Conjunctive Use of Surface and Groundwater to Improve Food Productivity in Vavuniya District in the Dry Zone Area

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Abstract: This research presents alternate policy decisions based on technical strategies to operate minor and medium irrigation schemes with integrated conjunctive use of surface and groundwater to improve groundwater systems in Vavuniya area for the economic pumping for agricultural and domestic water use, by optimizing the use of groundwater and surface water. Forty one domestic dug wells were identified as observation wells among the available domestic/agro wells within the study area of 185.23 km^2, to represent the aquifer in Vavuniya. This study area was divided into forty one Thiessen polygons. A complete water balance study for each polygon for each season was carried out. Water levels were predicted for changes in operational policy of minor and medium irrigation schemes by forgoing certain percentage of cultivation, boundary treatment to reduce the transmissibility in steps, and combination of both. The economic feasibility was analysed by taking the energy saved in pumping of raised groundwater as a benefit and boundary treatment cost and income loss due to change in operational policy of minor and medium irrigation schemes by forgoing certain percentage of cultivation as cost. The present worth of benefit and cost for various interest rate and project life period were calculated and compared. Change in operational policy of minor and medium irrigation schemes by forgoing one third of the cultivation under them or keeping one fourth of the storage of minor and medium irrigation schemes at any time together with 40% - 50% reduction in boundary permeability will recover an average of 60% to 70% of the loss of water table in any consecutive season in almost 95% of the area under consideration.

Keywords: Conjunctive, Thiessen polygons, hydraulic cycle, evapotranspiration

1. Introduction

It is observed that at present the water that is available is not utilized effectively to achieve maximum productivity in terms of food production. Food scarcity is a pressing problem in many countries of the globe. The problem is, however, 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 the food production, at least several times over the present supply. This can be done by the use of better viable and vigour 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 socio-economic legal and organisational support together with proper implementation of suitable alternate policy regarding the conjunctive use of surface and groundwater.

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.

2. Water Resources and its Management Problems

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. 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. Unlike other natural resources, water is a unique resource which renews itself. It is due to its constant circulation in the

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Ocean – atmosphere – earth – ocean system.
No matter how much water is consumed in daily life, its amount seldom dwindles. With time and under certain conditions water regains its property and becomes fit for reuse. This is probably the reason why water resource appears to be unlimited for a long time.

Water is available on earth in different forms and at different positions. Several types of resources of water on earth include:

- Fresh surface water in streams, lakes, reservoirs, estuaries, ponds and swamps
- Fresh groundwater in water table conditions, artesian aquifers, coastal aquifers, fractured rocks, karts and lava aquifers, etc.
- Precipitation from atmosphere in the form of rain, snow, ice, water vapour, etc.
- Soil moisture
- Surface or subsurface brackish waters with varying degree and nature of salinity
- Sea water, mixed estuarine water or desalinated water
- Effluent waters which may be partially or fully non treated

The key consumer of fresh water is agriculture rather than industry. Irrigation fields, orchards and estates claimed almost 80% of the water consumed the world over.

Unfortunately, 97.5% of all water resource on earth is saline. Consequently, fresh water including that in glaciers accounts for only 2.5%. Even here the most accessible one is the 0.3%. Moreover the natural distribution is extremely uneven. This unevenness is aggravated by the still greater unevenness of the geographical distribution of human settlement. Shortage is noticed where there is an excess of population and industry.

Irrigation is necessary in one form or other in all parts of the globe where the mean annual rainfall is less than 250mm. Experience has shown that over most part of the globe one in five years is a dry year and one in ten years is a severe drought year.

Impounding surface water was practiced from ancient times for a variety of purposes such as domestic needs, irrigation, industry and recreation. 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.

Utilisation of surface and groundwater singly or in conjunction is in vogue according to the relative availability of either in a locality. Of late, accent of intensive exploitation of groundwater has gained credence as a consequence of extreme pressures of population on water resources all over the world. The limited groundwater potential could not withstand the excessive exploitation and fast depleting water level.

Groundwater is an integral part of the hydraulic cycle. Its evaluation, planning and management have to be part of the total system. Most of these issues have therefore to be dealt with at the appropriate level of water resource system planning. Water resource potential assessment, conjunction of surface and groundwater development, groundwater quality assessment, groundwater recharge, conjunctive surface water - groundwater - energy planning, also nave to be taken in to consideration, while taking a policy decision regarding water resource planning. However, groundwater is a very important component of the water resource system and has special characteristics and management issues.

Necessities of stabilizing agricultural production in Asia where over 40% of the area is drought prone require 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. 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.

The groundwater in a basin is not at rest but is in a state of continuous movement, the increase in the storage volume of the groundwater by the downward percolation of rain and surface water storage, causing the water table to rise. At the same time decrease in the storage volume of groundwater caused by domestic consumption, industrial use, evapotranspiration, discharge to springs, overflow into streams and other natural drainage channels, cause the water table to fall.

When considered over a long period, the average recharge equals the average natural discharge and the state of hydrologic equilibrium exists. The water table is virtually stationary, with seasonal fluctuations around the average level.

Human interference can also cause water table to rise. For example when irrigation is introduced into an area, millions of cubic meters of water is transported to and distributed over that area, which earlier had only scanty rain. Part of it seeps to the underground from the canals and more of it percolates 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.

Man's two foes of nature related to water supply are drought and flood. Both cause a water problem. One is a shortage and the other an excess. If proper planning can be done then both the above mentioned dangers lose their destructive effect to a great extent. This is the purpose of integrated conjunctive management in the use of groundwater and surface water.

By a judicial management and use of both surface and groundwater, the water resources can be conserved and utilised economically for food production drive as well as industrial revolution. For a healthy economic growth of a country, management and utilization of the two resources needs to be scientifically planned and managed keeping in view the future demands which are inevitable to increase manifold for domestic, irrigation and industrial purposes.

To address these problems a self financed research was carried out by the writer, selecting a restricted area of 185 square kilometres with more than two thousand dug wells (including forty one observation wells), six medium irrigation schemes and forty minor irrigation schemes in Vavuniya District.

3.1 Objective of the Research

The main objective of this research is a complete water balance study in a restricted catchment (more than 150 square kilometres) area incorporating few medium irrigation schemes, several minor Irrigation schemes and a large number of dug wells to illustrate:

1. The development of a model to represent all the relevant variables connected with the movement and utilization of surface and groundwater
2. The usage of the above model to study the viability of conserving surface water by storage as groundwater by reducing the extent of cultivation using surface water and increasing the extent of cultivation using groundwater to achieve optimum crop yield
3. The economic viability of achieving optimum crop yield as in (2)
4. The creation of an artificial aquifer boundary to optimize the effectiveness of groundwater use to achieve optimum crop yield
5. The economic viability of the creation of artificial boundary in terms of productivity
6. Combining both 2 and 4 for the increased crop production
7. The economic viability of achieving optimum crop yield as in (6)

for the management and conjunctive use of surface water and groundwater resources in an efficient and economic manner to achieve optimum productivity in terms of food production.

3.2 Research Methodology

General relationship between crop yield and water applied to the crop shows a trend to increase linearly up to about 50% of the full irrigation and then going in a convex curvature to the optimum yield and then reduce the yield with increase in applied water

Farmers whose sole objective is to get optimum net income, tends to irrigate their crop by spending minimum cost for their irrigation water to get optimum productivity of 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.

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 185.23 km^2 as shown in figure annexed) in Vavuniya (having a shallowly weathered and rarely fractured crystalline rocks with thin soil mantle).

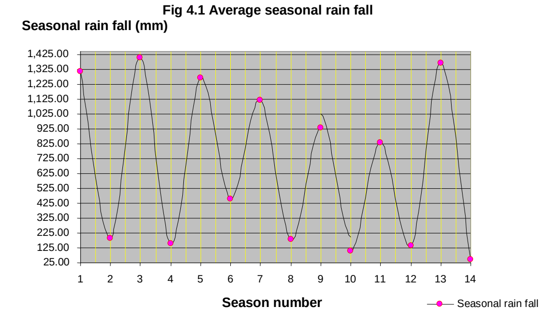
This model was used to find out an operational policy for conserving surface water by storage as groundwater by reducing the extent of cultivation using surface water and increasing the extent of cultivation using groundwater to achieve optimum crop yield under minor and medium irrigation schemes together with creation of an artificial boundary to lift the water table up.

4. Data Collection

The following inputs were processed from the data available in statistical handbook Vavuniya (1997 – 2005), District Integrated Agriculture Development & Extension Program Vavuniya (1997 – 2005), Administration report of Central and Provincial Irrigation Department (1997 – 2005) and data collected from NWS&DB Vavuniya.

- Capacity of water stored in Irrigation scheme (m^3)
- Water issued for cultivation in irrigation scheme (m^3)
- Rainfall volume (m^3)
- 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)

Fig 4.1 Average seasonal rain fall



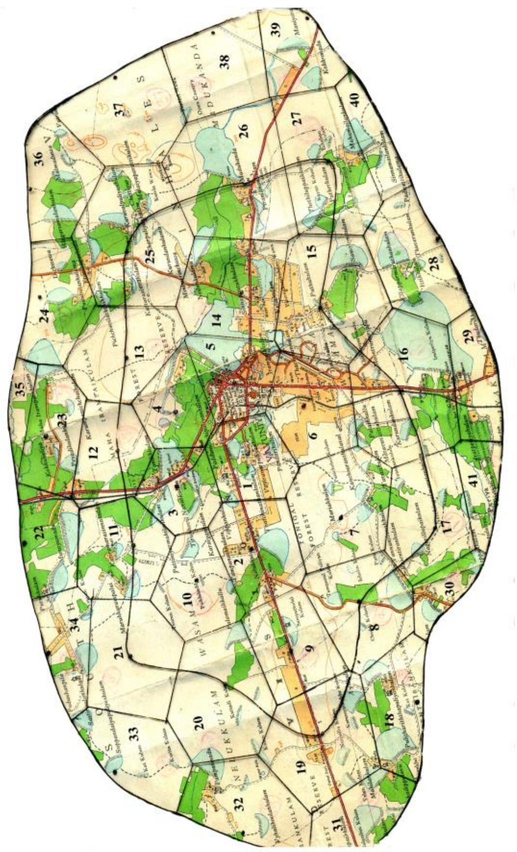
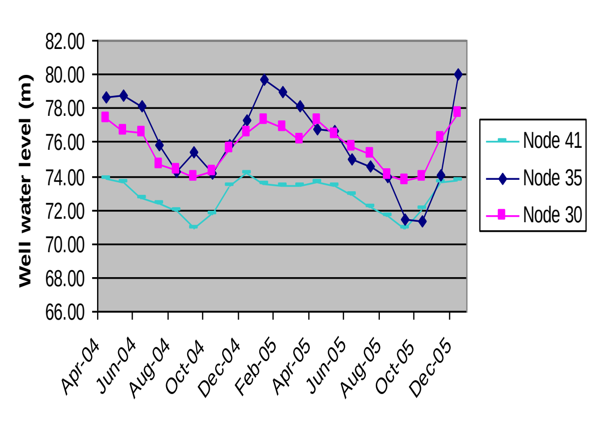


Fig 4.1 Study area with observation well numbers and polygons.

Table 4.1 Average seasonal rainfall

Period of months considered as seasons for this study	Season No	Seasonal rain fall (mm)
Oct 97 - May 98	1	1311.30
June 98 - Sep 98	2	190.00
Oct 98 - May 99	3	1409.00
June 99 - Sep 99	4	152.81
Oct 99 - May 00	5	1268.60
June 00 - Sep 00	6	455.80
Oct 00 - May 01	7	1118.80
June 01 - Sep 01	8	179.10
Oct 01 – May 02	9	936.90
June 02 - Sep 02	10	105.40
Oct 02 - May 03	11	836.10
June 03 - Sep 03	12	141.60
Oct 03 - May 04	13	1370.20
June 04- Sep 04	14	44.60

Fig, 4.3 Monthly Groundwater Level Fluctuation



5.1 Model Formulation

This study area was divided into forty one polygons by connecting the perpendicular bisectors of adjoining observation wells. Seven year seasonal water levels and one year monthly water levels, tank storage, field issues and total withdrawal from agro and domestic wells for each polygon were taken for the water balance of each polygon. A regional aquifer simulation model was formulated for this polygonal net work. Integrated finite difference method was used for the formulation of the model.

5.2 Model Calibration

Before the model can perform its task of predicting the future groundwater system behaviour it must be calibrated. 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.

5.3 Model Validation

To test the validity of the model, using the calibrated parameters and using 10th season (Sept. 2002) water level as initial water level and the rest of the inputs, the 11th season (May 2003) water level was predicted using the prediction model. In the same way, using 11th season (May 2003) water level as initial water level and the rest of the inputs, the 12th season (Sept. 2003) 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.

This led to an observed error in depth of water table of the magnitude ranging from -0.08% to +2.1%. 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.

6. Model Predictions for Various Operational Policies

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

- The possibility of reducing the extent of cultivation using surface water and increase the storage of groundwater for economic cultivation
- The possibility of creating an artificial aquifer boundary to reduce the lateral flow to raise the water table for economic pumping to reduce the cost of irrigation water to increase the productivity
- The possibility of combining both 1 and 2 to raise the water table by improving the groundwater storage capacity to increase the crop yield by increasing the extent of economic cultivation per unit of irrigation water

An operational research was carried out using the calibrated and validated prediction model for the above three policy alternatives 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 – Sept. This was done by assuming that, to keep 10 % of full capacity of a medium and minor irrigation scheme, 12 % of cultivation has to be forgone.
- The first interior boundary of the study area was selected for the creation of artificial boundary by the way of boundary treatment. To

create the artificial boundary, the transmissibility values (actually the permeability) were reduced in steps and behaviour of water table was observed. The **T** values between seventeen very extreme peripheral nodes (18, 30, 41, 29, 28, 40, 39, 38, 37, 36, 24, 35, 22, 34, 33, 32, 31) and fourteen interior adjoining nodes (8, 17, 16, 15, 27, 26, 25, 13, 23, 12, 11, 21, 20, 19) of the study area were reduced in steps of 2 – 3 m^2 /day and the water levels were predicted.

- During this analysis every step of one was carried out for all five steps of two. Accordingly twenty five trials were carried out. Even though this was a very cumbersome exercise an interesting shift was observed as an outcome.

7. Summary of Operational Research

The summary of results of the operational research considering different options is given below.

- Changing the operational policy of minor and medium irrigation schemes by forgoing 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 artificial aquifer boundary to optimize the effectiveness of groundwater in an elevated water table by peripheral boundary treatment to cause reduction of permeability by 35% to 45% is giving water table raise of nodes closer to treated boundary by 0.457 m to 0.838 m during recharging season.
- Combining peripheral reduction in permeability by 35% to 45% and forgoing cultivation of minor and medium irrigation scheme by 45% to 55% result 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 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.

Summary of the results of maximum water level change of the above operational research are given below in a tabular form for easy visualization and understanding of the water table behaviour.

Table 7.1 Summary of maximum water level change in m for various options

Options	**Steps of each option**	**Discharging period**	**Recharging period**	**Nodes on which raise in water level occurred**
Operational policy change	**Forgoing 24% - 36% cultivation**	0.762 to1.143	0.533 to 0.914	**Scattered except 37 and 38**
	Forgoing 48% - 60% cultivation	0.838to 1.371	0.610 to 1.067	**Scattered except 37 and 38**
Boundary treatment	**Reduction of permeability by 40%**		-0.381 to -0.610.	**18, 41, 29,35,34,33,32 and 31**
			0.305 to 0.686	**28, 39,36 and 24**
			-0.229 to -0.457	**13 and 14**
			0.457 to 0.838	**8,19,17,16,27,26,25,23,11,21,20 and 2**
Combination of policy change and creation of artificial boundary	**Step 4 of both options**	0.914 to 1.448		**95 % of the nodes within the catchment**

8. Impact of Economic Analysis on Outcome of the Considered Options

An economic analysis was carried out to find the economic viability of the research outcome to justify the economic implimentability of the objective achieved.

The main assumption adopted in this option regarding the optimum crop yield is economizing the cost of the irrigation water, leaving out the physiology of the crop. 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 indirectly contribute to GDP and to GNP. 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 the savings in electricity expenditure in pumping water for domestic agricultural and production by way of raise in water table during the implementation of this policy.

Summary of the economic analysis for all the three alternate options for the economically feasible steps is given below to get a very good idea of how the benefit/cost ratio varies for each options and steps.

Table 8.1 Summary of benefit/cost ratio greater than unity option and steps

<table>
<tr><th>Option</th><th>Steps of each options</th><th colspan="8">Benefit cost ratio</th></tr>
<tr><td rowspan="5">Operational policy change</td><td></td><td colspan="4">Discharging season</td><td colspan="4">Recharging season</td></tr>
<tr><td>2</td><td colspan="4">14.52</td><td colspan="4">1.59</td></tr>
<tr><td>3</td><td colspan="4">14.63</td><td colspan="4">1.46</td></tr>
<tr><td>4</td><td colspan="4">12.43</td><td colspan="4">1.33</td></tr>
<tr><td>5</td><td colspan="4">10.27</td><td colspan="4">1.13</td></tr>
<tr><td rowspan="5">Boundary treatment</td><td>Year of implementation</td><td colspan="4" rowspan="5"></td><td colspan="2">20</td><td colspan="2">25</td></tr>
<tr><td>Interest rate</td><td>7.5%</td><td>10%</td><td>7.5%</td><td>10%</td></tr>
<tr><td>3</td><td>0.73</td><td>0.97</td><td>1.15</td><td>1.66</td></tr>
<tr><td>4</td><td>0.88</td><td>1.17</td><td>1.39</td><td>2.01</td></tr>
<tr><td>5</td><td>0.83</td><td>1.10</td><td>1.30</td><td>1.88</td></tr>
<tr><td rowspan="5">Combination of policy change and creation of artificial boundary</td><td>Year of implementation</td><td colspan="2">20</td><td colspan="2">25</td><td colspan="2">20</td><td colspan="2">25</td></tr>
<tr><td>Interest rate</td><td>7.5%</td><td>10%</td><td>7.5%</td><td>10%</td><td>7.5%</td><td>10%</td><td>7.5%</td><td>10%</td></tr>
<tr><td>3</td><td>0.97</td><td>1.13</td><td>1.28</td><td>1.78</td><td>0.82</td><td>1.09</td><td>1.17</td><td>1.75</td></tr>
<tr><td>4</td><td>1.09</td><td>1.19</td><td>1.49</td><td>2.23</td><td>1.01</td><td>1.13</td><td>1.44</td><td>2.18</td></tr>
<tr><td>5</td><td>1.04</td><td>1.13</td><td>1.42</td><td>2.22</td><td>0.97</td><td>1.15</td><td>1.37</td><td>2.02</td></tr>
</table>

9. Summary of Economic Analysis of the Operational Research

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

- **The alternate policy on changing the operational policy of minor and medium irrigation schemes by forgoing cultivation by 25% to 35% 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**
- **The boundary treatment showed positive results for the life time of the project exceeding 20 years and for the interest rate of 7.5%**
- **The combination of the above two alternatives yielded further improvement that, at any time water table will reduce 60% to 70% of loss in between two consecutive seasons in 95 % of the catchment under study.**

10. Summary of the Research Finding

Summarizing all the three alternatives based on the operational research and economic analysis, the first and third alternatives out of the three alternatives mentioned previously would be the most economically feasible alternatives for implementation in any catchment.

- **A change in operational policy of minor / medium irrigation schemes by forgoing one third of the cultivation under minor / medium irrigation schemes or keeping one fourth of the storage of minor / medium irrigation schemes at any time will recover 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**
- **A change in operational policy of minor / medium irrigation schemes by forgoing one third of the cultivation under minor / medium irrigation schemes or keeping one fourth of the storage of minor / medium irrigation schemes at any time together with creating an artificial aquifer boundary to reduce the permeability of the catchment boundary by 40% to 50%, will recover an average of 60% to 70% of water table loss in between two consecutive seasons in almost 95 % of the catchment under consideration**

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 increase productivity in terms of food production.

11. Implementation of the Research Finding

This finding can be generalized with respect to time and space with suitable modification and does not require any additional resource to implement, but proper awareness about increase the extent of crop production in one unit of irrigation water, is required to implement this policy in field among the stake holders.

Even now the practice of alternate tract cultivation in different years depending on availability of water in the Irrigation schemes exists. Hence forgoing one third of cultivation extent will not be a serious problem in execution. It must be noted that the extent of cultivation underground water is increased considerably. Hence this policy implementation is very easy with proper knowledge based awareness among the stake holders.

12. 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.

Minor / medium irrigation schemes 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 minor / medium irrigation schemes prevent soil erosion and depletion of soil fertility. In the context of impending water deficiency looming large, 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 planning and execution of settlement and crop production projects.

This research finding shows that a change in operational policy of minor / medium irrigation schemes by forgoing one third of the cultivation under minor / medium irrigation schemes or keeping one fourth of the storage of minor / medium irrigation schemes 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.

The reduction of the loss of water table in any consecutive seasons will be between 60% - 70% in almost 95 % of the catchment under consideration by creating an artificial aquifer boundary to reduce the permeability of the

catchment boundary by 40% to 50%, in addition to the above change in operational policy of minor / medium irrigation schemes.

Growth of a Nation Depends on Effective Economic and Equitable use of Water

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