Water Flow Modules in River Basin

C. Gajendran, M. Manikanda Ramkumar

***Abstract:** To study the flow modules in the river basin indicating the map of study area with the flowchart for evaluating the geophysical conditions. The necessity of recharge of water flow has been assessed with the aquifer properties and the hydrology of the basin. The water flow in river basin is determined with the geophysical conditions and hydrogeological criteria.*

***Keywords:** flowchart for evaluating the geophysical conditions, necessity of recharge, hydrology of the basin.*

I. INTRODUCTION

The study area, a drought prone and hard rock region in Southern India, covering about 207.5 km2 is character-ized by poor soil, scarce vegetation, erratic rainfall, heavy runoff and lack of soil moisture during most parts of the year [1]. Recurring droughts, coupled with in-creasing exploitation of groundwater, have resulted in the decline of groundwater levels by more than 10 m at some places in the last three decades [2]. Existing shal-low wells reflect high drawdowns during the dry season (mainly January through to September) each year. The large drawdown or outright failure of wells results in poor availability of groundwater for drinking water pur-poses. Untreated effluents from 80 functioning tanneries, forming a tannery belt, have also considerably deterio-rated groundwater quality.

In order to meet the water demand of communities it is necessary to investigate the groundwater resource poten-tial in the tannery belt. Thus, the main objective of the present study is to determine groundwater velocity, which is vital for mass transport modeling, and to assess the aquifer response under different input and output stresses using Visual MODFLOW Premium, which was initially documented by McDonald and Harbaugh . In order to achieve the above objective, the following tasks are to be carried out: 1) characterization of geological formations through the interpretation of geo-physical data; 2) analysis of hydrogeological data for aquifer characteristics; 3) estimation of natural recharge by using well water level corresponding to rainfall; and 4) conceptualization of 2-D groundwater flow model for shallow aquifer making use of the available data and simulation for prognostication.

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II. MATERIALS AND METHODS

2.1. Background of the Study Area

The study area is a drought prone hard rock terrain, and is located about 600 km southwest of Chennai, the capi-tal city of Tamil Nadu, India.

It lies between 10013/44// -10026/47// N latitudes and 77053/08//-780 01/ 24// E longi-tudes , and encompasses an area of about 207.5 km2, covering parts of Tirunelveli Reddiar-chattram and Sanarpatti blocks. The area is characterized 86 N. C. MONDAL *ET AL*.

An aquifer model was constructed based upon a concep-tual approach. In order to construct the model, boundary condition, grid and time increments were decided, and applied stresses and hydraulic properties were also esti-mated.

Finally, these parameters were tested and adjusted during the calibration procedure, with the intention of reproducing a set of historically observed data.

Finally the model was evaluated, considering how reasonably it could represent the actual system.

Attempts are made to use well defined boundaries such as no flow or constant head boundaries alone, be-cause they are simplest to model, but this may not be always feasible. Such boundaries may be far away from the zone of interest or data (such as constant head levels) may not be available. Therefore it may become necessary to choose such boundaries where flux is expected to be constant and/or low, if not zero. Anderson and Woessner [10] have mentioned that regional groundwater divide are typically found near topographic high and may form beneath partially penetrating surface water bodies. In the present exercise, partially penetrating ephemeral rivers have been taken as model boundaries

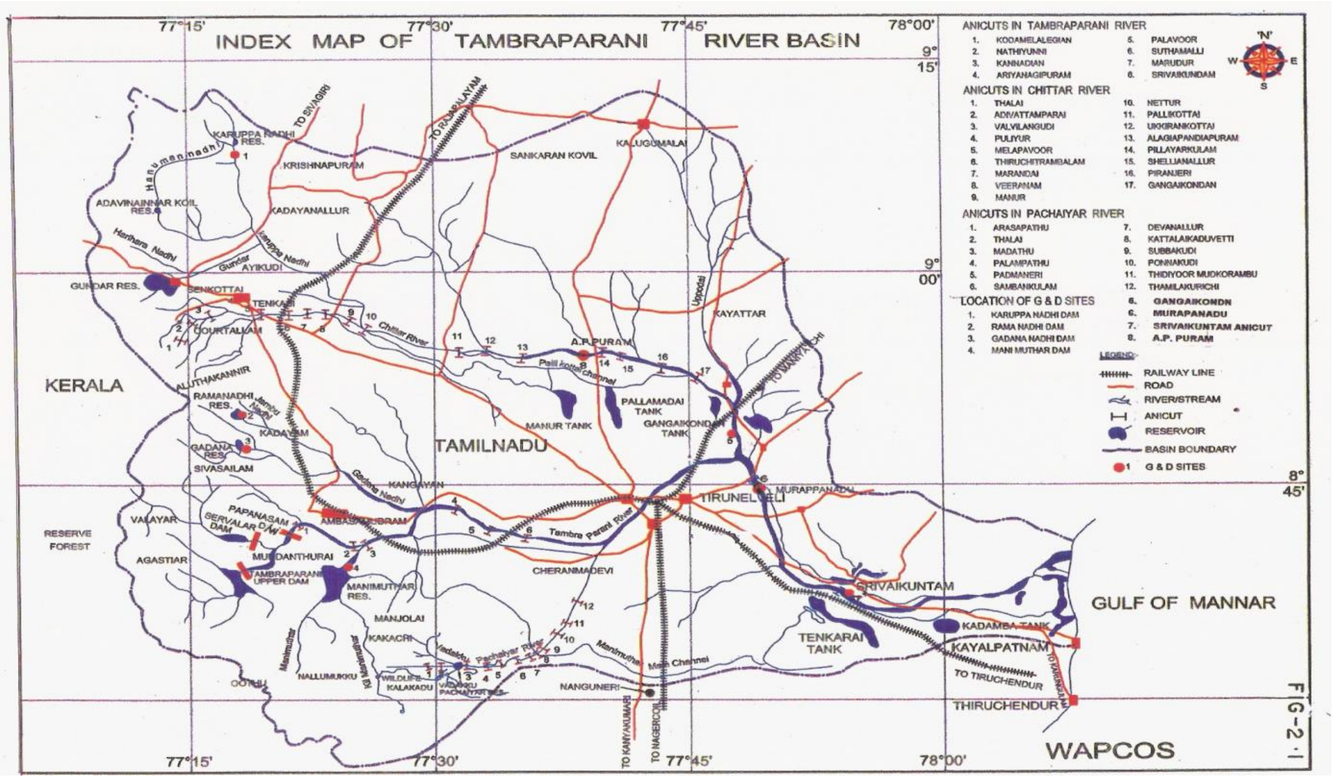

Figure 1. Location map representing the drainage pattern and PWD wells.

By undulating topography with hills located in southern parts, sloping towards north and northeast [6]. The high-est elevation (altitude) in the hilly area (Hill) is of the order of 1350 m (amsl), whereas in plains it ranges from 360 m (amsl) in the southern part to 240 m in the northern part. No perennial streams exist in the area, except for short distance streams encompassing 2nd and 3rd order drainage. Runoff from rainfall within the area ends in small streams flowing towards the main tamirabarani River. From a period of 1971-2007 the average annual rainfall is of the order of 905.3 mm. Normally, subtropi-cal climate prevails over the area without any sharp vari-ation. The temperature increases slowly to a maximum in summer months up to May and after which it drops slowly. The mean of the maximum temperature in plains ranges from 36.5°C to 41.8°C and in hills, it ranges from 7.9°C to 21.8°C. The mean of the minimum tem-perature in plains varies from 17.4°C to 24°C and in hills varies from 6°C to 8.5°C [1].

2.2. Geological and Hydrogeological Setting

Geologically the area is occupied with Archaean gran-ites and gneisses, intruded by dykes [7]. These forma-tions, including granite, granodiorities, gneissic granite and gneisses, are the most widespread groups of rocks which are mainly composed of gray and pink feldspar with quartz grains, biotite and hornblende [8]. These formations are crossed by sets of joints and fractures, which have also caused weathering of coarser rocks. Weathering occurs due to mechanical and mostly chemical processes that take place, while water in the fractures interacts with the formation. The shallow hard and massive rocks are exposed mostly in the southern part. Another most dominant formation is charnokite, which is found in the extreme southern and southeast-ern parts of the area (karaiyar hill) acting as a no flow boundary.

Groundwater occurs mostly in weathered and frac-tured zones, which are unconfined, semi-confined or confined. The thickness of weather zone varies from 3.1 to 26.6 m but black cotton soil exists in the middle part whereas red sandy soil in northern and southern parts of the study area. It's thickness varies from 0.52 m to 5.35 m. Such shallow weathered zones may not be stable sources of groundwater for meeting large demands for groundwater [2]. The weathered zone facilitates the movement and storage of groundwater through a network of joints, faults and lineaments, which form conspicuous structural features. Groundwater is extracted through dug well, dug-cum-bore wells and bore wells by bucket & pulley and electric motor methods for different pur-poses. The shallow aquifer gets both direct recharge from rainfall and indirect recharge as seepage from about 93 irrigation tanks and irrigated fields.

2.3.Methods

Hydrogeological, geophysical and entropy studies were carried out for deciphering subsurface litho zones, un-derstanding prevailing hydrogeological conditions, eval-uation of aquifer parameters, such as natural recharge, storativity, and hydraulic conductivity. Groundwater levels were monitored in 6 wells by PWD since 1971, and in addition also collected from 45 and 30 observation wells during April 2001 and February 2009, respectively. To determine aquifer properties, pumping tests were car-ried out at 3 locations and data was analyzed by numeri-cal methods [9]. A total of 37 Vertical Electrical Sound-ings (VES) were conducted using Schlumberger elec-trode configuration for a spread of 60-120 m. Initially VES data had been interpreted through a curve matching technique [10] and then interpreted by computer pro-gramme [11]. 6-

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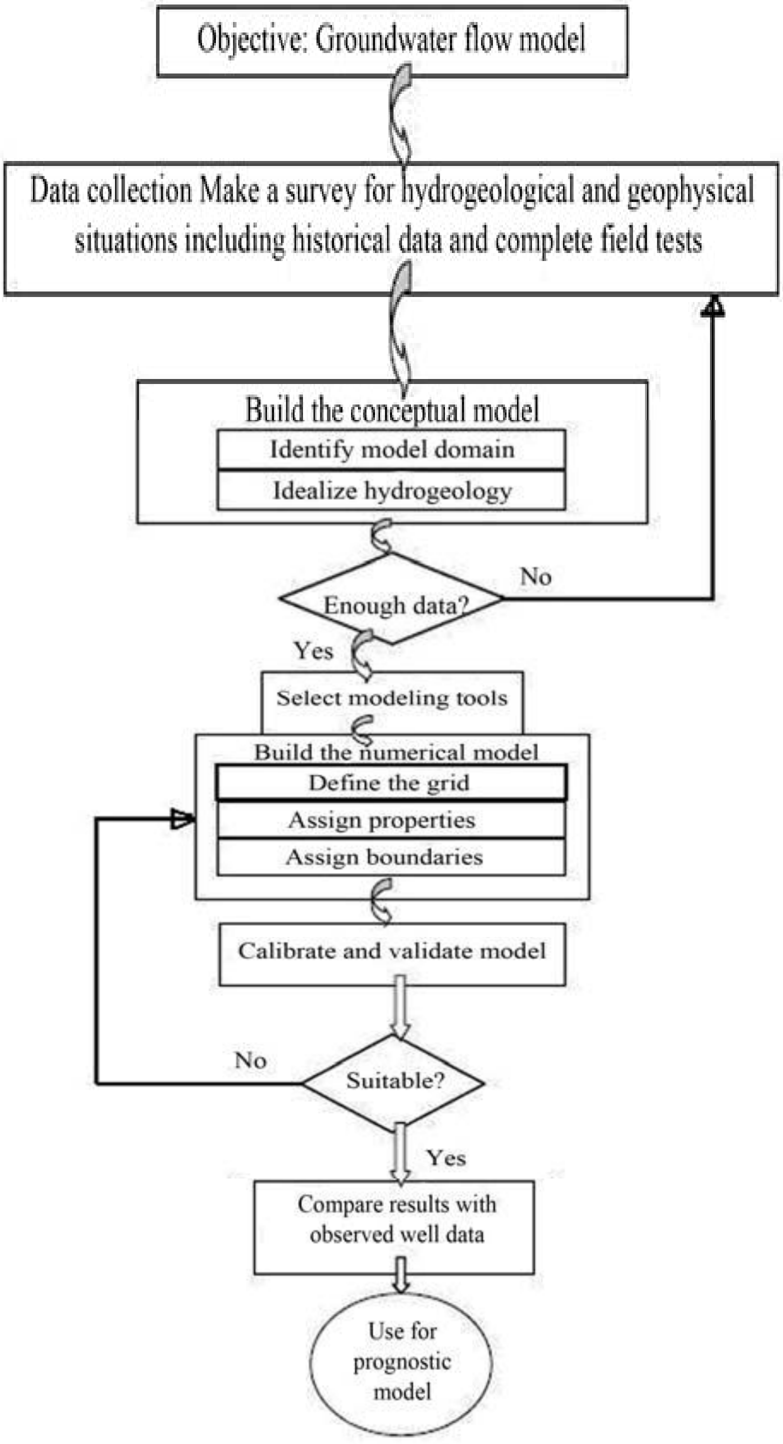
PWD dug wells were selected for the determination of average natural recharge by the entropy theory [12]. The generated data was utilized in the de-velopment of the groundwater flow model. The various steps involved in the modeling in the study are shown in **Figure 2**.

As a first step in development of groundwater flow model, the study area needs to be defined. The modeler needs to distinguish the area proposed to be investigated from the adjacent groundwater system. Consequently, a model boundary needs to be specified before taking up any groundwater modeling exercise. Model boundary is the interface between the study area and the surrounding environment



Flow chart for groundwater flow model.

III. RESULTS AND DISCUSSION

3.1. Hydrogeological Investigations

3.1.1. Water Level Measurements

Monthly water level data were available from 6 PWD wells, which are uniformly spread over the study area. A contour map was prepared, from which it was difficult to identify the hydrogeological characteristics of the aquifer with respect to the groundwater flow pattern. The con-tours don't follow the topography and drainage patterns.

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For this reason during April 2001 and February 2009, 45 and 30 water levels were collected and analyzed, respectively. The depth of water table varied from 1.00-22.80 m (bgl) with a mean value of 8.07 m (bgl) in April 2009 and 0.70-17.00 m (bgl) with a mean value of 5.64 m (bgl) in February 2009, because of the variations in weathered thicknesses, intensity of weathering and uneven with-drawal rates. The trend of PWD-well hydrographs closely followed the rainfall trend [6]. In most cases the water level returns to its original position after a good rainfall. This may be due to the rapid recharge taking place due to heavy rainfall and also irrigation return flow [2].

3.1.2. Aquifer properties

Aquifer parameters, namely transmissivity (T) and storativity (S), are vital for groundwater modeling. Several analytical methods have been developed to determine these parameters, however, the numerical approach has an advantage in that it incorporates actual field condi-tions with ease and hence parameters estimated are more realistic [9]. This method is described in detail by Rush-ton and Redshaw [13].

During field investigations, 3 existing large diameter open wells fitted with pumps (see **Figure 1**) were selected for pumping test. Most of these wells had been kept with-out pumping prior to beginning the test and water levels had been continuously monitored. The period of pumping varied from 45 to 126 minutes, whereas recovery times varied from 170 to 1313 minutes. Both pumping and re-covery data were used for interpretation using a forward modeling technique as suggested by Singh [9]. The nearby features, such as water body or lateral inhomogenities had been incorporated into individual interpretations. Initial parameter values were considered to generate time draw-down curves for individual tests, which were then com-pared with observed time- drawdown/recovery data. The aquifer parameters were varied until a close match was obtained. The best-fit match was considered as representa-tive aquifer parameters. The estimated T and S values va-ried from 15 to 200 m2/day and 1 × 10-5 to 3.5 × 10-4, re-spectively. It was found within the ranges of T and S val-ues from 4 to 1166 m2/day and 1 × 10-5 to 9 × 10-3, respec-tively, obtained in tamirabarani River Basin, tirunelveli and thothukudi Districts, Tamil Nadu [2].

3.2. Geophysical Investigations

The resistivity sounding technique [10,14,15] was em-ployed to identify the aquifer geometry. In total 37 Ver-tical Electrical Soundings (VES) were carried out with current electrode separation of 60-120 m. The curves obtained are classified as A and H-types, which describe the variation in the resistivity of progressive layers below the ground surface. The A and H-type sounding curves reflect the pattern of resistivity distribution with depth. If $\rho1$, $\rho2$ and $\rho3$ are the resistivities of three subsurface lay-ers beginning with $\rho1$ at the top, then $\rho1 > \rho2 < \rho3$ is de-fined as H-type and $\rho1 < \rho2 < \rho2$ *as* A-type.

The observed field curves were matched with theo-retical master curves to obtain initial parameter values

GROUND WATER SCENARIO

Hydrogeology

The aquifer in the proposed area consists mainly of two layers: one-weathered and two-fractured zones of the granite-gneiss formation. The weathered zone overlies the fractured zone (in bedrock), but its thickness varies from place to place. Bedrocks are at a depth of 12.00 to 27.67 m (bgl). The two layers have different hydraulic characteristics and especially the fractured zone has a lower storage coefficient than does the weathered zone. The weathered part of the aquifer was considered as equivalent to a porous zone.

Recharge from rainfall takes place between October and December. The percentage of rainfall that becomes re-charge was determined based on the estimated recharge values by entropy [12]. Then it was adjusted during the model calibration. The reason why no recharge takes place between January and September is low rainfall in conjunc-tion high temperature and evaporation. There is no surface water interaction with neighboring sub-watersheds. Gr-oundwater interaction with adjacent area was also consid-ered. The main recharge areas are in the south and south-east, and the main discharge area in the northern part. Thus, groundwater flows southwest, north and northeast. tamirabarani River acts as the main drainage route and flows north. However, it flows only during the wettest months of the year (October-December). The aquifer seems to be in interaction with the river and probably the water table is higher than the river stage. In order to satisfy irrigation, domestic and industrial needs, increasing groundwater abstractions take place in the area. Industrial and domestic abstractions are about 20% of the total ab-stracted volume. Irrigation abstractions most likely occur during the dry period (January to September). and finally these were used as input in the interpretation of resistivity data through software, namely, RESIST [11]. The interpreted results of VES, when compared with the existing 9 litho-log data [1] and cross-sections of nearby open wells, confirmed the resistivity ranges of different subsurface geo-electrical layers as:

- 2-95 Ω-m: Top soil cover/ clay with kankar
- 6-100 Ω-m: Weathered formation/saturated or sa-line aquifers
- 100-300 Ω-m: Semi-weathered/fractured granite and gneissic granite
- >300 Ω-m: Hard rock (gneissic granite and gneisses)

The shallow aquifer resistivity in weathered zone ranged from 6.08 to 264.27 Ω-m. The estimated thick-ness of the weathered zone varied from 5.30 to 26.62 m. It was confirmed that its value ranged from 15.00 to 26.62 m in the western part of tirunelveli town.

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The soil thickness ranged from 0.52 to 5.35 m, whereas the depth of bedrock with weathered thickness: 11.00-26.62 m ranged from 12.00 to 27.67 m (bgl) in western and southwestern parts of the town, which are potentially good groundwater zones.

3.3. Natural Recharge Estimation

For modeling of groundwater resources in the semi-arid area, it is essential to determine natural groundwater re-charge. There are several methods for determining groundwater recharge, such as groundwater balance [16]; lysimeters [17]; piston-flow model [18]; RS and GIS techniques [19]; photogeological [20], hydrogeological [21], geophysical methods [22], and 14C-age dating [23]; and regional groundwater models [24]. Among these methods, the tracer technique is one of the best direct methods for estimation of groundwater recharge [18]. This technique estimates recharge on the basis of piston flow model, and has been found useful [25,26]. Other methods are time consuming and sometimes even un-economical in developing countries, particularly when one has to deal with a large area.

Therefore, an entropy-based approach [12] is devel-oped for assessing natural recharge in this study area. Entropy of a random variable is a measure of the infor-mation or uncertainty associated with it. Measures of information include marginal entropy, joint entropy and transinformation. For a random variable *x*, the marginal entropy, *H*(*x*) can be defined as the potential information of the variable. For two random variables *x* and *y*, the joint entropy *H*(*x*, *y*) is the total information content con-tained in both *x* and *y*. The mutual entropy (information) between *x* and *y*, also called transinformation, *T*(*x*, *y*), is interpreted as the reduction in uncertainly in *x*, due
to the knowledge of the random variable y. It can also be defined as the information content of *x* that is contained in *y*. Entropy measures can be expressed using both dis-crete and analytical approaches [27].

Rainfall is considered as independent random variable (*x*) and the depth to water table for individual wells as the dependent variable (*y*). Then, transinformation, , is interpreted as the reduction in the original uncertainty of depth to water table due to the knowledge of rainfall. It can also be defined as the information con-tent of water table which is also contained in rainfall. In other words, it is the difference between the total entropy and the sum of marginal entropies of these two variables. This is the information repeated in both water table and rainfall, and defines the amount of uncertainty that can be reduced in one of the variables when the other vari-able is known. On the other hand, marginal entropy, *H*(*x*), is defined as the potential information of rainfall. Then, the ratio of to *H*(*x*) is simply a fraction of re-charge due to rainfall. Therefore, the percentage of rain-fall, *Re* (%), contributing to the natural groundwater re-charge of an unconfined aquifer.

To determine the fractional amount of rainfall (moni-tored for 8 years from January 2000 to December 2007 at Tirunelveli rain gauge station), called natural recharge, marginal entropies and transinformation of rainfall and depth to the water table (collected from 6 PWD wells for the same period, see **Figure 1**) were calculated. Then a ratio of transinformation to marginal entropy of rainfall was used as a measure for evaluating natural recharge.

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