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Management Policy of Water Table in Dry Zone of Sri Lanka to Subsidise the Pain of Non Rice Crop Cultivators for the Food Productivity Improvement

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Abstract: The growth of population in time span leads to very high and uncontrolled extraction of ground water in the dry zone of Sri Lanka. This leads the water table to go very low in non-monsoon seasons. This gives the poor farmers who cultivate non rice crops, very big burden in pumping cost for food production and domestic use. This burning issue has to be addressed by scientifically proved change of policy of distribution of available acute water resource in equitable manner among the paddy cultivators and others like non rice/paddy cultivators. To recommend a scientific decision tool a research was carried out to model a pilot catchment of around 200 square kilometer in Vavuniya in the northern Sri Lanka. A complete water balance of all the available surface water, ground water was studied by putting all the parameters connected to this pilot catchment in to a mathematical model formulated. This model was calibrated to predict the system response. Various options were analysed with their economic feasibility and final conclusion arrived. Keeping 25% of the storage of irrigation schemes at any time will gain an average of 40% to 60% of the loss of water table in any consecutive seasons in almost 80% to 90% of the catchment area under consideration. This outcome of the research has given very concrete guideline for the bureaucrats to take decision during the finalization of cultivation calendars of surface irrigation schemes in dry zones of Sri Lank

Keywords: mathematical model, cultivation calendar, gross domestic product, non rice crops

1. Introduction

With the increase in population, industrialization and urbanization, demand for water has increased. Population has increased from 18.7 million in 2001 to 19.67 million in 2005[1]. The non rice crop cultivation, domestic and industrial water use has to be given due consideration than the paddy cultivation water use. The industrial sector's share of the Gross Domestic Product was 27% in 2005, compared to about 17.2% for agriculture (which includes non rice crop cultivation, paddy cultivation and life stock development) forestry and fisheries in whole country[2]. Preliminary calculations based on per capita water use for domestic needs, water requirement for the irrigation (both rice crop as well as non rice crop) sector and projections for industrial and commercial water needs show a trend of increasing water demand.

1.1 Status of Water Resource

Even though the Government has been developing water resources (surface irrigation facilities as well as ground water extraction facilities) for the economic and social wellbeing of the community, it has found that the scope for further development is reducing gradually. Water resource augmentation is a limited option since new projects tend to be less technically feasible and less economically viable[3]. Therefore the importance of conservation and efficient management of available water resources should be addressed properly. Groundwater is used in the domestic, agriculture, commercial and industrial sectors. Several government organizations, non-governmental organizations, commercial enterprises and private sectors are promoting the extraction of ground water without any control or restrictions. This problem of unregulated groundwater use has led to over exploitation of shallow aquifers and water quality problems.

The major demand management consideration with respect to groundwater is that groundwater use is unregulated and controlled only by natural occurrence, recharge and the degree of impact by other groundwater users[4]. This is clearly an area requiring basic water resource (both surface water as well as groundwater) management as well as alternate policy implementation on improving the water table management with new scientifically proven methods.

1.2. Status of Agriculture and Irrigation

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 type users in ways which are equitable, efficient and sustainable. Recent research on Sri Lanka has shown that most of the dry zone districts are also facing serious water scarcity which will worsen overtime. Sri Lanka is the fourth driest Asian Country on per capita basis, and has very high rainfall variability[5]. Therefore, the Global Concerns about water scarcity do apply to this country.
Irrigation hold a special place in the water scarcity debate, as it uses more than 70 percent of the world's total water supply but Sri Lanka 96% of annual freshwater withdrawals for agriculture (Sri Lanka has world second highest percentage on annual fresh water withdrawals for agriculture) [6].
Proper management of water economically, 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. Water is 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 improvement and sustainability of food productivity.
The much-needed water for these sectors in dry and intermediate zones which covers about two third of Sri Lanka[6] 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 is very slim on account of limitations explained above. Introduction of Non-Rice crops (NRC) to the cropping pattern to justify economic feasibility to overcome this problem will be a matter in the past, owing to following reasons.

1. Wide gap between Non Rice Crop (NRC) Cultivators planned and accomplished in completed projects.
2. Where paddy and NRCs are cultivated the availability is always tied to the paddy cultivation and this compels NRC growers to produce to the glut created by rain fed cultivators thus reducing profits.
3. Absence of a mechanism to compensate those who switch to NRCs to enable others to grow paddy.

2. Problem Statement

Fresh water being one of the basic necessities for subsistence of life, the human race through the ages has striven to locate and develop it. Over ninety percent of liquid fresh water, available at any given moment on the earth, lies beneath land surface [4]. 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 and that comparably less investment is required over surface water and that it has readily absorbable high nutrition content for crop production.
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, oriented towards quantification of the resource, which is basic for the formulation of plans for its exploitation, management and conservation [4].

3. Development Strategy Proposed

The future of Sri Lanka is related to the best use of its land and water resources. The aim of this paper is to give a scientific proof for a shift from conventional strategy to a new water resource and agricultural development strategy by implementing new proven alternate management decisions as below.

Utilize the water resource in an economic manner by practicing Effective water management, Crop diversification, Micro irrigation and continuous recharge of groundwater for economic pumping for non rice cultivators, domestic and industrial water users

Shift from subsistence agriculture to a commercially oriented agriculture leading to increase production, especially of high value of items that would readily find a market, both domestic and external, promote greater employment and incomes and a higher standard of living.

The need for sustainability in agricultural development is fully appreciated. The strategy while aiming at increased productivity and improved farming systems also includes measures for conservation of soil, water and energy resources.

The principal features of the development strategy are

1. To conserve surface water by following strict water management techniques
2. To recharge ground water continuously by keeping at least 25% of the surface water stored in irrigation schemes all the time[7].
3. To stop boring new tube wells and prevent power (Electric or kerosene) pumping from existing tube wells
4. To conduct a detail ground water model study to identify recharge sensitive minor irrigation schemes and make a policy of keeping these recharge sensitive minor tank to recharge the ground water continuously and keep 25% water in all other surface water bodies for considerable recharge
5. To maximize the utility of rain fall available in the region by constructing as much as possible detention storage facilities to recharge the ground water and to store for other uses without affecting the forest cover.

A detail ground water model study was carried out and the new policy of recharging ground water continuously by keeping at least 25% of the surface water stored in irrigation schemes all the time was validated scientifically[8]

4. Research Methodology

A regional aquifer simulation model was formulated in integrated finite difference method and a non-linear error optimization method was used for calibration of the model to a selected restricted catchment (around 200 km^2 as shown in figure annexed) in Vavuniya which is having a shallowly weathered and rarely fractured crystalline rock with thin soil mantle.

This model was used to find out a management policy for conserving surface water by storage as groundwater by keeping a permanent storage of 25% within any surface water body

4.1 Equilibrium of Ground Water

The ground water in a basin is not at rest but is in a state of continuous movement. The increase in the storage volume of the ground water by the downward percolation of rain and surface water, causing the water table to rise. At the same time decrease in the storage volume of ground water caused by evapotranspiration, discharge to springs, over flow into streams and other natural drainage channels, causing the water table to fall. When considering over a long period, the average recharge equals to the average discharge and the state of hydrologic equilibrium exists (Fig. 1). The water table is virtually stationary, with seasonal fluctuations around the average level.

Human interference in this hydrological equilibrium may create undesirable consequences. The abstraction of ground water from wells, for example, will lower the water table; allow the natural recharge to increase, and cause the natural discharge to decrease. If the abstraction is kept within certain limits, increase in recharge and decrease in discharge will balance the abstraction and will establish new hydrologic equilibrium. The water table will again be almost stationary, although at a deeper level than before. If this level is too deep, it may affect agriculture in that area. Excessive abstraction from wells can cause a continuous decline in the water table, which means that the ground water reservoirs are being depleted.

Similarly this can also cause water table to rise. When irrigation is introduced into an area, for example millions of cubic meters of water is transported to and distributed over an area, which earlier had only scanty rain. Part of it seeps to the underground from the canals and more of it percolate downwards from the irrigated fields. These water losses cause the water table to rise, because the recharge exceeds the natural discharge. This may eventually leads to water logging, in arid areas usually accompanied by salination of the soil which can render once fertile land into waste land, to the detriment of local farmers and even of national economy.

4.2 Ground Water Flow Problems

Ground water and the laws that govern its flow has been a subject of interest to many engineers, with most of their research focused on finding solutions to specific problems of ground water flow. For ideal situations of ground water flows, analytical solution of differential equations obtained by combining Darcy's equation and the equation of continuity are obtained for given boundary and initial conditions. Unfortunately there are many ground water flow problems for which analytical solutions are difficult and impossible to obtain. The reason is that these problems are complex due to aquifer being non homogeneous and anisotropic and may possess non-linear features including variation in an aquifer's transmissibility, boundary conditions that changes with time and other long term time dependent effects. Owing the difficulties of obtaining analytical solutions to complex ground water flow problems, there has been a need for techniques that enable meaningful solutions to be found. Such technique exists in the form of numerical modeling. Although the technique of solving ground water flow problems numerically is not new, it is only since the development of high-speed digital computers that the technique has become widely used.

4.3 Systems and Modeling Concepts.

It is impossible to carry out experiments and tests on real water resources systems in order to find their suitability. It is necessary to consider models of the system. We manipulate the model and use the results obtained from the model for making decisions regarding the real system. The model chosen to represent the real system should be representative and simple. Yet it should not be too simple to make the solution not applicable in reality. If we make the models too complex we may not be able to solve them. Further, it is meaningless to choose such a model, which can give very accurate results where the input data is much less accurate. There is no unique model for a given region. One should have a hierarchy of models of increased refinement and the appropriate one from the point of view of need, cost and availability of data should be selected in each case. The selected model must be calibrated to determine its parameters, if unknown and verified. If such information is already available past data is used for calibration.

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4.4 Numerical Models

Numerical models using digital computers are nowadays the major modeling technique used for groundwater system studies. Much effort has been developed in many parts of the world to the development of techniques for numerical solution of the partial differential equations that govern the flow of water in aquifers. Many computer programs have been developed and published those groundwater hydrologists and engineers can apply them to their specific problems without having to write their own programs. While thoughtless applications of these programs are not recommended, many of these programs have been well documented and can be used with a minimal background in numerical methods and programming skills .The two numerical methods that are commonly used are the finite difference method and the finite element method. The finite difference method is described below in detail for solving the flow problem in aquifers.

4.4.1 Finite Difference Method (FDM)

The fundamental equation governing two dimensional flow of water in saturated non-homogeneous

$$\frac{\partial}{\partial x}\left(Tx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial u}\left(Ty\frac{\partial h}{\partial y}\right)=S\frac{\partial h}{\partial t}Q$$

anisotropic aquifers is given as

Where Tx, Ty are the aquifer transmissibility in x and y direction, h is the head, S is the storitivity of the aquifer, and Q is the net groundwater withdrawal rate per unit area of the aquifer.

The finite difference equations can be derived either by replacing the derivatives in the above differential equation by their difference approximation or from physical standpoint involving the conservation of mass and Darcy's law.

4.4.2 Integrated Finite Difference Method (IFDM)

A modified form of FDM is called as IFDM. This method also can be used for ground water system models. Unlike FDM where square or rectangular grids are used, this utilizes an arbitrary grid.
In IFDM the region of interest is divided into smaller polygonal areas, since they each have a node which is used to connect each area mathematically with its neighbors. It is assumed that all recharge and abstraction in a nodal area occurs at the nodes, in other words, each node is considered to be the representative of its nodal area. For each node a certain storage coefficient or specific yield and recharge coefficients are assigned, which are constant and representative for that nodal area. A certain hydraulic conductivity is assigned to the boundaries between nodal areas, thus allowing directional anisotropic condition.

4.4.3 Polygonal Net Work

This method assumes a linear variation of the measured quantity between each pair of two close observation points. Perpendicular bisectors of the lines connecting adjacent observation points from polygon corresponding to that point. For each polygonal cell one can write a set of simultaneous equation as given below.

$$Min\sum_{m=1}^{M}\left[T_{im}W_{im}\frac{h_m^{r+\Delta t}h_r^{r+\Delta t}}{s_{i,m}}\right]-N_{1=}S_1A_1\ \frac{h_m^{r+\Delta t}h_r^{t}}{\Delta_t}$$

Where M is all the nodes surrounding the node I under consideration, W (i,m),S(i,m) are show in fig2.

4.5 Aquifer Simulation Model.

The aquifer simulation model developed by using the integrated finite difference method can be used to determine the response of the aquifer for various management policies such as location of pumping wells, recharge wells, the quantity to be pumped and the quantity to be recharged, etc. Before application it should be calibrated using observed data. During calibration the aquifer parameters such as Transmissibility, Storitivity, recharge coefficients etc, are so adjusted such that, the computed levels match with the observed levels. If there are results of some pumping tests in the aquifer they should be used. This process of determination of aquifer parameters is called inverse modelling.

4.5.1 Determination of Aquifer Parameters.

The basic idea of inverse modeling is simple. It consists of using past information on both aquifer stresses such as pumping and aquifer. Responses such as water levels and determining the values of the aquifer parameters which will cause the model equation relating the two sets or data to be satisfied. For example, consider equation in para 4.4.3 Let net withdrawal rate N is equal to L+R-P where L be the natural recharge and P be the pumping. In the forecasting problem, we know the aquifer parameters Tx(i.j), Ty(i.j), S(i,j) and natural replenishment L(i,j,k) for a period of time in the past and we seek a solution of the above equation for the aquifer parameters Tx(i.j), Ty(i,j)and S(i,j).

4.5.2 Regional Aquifer Parameters

Pumping tests determine aquifer parameters in the vicinity of pumping wells. Regional values of aquifer parameters may be different from the local values obtained by pumping tests. Regional values are better determined by calibration of the model. In this method a trial set of aquifer parameters is used in the model. The calculated response of the aquifer model then compared with the observed in the field. If the computed values do not match with observed values, the aquifer parameters are suitably modified. This process is repeated until the calculated and observed value matches. The main disadvantage of this trial and error method is that it does not incorporate any algorithm for approaching the best solution in a systematic way[9].

Attempts have been made in this research to obtain optimal set of aquifer parameters by minimizing one or more error criteria. In the following section derivation of an optimal set of aquifer parameters by using a single error criterion is described.

4.5.3 Optimal Set of Aquifer Parameters.

It is desirable to discrete the given region into a number of aquifer cell of large size for the purpose of determination should be used in deciding the number and size of cell. An equation similar to the above, written for each cell can be rewritten in the following form.

$$\sum_{m=1}^{M} g_m T_m + F_m^{k+1/2} S_m = P_{k-1}^{k+1/2}$$

Where, M=Number of adjoining modes

The values of a,b,c and e can be found from respective values of head difference and conductance factor for each connectivity of the node under consideration.

$$f_{i,j}^{k+1/2} = \frac{h_{i,j}^{k+1} - h_{i,j}^{k}}{\Delta t} \qquad P_{i,j} = \frac{N_{i,j}}{\Delta x \Delta y}$$

K+1/2 stand for the average values for time interval k and k+1. Other terms like natural replenishment can be include.

Different criteria for error minimization can be used. For example the following are some of the criteria.

Criterion A: Minimize the sum of the absolute values of all deviations.
Criterion B: Minimize the sum of the square of the deviations.

The first one leads to a linear programming problem. And the second one leads to a quadratic programming problem. The liner programming problem can be stated as.

$$MinF = \sum_{k} \sum_{j} \sum_{i} U_{i,j}^{k+1/2}$$

Where,

$$\left| \sum_{m=1}^{M} g_m T_m + f_{i,j}^{k+1/2} s_{i,j} - p_{i,j}^{k+1/2} \right| = U_{i,j}^{K=1/2}$$

Subject to the constraints,
Hence the above equation can be rewritten as

$$\sum_{m=1}^{M} g_m T_m + f_{i,j}^{k+1/2} s_{i,j} - U_{i,j}^{K=1/2} < p_{i,j}^{k+1/2}$$

$$\sum_{m=1}^{M} g_m T_m + f_{i,j}^{k+1/2} s_{i,j} + U_{i,j}^{K=1/2} > p_{i,j}^{k+1/2}$$

Subject to

$$T_{i,j} S_{i,j} U_{i,j}^{K=1/2} > 0$$

The quadratic programming problem can be stated as.

$$MinF = \sum\sum\sum \left(\sum_{m=1}^{m} g_m T_m + f_{i,j}^{k+1/2} S_{i,j} - p_{i,j}^{k-1/2} \right)^2$$

Subject to Ti,j, Si,j>0

5. Model Formulation

5.1 Description of the Model

5.1.1 General

The model to be used in this research is as an aquifer simulation model developed by, using the advanced numerical modelling technique called integrated finite different method. The model has to be calibrated by the technique called optimal set of aquifer parameters explained in section 4.5.3. The following features and restriction are to be incorporated in this model for the Vavuniya restricted catchments.

The aquifer is treated as a two –dimensional flow system.

1. Only one aquifer system is modelled with one storage coefficient in vertical direction.
2. The aquifer is bounded at the bottom by an impermeable layer.

3. The upper boundary of the aquifer is an impermeable layer (confined aquifer), a slightly permeable layer (semi confined aquifer) or the free water table. (Unconfined aquifer).
4. Darcy's law (Linear resistance to laminar flow) and Dupuit's assumption (vertical flow can be neglected) are applicable in the aquifer.
5. The processes of the infiltration and percolation of rain and surface water and of capillary rice and evapotranspiration taking place in the unsaturated zone of the aquifer (above the water table) need not be simulated. This means the net recharge to the aquifer must be calculated manually and prescribed to the model.

5.1.2 Physical Background

The model is based on the two well-known equations, Darcy's law and the equation of conservation of mass. The equation of continuity of an unconfined aquifer in which there is no vertical variation of properties is:

$$\frac{d}{dx}(mVx)+\frac{d}{dx}(mVy)+Sy\frac{dh}{di}+Q=0$$

Where Vx&Vy=Velocities of flow in X&Y direction
m=thickness of saturated portion at the point of consideration, Sy=specific yield

$$-\tfrac{d}{dx}(km\tfrac{dh}{dx})-\tfrac{d}{dy}(km\tfrac{dh}{dy})+Sy\tfrac{dh}{dt}+Q=0$$

Q=Volumetric flow rate per unit area in vertical direction, t=time
Applying Darcy's Law, the above equation can be rewritten as
Where T= Coefficient of transmissibility

The solution of this equation is possible by knowing the hydrologic condition comprising transmissibility and specific yield describe the capacity of the aquifer to transmit and release writer. Initial and boundary condition such as potential, geologic boundary condition such as potential, geologic boundaries of the model, etc have to be specified. Analytical solution of the equation is not possible for complex natural system. Hence numerical methods are necessary to solve the said equation. In this case Integrated Finite Difference Method (IFDM) which is a modification of finite difference method has to be used.

5.1.3 Numerical Approach

The finite difference form of the differential equation can be written as.

$$\sum(h_i-h_b)Y_{iB}=A_BS_B\frac{dhB}{dt}+A_bQ_b \qquad (1)$$

Where,
h_i - piezometric head of node I, h_B - peizometric head at node B, Y_{iB} = (J_{iB}/L_{iB}) - conductance factor
T_{iB} - transmissibility at midpoint between node B and I, J_{iB} - length of perpendicular bisector associated with node B and I, L_{iB} - distance between nodes i and B, A_B - polygonal area of node B
S_B - storage coefficient of node B, Q_B - volumetric flow rate per unit area at nodeB.

Fig.3 gives schematic diagram a typical node, point B and its association with its neighborhood node with particular reference to node i. Hence Eqn.1 can be reduced by implicit numerical integration technique to the form at the time interval j and j+1 with time step Δt.

$$\sum(h_i^{j+1}-h_B^{j+1})Y_{iB}T_{iB}-\tfrac{S_B}{\Delta t}(h_B^{j+1}-h_B^{j})A_B+A_BQ_B^{j+1}$$

The subscript j denotes the points along time horizon.

5.1.4 Computational Procedures

The computational procedure is essentially that of Gauss-Seidal. The initial values of $h_B(0)$ are fist recorded as h_B(B=1,2,3………..M=number of interior nodes) for a given set of coefficients Y_{iB},S_B and $Q_B^{J+1,}$ the values of h_B^{j+1} are determined, these values become the initial water levels for the next

$$QQ_B^{j+1} = \sum_{i=1}^{M} (h_i^{j+1} - h_B^{j+1}) Y_{iB} \text{................}(2)$$

succeeding step in time. The sequence of iteration is given below.

Where QQ_B^{j+1}=sub surface flow, Vertical flow= $AQ_B^{j+1} = A_B Q_B^{j+1}$ …………(3)

$$STOREB^{j+1} = \frac{A_B S_B}{\Delta t}(h_B^{j+1} - h_B^{j} \text{............}(4)$$

Where STORE B^{j+1} = change in storage

The equation 2 ,3, 4 are balanced for each node by setting their sum equals to a residual term as give below.

$$RES.^{j+1}_B = QQ_B^{j+1} + AQ_B^{j+1} - STORE_B^{j+1} \text{......}(5)$$

But the model proposed in this research the residue of Eqn. 4 in each node is computed in terms of Sy, T and recharge coefficients. The sequence of calculation for a node is as follows

Subsurface flow, Vertical flow, Change in storage can be found from Eqn.2,3,4 If observed water levels don't have any error. Subsurface flow +Vertical flow = Change in storage.

Because of error in observed water level there will be a residue = Subsurface flow +Vertical flow- Change in storage. Here the residue is in terms of Sy, T and recharge coefficients. The square of the residue for all seasons are to be added and minimized by GINO non liner optimization package to find Sy, T and recharge coefficients.

6. Study Area

6.1 Location and Size

The study area is located in the northern part of Sri Lanka in the Indian Ocean between 9^o 22' and 9^o 52' North latitude and between 79^o 52' and 80^o 49' East longitude. The area covers 5 medium tanks, 52 minor tanks, around 1000 shallow wells and covering around 200 sq.km in both Vavuniya & Vavuniya south Divisional Secretary's Divisions in Vavuniya District.

6.2 Climate

The area falls within the dry zone of Sri Lanka and in the Agro-ecological region of DL1. Average rainfall of the district is around 1400mm. The main rainy season extends from early October to late January and the sub rainy season extends from March to late May. The monthly average temperature is around 27.5^o C and it is found lower than this during October to January.

6.3 Soil and Ground Water

The general landscape of this aria is with 3-4 percent slopes contains minor & medium watersheds and catchments 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 thin soil mantle with limited ground water potential, determines the substrata of the study area. For the cultivation of subsidiary food crops of about 0.2 to 1.0 hectare lots mostly shallow duck well have been constructed with 4 to 6m diameter and about 9m depth.

6.4 Nodal Network and Polygon Geometry.

The study area has been sub-divided into 41 polygons. The polygonal theory assumes same ground water elevation all over the polygonal aria as at the node itself. This assumption necessities construction of polygon such that the aerial extent of the polygon represents, more or less, the same ground water elevation. After finalization of nodal network, computations of polygonal geometry such as polygonal areas and the ratios of perpendicular bisectors to the distance between the connected nodes were calculated manually.

6.5 Fixation of Time Step

Selection of time step mainly depends on the purpose of study, availability of data and accuracy required. All the time sreps need be equal. In this study, each year is broken up into two season time step. The monsoon season of 8 months stats from 1st October to 31st May. The non monsoon season of 4 months starts from 1st June to 31st September. Since the initial values are taken as 8 months followed by 4 months. These time steps are to be used alternatively throughout the calibration period from October 1998 to September 2001, and for the next two years up to September 2003 one month to be taken as time step.

6.6 Tolerance Level

The Selection of tolerance level depends on the accuracy of the computation needed. The adoption of large tolerance level leads to inaccuracy, where as very small tolerance level consumes excess computer time. So the tolerance level must be chosen carefully so that the required degree of accuracy can be obtained without wasting lot of computer time in this study the accuracy in water level is to be taken as fraction of centimeters.

6.7 Nodal Coordinate

A Cartesian coordinate system with X and Y coordinates for all the node points with respect to an arbitrary chosen origin has been drawn on the topo map of the nodal net work.

6.8 Specific Yield and Storage Coefficient

For unconfined aquifers the calculation of any change in storage of ground water require respective values of the specific yield in each nodal area. For confined aquifers the storage coefficient for each nodal area is required. For confined aquifer the storage coefficient for each nodal area is required. For semi-confined aquifer both specific yield and storage coefficient are required. In this study the values of specific yield have to be obtained during the calibration by optimizing the error.

6.9 Transmissibility Coefficient

The value of the transmissibility coefficient, T can be found from aquifer test. Also if we know the hydraulic conductivity, k, and the aquifer thickness, m, transmissibility can also be found by multiplying k & m.

6.10 Water Level Data

The seasonal water levels of wells in study area are obtained from farmer's organizations operating in the area from October 1998 to date. From September 2001 to September 2003 water levels were taken monthly. The area where the irrigation schemes is governing the water table, I m below FSL of the tank was taken as water table elevation.

6.11 Rainfall Recharge Values.

The rainfall data of Vavuniya is obtained from Irrigation Department. As all the polygons are around Vavuniya rainfall station, this value can be used for all the area under study. For preliminary study, 20% of rainfall has to be assumed as recharge to the ground water basin and during calibration correct value has to be found.

6.12. Recharge from Canal Seepage

The entire canal systems in the area are unlined. The rate of seepage losses from the canal mainly depends on factors such as channel dimensions (wetted perimeter), coefficient of permeability of the soil, distance of the natural drainage, difference in the water levels of canal and drainage, etc. The computation of seepage losses for different canals at various locations is difficult due to lack of availability of sufficient data. Hence imperial methods have to be used to determine the seepage losses from the canal. Around 25%of the total volume of water issued from the scheme can be taken as percolation downwards. Out of this volume about 50% reach groundwater basin. For preliminary study these values can be taken and modified during calibration.

6.13 Recharge from Irrigation Fields

Out of the irrigation water supplied to the field part is stored in the root zone and remaining is lost as surface runoff and deep percolation. Ratio of the water stored in the root zone and available for consumptive use by the crop to the total irrigation water applied is known as irrigation efficiency. The efficiency of irrigation depends upon the method of irrigation, discharge of the outlet, type of soil, topography, skill of the irrigation and several other factors.

In the absence of actual filed observation the irrigation efficiency can be assumed as 60%. Out of the 40% lost, 75% can be assumed to reach the ground water reservoir. For preliminary study these values can be taken and modified during calibration. The factors for finding field input for each node are taken as the ratio of the irrigated area in each node to the total irrigated area.

6.14 Withdrawal from Ground Water Reservoir

Withdrawal from ground water reservoir in the study area is drawn through domestic wells, agro-wells and pumping stations of water supply and Drainage Board. The total drawls seasonally, node wise is calculated from collected data. For preliminary study withdrawal factor has to be taken as 15% and modified during calibration.

7. Calibration

7.1. General

Any model formulated should be calibrated before the model can perform its task of predicting the future ground water system behaviour. This means the a check must be made to see whether the model can correctly generate the past behaviour of the ground water system, as it is known from past records.

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Calibration is to be done for the period for which observed records are available. In this study, the calibration has to be done for the period from 1998 to 2001. The relevant hydrological information and observed data are to be fed into the computer, which calculate the water table elevation for each nodal point. These values are to be then compared with the water table elevations, as they are known from observed records. In case the computed levels do not match the observed level the aquifer parameters or hydrological stress values are to be modified and the water levels to be re-evaluated. This process is to be continued till the calculated values satisfactorily match with the observed values.

7.2. Source of Errors

Errors in input data can be from two categories of sources.
Errors in the physical properties of the aquifer.

1. Transmissibility 'T'
2. Specific yield 'Sy'
3. Water table elevation
4. Type of aquifer

Errors in the hydrological stress exerted on the aquifer.

1. Recharge from precipitation
2. Recharge due to seepage in the conveyance and distribution system and application of irrigation water in fields.
3. Lateral ground water flow through boundaries.
4. Ground water abstraction.

This list shows almost all input data are subjected 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 has been made.

7.3. Calibration Procedue.

As deviations between calculated and observed water tables can be due to either errors in individual input parameters or to a combination of such errors, the problem one faces in changing the values of which are not known exactly and can cause error in values of these parameters lead to residue in the equation. The values of the parameters can be determined so as to minimize the residue.

Continuity or mass balance equation can be written as,

$$\sum\left(h_1^{k+1} - h_B^{k+1}\right)J_{1B}\frac{T_B}{L_B} + AQ_B^{k+1} - \left(h_B^{k-1} - h_B\right)A_B S_B / \Delta t = 0$$

For the calibration periods, the values of $h_t^{k+1}, h_B^{k+1}, h_B$ and Δt are know, In case the values of $T_{iB,} S_{B,}$ and AQBk-1 are known accurately the equation should be exactly satisfied. In case the values of these parameters are not known accurately, the equation will not balance and will not equal to zero. During calibration, objective is to determine the values of $T_{iB,} S_{B,}$ and AQ$_B^{k-1}$ so as to minimize the square of the residue.

Therefore objective function is

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$$Min\sum_{n=1}^{N}\left[\left(h_1^{k+1}+h_B^{k+1}\right)\frac{J_{1B}T_{1B}}{L_{iB}}+AQ_B^{k+1}-\left(h_B^{k+1}-h_B\right)\frac{A_BS_B}{\Delta t}\right]^2$$

Subject to

$0 < S_B < 0.3$

$0 < T_{iB}$

$0.12 < C < 0.25$

$0.15 < F < 0.3$

$0.60 < D < 1.2$

$0.10 < R < 0.3$

Where C, F, R are the recharge coefficients of canal input, field input, and rainfall respectively, dies the withdrawal factor.

The objective function is nonlinear and has large number of carioles. Non linear optimization package GINO can handle variable up to 200 with constrains up to 100. It is therefore, not been possible to obtain optimal values for parameters so as to minimize total error in all the nodes. Optimal values of the parameters are to be determined for each node and its connection. These values are then to be taken up as initial values for further calibration.

Firstly for each node, models for minimization of the residue can be formulated. By GINO non-linear optimization package all the values of S, T, C, F, D and R can be found. Taking these values of S, T, C, F, D and R as initial values to the ground water model, residue in each node has to be found. Wherever the residue is not within the tolerance level, water level has to be adjusted and the residue for the first iteration can be found. By observing the trend of change in residue, within third or fourth iteration the residues in all the nodes can be brought to the tolerance level.

8. Prediction

8.1 General

All the work of collecting data, preparing the data and calibrating the model is only allowed us to reconstruct the measured water table elevation. But the true purpose of a model is to indicate what the long term behaviour 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 future behaviour of the ground water system, if a certain development plan is implemented. Such plans may introduce either recharge or abstraction or both are different from the recharge or abstraction in the past. A new irrigation scheme, for example, introduces additional percolation through irrigation losses in canals and fields and leaching practices, if any. A new pumping station for domestic water supply or for irrigation introduces new locally high, abstraction rates. A more complex situation is one in which an area is already being irrigated with water from a river but, since the river flows vary greatly , a plan is being drawn up to use ground water as an auxiliary supply. Such a plan not only means rate of ground water abstraction that will vary in accordance with the total water demand and river flows but also leads to changes in vertical flows and river aquifer interaction. In a complex situation like this, the model enables us to examine what consequences a certain development plan will have on the water table. It also allows us to study the consequences of a number of alternatives within the development plan. Possible alternatives are

1. Whether irrigation canals to be lined or not
2. Which is the best site for pumping station?
3. What are the effect of changes in the relative contribution of surface water and ground water?
4. Whether there is any possibility of raising the water table by reducing the permeability of peripheral area of restricted catchments.

By simulating such alternatives, one can provide the decision maker with a sound basis to select the most appropriate plan. The period over which the model can simulate future conditions is prediction runs depends upon several factors which included period for which the model had been calibrated and the pattern of developmental activities during the calibration as well as prediction period (Faust and Mercer, 1980) suggest the one should not predict more than about twice the period used for calibration. In the process with increased data recalibration is also possible to extend the prediction period.

8.2 Data Requirement.

The important data for prediction run are, Data on initial water table elevation
1. Data on recharge and abstraction rates.
2. Data on boundary condition

Each of the above can be explained below

Initial water table elevations must be prescribed for all internal nodes and for any external nodes. To obtain these elevations one needs the most recently recorded data.

The future assumed percolation and abstraction data in each nodal area must be prescribed for each prediction run. First the recharge and /or abstraction rates as these are contemplated under the development plan are to be calculated. These rates are then to be superimposed on the present rates, which may consist of recharge from rainfall, ground water inflow and/or outflow over the boundaries of the area, abstraction from wells, etc. The final rates must be prescribed for each season and for the number of years one wants to simulate.

The introduction of surface water irrigation or ground water abstraction may cause a change in the boundary conditions of the study area. These future boundary conditions must be prescribed or stated on the model. Impervious boundaries constitute no problem because they remain unchanged. Leaky, river, lake or ocean boundaries, however, require a projection of how they may change under future conditions. A way to avoid this problem is to extent the network over such a large area that no matter what the future conditions are, they will not exert any influence on the boundaries of the aquifer, if such an extension is impossible, one must analyses the behaviour of the boundary conditions in the extrapolate this into the future.

8.3 Prediction Procedure

Even though the model is formulated season wise predication is possible monthly or even weekly by changing few cells formula and adding few more cell formula. First expected inputs and their respective recharge factor to be fed in to the model. Secondly change the Δt as 1 for monthly prediction, and 0.25 for weakly prediction thirdly instead of calculating error in water level rewrite this cell formula to calculate water level take these water levels as initial water levels for the next time step and proceed up to required time. The following inputs were processed from the data available in [10], [11], [12] and data collected from NWS&DB Vavuniya.

1. Capacity of water stored in Irrigation scheme (m^3)
2. Water issued for cultivation in irrigation scheme (m^3)
3. Rainfall volume (m^3)
4. Net pumping volume (m^3) that consists of the following

- Pumping from domestic wells (m^3)
- Pumping from agro wells (m^3)
- Pumping from production wells (m^3)

8.4 Model Calibration

Any model before it performs its task of predicting the future groundwater system behaviour it must be calibrated. This means that a check must be made to see whether the model can correctly generate the past behaviour of the ground water system, as known from past records. A non-linear error optimization method was used for calibration.

The calibration was done for the period from 1997 to 2002. The relevant hydrological information and observed data were fed into the computer model, which calculate the water table elevation for each nodal point. These values were then compared with the actual water table elevations, as they were known from observed records. Where ever the predicted values were not matching with the observed values the aquifer stress parameters and the hydrological stress parameters were systematically slightly adjusted to get a good match, and the water levels re-evaluated. This process was continued till the calculated values satisfactorily match with the observed values.

8.5 Model Validation

The validity of the model was tested using the calibrated parameters and using 10th season water level as initial water level and the rest of the inputs, the 11th season water level was predicted using the prediction model. In the same way, using 11th season water level as initial water level and the rest of the inputs, the 12th season water level was predicted using the prediction model.

In the same way, the water levels of May 2004 and Sept. 2004 were predicted and compared with observed water levels. An error in depth of water table of the magnitude ranging from minus 0.08% to plus 2.1% was observed. For a groundwater simulation model in integrated finite difference method, an error of this magnitude may be regarded as acceptable depending on the scope and purpose of the project.

8.6 Model Predictions of water levels.

This calibrated model was used for several prediction runs to determine the behaviour of water levels. The possibility of keeping various percentage of permanent detention in any possible surface water body and increase the storage of groundwater for economic cultivation was analysed. An operational research was carried out using the calibrated and validated prediction model for the above as below.

The behaviour of water table of this catchment was analysed by keeping 10%, 20%, 30%, 40% and 50 % of the full capacity of the Irrigation schemes during season June – September.

Keeping permanent water storage of 20% to 30% to conserve surface water by storage as groundwater is giving water table gains in almost all nodes 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.

9. Economic Analysis

The water table behaviour for various percentage of permanent storage of water in surface water bodies was analysed for its economic viability of the research outcome.

Assumption adopted in this new strategy regarding the optimum crop yield is economizing the cost of the irrigation water. The gain in water table will reduce the cost of energy by way of fuel and electricity. This will increase the economic crop yield by increasing the extent of economic cultivation per unit of irrigation water. This will definitely benefit the NRC cultivators in the dry zones

The return was calculated based on the savings in energy expenditure in pumping water for NRC cultivation and production by way of raise in water table during the implementation of this policy.

From the detailed cost benefit analyses for all the steps of the operational research the following findings were arrived.

Keeping 25% of storage of any surface body at any time gave the benefit cost ratio based on present worth greater than unity with considerable rise in 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

8 Conclusion

In many regions in the world there is excess precipitation in one season and less or no precipitation in the rest of the year. This is especially true in the dry zones of Sri Lanka where during the monsoon period of about four months we get most of the rains and practically very minimal rain during the rest of the year. Surface storage is created to hold the excess water during monsoon for use in the non-monsoon seasons and supplementary irrigation for maha season. Where the hydro geologic conditions are favourable it would be possible to consider storing of the excess water in aquifers or keep apart a percentage of surface water to recharge the groundwater during the dry season.

Surface water bodies conserve surface run off and covey most part 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 Surface water bodies prevent soil erosion and depletion of soil fertility. In the context of impending water deficiency looming large, construction of new irrigation schemes will be a dependable infrastructure in the development of water potential in any catchment. Acknowledgement of the remarkable role played by the Surface water bodies on replenishment of groundwater and its spread over a large area would be a great asset in planning and execution of settlement and crop production projects.

This research finding shows that keeping one fourth of the storage of any surface water body at any time will gain an average of 45% to 65% of the loss of water table in any consecutive seasons in almost 80% to 90% of the catchment area under consideration. This wills Subsidise the pain of non rice crop cultivators for the food productivity improvement by way of low energy expenditure in pumping water for NRC cultivation

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