^3 of agricultural pumping and 80,750 m^3 of production well pumping in season 14. This saving in expenditure in pumping water for domestic agricultural production by raising the water table was taken as the return from the implementation of this policy.

Economic Analysis for Boundary Treatment

The boundary treatment was proposed to reduce the average transmissibility in steps of 79 %, 70 %, 61 %, 53 %, and 44 %. Hence, the cost of cut off was taken as per Irrigation Department data for costing. The present worth factors were taken from relevant tables. This was calculated based on the savings in electricity by way of raised water table for average steps 0.14 ft., 0.46 ft., 0.67 ft. and 0.75 ft. for 1,679,190 m^3 of domestic pumping, 2,149,900 m^3 of agricultural pumping and 80,750 m^3 of production well pumping in season 13.

Economic Analysis for the Change in Operational Policy of Minor/Medium Schemes Together with Boundary Treatment

The 25 combinations for the combined alternatives of one and two were analyzed. The direct cost would be the boundary treatment cost. As the indirect cost and direct benefit are annual in nature, the net values and the present worth of various policy implementation periods (project life period) of 10 years, 15 years, 20 years and 25 years with interest rates of 5 %, 7.5 % and 10 % were calculated and analyzed.

Due to very heavy expenditure on boundary treatment, the present worth of return was less for up to 20 years of project life time, than the present worth of cost up to step three of the boundary treatment. Even though there was a considerable shift in water level gain, with a 60 % to 70 % of water table loss in between two consecutive seasons in 95 % of the catchment under research and the high cost of treatment reduced the benefit up to the last three steps. Normally, for any water resource project, the life period is taken as 30 – 50 years (RBMP 1990). Hence, this option is also economically viable.

Summary of Economic Analysis of the Operational Research

The alternative to the operational policy of minor and medium irrigation schemes by foregoing cultivation by 25 % to 35 % gave the benefit cost ratio based on present worth greater due to considerable rise in the water table. The rise in water table occurred almost above 80 % of the observation wells. The rise in water table was around 45 % to 65 % of the loss in water table between two consecutive seasons. This will reduce the cost of irrigation water and in turn increase the extent of cultivation per unit of irrigation water. This will increase the crop yield per unit of irrigation water and lead to increased productivity in terms of food production. The boundary treatment showed positive results when the lifetime of the project exceeded 20 years and for the interest rate of 7.5 %.

For most of the water resource projects the project life time is more than 30 years and the interest rate can go up to 10 % as per the guidelines for the preparation of ‘River Basin Master Plan 1990’ of the Central Water Commission if India, and the technical guidelines of the Irrigation Department (Ponrajah 1985). This implies that the boundary treatment is also economically feasible with certain limitations such as a minimum project life period of 20 years and maximum borrowing rate of 7.5 %, as assumed in the options considered.

The combination of the above two alternatives yielded further improvement whereby at any time the water table will reduce 60 % to 70 % of the water loss in between two consecutive seasons in 95 % of the catchment under study. This implies that the boundary treatment, combined with changing the operational policy of minor and medium irrigation schemes by foregoing a part of the cultivation, is an economically feasible policy alternative with certain limitations such as a minimum project life period of 20 years and a maximum borrowing rate of 7.5 %.

After completion of the project investment, the average cost of irrigation water will be reduced considerably due to less energy costs, and this in turn will increase the extent of cultivation per unit of irrigation water.

A summary of the economic analysis for all three alternate options of economically feasible steps is given below.

Summary of benefit/cost ratio greater than unity option and steps.

Option	Steps for each season	Benefit cost ratio							
		Discharging season				Recharging season			
Operational policy change	2	14.52				1.59			
	3	14.63				1.46			
	4	12.43				1.33			
	5	10.27				1.13			
Boundary treatment	Year of implementation					20		25	
	Interest rate					7.5 %	10 %	7.5 %	10 %
	3					0.73	0.97	1.15	1.66
	4					0.88	1.17	1.39	2.01
	5					0.83	1.10	1.30	1.88
Combination of policy change and creation of artificial boundary	Year of implementation	20		25		20		25	
	Interest rate	7.5 %	10 %	7.5 %	10 %	7.5 %	10 %	7.5 %	10 %
	3	0.97	1.13	1.28	1.78	0.82	1.09	1.17	1.75
	4	1.09	1.19	1.49	2.23	1.01	1.13	1.44	2.18
	5	1.04	1.13	1.42	2.22	0.97	1.15	1.37	2.02

Conclusion

Minor / medium irrigation schemes conserve surface run off and convey most of it to recharge groundwater, and as such serves as a recharge shed for the wells situated in the zone of influence. It is an insurance against water scarcity as the yield increases considerably for every unit of rainfall. The minor / medium irrigation schemes prevent soil erosion and depletion of soil fertility. In the context of impending water deficiency, the construction of minor/medium irrigation schemes will be a dependable infrastructure in the development of water potential in any catchment. Acknowledgement of the remarkable role played by the minor/medium irrigation schemes on replenishment of groundwater and its spread over a large area would be a great asset in the planning and execution of settlement and crop production projects.

This research leads to the conclusion that a change in operational policy for minor/medium irrigation schemes by foregoing one-third of the cultivation under minor/medium irrigation schemes; or keeping one-fourth of the storage of these irrigation schemes at any time, will gain an average of 45 % to 65 % in the loss of water table in any consecutive season in almost 80 % to 90 % of the catchment area under consideration.

Recommendations

It is recommended to construct new irrigation schemes or re-construct the abundance of minor /medium irrigation schemes with 25 % of storage exclusively for recharging groundwater. In the existing minor/medium irrigation schemes the sluice to be raised to store 25 % of the total capacity of the schemes to recharge groundwater and to store 25 % as dead storage. This change in operational policy will lower energy costs and reduce considerably the average cost of irrigation water for OFC cultivation, and this in turn will increase the extent of cultivation per unit of irrigation water and lead to an increase in productivity.

Hence, it is recommended new irrigation schemes be constructed with dead storage at 25 % of full capacity, and the sluice to be raised (during any re-construction of existing sluices) to retain 25 % of storage as dead storage in the future.

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