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Diurnal Variations in Electrical Conductivity of Water in a Small Stream

Ulla Maria Calles

Div. of Hydrology, University of Uppsala, Sweden

Diurnal fluctuations in electrical conductivity of water have been observed in a small stream draining a basin 12 km^2 in size. An attempt to explain the cause of these variations is presented. The two influencing factors studied are evapotranspiration and earth tide effects.

Introduction

As a subproject within the International Hydrological Programme (IHP) monitoring of electrical conductivity of water and water temperature was performed in a subcatchment of the former Representative Basin of Kassjöån in Central Sweden. When evaluating the recorded data a short-term cyclic variation in conductivity was noticed. The cause of this variation is not obvious.

The data discussed in this paper emanates from a small stream draining a catchment 12.1 km^2 in size. Bedrock is granites and overburden is till. Bogs cover approx. 19% of the area and lakes 1.3%. The altitudes range from 360 to 500 m.a.s.l. (Fig. 1). Intense forestry in the region has produced large clear-cuttings in the drainage basin.

Data on conductivity and water temperature were recorded on a modified battery powered Rustrak recorder. Temperature data were used to compensate the conductivity data to a reference temperature of 20°C. Careful evaluation of the results confirmed that the fluctuations are genuine and do not reflect instrument instability or temperature effects. Analyses of water samples never revealed so low pH-values that correction of conductivity data due to this influence was

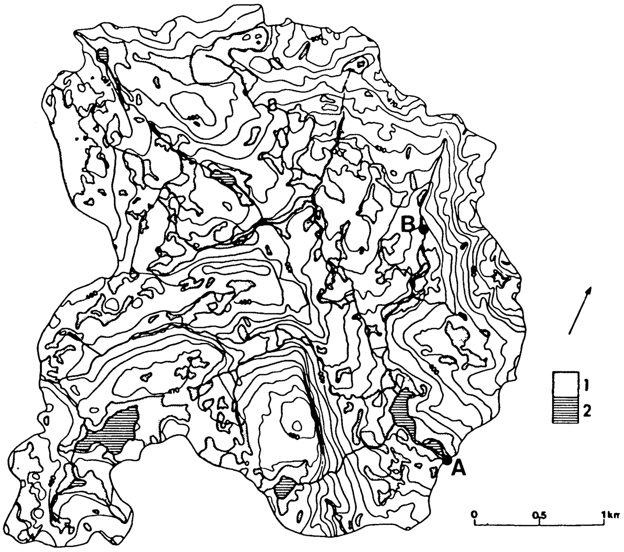

Fig. 1. The drainage basin discussed. A) is the observation point in the main stream and B) the observation point in the tributary. 1) bogs 2) lakes. Contour interval 10 m.

necessary. Water discharge data were computed from a recording gauge with a resolution of approx. 0.5 cm. Resolution of conductivity was 0.2 μS/cm and temperature resolution was 0.1 °C.

The time series comprises 106 days, from July to October 1976. In Fig. 2 is shown part of the data series and some of the factors that might influence the variation in conductivity. Conductivity data have been compensated to 20°C. The large-scale pattern is primarily governed by precipitation events and the amount of precipitation. The daily variations in conductivity and water temperature are not exactly in phase. Conductivity versus gravity seems more complex. Groundwater level was recorded in a well in the vicinity of the study area. The daily stage variation is obviously in phase with the fluctuations in gravity. Atmospheric pressure seems to be of insignificant importance for the variation in stage. Values on gravity or to be more correct, changes in gravity caused by tidal effects have been computed using data and formulae published by EAEG, Tidal Gravity Corrections (1976).

To explain the cyclic variation pattern, different influencing factors can be considered responsible. Two mechanisms are more likely than others to give rise to the observed phenomenon namely evapotranspiration and earth tide effects. The effect of earth tides is assumed to influence the fissures in the bedrock. The groundwater contributing to the run-off will accordingly get a periodic change in composition due to mixing of groundwater of different conductivity.

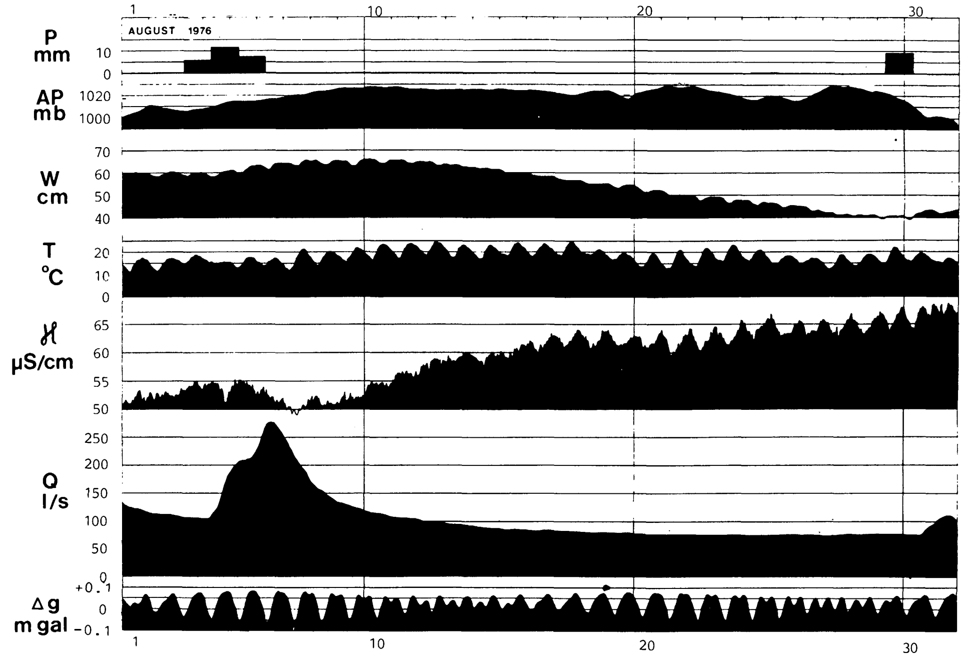

Fig. 2. Variation of a number of parameters at station A (Fig. 1) in August 1976. P) precipitation AP) atmospheric pressure W) groundwater stage T) water temperature K) electrical conductivity of water at 20°C Q) water discharge Δ g) gravity variation.

Effects of Evapotranspiration

A number of authors (e.g. Dunford and Fletcher 1947, Hylckama 1968, Federer 1973, Palange and Aylor 1975 and Bren 1980) have described discharge variations caused by evapotranspiration both in a long-term sense as well as on a diurnal scale.

The study of short-term cyclic variation of dissolved solids has not been extensive and very little has been written on the subject. Already in 1948 it was noted by Hem (Hem 1948) from investigations in Southwestern United States that diurnal variation in specific conductance sometimes occurred. Since this variation was in phase with variation in water discharge it was suggested that the cause of the fluctuations was an accumulation of soluble salts when the water level fell due to evapotranspiration. When the level rose again, these salts were at least partly redissolved. The peak of discharge and concentration of dissolved solids would thus, more or less coincide in time.

In 1974 Walling published results from monitoring of a number of small streams in Devon and noted the occurrence of a diurnal fluctuation in conductivity. Maximum values occurred in the early morning hours. The fluctuations observed were not accompanied by a variation in water discharge. The absence could however be due to the insensitivity of the recording gauges. Walling suggested that the diurnal variation in conductivity reflected changes in the pattern of groundwater seepage to the stream. No cause for the variation in groundwater seepage was suggested.

Gjessing et.al. (1976) noted a diurnal variation in both pH-values and conductivity with maximum values occurring 8-9 a.m. However, the authors dismissed the pH-variations as beeing the result of measuring errors due to temperature variations. No comments were given on the variation in conductivity which evidently was observed to be i phase with the pH-fluctuations.

Let us here make some computations to try to conclude whether evapotranspiration is a plausible cause or not of the observed variation in conductivity of the data series presented in this paper. Assume an evapotranspiration of 3 mm/day, a reasonable value since the mean potential evapotranspiration in August is 2.4 mm/day according to Eriksson (1981). Assume also that the evapotranspiration which causes fluctuations in conductivity takes place along a 5 m broad band along the whole stretch of the stream only in daytime. Since the total stream length is about 15 km evapotranspiration would in this manner cause a mean decrease in discharge by 5 l/s during 12 hours. This would mean a change in water stage at the discharge station of approx. 0.5 cm which implies that it could have passed undetected by the recording gauge.

Discharge in late August is approx. 75 l/s and 5 l/s is thus 7%. The observed variation in conductivity is approx. 6% which is in the same order of magnitude and evaporation could then be a possible cause of the observed variation.

Let us apply the same procedure of calculation to the October conditions when the variation in conductivity is still present even if the air temperature is approaching 0°C. The mean potential evapotranspiration during this period is only 0.2 mm/day (Eriksson 1981) but conductivity varies with approx. 3% which would indicate an evaporation of 1.6 mm/day. To reach that figure would need a width of the contributing area of 30 m. This is, however, not very plausible.

During a short period of the summer season 1980 the same type of data as mentioned above were monitored in a tributary (B in Fig. 1) to the previously investigated basin. A change of recording equipment made it possible to record stage variations of 1 mm. The same type of fluctuations occur in this small stream as well and a variation in stage can also be observed.

A simple model was constructed to see if evapotranspiration was as reasonable cause of the variations observed in this tributary (Fig. 3).

R is the amount of water added to the stream, V is volume, E represents evapotranspiration, c concentration of stream water and c_0 concentration of water added to the stream. The volume V represents water in the stream itself even if evapotranspiration has affected that water before it entered the stream provided

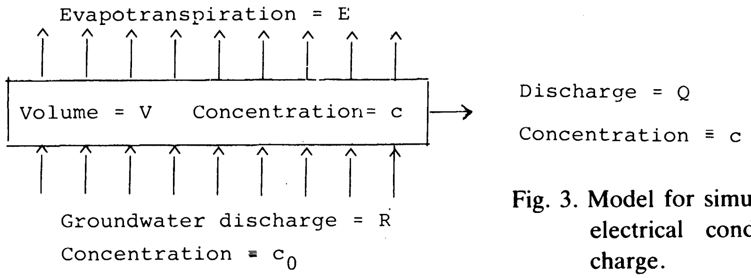

Fig. 3. Model for simulating variations in electrical conductivity and discharge.

that only a very thin layer of water in the discharge area is affected by evapotranspiration. The following equation can be stated.

$$Q = R - E \tag{1}$$

Assuming that fluctuations in V are small and neglectable the change in amount of salt per unit time will be

$$V\frac{dc}{dt} = Rc_0 - Qc = Rc_0 - (R-E)c \tag{2}$$

$$\frac{dc}{dt} = \frac{Rc_0}{V} - \frac{R-E}{V}c \tag{2a}$$

If the value of c is not changed very rapidly c_t can be approximated by c_{t-1} which leads to

$$c_t - c_{t-1} = [\frac{Rc_0}{V} - \frac{Rc_{t-1}}{V} + \frac{E}{V}c_{t-1}]\,\Delta t \tag{3}$$

where Δt is time interval considered. Let the evapotranspiration

$$E = A(1-\cos\frac{2\pi t}{T}) \tag{4}$$

thus supposing that evapotranspiration follows a daily variation of cosinus type. The amplitude A is adjusted to the observed diurnal water discharge variations. In this example the discharge is also observed to be slowly decreasing. To make the calculated values follow this pattern, the value of R has been assumed to vary like $R_t = \alpha R_{t-1}$ where α is a constant smaller than 1.0. The result of the calculations when using Eqs. (1) and (3) is shown in Fig. 4 together with the observed values. The computed values are obtained for V = 72,000 1. Since the length of the stream is 750 m this means a volume of about 100 l/m of stream length. The stream is about half a metre wide hence a mean depth of 0.2 m will give the average volume 100 l/m.

Using the same June-data from the small tributary and determining the amount of water lost by evapotranspiration from the discharge curve one arrives at a figure of 5.5 mm/day if the width of the ground water discharge area is 5 m and the

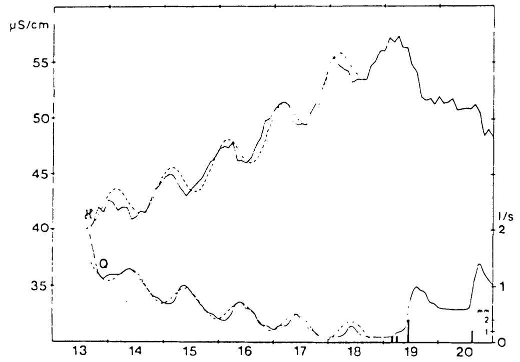

Fig. 4.
Observed (——) and calculated (---) values of discharge and conductivity and observed values on precipitation.

total length of the tributary is 750 m. If the "active" width is 10 m around the stream the evapotranspiration would be 2.8 mm/day. The mean potential evapotranspiration in June is 3.8 mm/day (Eriksson 1981).

The result of this simulation lends support to the assumption that evapotranspiration is at least partly responsible for the diurnal variation in electrical conductivity.

Effects of Earth Tides

It has long been noted by a large number of authors that earth tides give rise to stage variations in wells drilled in rock. A number of the published works have been studied and compiled by e.g. Melchior (1966) and Bredehoeft (1967).

In order to study the eventual impact of earth tides on the variation of conductivity 25 precipitation-free days were used. The mean daily variation was computed and subtracted from the series in order to eliminate the influence from meteorological factors having a period of 24 hours. Filtering of this new series was peformed in order to assure that the fluctuations are genuine and not only consisting of 'noise'. The following filter was used

$$X_t = \frac{1}{16} Y_{t-2} + \frac{1}{4} Y_{t-1} + \frac{3}{8} Y_t + \frac{1}{4} Y_{t+1} + \frac{1}{16} Y_{t+2} \qquad (5)$$

where X_t is the new value at time t, Y_t is the value at time t in the original series, t-1 is one time-step backwards in the original series and t+1 one time-step forward in the original series. Subtracting then the daily mean values of concentration from the series of data will eliminate the long-term variation.

Multiple correlation analysis was performed on the resulting data series for conductivity and on the gravity series. Two time-steps were tested.

$$\kappa_t = 1.396\kappa_{t-1} - 0.540\kappa_{t-2} + 0.00005g_t + 0.0004g_{t-1} - 0.003g_{t-2} \qquad (6)$$

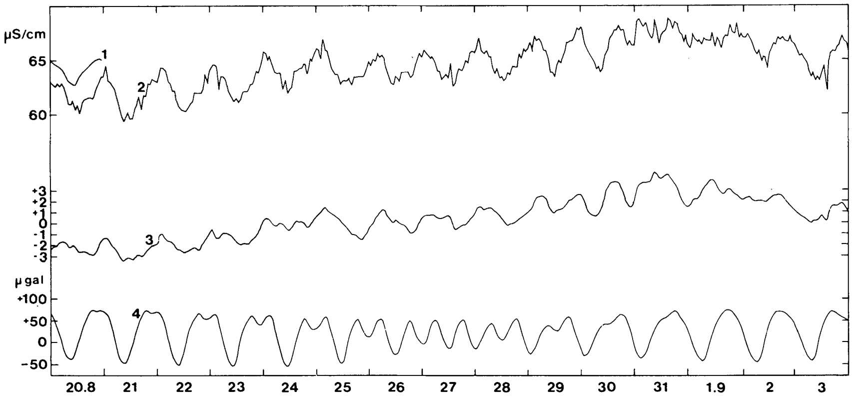

Fig. 5. Variation in electrical conductivity of water and gravity from August 20 to September 3. 1) Mean daily variation (Aug. 15-Sep. 9) 2) Original series 3) The same series after subtracting mean daily variation 4) Variation in gravity.

The result indicates that the autocorrelation in conductivity is responsible for the main part of the short-term variation. Of the gravity-terms at least g_{t-1} is significant.

According to Box and Jenkins (1976) the following statement can be made

$$\kappa_t \equiv 1.397\kappa_{t-1} - 0.539\kappa_{t-2} + 0.0013 \qquad (7)$$

This can be regarded as a second-order autoregressive process that has the characteristic equation

$$\lambda^2 - 1.397\lambda + 0.539 = 0 \qquad (8)$$

having the roots $\lambda = 0.70 \pm 0.23i$. Since the roots are complex one may draw the conclusion that we are dealing with a pseudo-periodic behavior. The damping factor *d*, and frequency *fo*, are

$$d = \sqrt{0.539} = 0.734$$

$$\cos 2\pi fo = \frac{1.397}{2\sqrt{0.539}} \qquad fo = 0.05$$

The period is approx. 18 hours. This is not readily explained but the influence from gravity changing phase during the investigation period may play a part.

Only five of the major gravity components are of geophysical interest (Melchior 1964). The main lunar components have periods of 12h 25m, 12h 39m and 25h 49m. A solar component has a period of 12h 00m and a lunisolar component 23h 56m. The individual influence on the aquifer from the different components are not equal.

Conclusions

This investigation has shown that no single factor is solely responsible for the observed variation in conductivity. Evapotranspiration seems to be the most important agent even if certain examples give unlikely results. The influence from gravity variations is not as clear but cannot be neglected.

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Address:
Division of Hydrology,
Department of Physical Geography,
University of Uppsala,
Box 554,
S-751 22 Uppsala, Sweden.