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Evaluation of Geological and Recharge Parameters for an Aquifer in Southern Sweden

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Groundwater levels fluctuate as a result of changes in the relation between inflow and outflow to the aquifer, and the magnitude of the fluctuations are also depending on the geologic conditions in the aquifer. Of special interest when studying groundwater is to estimate the inflow to the aquifer, the recharge, as it is the renewable part of a water resource. Here a simple method for modelling the relation between inflow and outflow from groundwater level variations is described, a method that also relates to the geologic features of the aquifer. Input data are groundwater level observations from several years, data that are often readily available. From these data longer periods of decreasing groundwater levels are chosen, during which the recharge is assumed to be zero. An exponential recession curve is established by a least-square fitting to all the chosen periods, and from this curve a base level for zero groundwater runoff is evaluated, together with a geologic reservoir parameter that consists of the storage coefficient, the area of the aquifer, and a groundwater runoff coefficient. A recharge parameter that is proportional to the recharge is then evaluated.

Introduction

The variation of groundwater levels in an aquifer is the result of changes in the relation between inflow to an outflow from the aquifer. This will give a change of storage, which will raise or lower the groundwater level. The relation between storage and level changes depends on geologic factors, thus the change in groundwater level is a function of geologic conditions, as well as in and output.

One crucial point in groundwater studies is to estimate the inflow, or recharge. The recharge is that part of precipitation that reaches the groundwater. It is affected by a number of factors, such as evapotranspiration, soil conditions, plant uptake etc, which makes it difficult to estimate.

Different methods to estimate recharge have been developed and there are two major ways to approach the problem. The first are the *direct* methods which try to explain and define the actual physical processes and then calculate the recharge, involving identification and calculation of flow processes. Examples are soil moisture accounting models. These types of models were described by Rushton and Ward (1979), Alley (1984) and Barton and Thomson (1986) among others.

Indirect methods, also referred to as response models, are those using groundwater levels to evaluate the recharge. These methods are very attractive since groundwater level data are easily achieved and require no advanced equipment. One advantage is if some geologic features of the aquifer can be evaluated at the same time. Indirect methods have been described as inaccurate by Rushton (1987) and Johansson (1987).

Olsson (1980) described a method to estimate the effective porosity and recharge from groundwater levels. For unconfined aquifers the specific yield was equal to the effective porosity, and thus the rise in groundwater level will be a function of the effective porosity.

Johansson (1987) described a method where a recession curve was used to directly transform level variations to equivalent amounts of recharge using the specific yield. The results are discouraging, since the time distribution for the recharge estimated with this method was quite different from that obtained with a traditional soil model.

Das Gupta and Paudyal (1988) developed a model that was a mixture of indirect and direct methods. The recharge was estimated for an unconfined aquifer using monthly rainfall, temperature and water levels at a few wells. A recharge parameter was introduced which represented the integrated effect of several physical, climatic and model characteristics. This parameter was evaluated from groundwater level data, using nonlinear regression analysis. This method can also be applied to evaluate the storage and the transmissivity. The use of the method shows good correlation with the estimations made with the indirect methods, though the method is described as an approximate method only.

The approach to modelling recharge and groundwater levels will always be a balance between simplicity of the model and accuracy in the results. The direct methods which try to explain the actual processes are complicated models with a large number of parameters that have to be defined, while the indirect methods are often of a simpler form. The uncertainties in the process of evaluating many parameters will always affect the results. Even a physically complicated model has its limit in the accuracy of the input data, and the accuracy of the results are not always a function of the number of parameters and the complexity of a model, Bergström (1991). The approach in this paper is a simple response model with few parameters.

The main objectives of this study is to find an easy way to model and understand the mechanisms of an aquifer and the way it will respond to changes in inflow and outflow, and to define the geologic factors and their influence. The great advantage of the model is the ease with which the input data can be collected. Input data is several years of groundwater level observations, which today exists for many places, but not always have been used for a specific purpose. Since the model is rather simple it is also easy to use. It is used to calculate the time distribution of the recharge and a threshold value for the groundwater level, *i.e.* a value for the lowest groundwater level that will occur after a prolonged period of no recharge. The geology of the aquifer is described by a lumped parameter, containing a groundwater runoff coefficient. This runoff coefficient will be fundamental in the future developement, because if it can be separated from the lumped parameter, both discharge and recharge can be calculated. In this study the behaviour of the model and the lumped parameter is studied.

The Aquifer as a Linear Reservoir

The groundwater reservoir is assumed to be linear, which means that there is a linear relation between outflow from the reservoir and the groundwater level above a base level. Groundwater reservoirs as linear reservoirs were described by Eliasson (1971). He showed that if an average groundwater level was calculated for a linear reservoir, the departures from this average level can be used for the modelling. A response function for the groundwater level response to recharge can be calculated, and when it is known the change in groundwater level can be calculated by using a convolution integral. From this convolution it can be shown that the reservoir acts like an infinite series of parallel reservoirs, where the major portion of the flow is represented by the first reservoirs. Thus the four first terms in the series represent 90 % of the flow.

Consider a water budget for the reservoir in Fig. 1, where

$$R = Q + \frac{dM}{dt} \tag{1}$$

where

Q – runoff,
R – recharge,
dM/dt – change in storage with time.

Assuming that both runoff and inventory are functions of the groundwater level an expression for the recharge can be written as

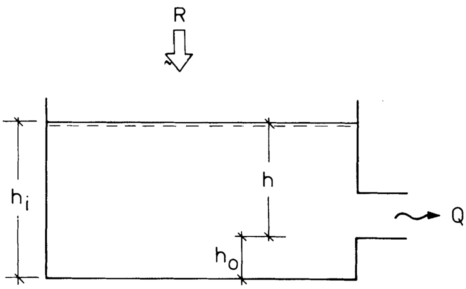

Fig. 1. A schematic figure of the aquifer, with the notation used. h_i represents the measured groundwater level above a used reference level, h_0 the base drainage level above the same reference level, and h is the elevation of the groundwater above the base level. The outflow from the aquifer, Q, is proportional to h, which makes h the relevant parameter to calculate.

$$R = Q(h) + \frac{dM}{dh}(h)\,\frac{dh}{dt} \tag{2}$$

Assuming a linear reservoir we can introduce a groundwater runoff coefficient H and write the runoff as

$$Q = H\,h \tag{3}$$

where h is the elevation of the groundwater table above the baselevel, h_0. Knowing that for linear reservoirs

$$\frac{dM}{dh} \equiv SA \tag{4}$$

where

S – storage coefficient
A – area of the aquifer

Eq. (2) for the recharge becomes

$$R \equiv Hh + SA\,\frac{dh}{dt} \tag{5}$$

Making the assumption that for sustained periods of declining groundwater levels the recharge is zero, ($R = 0$), the solution to Eq. (5) becomes

$$h \equiv (h_s - h_0)\;e^{-Ht/SA} \tag{6}$$

where h_s is the first value in a series of decreasing levels. Thus the recession curve is an average of all the used series.

If we devide Eq. (5) for R by H, a coefficient that is proportional to the recharge can be evaluated as

$$h_w \equiv \frac{R}{H} \equiv h + \frac{SA}{H}\frac{dh}{dt} \qquad (7)$$

where R/H is denoted with h_w, and can be interpreted as the equilibrium level at which the groundwater level would stabilize for a constant recharge, R. Now Eq. (7) can be solved since SA/H and h are known.

Example

The method was tested using groundwater data from one well in an aquifer in southern Sweden, Liatorp 4003, in the groundwater network monitored by the Geological Survey of Sweden. The aquifer is unconfined and the aquifer material is mostly sand and till. From these data eight periods of sustained decreasing groundwater levels have been chosen, covering a time period from 1973 to 1989. Each series contains 8-12 observations with a time period between observations ranging from 12 to 20 days, Fig. 2. Two values were considered to be incorrect and were

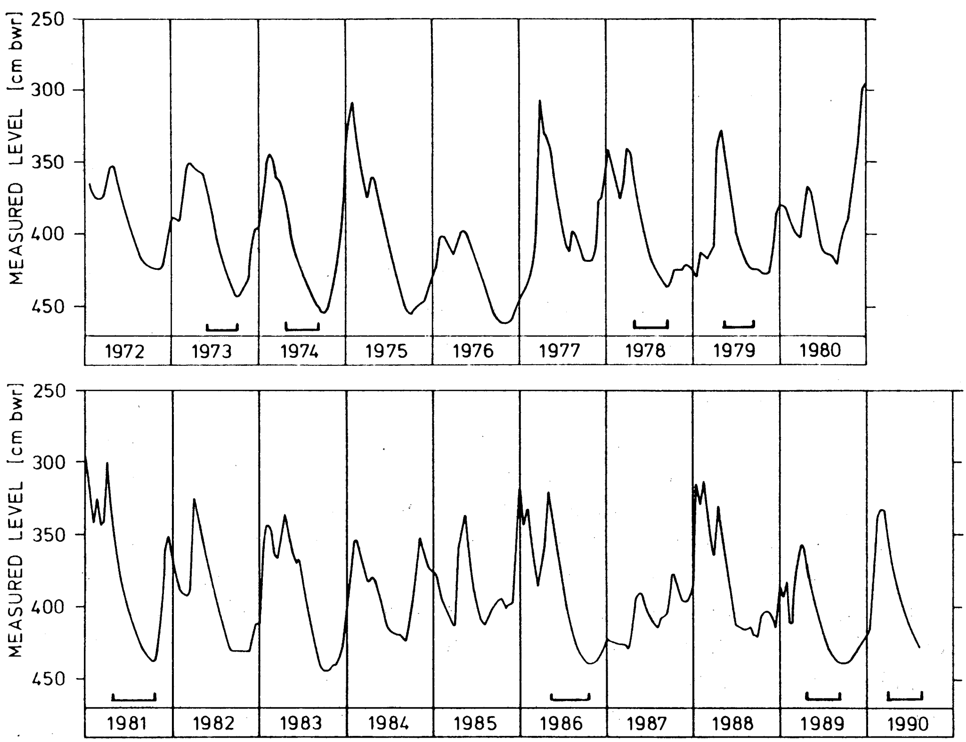

Fig. 2. Groundwater level data from the Geological Survey of Sweden, station Liared 4003, in the groundwater network. These data have been used to choose periods of declining groundwater levels, from which an exponential recession curve is established. The chosen periods are marked.

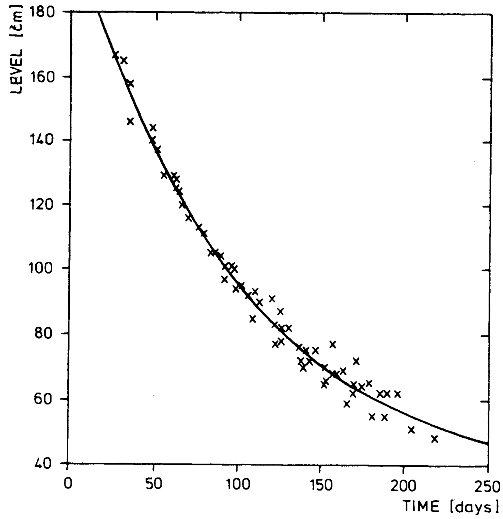

Fig. 3. Fitting of the exponential function $h \equiv (h_s\text{-}h_0)e^{-Ht/SA}$, to the chosen periods. The base level h_0 and the geologic reservoir parameter H/SA are evaluated from the exponential function.

altered. The recession periods occur during the spring – summer period, which is part of the normal annual fluctuations in this part of Sweden.

From the recession curve the baselevel, h_0, for zero groundwater runoff is established, together with the aquifer parameter H/SA. The geologic conditions in the ground, such as storativity, will directly influence the behaviour of the aquifer, therefore this parameter can be valuable when trying to understand and predict the aquifer response to different influences.

The fitting of Eq. (6) to these periods is shown in Fig. 3. It was done with a standard Fortran routine for least-square fitting. This gave a calculated baselevel at h_0 = 33.84 cm above the used reference level, and the paramter H/SA was found to be 0.0103 day^{-1}. Eq. (7) is then evaluated for the whole period, not only for recession periods. The term dh/dt is evaluated by adapting a parabola between three neighboring points on the measured curve, and then taking its derivative.

The results are plotted in Fig. 4, which is discussed in the following section. The net precipitation, which is used as a comparison for the model, is calculated as precipitation minus actual evapotranspiration for each observation period. Precipitation data are from the Swedish Meteorological and Hydrological Institute, observation station 6441 Hyltan. The actual annual evapotranspiration has been calcultated as the difference between revised precipitation and runoff for a catchment area, where mean annual values from a thirty-year period 1931-1960 are used. These data originates from the Swedish Meteorological and Hydrological Institute and were published by Söderblom *et al.* (1987). This actual annual evapotranspiration has then been distributed over the year according to an average potential evapotranspiration curve, compiled by the Swedish Meteorological and Hydrological Institute. The net precipitation is then calculated.

This is a very rough estimation of the evapotranspiration, and it is more to be seen like an average value than an actual. It is, however, only used to estimate the net precipitation, and does not cause errors in the model itself, since it is not a part of it.

Conclusions and Discussion

The results of the model are shown in Fig. 4, for the period from 1981 to 1990. The groundwater level is the input in the model, and the recharge parameter h_w is the calculated output. Net precipitation is shown as a comparison for the recharge parameter. The results seem fairly reasonable, the rises in groundwater level correspond to a previous rise in the recharge parameter, as well as a lowering of the groundwater level corresponds to lower values of the recharge parameter.

The recharge parameter h_w expresses an equilibrium level for constant recharge, *i.e.* a level at which the groundwater would stabilize for a constant recharge. This can be seen at the end of 1982 when the groundwater level for a period is constant, and thus coincides with the h_w-level.

During the summer when the recession periods occur, precipitation is plentiful. However, the evapotranspiration is also high, due to high temperatures, which means that the net precipitation is less than zero. In Fig. 4 it can be seen that the recharge occurs during periods of positive net precipitation, mainly during the autumn and winter months, and that during the recession periods when the recharge has been assumed to be zero, the net precipitation is negative.

The groundwater levels can be affected by evapotranspiration and soil moisture conditions in the unsaturated zone during the summer and vegetation period, especially for shallow groundwaters, Johansson (1987). A transport of water from the groundwater table to the soil moisture zone due to a developed soil moisture deficit, could explain the negative h_w, which occurs during periods with high evapotranspiration. Negative h_w can also be a result of differences between the fitted recession curve and the actual drainage function.

Johansson (1987) sought the most rapid recession during the winter months, november-april, to make sure the recession was unaffected by evapotranspiration. The winter recession periods in this part of the country are much too short to be used with the method described here, and it would require specific climatic conditions. If the recession during the summer is affected by the evapotranspiration, the recession will be faster and thus give a steeper curve, therefore it is not sure that the steepest curve will give the true recession in this case.

Groundwater level data for several years are required. When choosing the reces-

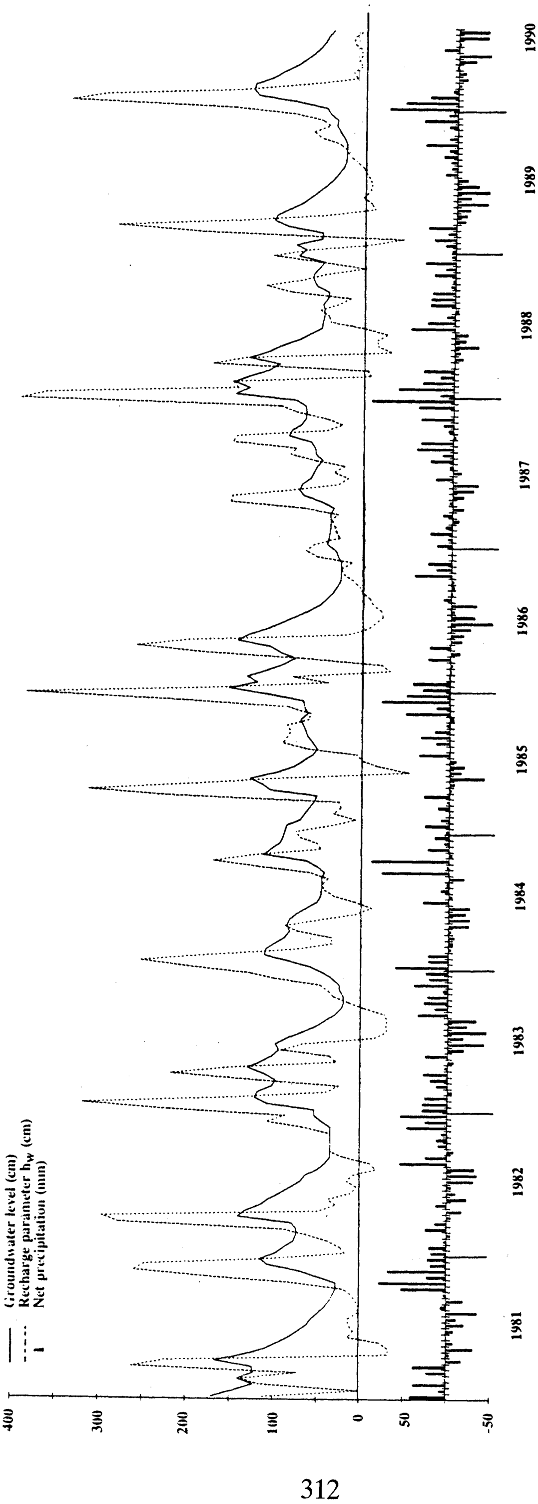

Fig. 4. Results from the method showing the groundwater level, h, above the base level, which is used as input data, the calculated recharge parameter, h_w, and the net precipitation for the time period of 1981 to 1990. The precipitation is not a part of the model, it is merely used as a comparison for the recharge parameter. A negative net precipitation indicates that the evapotranspiration is greater than the precipitation.

sion periods it is important that the whole period is long enough. The used interval between observations of 12-20 days seems to be sufficient. This gives a total recession period of two to three months.

When evaluating recharge with a soil moisture balance a daily evaluation period is recommended, Howard and Lloyd (1979), since the input, especially the evapotranspiration, is sensitive to the used time period. In this example the recharge parameter has been evaluated with the same observation period, though there seems to be no restriction for the use of the model to evaluate h_w on a daily basis, as long as the groundwater level records exist with daily observations. Although evapotranspiration is no input in this model, the estimation of h_w is still likely to give a more true value if it were to be evaluated on a daily basis. Due to the rather long observation period, and the fact that the precipitation during an observation period is summarized, the response in groundwater level to certain rainfall occasions will be lost. The very rough estimation of the evapotranspiration used as comparison can therefore be considered to be sufficient for this purpose.

The fit between the groundwater level curve and the measured h_w-curve in Fig. 4 indicates that the geologic reservoir parameter fairly well describes the response of the aquifer. Whether the estimation of the geologic reservoir parameter is good or not remains to be evaluated. More data from different aquifers have to be tested and the actual parameters evaluated in the field to be used for comparison. If the development of the method is successful the method will be a very useful and easy way to examine the response of an aquifer to recharge.

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