A new approach for depth to groundwater calculation (hydro-FaBer) using hydrographical information

R. LÄHNE, W. GOSSEL & P. WYCISK

Institute of Geosciences, Department of Hydrogeology and Environmental Geology, Martin Luther University, Halle (Saale), Germany

ronny.laehne@geo.uni-halle.de

Abstract A spatial depth to groundwater distribution is essential for a wide range of applications in hydrogeological assessment methods, e.g. for assessing groundwater recharge, vulnerability mapping or as data input for numerical groundwater models. An area-wide calculation of this basic parameter is complicated for hard rock areas because the available database for an interpolation is mostly insufficient. A new method has been established that uses springs and creek courses to interpolate reasonable water levels in the top hard rock aquifer which is assumed to be connected to the surface water level. The method named Hydro-FaBer (hydrographisches Flurabstand-Berechnungsverfahren, hydrographical method for calculating the depth to groundwater) has been developed for sandstone and limestone catchment areas without observation well data in Hesse, Germany.

Keywords depth to groundwater; hydrographical method; hard rock area; Digital Elevation Model, Eschwege, Hesse

INTRODUCTION AND BACKGROUND INFORMATION

In context of different methods for groundwater recharge calculations (e.g. TUB-BGR-method, Wessolek el al., 2004) and for estimating the groundwater pollution potential (e.g. DRASTIC, Aller et al., 1987; Hölting el al., 1995, Armbruster et al., 2004, Leppig, 2004), the depth to groundwater is an important parameter.

There are many methods based on topography for hydraulic, hydro chemical (Tanaka & Suzuki, 2009; Fujimaki et al., 2008; Tetzlaff et al., 2009) and evaporation issues (Li et al., 2008) on the catchment area scale. Further current developed methods are using the interpolation method Kriging combined with a DEM (Digital Elevation Model) to calculate the depth to groundwater (Marklund, 2009; Haitjema & Mitchell-Bruker, 2005; Desbarats et al., 2002).

To calculate the depth to groundwater e.g. by using the method of Desbarats et al. (2002), it's necessary to test the data whether the groundwater surface depends on the topography or on the groundwater recharge (Haitjema & Mitchell-Bruker, 2005). This test was done for the investigation area and this groundwater surface is influenced by both aspects. That's why the method of Desbarats et al. (2002) can't be implemented. For areas with an influence of the groundwater recharge to the groundwater surface, a new method was developed.

The following workflow will give a short overview about the developed method.

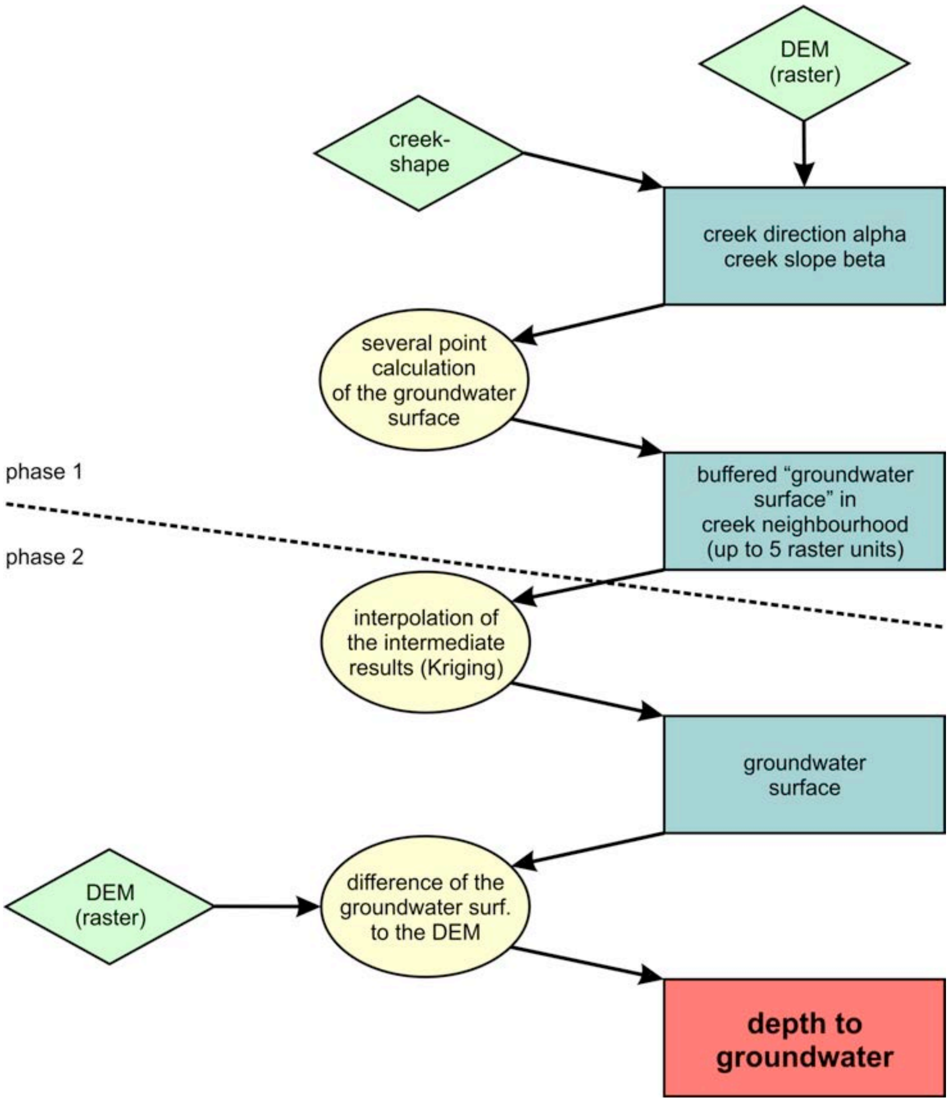

Fig. 1 Workflow of the developed method (Hydro-FaBer).

REQUIREMENTS FOR THE DEVELOPED METHOD

There are some requirements necessary to estimate the depth to groundwater by using the presented method:

(1) The springs are declared as a groundwater outflow and can be used for the developed method.
(2) The creeks are connected to the groundwater.
(3) The creeks represent areas with a depth to groundwater of 0.00m.
(4) The investigated area is under effluent conditions.

Furthermore, there are some additional assumptions which are derived of other geometric requirements:

(5) The slope of the creek course is assignable to groundwater surface slope near creeks (Fig. 2).
(6) Vertical to the creek direction, the groundwater surface slope has the same value like the DEM at the creek in flow direction (Fig. 3).

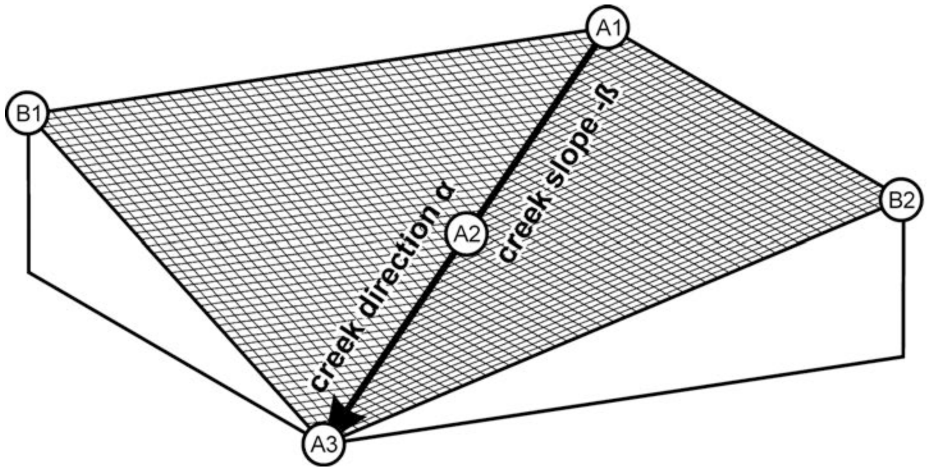

Fig. 2 Creek course (creek direction α), by passing the point A1, A2 and A3 with surrounding matrix dots B1 and B2, and the creek slope – β as the DEM slope at the creek (the groundwater surface slope is simplified by using a digital raster).

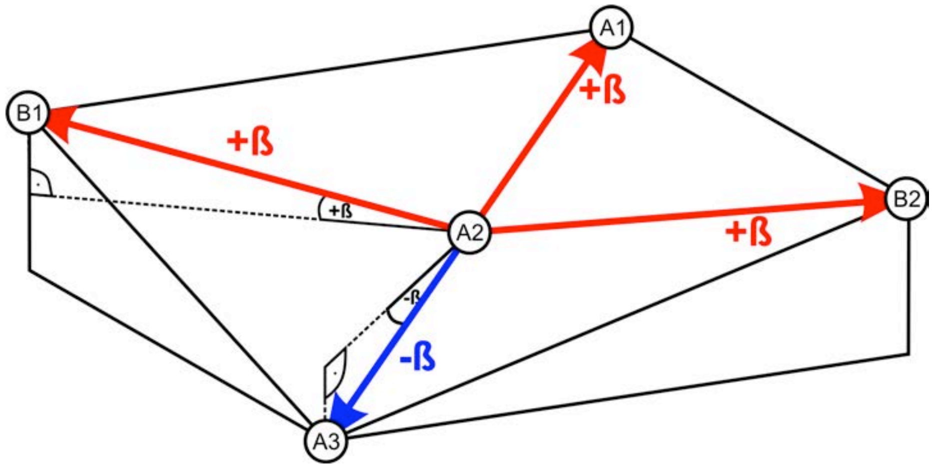

Fig. 3 Creek slope – β (view from the observation point A2 in direction A3) as quantity for the groundwater surface slope near creeks (points B1 and B2) in neighbourhood of the observation point A2 in the middle of the figure.

For the whole upstream area of the point A2, the groundwater surface slope β gets the negative value of the creek slope – β (Fig. 4). In the downstream area of point A2, the groundwater surface slope (relative slope β') concerning the creek slope gets values between + β and – β. Based on the observation point A2, there are also directions (to point C3 and to point C4) which have a relative groundwater surface slope of zero degree (Fig. 4). This fact is a result of the geometric positions of point C3 and C4 between one direction with a slope of + β and another direction with a slope of – β.

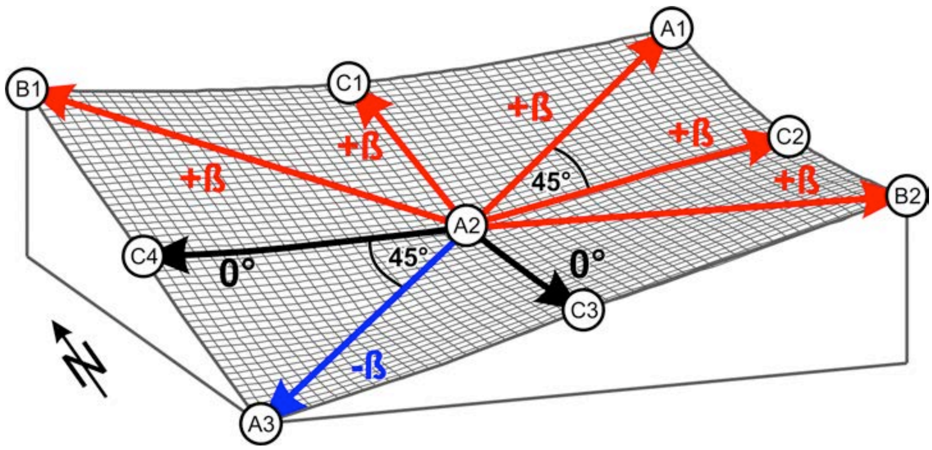

Fig. 4 Scheme of the relative groundwater surface slopes (– β … 0° … + β) in the neighbourhood of the observation point A2 in the middle.

POINT BASED CALCULATION OF THE GROUNDWATER SURFACE

At the first step all points representing the creek course get projected to the DEM raster (within a distance of ½ raster units to the creek) and they get the ID = 1 (creek = true). Due to this step, a raster cell with the ID=1 characterises the creek. Furthermore, this raster unit with die ID = 1 carries information about the creek direction and the creek slope.

Vertical to the creek direction α, the depth to groundwater within a defined

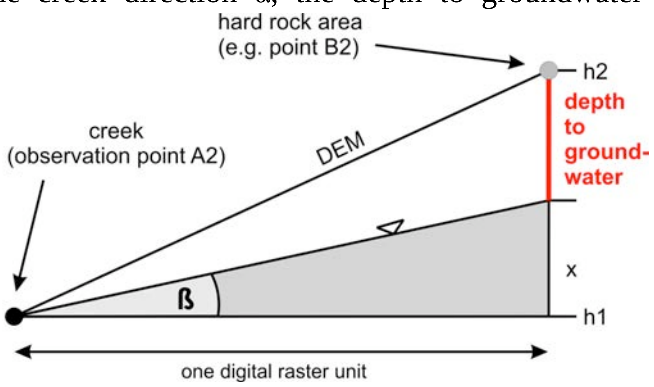

Fig. 5 Method to calculate the depth to groundwater, vertical to the creek direction (h1 = elevation of the creek bed, h2 = elevation of the hard rock top).

distance to the creek can be calculated by using the creek bed elevation (h1) and the DEM slope at the creek bed **–** β (Fig. 5).

$$x = \text{distance} \cdot \tan(\beta)$$
$$\text{depth to groundwater} = h2 - h1 - x$$
$$\text{depth to groundwater} = h2 - h1 - \text{distance} \cdot \tan(\beta)$$

At the first step of the method Hydro-FaBer, all points within a distance to the creek of one raster unit are the considered points, e.g. point B3 at Fig. 6. The method will use the information (creek direction and creek slope) of the points A3, A4 and A5 in the neighbourhood of target point B3 to calculate the groundwater surface elevation at this matrix dot.

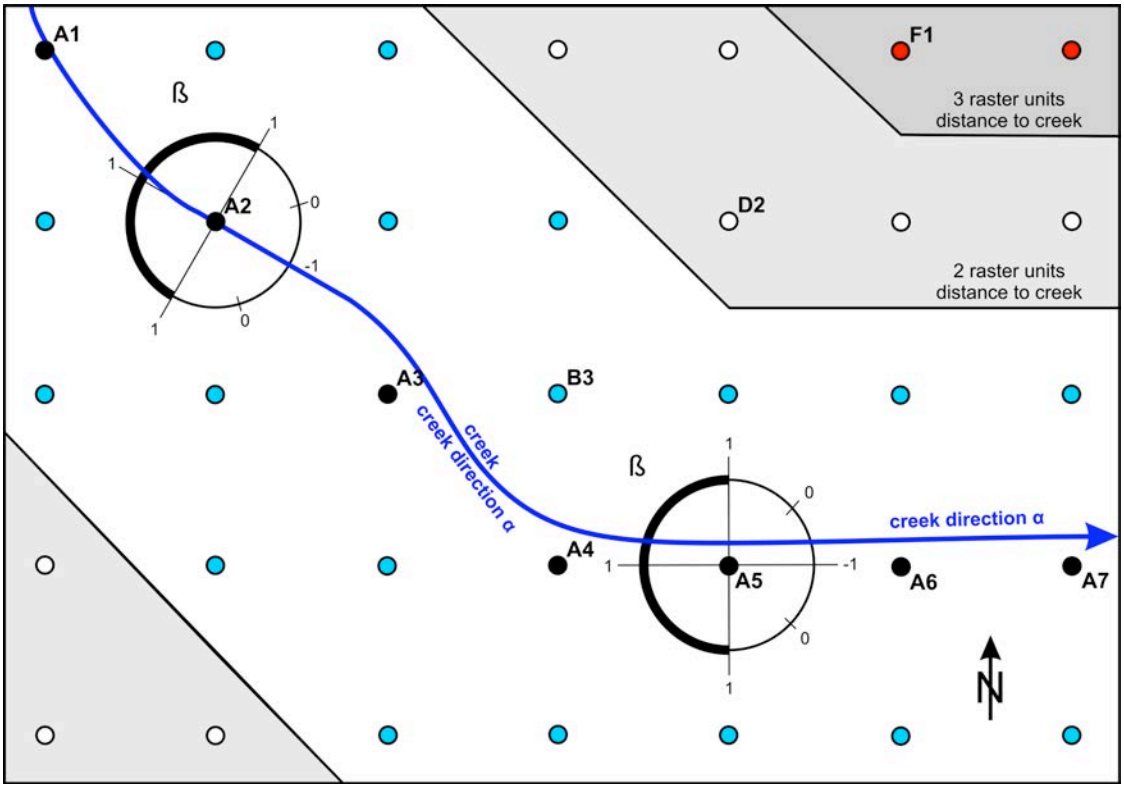

Fig. 6 Scheme of the raster based calculation of the groundwater surface slope (β) based on the creek direction α and the calculation of the relative groundwater surface slope (β').

Point D2 has no creek neighbour within a distance of one raster unit. That's why all points within a distance of two raster units are selected for the calculation. In this case these points are A3, A4, A5, A6 and A7. For the hard rock area point F1, all points within a distance of three raster units to the creek are relevant. These points are A3, A4, A5, A6 and A7.

The exemplary calculation of the groundwater level at point B3 is performed by considering the three relevant points (A3, A4 and A5), by using their distances and the according groundwater surface slopes (Fig. 6). Afterwards, all values below the DEM are averaged, if there is no surface water body at this matrix dot.

DETAILED DESCRIPTION OF THE CALCULATION

Depending on the creek direction α, different relative slopes (β') of the neighbouring matrix dots exist, for which the groundwater surface is calculated (Fig. 6). In the lower circle segment (Fig. 6) the values of the relative slope β' range from 0° to – β (90° to 270° in Fig. 7).

For the case, that the creek flows to the South-East (120°), the rotation is about 60° varying from the normal direction south (180°). By combining this rotation angle (60°) with the viewing direction to the East (90° from point A3 to point B3 in Fig. 6), the result is an angle of 150°. For this angle, the relative slope from the observation point to the viewing direction can be estimated. In this case (A3 to B3), the relative slope (viewing direction East) is $-0.333 \cdot \beta$ (Fig. 7). This resulting angle is groundwater surface slope in the viewing direction.

After the derivation of the angle β', the calculated creek bed elevation h1 is added to the product of the tangent of the relative slope ($-0.333 \cdot \beta$) and the distance. This result is the first value of the groundwater surface of the target matrix dot in the creek neighbourhood (Fig. 5). For this target matrix dot (e.g. point B3 in Fig. 6), all other available values of the groundwater surface will be generated. The overall resulting groundwater surface at the target matrix dot is the average of all available values for

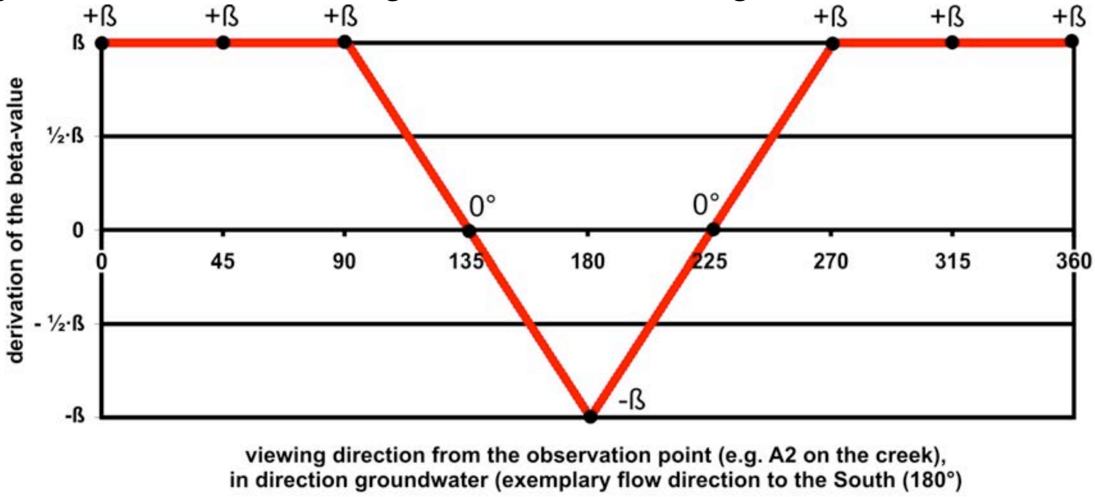

Fig. 7 Estimated groundwater surface slopes in the neighbourhood of a arbitrary observation point (0° on the x-axis equates the creek upstream, 180° equates to creek downstream), e.g. an angle von 45° is the result, when the viewing direction is East and the creek flow direction is South East (Fig. 4).

this matrix dot.

ESTIMATION OF THE DEPTH TO GROUNDWATER

The calculation of the depth to groundwater occurs by processing the next 3 working steps:

1. The above described part of the method has to be done for all matrix dots within a distance of 5 raster units to the creek. First points are chosen which are surrounded by many direct creek neighbours. For each target matrix dot, the groundwater elevation is calculated by averaging all groundwater elevation information of the point which are below the DEM.

2. Then, the interpolation method Kriging is used to calculate values for all matrix dots which have no information about the groundwater elevation yet. This interpolation method was chosen, caused by the ability to extrapolate trends. The given trends near the creek are the basis for calculating the groundwater elevation at all matrix dots with a further distance to the creek.

3. Finally, the groundwater surface is subtracted from DEM to calculate the depth to groundwater.

EXEMPLARY CALCULATION AND VISUALISATION

Based on the described working steps, a groundwater surface is calculated. The calculation of the groundwater elevation at matrix dot B3 is shown in Fig. 8.

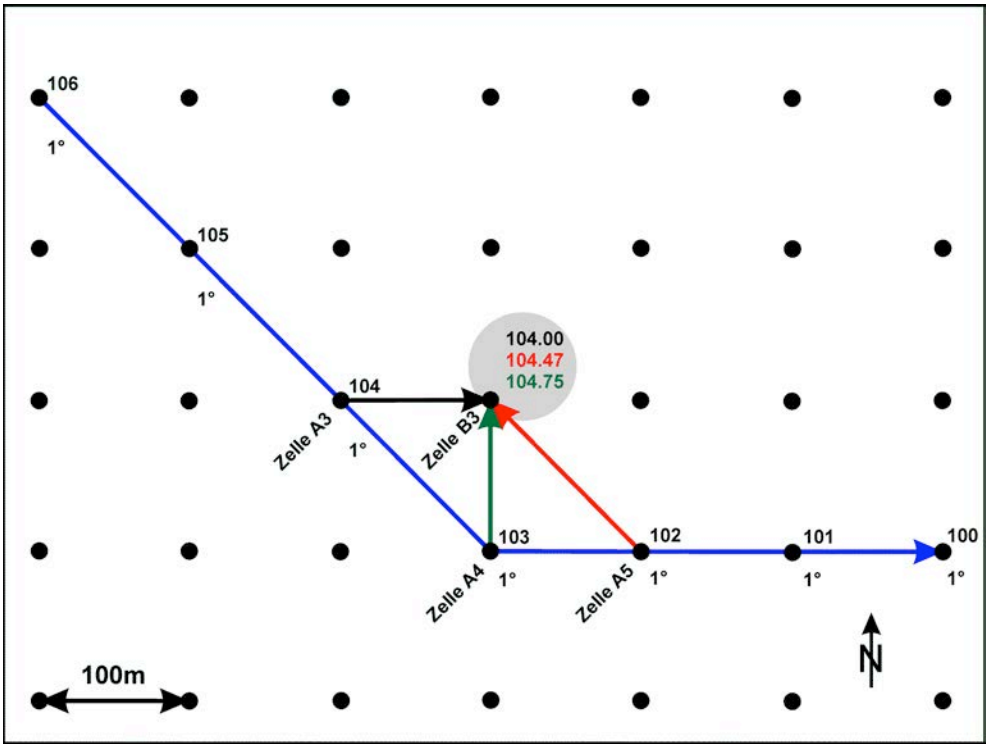

Fig. 8 Calculation of the groundwater elevation at matrix dot B3.

At the next step, the groundwater elevation in the neighbourhood of the creek will be calculated for the available matrix dots (Fig. 9).

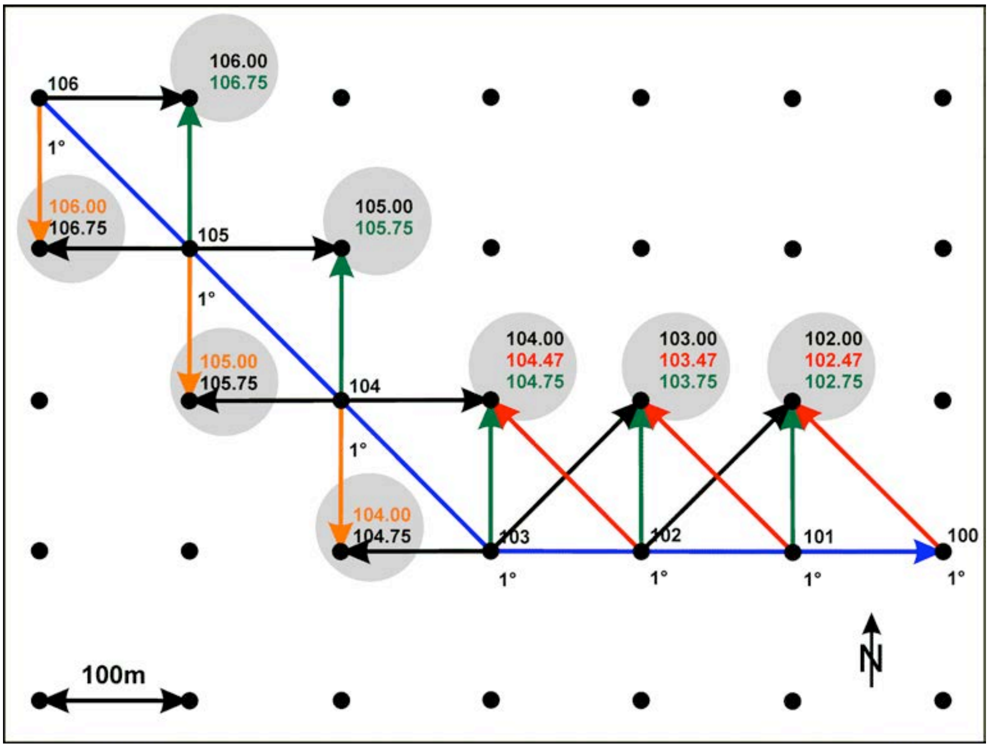

Fig. 9 Calculation of the groundwater elevation at several points near creek.

After this, the average will be calculated for all points. After the following interpolation by using the method Kriging, the groundwater surface is generated (Fig. 10) and can be subtracted by the DEM to get the depth to groundwater (Fig. 11).

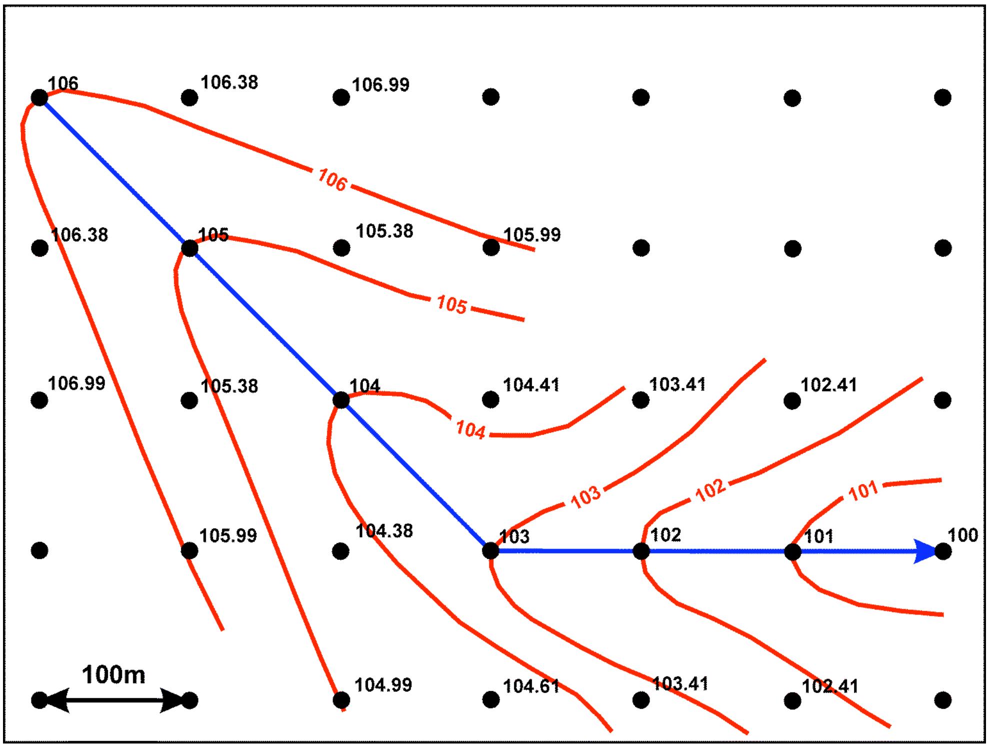

Fig. 10 Generated groundwater surface by using the estimated value at the matrix dots and the following interpolation by using Kriging.

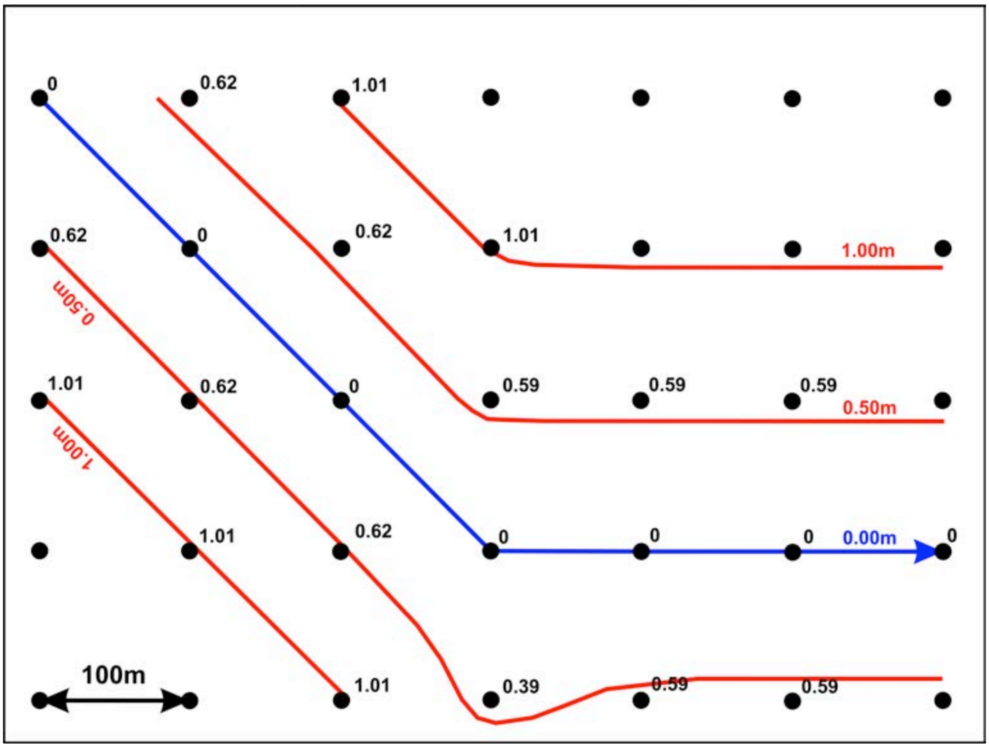

Fig. 11 Generated depth to groundwater map by using the developed method Hydro-FaBer.

CONCLUSIONS

The method Hydro-FaBer can be used in areas with poor data amount about the groundwater surface to create an overview and an input parameter for the hydrogeological modelling process. Especially for assessing groundwater recharge, vulnerability mapping or as data input for numerical groundwater models in hard rock areas this method produces very good results for the groundwater surface.

The needed data is easily obtainable. For this method only data about the creek slope, the creek direction and a DEM are needed. Therefore, the developed method studs for generating reasonable depth to groundwater, represented by a poor database.

REFERENCES

Aller, L., Bennett, T., Lehr, J. H., Petty, R. J. & Hackett, G. (1987): DRASTIC: A Standardizised System for Evaluating Ground Water Pollution Potential using Hydrogeologic Setting. – US EPA, EPA/600/2-87/035, 622 S.

Armbruster, V., Dudda, W., Hammer, J., Häffelin, H., Herre, H., Kilger, B.-M., Plum, H., Ruoff, H., Sieber, A., & Waldmann, F. (2004): Hydrogeologische Erkundung Baden-Württemberg, Grundwasserdynamik, Grundwasserhaushalt, Grundwasserschutz, Enztal-Pforzheim, Mappe 3. – LGRB Baden-Württemberg.

Desbarats, A. J., Logan, C. E., Hinton, M. J. & Sharpe, D. R. (2002): On the kriging of water table elevations using collateral information from a digital elevation model. Journal of Hydrology, 255(1-4), 25-38

Fujimaki, R., Kawasaki, A., Fujii, Y. & Kaneko, N. (2008): The influence of topography on the stream N concentration in the Tanzawa Mountains, Southern Kanto District, Japan. – J. For. Res., 13 (6), 380-385

Haitjema, H. M. & Mitchel-Bruker, S. (2005): Are Water Tables a Subdued Replica of the Topography? – Ground Water, Vol. 43(6), 781-786

Hölting, B., Haertle, Th., Hohberger, K.-H., Nachtigall, K.H., Villinger, E., Weinzierl, W. & Wrobel, J.-P. (1995): Konzept zur Ermittlung der Schutzfunktion der Grundwasserüberdeckung. – Geologisches Jahrbuch, C 63, 5-24.

Leppig, B. (2004): GIS-gestützte Methoden zur räumlich-geometrischen Modellierung der Grundwasserdruckhöhe im Festgestein. – Mitt. Ing. Hydrogeol., 88, 11-25, Aachen

Li, H. T., Kinzelbach, W., Brunner, P., Li, W. P. & Dong, X. G. (2008): Topography representation methods for improving evaporation simulation in groundwater modelling. – Journal of Hydrology, Vol. 356 (1-2), 199-208

Marklund, L. (2009): Topographic Control of Groundwater Flow. – PhD-Thesis, Royal Institute of Technology (KTH), Stockholm, 44 S.

Tanaka, M. & Suzuki, K. (2009): Influence of Watershed Topography on the Chemistry of Stream Water in a Mountainous Area. – Water Air Soil Pollut, Vol. 196 (1-4), 321-331

Tetzlaff, D., Seibert, J. & Soulsby, C. (2009): Inter-catchment comparison to assess the influence of topography and soils on catchment transit times in a geomorphic province; the Cairngorm mountains, Scotland. – Hydrol. Process. 23, 1874–1886

Wessolek, G., Duijnisveld, W. H. M. & Trinks, S. (2004): Ein neues Verfahren zur Berechnung der Sickerwasserrate aus dem Boden: das TUB-BGR-Verfahren. – In: Bronstert, A., Thieken, A., Merz, B., Rohde, M. & Menzel, L. (Hrsg.): Wasser- und Stofftransport in heterogenen Einzugsgebieten. – Forum für Hydrologie – Wasserbewirtschaftung, ATV-DVWK, Heft 05.04, Beiträge zum Tag der Hydrologie, Band 1: 135-145.