Flow measurement using the salt dilution method at the mine water influenced Tweelopiespruit, Witwatersrand, South Africa

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Abstract

Out of the different flow measurement methods available, the salt dilution method is highly accurate for measurement under turbulent flow conditions. Not well known in South Africa, the main purpose of this article is to introduce the technique at the Tweelopiespruit, Witwatersrand, South Africa. At five different sites along the stream, measurements in June and October 2014 were conducted. Different from previous investigations it could be shown that the general flow increases during the course of the rivulet and that only minor localized discharge losses can be observed.

Keywords: Flow measurement, discharge, salt dilution method, tracer, Witwatersrand/ South Africa

Introduction

In the past few years, there has been a growing interest in the mine water discharging in the Western Basin of the Witwatersrand, South Africa. After flooding of the abandoned gold mines, first mine water discharges occurred in late August 2002 (Coetzee 2011). The Tweelopiespruit, a stream predominantly recharged by mine water and treated mine water, is highly influenced by its sources (Hobbs & Cobbing 2007). This paper describes the "sudden injection ('gulp') method" by using diluted salt as a tracer substance ("salt dilution method") (Wolkersdorfer 2008) and investigates potential stream loss into the underlying dolomitic aquifer in the reach of the Krugersdorp game reserve. Background of this investigation is the hypothesis that the caves of the world heritage site "Fossil Hominid Sites of South Africa" (vulgo "Cradle of Humankind") might be negatively effected by the mine drainage form the Western Pool of the Witwatersrand Gold Fields.

Methods

Originating at Robinson Lake, the Tweelopiespruit flows over a distance of approximately 10 km west of Krugersdorp, which is located 30 km WNW of Johannesburg. Eventually, it flows from south to north through the Krugersdorp Game Reserve and the dolomitic outcrops there.

Underlying the Krugersdorp Game reserve is dolomitic strata, an outlier within the Black Reef Formation quartzite, belongs to the Malmani Subgroup and is characterised by its very porous composition. Mainly, the stream is fed by treated mine water, discharging at various locations along the stream. Additionally, the Tweelopiespruit is assumed to be fed by dolomitic groundwater.

To measure the discharge at six locations in the Tweelopiespruit, the salt dilution method was used, which is discussed in detail by Moore (2005). A high accuracy of the procedure and the possibility to measure under turbulent flow conditions are characteristic for this method. Yet, thorough mixing between the injection and measuring site must be guaranteed. Sodium chloride was chosen as the tracer substance and used for on site measurements of the electrical conductivity change during the course of the study. At each site, 1000 to 2500 g of carefully weighted sodium chloride were dissolved in a 10 L bucket of stream water.

Injecting the tracer into the stream water took place as quick as possible with carefully rinsing the bucket to ensure all tracer was injected. This is referred to as "sudden injection ('gulp')" or "slug method" (Wolkersdorfer 2008, Moore 2005). Simultaneously, recording of the electrical conductivity started.

Breakthrough curves represent the relationship between electrical conductivity and measuring time (t). By using the calibration coefficient, the integral for the concentration over time can be calculated, resulting from the linear relationship between electrical conductivity and the dissolved salt content. The discharge (Q) is the quotient of injected salt mass (M) divided by the concentration-time-integral (c_t) (Eq. 1).

$$Q = \frac{M}{\int_{t_0}^{\infty} c_t \, x \, dt} \qquad (1)$$

Results and Discussion

An increase in the flow in the course of the Tweelopiespruit can be observed. After the inflow into the game reserve, the flow is increasing. A first peak is reached at measuring point TFS, where after the flow is decreasing again. The increase in flow before TFS is in the same range as the decrease at this measurement point. This is clearly evident in the June 2014 measurement. After measuring point ALS, the following values from June and October 2014 differ substantially. In June 2014 the flow increased by more than 660 L s^{-1}. Then it decreased, with high discharge values over 1000 L s^{-1}. The same trends can be seen in the October measurement with flows being substantially lower.

Flow changes before and after location TFS by approximately the same discharge might be explained by the fact that around this point a larger flow in the gravel bed is occurring. Large infiltration of stream water into the ground is not to be expected.

At measuring point DAD and N14 the discharge for June and October 2014 is substantially different. In June 2014, the measurement was carried out at the beginning of the dry winter season, and little feeder streams above point DAD may have been water bearing. During and after rain events a strong flow increase in Tweelopiespruit by these sources is to assume. The measurement in October 2014 was conducted towards the end of winter, after a long season with no precipitation. The small rivulet upstream point DAD has dried up, hence no increase in discharge can be observed. This lack of precipitation is also responsible for the low mean discharge during the October measurements.

Conclusions

One of the purposes of this paper was to introduce the salt dilution method for flow measurements in South Africa. The method is an effective way for precise flow measurement under turbulent flow conditions, as in the case of the Tweelopiespruit. Sodium chloride as a tracer substance is cost effective and easy to handle.

A strong increase of the flow rate in June 2014 from point DAD can be explained by an additional inflow near the north-western entrance to the lion's camp. However, the degree of inflow needs more detailed investigation. Supplementary measurements with the salt dilution method in the Tweelopiespruit are therefore necessary to verify the findings. Recommended are the establishment of additional measuring points and the implementation in different seasons. Summing up the results of the flow measurement in the Tweelopiespruit, it can be concluded that the flow increases over the measuring distance. Loss of stream water into the underlying karst, and therefore a potential negative influence of the world heritage caves, is not a predominant process.

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