Development of Guidelines for Efficient Use of Agro-Wells

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ABSTRACT

Agro-wells have been introduced to use the precious groundwater resources to overcome the problem of water shortage in the dry and intermediate zones of Sri Lanka. 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 agro-wells without recourse to scientific investigations has caused serious problems such as drying of wells in the mid-season, low recovery of wells after long pumping and interference between neighboring wells.

Therefore, a study has been carried out in the North Western Province of Sri Lanka, to study the recharge, well performance for short- and long-term-pumping, recovery of the wells after pumping, and aquifer flow mechanisms. Based on the study results a methodology was developed to regulate groundwater resources in agro-well systems by proper designing of well dimensions. Through this methodology, a set of nomographs is developed for the particular case study area. It is possible to identify the safe volume of water that could be abstracted from known dimensions of a well. The 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 agro-well constructions could adopt these findings in the policy development and, based on these nomographs, educate farmers about the safe volume of water that could be abstracted from their own wells. Optimum well dimension could be decided if a farmer is constructing a new well, so that the farmer himself can regulate his own groundwater resources to avoid overexploitation. A similar nomograph is developed for the Huruluwewa watershed and it could be developed for any part of Sri Lanka with the basic data available, using the methodology introduced in this study.

INTRODUCTION

The mean annual rainfall in dry and intermediate zones of Sri Lanka ranges from 800 mm to 1,500 mm. More than 90 percent 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 (from January to September).

Rapid development of the country and increase in rural population places a high demand for water. Water is extensively used by industries and agriculture in addition to domestic

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purposes. Intensive and successful agricultural practices are largely dependent on the availability of assured water resources. Fluctuating weather conditions change the rainfall patterns and the usual amount of seasonal rainfall was not received during the last few years. Hydropower became scarce due to insufficient storage in the hydro-catchments. In this state of affairs, groundwater is the only source if there is a severe water shortage.

In Sri Lanka, nearly 90 percent 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 Peninsula in the extreme north of the island, where the rich aquifers are associated with Miocene limestone and sand aquifers in coastal areas like Kalpitiya, groundwater has never been used on a large scale in dry and intermediate zones till the late eighties. The Government of Sri Lanka implemented a nationwide agro-well program for supplementary irrigation in these zones in the late eighties.

However, the development of agro-wells has taken place in a haphazard way without proper assessment of the hydrogeological 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 than the requirement to irrigate their 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 (De Silva 1993; De Silva and Weatherhead 1994). Further, indiscriminate opening of new agro-wells may lead to serious problems in the future.

Therefore, supplementary irrigation using agro-wells in the hard rock aquifers of Sri Lanka should be carefully planned through a systematic research approach with respect to hydraulics of groundwater aquifer and recharge. Groundwater must be regulated so that establishing well dimensions can regulate the rights of water under individual lands. The objective of this paper is to introduce the methodology developed through a systematic research approach for groundwater regulation in the hard rock aquifer.

CASE STUDY AREA

To attain the above objective, a case study was conducted in a typical agro-well system in Kobeigana in the North-Western Province of Sri Lanka. Farmers in this study area have never had large schemes for irrigation. During the late eighties, agro-wells were introduced to these areas. An agro-well in this area is 6 m in depth and 6 m in diameter; walls are lined with brick from the bottom to the top of the well. After the construction of large diameter wells (agro-wells) paddy is cultivated during the wet season (rain-fed) and vegetable and cash crops during the dry season in both uplands and lowlands with agro-well irrigation. A 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 agro wells in several villages of Kobeigana. These agro-well sites were intensively equipped with observation boreholes, rain gauges, and evaporation pans. Daily field monitoring was carried out on groundwater levels, changes in groundwater levels due to pumping, and 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 a systematic research approach is presented in figure 1. This methodology was developed after studying the agro-well systems in the hard rock aquifer in detail and understanding the aquifer flow mechanisms and the agro-well performance during the dry and wet seasons. This methodology could be used with the basic data available in any agro-well 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 (RFM) (De Silva and Rushton 1996), which simulates radial flow towards the agro-well.

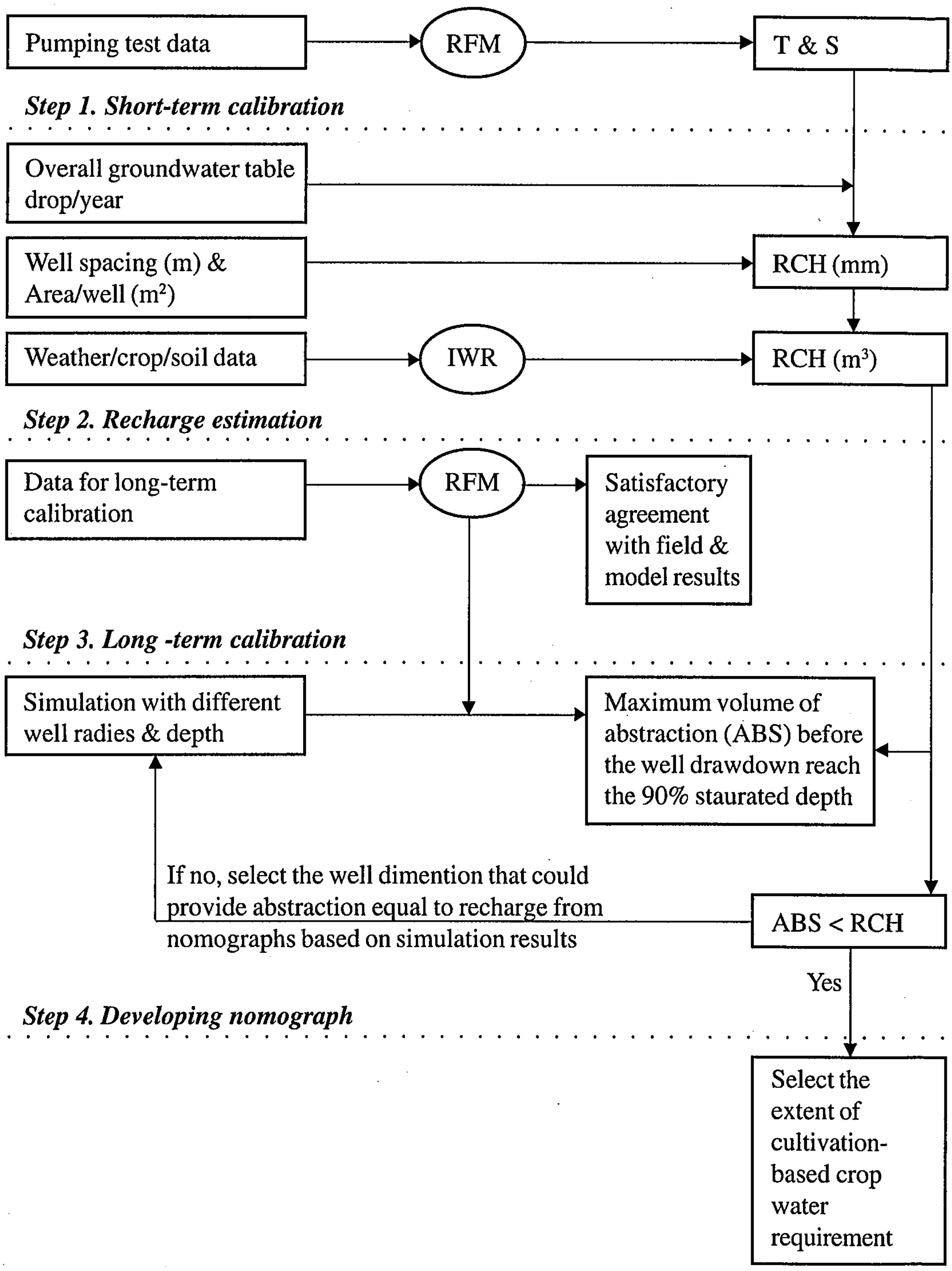
The radial flow model is used with the features of seepage face, well storage, varying saturated depth, and varying outer boundary (no-flow or rechargeable boundary) to analyze the pumping test and estimate the aquifer transmissivity and specific yield (De Silva 1995). By analyzing the pumping test it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

Step 2. This is a soil moisture balance method based on a 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 runoff 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 could be used to estimate the annual average actual aquifer recharge for several years depending on the availability of reliable data.

Once the specific yield is estimated in 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. This could be checked with the results obtained from the IWR model.

Step 3. The radial flow model could be used for analyzing different scenarios of well dimensions after calibrating for the long-term behavior of the agro-well. The long-term behavior could be calibrated only when detailed groundwater level monitoring is available for a long period (preferably daily data for a complete year).

Figure 1. Flowchart of the methodology developed in this study.



Step 4. The model calibrated for long-term behavior is then used for simulations. Different well radii, well depths, and distance to the outer boundary could be tested. The distance to the outer boundary is an important parameter in agro-well systems. The existence of a number of agro-wells 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 supplies water for abstraction without reaching the excessive drawdown limit of 90 percent 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 percent of recharge could be used for irrigation. The cultivated extent could be decided based on the cropping pattern, crop water requirement, and the amount of water available for irrigation from the well.

APPLICATION OF THE METHODOLOGY

The methodology developed was applied to the case study area to develop a set of nomographs for groundwater regulation. Results obtained are discussed below.

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

The actual recharge of the study area was calculated using the IWR model. The 10-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 consists of only 60 percent of land with brinjal, chili, long bean, cucumber, and paddy. The rest of the land is grass comprising small and large trees.

Well no. 1 dimensions and the growing season (210 days) of the study period from February to September were taken as an example to calibrate the long-term behavior of the agro-wells in the study area. It is assumed that the well is fully penetrating the aquifer and the aquifer is fully recharged. The maximum pumped drawdown in the model was set as 90 percent of the saturated depth so that there would always be 10 percent of the saturated depth of the water at the bottom of the well. When this drawdown 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 the groundwater table was introduced to the model (De Silva and Rushton 1996).

The radial flow model calibrated for the long-term behavior of the study area then carried out the simulations. Well radii from 1 m to 8 m and well depths from 3 m to 10 m were tested with four different distances to the outer boundary (no-flow boundary). Results obtained were developed into nomographs shown in figure 2. These nomographs indicate the volume of water that could be abstracted from an agro-well 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 in 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 radius, well depth, and well spacing.

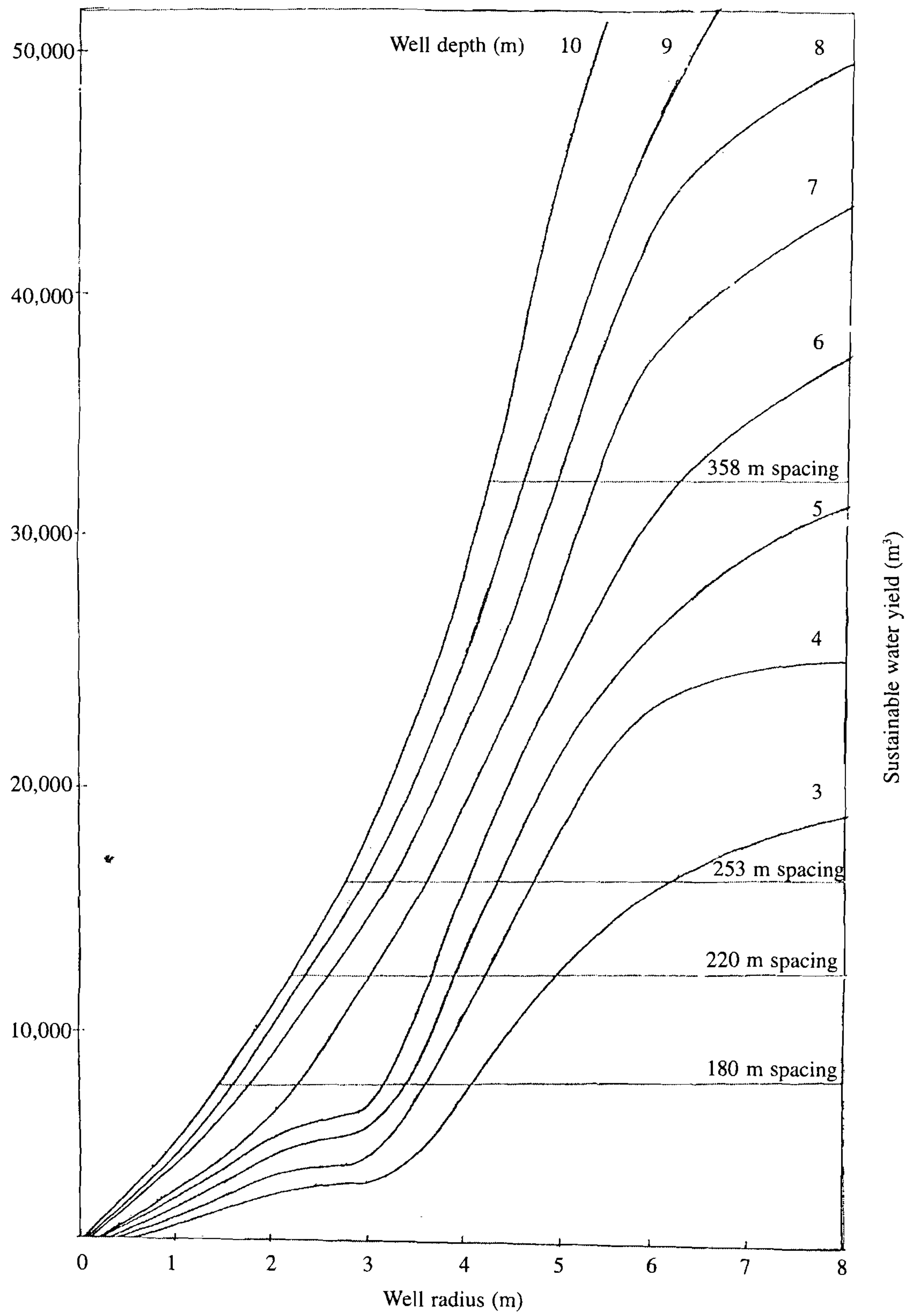
The safe yield of water that could be abstracted from the well did not increase beyond 180 m well spacing. It shows that at larger well spacing the ability of the well to draw water from the distant parts of the aquifer is limited. However, closer spacing of the wells may lead to reducing yields and restricting 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 agro-well program.

For example, the agro-well 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 32,400m^2. The average recharge for that year was 250 mm. Therefore, the recharge available per well is 8,000 m^3. If the volume of water available for abstraction is 50 percent of the total, the volume of recharge per well is 4,000 m^3. From the nomograph, the maximum water that could be abstracted from the same well is 15,340 m^3. Therefore, it does not imply that is possible to abstract all the 15,340 m^3. Considering the recharge it is possible to abstract only 4,000m^3. If the farmer exceeds this amount there will be overexploitation and interference with nearby wells. In addition, if the farmer is abstracting only 4,000 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. The author has already adopted this methodology successfully and nomographs have been developed for the Huruluwewa watershed (De Silva et al. 1998), and the preparation of the nomograph for the Tirappane tank cascade system is in progress.

GROUNDWATER REGULATION

The organizations responsible for constructing these agro-wells, and policy makers responsible for funding agro-well construction are playing a major role in implementing this methodology to regulate groundwater. Similar nomographs could be developed for areas where the

Figure 2. Nomographs of agro-well design for groundwater regulation.



agro-wells 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 overexploitation for respective well radii, depths, 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 the construction of large agro-wells.

Further, it is necessary to educate farmers about the safe yield of water that could be abstracted from their wells according to the well dimensions to avoid overexploitation. The land area that could be cultivated in each farmer's field using agro-well water is decided by the cropping pattern and the crop water requirements. Crop water requirements could be calculated by using the CROPWAT computer model and farmers could be advised depending on their selection of crops. High-value crops with low- water requirements should receive sufficient attention. Vegetable cultivation under agro-well 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 is 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 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 overexploitation. 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 agro-well 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.

RECOMMENDATIONS

- Develop nomographs for the areas where intensive agro-well construction and irrigation are practiced.
- Identify the safe yield of water that could be abstracted from a well of given well radius, depth, and spacing, considering the recharge from the nomographs and advise the farmers accordingly.

- Advise farmers to keep a daily record of the amount of water that they abstract for irrigation by measuring the drop in the water table in the well multiplied by the plan area of the well.
- Identify the crops cultivated by interviewing farmers to calculate the crop water requirement in order to advise the farmers on the extent of cultivation based on the volume of water that could be abstracted safely.

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