Tropical Agricultural Research Vol. 9 1997, 288-301

Groundwater Regulation Through Design of Agrowell Dimensions in the Hard–Rock Aquifer – A Case Study in the North Western Province of Sri Lanka

C.S. De Silva

Department of Agricultural and Plantation Engineering
Faculty of Engineering Technology
The Open University
Nawala, Nugegoda, Sri Lanka

ABSTRACT. *To overcome the problem of water shortage in the dry and intermediate zones of Sri Lanka, agrowells have been introduced to use the groundwater as a supplement to the rainfall. Due to the underlying crystalline hard rock formations which have very low storage and transmissivity, the groundwater resources in these areas are limited. However, haphazard development of agrowells without recourse to scientific investigations will lead to serious problems related to groundwater resources in future. At present there is no groundwater regulation in these agrowell systems and the farmers have the freedom to abstract any amount of water from their wells. Due to this, the problems such as drying of wells in the mid season, low recovery of well after long pumping and interference between neighbouring wells, have been observed in these areas.*

Therefore a study has been carried out in North Western Province of Sri Lanka, to study the recharge, well performance for short and long term pumping, recovery of the wells after pumping, aquifer flow mechanisms and to develop a methodology to regulate groundwater in agrowell systems by proper designing of well dimensions. Through this methodology, a set of nomographs are developed for 8 well radii and 8 aquifer depths for the particular case study area. It is possible to identify the safe volume of water that could be abstracted from a known dimensions of a well. Extent of cultivation could be decided according to the crop water requirement of the crops selected for cultivation with the safe volume of water available per well.

Policy makers and the organizations involved in agrowell constructions could educate farmers based on these nomographs about the safe volume of water that could be abstracted from his own well, optimum well dimension if a farmer is constructing a new well, and crop water requirements,

so that the farmer himself can regulate his own groundwater resources to avoid over-exploitation. Similar nomographs could be developed with the basic data available for any part of Sri Lanka using the methodology introduced in this study.

INTRODUCTION

Water shortage is a major constraint for agricultural development in dry and intermediate zones of Sri Lanka. The mean annual rainfall ranges from 800 mm to 1500 mm. More than 90% of the annual rainfall is received during the wet season (from October to December). In most years precipitation is insufficient to meet the crop water requirements for 7 to 8 months during the dry season.

Rapid development of the country and increase in rural population places a high demand in water. Water is extensively used by industries and agriculture in addition to the domestic purposes. More intensive and successful agricultural practices are largely dependant on the availability of assured water resources. Fluctuating weather conditions changed the rainfall patterns and the usual amount of seasonal rainfall was not received during the last few years. At this state of affairs. groundwater is the only source available if there is a severe water shortage.

In Sri Lanka nearly 90% of the land area is occupied by metamorphic crystalline rocks, called "hard rocks". Therefore the groundwater potential in dry and intermediate zones is limited due to low storage and transmissivity of the underlying aquifer formations. Except in the Jaffna peninsular in the extreme north of the island, where the rich aquifers are associated with Miocene limestone and sand aquifers in coastal areas like Kalpitiya peninsula, ground water has never been used on large scale in the dry and intermediate zones till the Government of Sri Lanka implemented a nation-wide agrowell programme in late eighties.

However, the development of agrowells has taken place in a haphazard way without proper assessment of the hydro-geological properties, spacing of wells, safe yield, recharge and a rational siting of wells. Farmers are not guided enough to use the national groundwater resources efficiently. Usually farmers use more water to irrigate than required by the crop (De Silva, 1995). The density of wells per unit area has increased without proper spacing between wells. As a result, there is evidence of salinity problems, interference between wells and drying of wells in mid season. Further, indiscriminate opening of new agrowells may lead to serious problems in the future.

Therefore, supplementary irrigation using agrowells in the hard rock aquifers of Sri Lanka should be carefully planned with respect to hydraulics of groundwater aquifer and recharge. Groundwater must be regulated so that the rights of water under individual lands can be regulated by establishing well dimensions. The objective of this paper is to introduce a methodology to develop a set of nomographs to determine well dimensions and the amount of water that could be abstracted safely.

MATERIALS AND METHODS

Case study area

In order to fulfil the objective, a case study was conducted in an typical agrowell system in Kobeigana in North Western Province of Sri Lanka. Kobeigana is located on the boundary of the intermediate and the dry zones where many rural inhabitants suffer a shortage of water for domestic and irrigation purposes during the dry season.

Farmers in this study area have never had large schemes for irrigation. During late eighties, agrowells were introduced to these areas. After the construction of large diameter wells (agrowells) they cultivate paddy during the wet season (rainfed) and vegetable and cash crops during the dry season in both uplands and lowlands with agrowell irrigation. A typical agrowell in the case study area is 3 m in radius and 6 m in depth, lined with bricks, and plastered with cement for the top 1 or 2 m. Spacing between wells varies from 50 m to 500 m depending on the farmer population. Farmer normally irrigates using a 50 mm pump with portable hose pipes leading directly to short furrows (10 to 20 m long) or small basins (25 to 100 m^2). The well storage allows the pump to be used at its optimum rate. The well is then left to refill slowly before the next irrigation.

The study considered thirty (30) wells in several villages of Kobeigana. These agrowell sites were intensively equipped with observation bore holes, raingauges and evaporation pans. Daily field monitoring was carried out on groundwater levels, changes in groundwater levels due to pumping, pumping rates for 21 months along with the rainfall and evaporation data. Several pumping tests were conducted during early and late dry seasons to study the aquifer parameters and flow mechanisms. Investigations were also made of the properties of the aquifer to understand the hard rock formation in the study area.

Methodology for groundwater regulation

The methodology developed for the groundwater regulation through the agrowell dimensions is presented in Figure 1. This methodology could be used with the basic data available in any agrowell system. But the accuracy depends on the validity of the data.

Step 1

Basically two computer models are used in this methodology. The first model is a radial flow model (De Silva and Rushton, 1996) which simulates radial flow towards the agrowell.

The radial flow model is used with the features of seepage face, well storage, varying saturated depth and varying outer boundary (no–flow or rechargeable boundary) to analyze the pumping test and estimate the aquifer transmissivity and specific yield (De Silva, 1995). By analyzing pumping test it is possible to calibrate the model for a particular study area.

Step 2

Second is a soil moisture balance method based computer model named IWR (Irrigation Water Requirement), which runs on historic weather data with crop and soil information (Hess, 1990). In the soil moisture balance method a daily estimate of the soil moisture balance is made with an input of precipitation plus irrigation minus run–off and losses due to actual evapotranspiration and drainage which may include aquifer recharge. When the soil moisture deficit is zero, water can pass through the soil zone to the aquifer provided that the aquifer can accept water. The IWR computer model was used to estimate the annual average aquifer recharge for several years depending on the availability of reliable data.

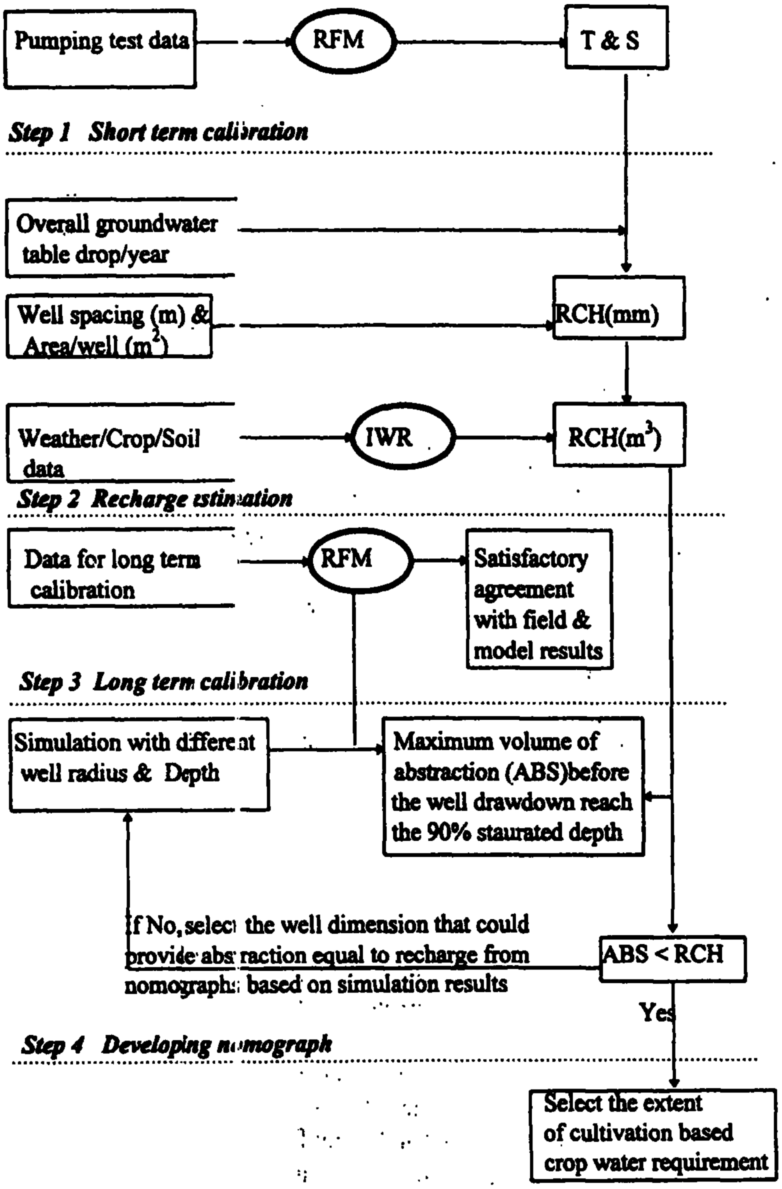

Figure 1. Flow chart of the methodology developed in this study.

Once the specific yield is estimated in the Step 1, it is also possible to estimate the approximate annual average aquifer recharge by multiplying the overall groundwater drop per year (if known) by the specific yield, which will give the estimate of the annual average aquifer recharge in the absence of weather, crop and groundwater level data.

Step 3

The radial flow model could be used for analysing different scenarios of well dimensions after calibrating for the long term behaviour of the agrowell. The calibration of long term behaviour could be done only when detailed groundwater level monitoring is available.

Step 4

The model calibrated for long term behaviour is then used for simulations. Different well radii, well depth and distance to outer boundary could be tested. The distance to the outer boundary is an important parameter in agrowell systems. The existence of a number of agrowells in an area means that an area of aquifer is associated with each well. This can be represented adequately as a circular aquifer with an equivalent outer radius on which a condition of no flow crossing the boundary is enforced (De Silva, 1995).

For simulations the abstraction is increased by factors until the well supply water for abstraction without reaching the excessive draw down limit of 90% of the saturated depth within the growing season. This procedure could be repeated for different well radii, depth and distance to the outer boundary. The results obtained in the simulation could be developed into nomographs. For sustainable irrigation the abstraction should be less than the recharge. The recharge available for the area associated with the well could be calculated from the distance to the outer boundary. Then the area associated with the well could be multiplied by the average annual recharge estimated in step 2 to calculate the volume of recharge available for abstraction. The amount of abstraction equal to or less than the 50% of recharge could be used for irrigation. Cultivated extent could be decided based on the cropping pattern, crop water requirement and the amount of water available for irrigation from the well. The methodology introduced in this study was applied to the case study area to develop a set of nomographs for groundwater regulation.

RESULTS AND DISCUSSION

Groundwater fluctuation

Daily groundwater level fluctuation was measured in the case study area in several observation bore holes for two years (Figure 2). The trend of the groundwater fluctuation in this area indicated that the groundwater levels were near to the ground surface from October to March. From March onwards the groundwater table decreased steadily towards the end of dry season in September. The groundwater table decreased from March to September mainly due to pumping for dry season irrigation and evapotranspiration losses. The maximum groundwater table drop observed in the first and the second years were 3.25 and 3.75 m, respectively. With the onset of the north east monsoon rains, the groundwater table rose quickly and reached the ground surface in 30 days and 50 days in the first and the second years, respectively. From November the groundwater was maintained near to the ground surface till the end of wet season rains in January. The quick response of groundwater levels to the rainfall and drought showed the unconfined nature of the aquifer.

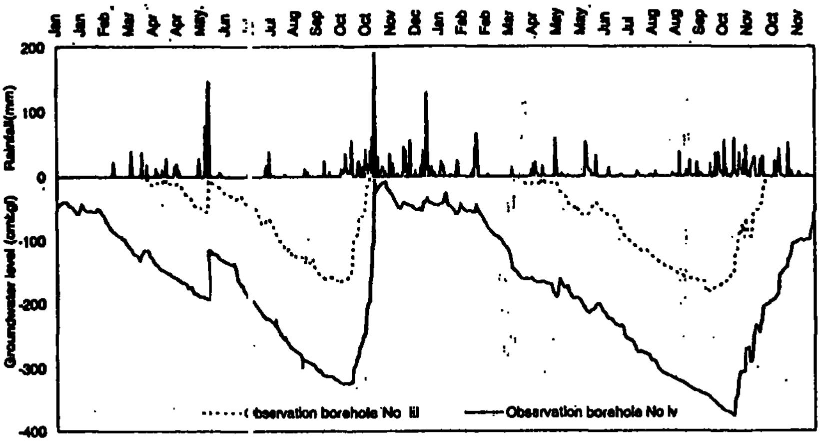

Figure 2. Daily groundwater fluctuation measured in two observation bore holes of the study area during 1994 and 1995.

Recharge characteristics and aquifer capacity

Generally the aquifers in the dry and intermediate zones of Sri Lanka recharged during the wet season rains from October to January. It is evident from the rise of the groundwater table by about 3–4 m and almost to the ground level during wet season. The main feature of hard rock aquifers in dry and intermediate zones is its shallow saturated depth varying from 4 m to 10 m.

Therefore the aquifer capacity is limited and even if there is substantial rainfall, the aquifer is unable to hold more than its capacity, which is evident by the excess runoff and stream flows during wet season. Recharge received during the wet season which is limited due to its capacity and/or insufficient rainfall should be used carefully during the dry season as there is very little or no recharge to the aquifer during the dry season. On any occasion when the abstraction exceeds the total volume of recharge during wet season, it will lead to over exploitation of the groundwater resources and result in permanent ground water depletion.

Figure 3 shows the diagrammatic representation of differences between the dry and wet seasons in a typical agrowell system. During the wet season the aquifer is full and the groundwater table is near to the ground surface when farmers cultivate paddy.

During the wet season it is difficult to cultivate cash crops and vegetables unless there is proper drainage. From March to September the farmers are entirely dependant on the residual moisture and irrigation from agrowells for vegetable crop cultivation. Therefore, the agrowells are used intensively during dry season from March to September. Since the recharge is limited due to poor rainfall and/or limited aquifer capacity, usage of agrowells during dry season should be considered carefully.

Performance of agrowells

Results obtained from the case study area indicated that the contribution of the well storage to the total abstraction is more than 80%. Aquifer flows are very small during pumping and recovery phase. When the pump is switched off, water continues to be withdrawn from the aquifer to replenish the well storage, but takes a long time due to the low transmissivity. According to the results, the 50% recovery after pumping (for 4 h) is reached only 24 h after the pump is switched off. After a long duration pumping (8–12

h) at least 3 days are required for 50% recovery (De Silva, 1993; De Silva and Weatherhead, 1994). Therefore the groundwater resources in hard rock aquifers are limited by the aquifer capacity and the ability of the well to draw water from the distance parts of the aquifer due to shallow gradient and low transmissivity.

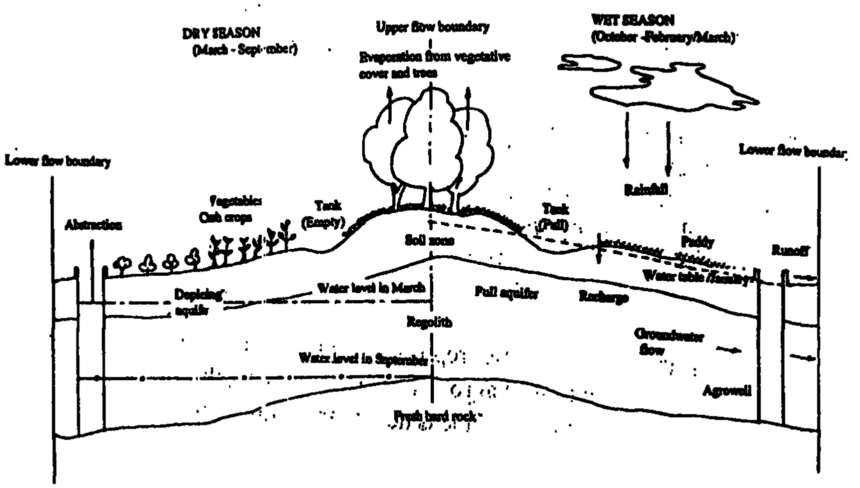

Figure 3. Diagrammatic representation of the study area during dry and wet season.

Application of the methodology

The radial flow model was used to analyse the pumping tests conducted in the study area. The model results were compared with the draw down in the pumped well and also in the observation bore hole at 13 m and 43 m from the well centre respectively. A range of parameter values were tried and the satisfactory agreement between the field and model results were obtained. The estimated average horizontal hydraulic conductivity, and specific yield were 6.0 m/d and 0.07, respectively.

Actual recharge of the study area was calculated using IWR model. Ten year average annual recharge for the study area was 250 mm. The typical cropping pattern used by the farmers in the field was considered for this calculation. This cropping pattern consisted of only 60% of land with brinjals, chilli, long bean, cucumber and paddy. Rest of the land is grass comprising small and large trees.

The dimensions of the well No. 1 and the growing season (210 days) of the study period from February to September was taken as an example to calibrate the long term behaviour of the agrowells in the study area. It is assumed that the well is fully penetrating the aquifer and aquifer is fully recharged. The maximum pumped draw down in the model was set as 90% of the saturated depth so that there will always be 10% of the saturated depth of the water in the bottom of the well. When this draw down was reached in the simulation, the pump was automatically switched off and the well supply was regarded as having failed. To obtain a satisfactory agreement the tall tree evaporation from ground water table was introduced to the model (De Silva and Rushton, 1996).

The simulations were then carried out by the radial flow model calibrated for the long term behaviour of the study area. Well radii from 1 to 8 and well depth from 3 to 10 were tested with four different distances to the outer boundary (No–flow boundary). Results obtained were developed into nomographs showed in Figure 4. These nomographs indicate the volume of water that could be abstracted from an agrowell with increased well radius and well depths (De Silva *et al.*, 1996; De Silva and Weatherhead, 1996). But the more important inference is sustainability of these wells. It is not possible to abstract all the water that is available at a well. Instead, it should be checked with recharge during the previous wet season to calculate the volume of recharge available for a well of that particular well radius, well depth and well spacing.

The safe yield of water that could be abstracted from the well did not increase beyond 180 m well spacing. It shows that at larger well spacings the ability of the well to draw water from the distant parts of the aquifer is limited. However, closer spacing of the wells may lead to reduced yields and restriction of the area under cropping, thus jeopardizing the economic interests of the farmers who venture into groundwater irrigation. Further it, may negate the positive aspects of the agrowell program.

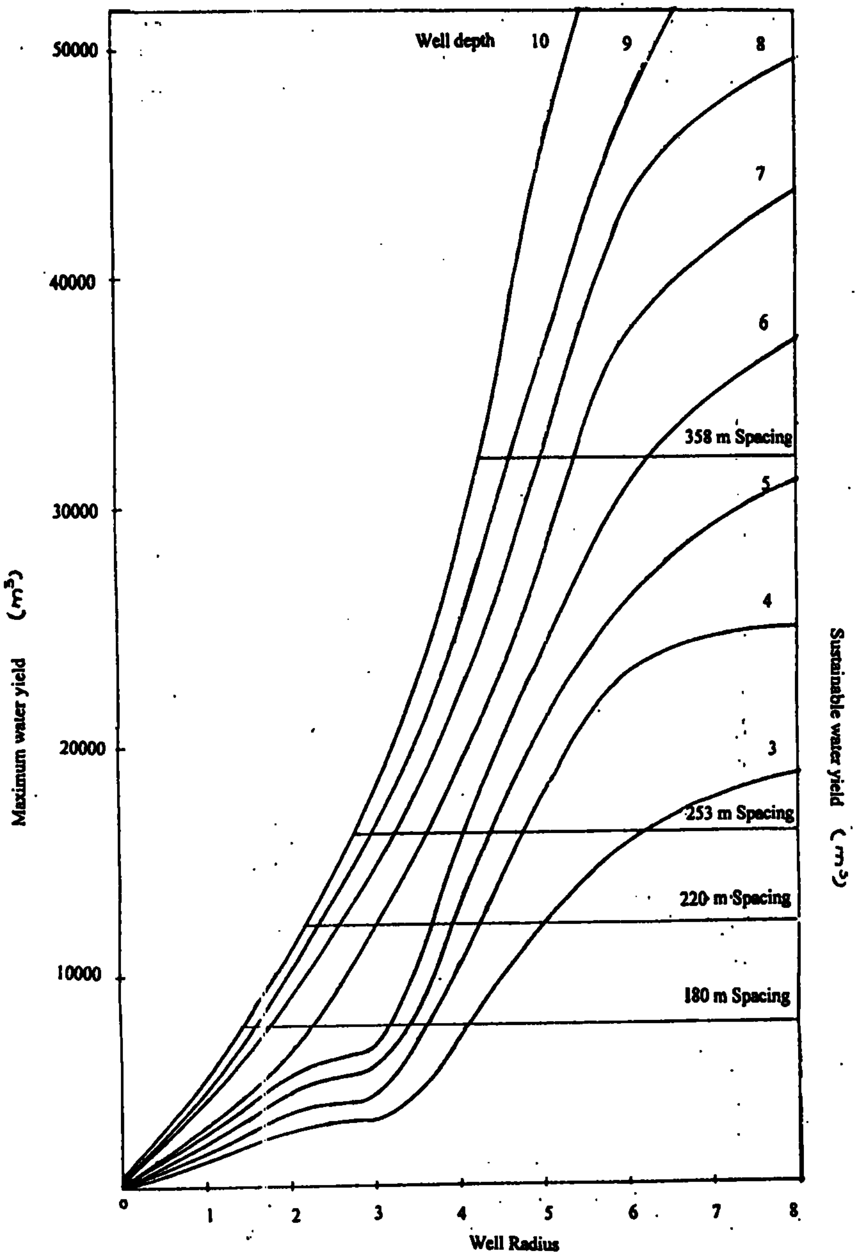

Figure 4. Nomographs of agrowell design for groundwater regulation.

For an example, the agrowell of 6 m depth and 4 m radius with the distance to the no–flow boundary of 101 m which is equal to an average spacing between two nearby wells of 180 m is considered. The area associated with each well is 32400 m^2. The average recharge for that year was 250 mm. Therefore, the recharge available per well is 8000 m^3. If the volume of water available for abstraction is 50% of the total volume, the recharge per well is 4000 m^3. From the nomograph, the maximum water that could be abstracted by the same well is 15340 m^3. Therefore it does not imply that is possible to abstract all 15340 m^3. Considering the recharge it is possible to abstract only 4000 m^3. If the farmer exceeds this amount there will be over exploitation and interference with near by wells. In addition, if the farmer is abstracting only 4000 m^3 per growing season then a well of 1.5 m radius is more than enough to supply the same volume of water. By this, the farmer could avoid the unnecessary cost of constructing a 4 m radius well. This methodology is already adopted by the author successfully and nomographs have been developed for Huruluwewa and Trippane in North Central Province of Sri Lanka.

Groundwater regulation

The organizations responsible for constructing these agrowells and policy makers for funding agrowell construction are playing a major role in implementing this methodology to regulate groundwater. Similar nomographs could be developed for areas where the agrowells are being intensively used in Sri Lanka by adopting the methodology given in this paper. These nomographs could be used to identify the safe yield of water that could be abstracted without over–exploitation for respective well radii, depth and spacing. In addition, it is also possible to identify the well radius for a given aquifer depth and spacing. By this it would be possible to cut down the unnecessary cost involved in construction of large agrowells.

Further, it is necessary to educate farmers about the safe yield of water that could be abstracted from their well according to the well dimensions to avoid over exploitation The land area that could be cultivated in each farmer's field using agrowell water is decided by the cropping pattern and the crop water requirements. Crop water requirements could be calculated by using CROPWAT computer model and farmers could be advised based on their selection of crops. High value crops with low water requirements should receive sufficient attention. Vegetable cultivation under agrowell irrigation can be easily adjusted to coincide with the periods of high demand owing to shortage of supply.

Since the ultimate objective of all these changes to give the maximum benefit to the farming community, strategies should be evolved to seek the active participation of the farmers. Farmer representation in local–level committees pertaining to groundwater development will be a significant step forward as the beneficiaries will thus be involved in the decision–making process. Effective farmer training in crop water requirement, selection of high value crops with and low water requirement, irrigation methods, groundwater resources and safe yield should be developed to enable the farmers to regulate the groundwater resources on their own.

CONCLUSIONS

The methodology developed under this study enables the regulation of groundwater resources without over–exploitation. Further, a set of nomographs could be developed for the respective areas using basic data available and the radial flow model. The study results indicated that the groundwater resources in hard rock aquifers could be regulated through proper designing of agrowell dimensions and farmer training on crop water requirements, groundwater resources and safe yield. These nomographs are useful to identify the amount of water that could be abstracted safely during a growing season based on the well radius, depth and spacing. It is also possible to identify the well radius for a given aquifer depth and spacing to minimize the construction cost.

REFERENCES

De Silva, C.S. (1993) A preliminary study on agrowells in hard rock aquifer with special reference to well performance. Trop. Agric. Res. 6: 223-227.

De Silva, C.S. (1995). The use of agrowells for supplementary irrigation from hard–rock aquifers in Sri Lanka. PhD. Thesis, Silsoe College, Cranfield University, UK.

De Silva, C.S. and Rushton, K.R. (1996). Interpretation of the behaviour of agrowell systems in Sri Lanka using radial flow models. J. of Hydrological Sci. 41(6): 825-835.

De Silva, C.S and Weatherhead, K. (1994). The use of large diameter wells (Agrowells) for supplementary irrigation in the dry zone of Sri Lanka. Proc. Inter. Conference on Water Down Under '94. Institute of Engineers, Australia. 2B: 595-599.

De Silva, C.S. and Weatherhead, K. (1996). Optimizing agrowell dimensions for sustainable irrigation from hard rock aquifers in Sri Lanka. J. Agric. Water Mgt. 33: 117-126.

De Silva, C.S., Weatherhead, K. and Rushton, K.R. (1996). Sustainability of agrowell irrigation on hard rock aquifers of Sri Lanka. Trop. Agric. Res. 8: 163-174.

Hess, T. (1990). Balance: A soil water balance programme. Silsoe College, Cranfield University, UK.