Improvement of Water Level Measurements in Saltwater-Influenced Monitoring Wells - Application of the Base Pressure Method

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ABSTRACT

The water levels in saltwater aquifers are substantially influenced by the higher density of salt water compared to freshwater with a density close to 1 g/cm^3. Without correction, the measured water level data cannot be used for hydrological purposes like groundwater level maps or groundwater modelling. Examples of the area monitored by HAMBURG WASSER illustrate the at times considerable influence of density effects on the analysis of groundwater data. Possible situations might be a density-driven shift in watershed boundaries or water level fluctuations caused by sampling of monitoring wells. Therefore, data have to be converted into corresponding freshwater heights. For this purpose, several measuring methods exist. Most important approaches are the analysis of chemical/physical profiles, geophysical logging methods and the base pressure method (subject of this article). Applicability of the base pressure method has been proved in numerous investigations by HAMBURG WASSER. Based on the pressure at the base of the monitoring well, water level and air pressure, the equivalent freshwater height is calculated. The fundamentals, application and possible sources of error of this method are presented here.

INTRODUCTION

HAMBURG WASSER performs routine measurements of the groundwater level at about 1400 monitoring wells. A small part of these monitoring wells exhibits elevated salt concentrations. The salinization of ground water results from solution processes at the edge of salt domes. If these leaching waters spread into the aquifer, normally a density-driven layering with the saltwater at the basis of the aquifer is formed.

The piezometric level of a water column depends on the air pressure as well as the density of the water and therefore on the concentration of dissolved substances and on water temperature. Under hydrostatic conditions, the pressure head of the saltwater column is lower than the appropriate freshwater column, due to the higher water density of the salt water (Figure 1). In consequence, groundwater level data from monitoring wells influenced by salt water should not be analyzed together with data from wells screened in freshwater without an appropriate correction. For hydraulic evaluations, such as the determination of the flow direction of the groundwater or the delineation of a catchment area, the water level data of the different monitoring wells have to be comparable. The groundwater level data of monitoring wells influenced by saltwater may only be used after an appropriate density correction.

Chloride concentrations, even in the range of only a few grams per liter, cause deviations of the water level up to some decimeters. In some of the deep monitoring wells of HAMBURG WATER the maximum salt concentrations reach about 60 g L^{-1}. With water column heights up to 590 m the equivalent freshwater heights lie up to about 31 m above the actually measured water height. Normalizing water level data to freshwater data requires determination of an equivalent freshwater height. If the density of freshwater ρ_f is used as a reference, one gets the equivalent height of the freshwater column h_f as the result. The density of freshwater as reference for the groundwater zone is most suitable for most practical applications as variability in the densities in the corresponding saline waters is usually negligible. The physical relations are described amongst others by Rushton (1980) or Fetter (1994).

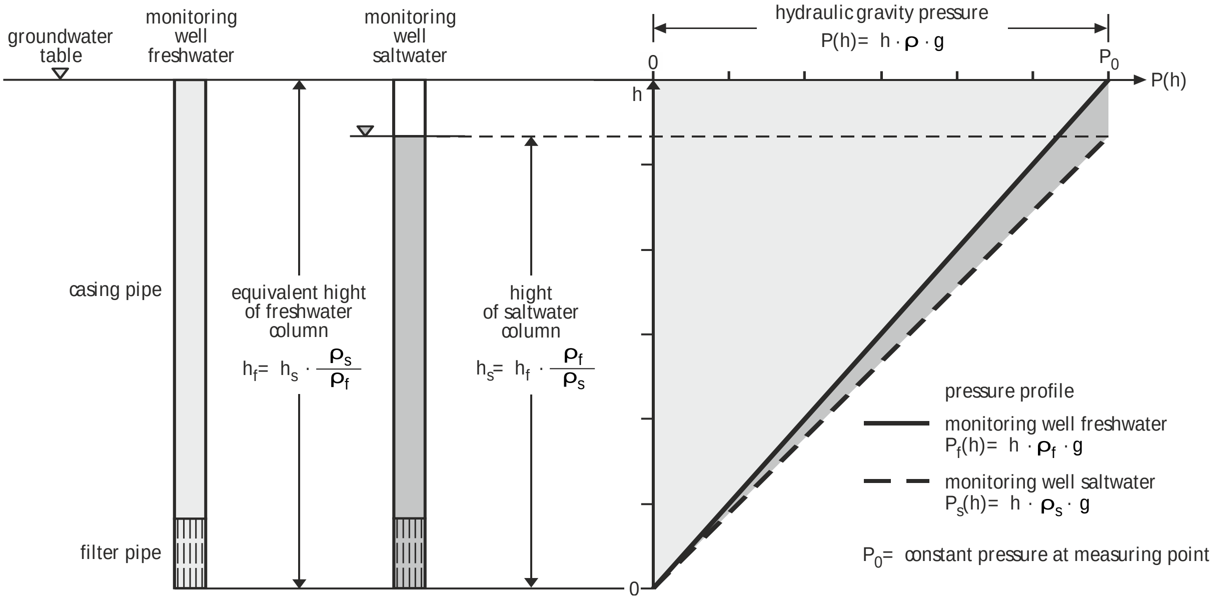

Figure 1: Visualization of the conditions in monitoring well in freshwater and saltwater

For the implementation of the corrections of water levels influenced by saltwater, base pressure measurements are used by HAMBURG WASSER. This method enables the efficient determination of the hydrostatic pressure and therefore the derivation of equivalent freshwater heights. Based on base pressure measurements from 2004 up to 2009 as well as accompanying measurement of the conductivity in the monitoring wells, the cluster of wells influenced by saltwater has been divided in two groups, one with stable and another group with variable salt concentrations. The first group of wells with stable salt concentrations usually show completely salinized water columns with small or no variations in salt concentration. The variation of density in the water columns is negligible and therefore the correction values for the transformation of the water level data are practically stable. For this group, the base pressure measurements are repeated every five years. As for the second group of monitoring wells with varying salt concentrations in the water column, variations of density have to be taken into account and detailed drift corrections are essential. For this group, the base pressure measurements are performed each year.

METHODS

With simple standard measurement methods (electrical contact gauge, data logger) only the density-influenced groundwater level can be detected. For the evaluation of the equivalent freshwater height, additional information has to be collected. Most of the existing methods focus on the determination of the average density in the saltwater column. Examples are density calculations on the base of chemical-physical parameters along depth profiles of the water column, the direct determination of the density in a depth profile by light refraction measurements, measurement of the hydrostatic uplift, of the resonance or by radiometric methods. With these measurement methods a step-by-step or a continuous density evaluation of the water column in the monitoring well is required. Besides, these methods are time-consuming and they are influenced by methodical or systematical problems (disturbance of inhomogeneous water column by the inspection with the gauge or the sampling device, interpolation errors based on a limited number of sampling points, differences between the composition of the groundwater in the water column of the well and the aquifer).

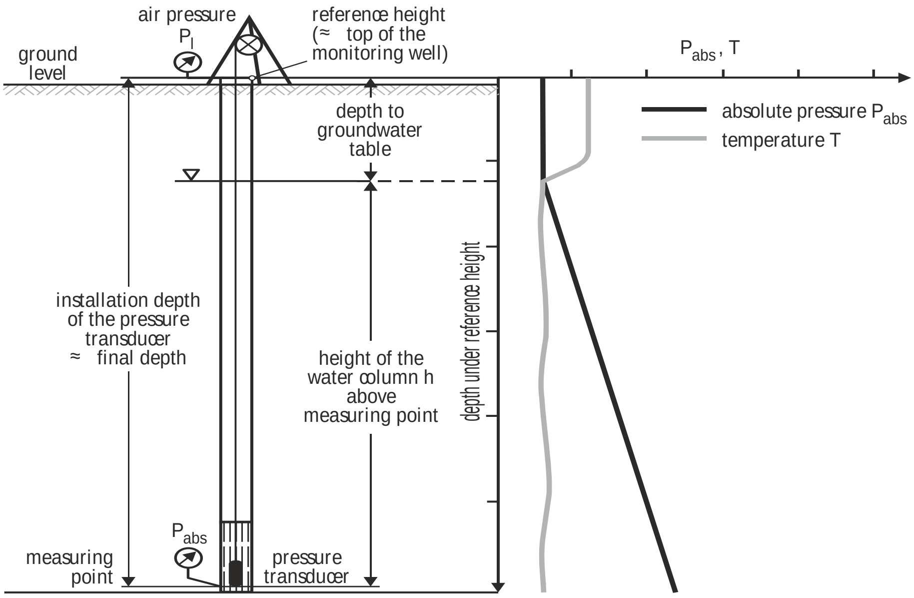

Figure 2: Principle and measured variables of the base pressure method

In contrast the base pressure method exhibits several advantages. For the determination of the hydrostatic pressure of the saltwater column at the bottom of the monitoring well as the decisive parameter, only a single direct measure is necessary and does not need to be derived from a series of interpolated values from a measuring profile. The measuring procedure and the evaluation of the data are considerably simplified as just an absolute pressure transducer has to be sunk to the final depth of the monitoring well. At the bottom of well, the absolute pressure P_{abs}, the distance between the reference height of the monitoring well and the measuring position as well as the water temperature have to be measured (Figure 2). At the same time the air pressure P_{atm} at the reference height is measured for the calculation of hydrostatic pressure P_s with the equation $P_s = P_{abs} - P_{atm}$ and the distance between water level and reference level of the monitoring well. The hydrostatic pressure P_s is inserted into the equation $h_w = P_s (\rho_f\ g)^{-1}$, where ρ_f is the freshwater density (Figure 1).

The only precondition for the application of the base pressure method is a monitoring well or an accessible vertical drilling with a diameter of sufficient width for the access with the pressure transducer. For precise determination of the equivalent freshwater height it is necessary to know the actual measuring depth.

DISCUSSION AND CONCLUSIONS

The essential sources of error connected with the base pressure method and the dimension of the errors are listed together with proposals for their minimization of those errors in the table below (Table 1). For the measuring equipment presently used by HAMBURG WASSER it is assumed that the total error for the calculation of the freshwater column corresponding with the absolute pressure is smaller than 0.1 % of the measuring depth, that means about +/- 0.1 m in relation to 100 m of water column height. Under these conditions the use of the measuring method is reasonable for groundwater with a mineralization of more than 1.5 g L^{-3} or a conductivity of more than 2.000 µs cm^{-1}, respectively. For water with lower mineralization the method is suitable to detect the dimension of the equivalent freshwater column.

Table 1: Basic error sources connected with the base pressure method to determine density-corrected groundwater levels listed together with methods for the minimization of those errors

Error – Error range	Error handling, error minimization
Pressure measurement (detection of the equivalent freshwater height)	
Measurement error of the (base) pressure transducer – maximum 0.1 % of the measuring range	Use of a pressure transducer with improved measurement accuracy (best available class of accuracy presently is 0.05 % of the measuring range), adaption of the measuring range of the transducer to depth of the measuring point
Measurement error of barometer (measurement of air pressure) – maximum 0,1 % measuring range	Use of measurement device with improved accuracy
Determination of the reference point for the correction of the water column height	
Elongation of the line of the plump for the depth measure – 0,01 to 0,09 % in relation to the measuring depth	Correction of the length value assuming an elastic elongation of the line
Inaccuracy of the depth counter during metering with check marks on the rope – max. +/- 1 m reading error	Use of a calibrated depth counter or impulse generator
Deviation of well casing (borehole) from the plumb line – maximum error of the measuring depth 1.5 % at a maximum deviation of the borehole of 10° from the plumb line	Correction on the base of dip-meter logging
Calculation of the equivalent freshwater height on the basis of the density of pure water at a temperature of 10° C	
Local variations of the freshwater density of the non-saline groundwater in the investigation area – maximum 0,02 % of the height of water column	Calculation of the equivalent freshwater height on the basis of the average density of the non-saline groundwater in the groundwater body investigated
Deviation between reference temperature (e.g. 10°C) and temperature in the water column in the monitoring well inspected – maximum 0,11 % of the height of the water column	Correction of the calculated density of the freshwater density in the monitoring well inspected on the basis of a temperature profile of the well

REFERENCES

Rushton, K. R. 1980. Differing positions of saline interfaces in aquifers and observation boreholes. J. Hydrology, Nr. 48, S. 185 – 189.

Fetter, C. W. 1994. Applied Hydrogeology. Prentice Hall, New York

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