Space-Time-Modelling of Ascending Salty Sewage Water in the Werra-Potash District *(Middle Germany)*

Raimund Rödel

Institut of Geography at the-University of Greifswald, Jahnstr. 16,
17487 Greifswald, Germany
roedel@rz.uni-greifswald.de

Abstract. *Since 1925 salty sewage water of the potash-industry (Werra-region, Middle Germany) has been deposited in the geological setup. A quasi-closed system was assumed. It was found out that a part of the salt water ascend to the surface again. Time series-analysis allow a precise analysis of the outcoming salt water. To separate trend and periodical shares the time series were filtered numerically. The Fourier-transformation allows an investigation of the periodic shares. After the evaluation of the data it seems possible that two bodies of water united into one single body of waste water. The spreading of salty water in the underground was modelled by the concept of cellular machines.*

Keywords. *time series-analysis, groundwater modelling, numerical filtering, periodogram analysis, cellular automata*

1 Introduction

In considering the arrow of time, the study of geosystems has become an important aspect to understand fluctuations such as accelerations and retardations. Fluctuations mean the periodic shares, accelerations and retardations mean the behaviour of trends. According to the findings of system theory these phenomena have a great importance in the modelling changes of composition balances and energy in past, present and future. (AURADA, 1992a)

In the Werra-potash district in the middle of Germany the formation of Zechstein ranges from the Werra-salinar with the potash horizons of Thuringia and Hesse, to the Leine-salinar. Leine-salinar falls into a stratum of halite and karstified limestone on the top. The limestone is known as sheet dolomite. Layers of clay- and siltstone are situated above and below the sheet dolomite. Therefore it is assumed as a quasi-closed system. Because of its high cavity volume, sheet

B. Scholz-Reiter et al. (eds.), Process Modelling

dolomite is suitable for the deposition of the salt-containing waste water from the production of potash fertiliser. The permeability coefficiency of this layer is comparable with a medium-grained sand. It is assumed, that heavy salt water flows off into the depth because of a synclinal structure underground. (DVWK, 1993)

In figure one you can see the surface of the sheet dolomite in the Werra-potash district. A trough is visible, which is known as the Eiterfeldian trough. A line shows the assumed front of the flowing off of waste brine. This line is based on ground water measurements and the underlying assumption, that heavy salt water substitutes formation water. The river Werra with the potash fertiliser factories and the disposal wells are also visible. There are disposal well regions around Widdershausen, Eichhorst and Kleinensee. Important flood measuring points are situated in Unterrohn, Tiefenort, Widdershausen and Gerstungen. (DVWK, 1993)

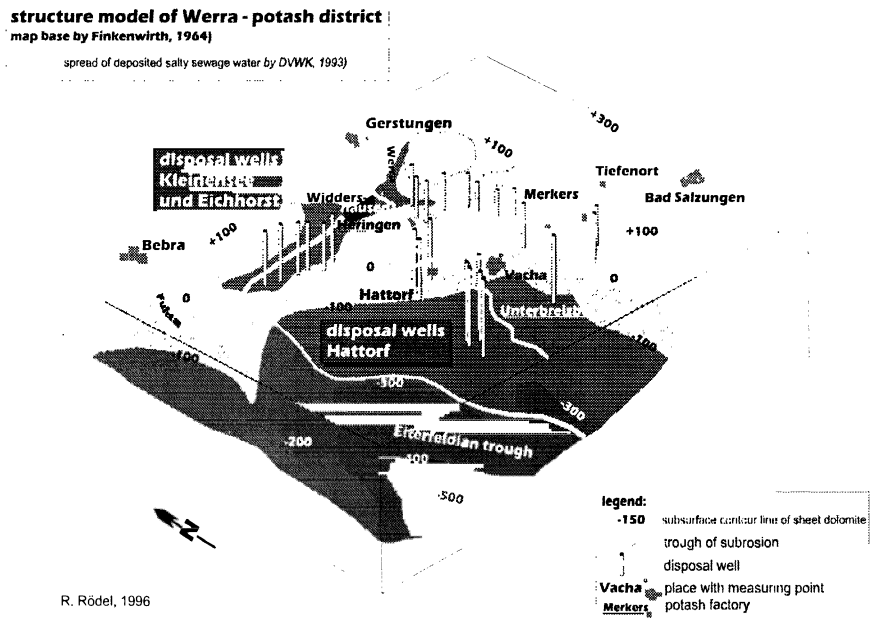

Fig. 1

Shortly after the feeding in the waste brine into the karstified dolomite in 1925, they found out that the formation water in the sheet dolomite and a part of the disposal salt water had ascended to the surface again. Favoured paths are the geological zones of weakness along faults and basaltic dikes. The amount of this ascending water is not be regulated and not exactly known.

The quantity of diffuse ascending sewage water has been balanced by AURADA. (AURADA, 1992B)

The following picture (Fig. 2) shows the underlying idea. The diffuse ascending of salt-containing waste water be comes obvious in the differences of chloride and hardness freight-measurements between two flood measuring points. The flow chart shows all measuring points in the Werra-potash district and the equation used to define their freights. The most important zones of diffuse ascending sewage water are between Unterrohn and Tiefenort as well as Widdershausen and Gerstungen. A common consent of the flood measuring point in Unterrohn was defined to show the natural salty freights, also known as geogenic background.

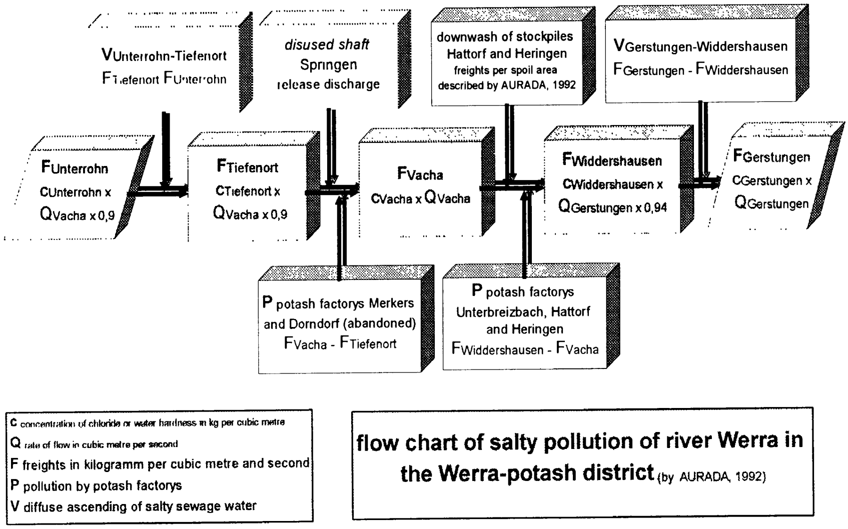

Fig. 2

2 Methods / Results

Referring to what was said in the beginning, stochastic is a better tool to describe the natural processes with the keys of numeric models. The study of AURADA (AURADA, 1992B) is based on annual meaning freight values up to 1976. Long detailed time series with daily values of thirty years have now allowed a precise analysis of outcoming salt water that reaches the river Werra. In this case, the changes and development of ascending sewage water should be investigated.

At first the time series were filtered by Gaussian high- and low pass filters. The method is designed to divide time series into a share of short time fluctuations and a share of trend. Statistical methods such as modelling of autoregressive processes presuppose that the trend is disposed from the original time series. (SCHÖNWIESE, 1992)

Specially chosen filter weights enables the division of time series into short time fluctuations as well as into the share of monthly trend. Taking all this into consideration, it is possible to model autoregressive processes and to compare the annual trend with annual results of deposited waste brine.

We leave the question of trend influenced share in the time series aside and look at the share of periodic fluctuations. This is the high-pass filtered part. Estimating the autoregressive processes it is possible to obtain knowledge about the memory effect.

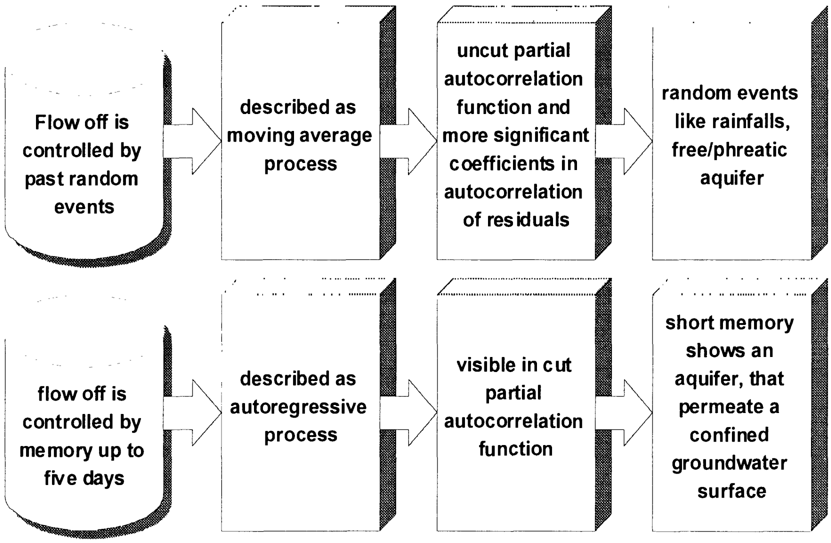

Fig. 3

The partial autocorrelation of chloride and hardness freights of geogenic background as well as hardness freights of assumed ascending water may be considered to describe autoregressive processes in the eighth ordinal. The autocorrelation function of residues is cut later than lag ten. A moving average process with ten or more ordinals lies behind the autoregressive process. Therefore a long memory effect is assumed in there freights.

In this case, the question is how the stochastic processes describe the controlling of ground water discharge. A common consent is that autoregressive processes show a to have short time memory. Moving average processes are controlled by past random events. There are two ways of controlling aquifer discharge. On the one hand, the discharge is controlled by past random events like rainfalls in a karstified water bearing stratum. This process is known as moving average process. It is assumed, that the freights of geogenic background and the freights of hardness in Unterrohn, which were described as moving average rocess, came out of a phreatic aquifer. It is possible to regard it as the aquifer of formation water in sheet dolomite.

On the other hand these is the ascending of salt-containing water, which is visible in the time series of chloride freights between Unterrohn and Tiefenort. There, groundwater discharge is controlled by short time memory. The underlying process is an autoregressive one. It is possible to draw the conclusion, that the layer of heavy salt water lies below the formation water in sheet dolomite. Only with time has the salt water permeated the confined groundwater surface. The short time memory of their discharge can be explained by this process.

In summary, we can say that the analysis of periodic shares supports the thesis of ascending waste brine. Another investigation into periodic shares is Fourier-analysis. The one gets a power spectrum. If one has a long time series, a moving power spectrum shows fluctuations of amplitude. (SCHÖNWIESE, 1992)

Figure four shows the moving power spectrum of trend-eliminated chloride freights. Fluctuations of amplitude in the time series between 1976 and 1984 are seen here. Look at the y-axis. The chart indicates an amplitude of over thirty kilogramms per second.

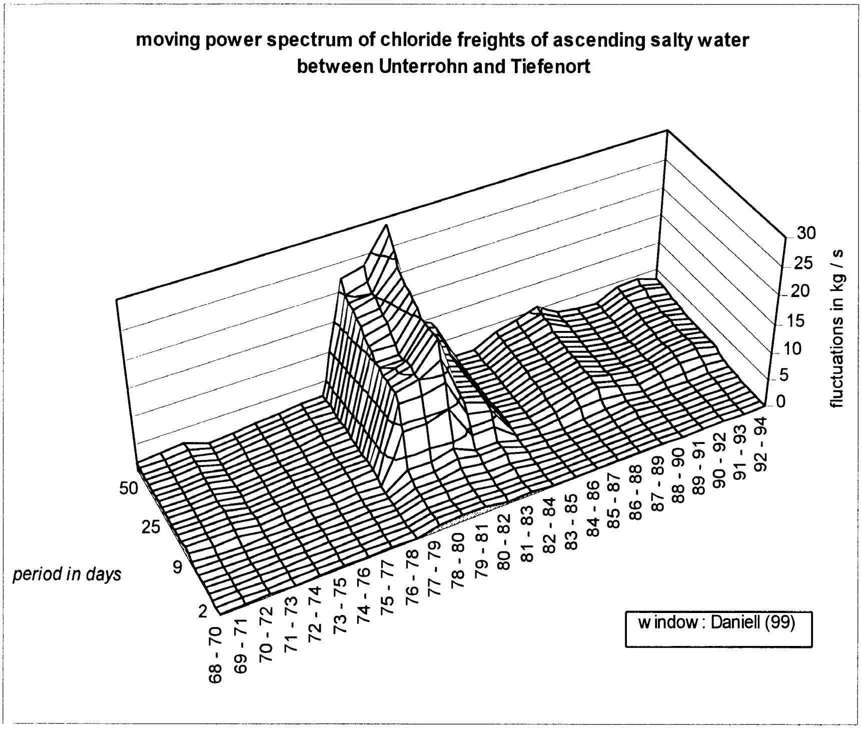

Fig. 4

It is interesting to know, that chloride and hardness freights reached peaks within this time. A thaw-salt down-wash from streets was assumed, because some of these freight peaks are at the same time, as high water in spring. One knows that thaw salt is magnesiumchloride.

I must admit that difficulties can arise by using the model of thaw-salt wash-down. Provided that the freight peaks result from the wash-down of magnesiumchloride, the question arises why there were such peaks during summer high waters, for instance in 1980 and 1981.

One has to take into account that measuring results in the flood containment area may be inaccurate in times of high water. Yet there must be another explanation for the freight peaks, because they only appeared between 1976 and 1984.

The next chart (Fig. 5) shows a comparison of the yearly trend of ascending chloride water with the rate of yearly deposited waste brine. The black line shows the results of yearly trend of ascending chloride water between Unterrohn and Tiefenort. Bars demonstrate the yearly means of disposal chloride waste brine of the three disposal wells.

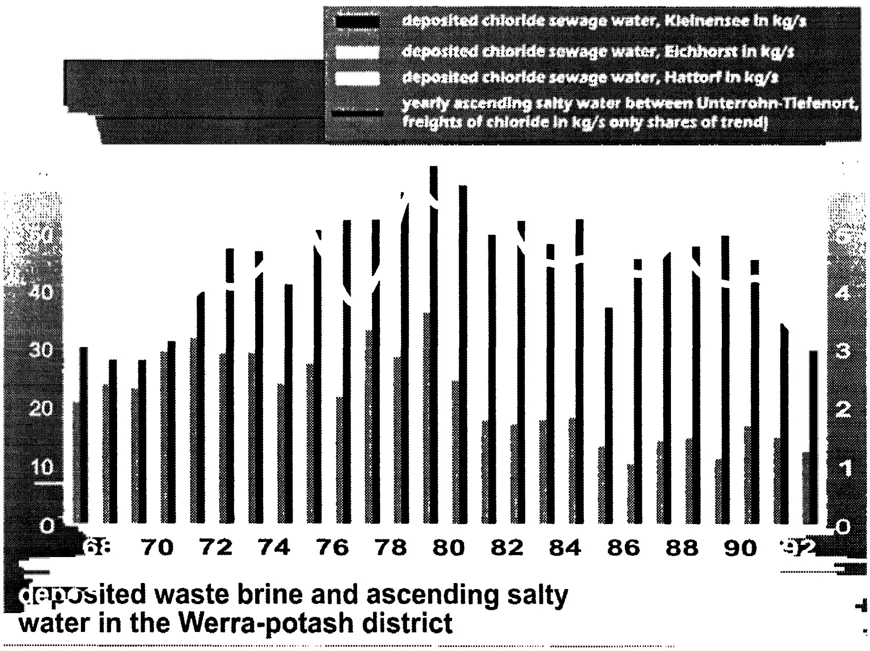

Fig. 5

Thuringia disposed its waste brine into the sheet dolomite only up to 1968. The end of the waste brine deposition carried out by Thuringia is visible on the chart up to 1971 by the descending black line.

Since 1979, a coherence has been detected between yearly values of ascending salt water in the region of Tiefenort and the rate of deposited waste brine. In statistical modelling this coherence may be considered as a multiple linear regression. In that assumption a coefficiency of determination of 0,75 was calculated. That means that 75 per cent of the freight level line is determined by the rate of deposited waste brine. Only the values of the disposal wells of Eichhorst are significant at 95% confidence-level.

In contrast, a coherence between the yearly chloride freights of ascending salt water in the region of Widdershausen and Gerstungen and the rates of deposited waste brine up to 1979 is observed. In the assumption of also multiple linear coherence a coefficient was found from a determination of 0,62.

Linear regression may be considered as not to be the best from this point of view. But let us come back to what was said at the beginning. Taking all that into consideration, there is a possibility to explain the freight peaks of chloride between 1976 and 1980.

What has happened? In common consent, the heavy sewage water that has been deposited in the underground, flows off into the centre of Eiterfeldian trough. But, if as the saying goes, the exception proves the rule and therefore this is not possible, as there is confined formation water in the geological set-up.

In my opinion the disposed waste brine does not substitute the confined formation water in sheet dolomite, in that the volume of disposal site is much smaller than geologists had assumed. The coherence between the rate of disposal waste brine and ascending salt water in the region Widdershausen-Gerstungen assumes that salty springs were controlled by the rate of disposal in Widdershausen up until 1979. Because of the continual depositing of waste brine by potash factories in Hesse the disposal site nearly overflowed in 1980.

Geologists (DVWK, 1993) assumed that there were two bodies of water in the setup because there is a swell between the disposal wells in Thuringia and Hesse where the salt water was pumped underground. After the evaluation of the data it seems possible that the two bodies of water united into a single body of water around 1980. Disposal waste brine did flow from the higher disposal wells near Eichhorst over the swell into the region between Unterrohn and Tiefenort. So it is possible to explain the significant coherence between disposal wells in Eichhorst and the freights of ascending salt water in Tiefenort up to 1980.

Summarising we can say that the assertion of a disposal site for waste brine from potash fertiliser production (DVWK, 1993) in the Werra-potash district cannot bye proved. The fact is that the ascent of waste brine is indisputable. The argument, that the heavy sewage water flows off into the depth of Eiterfeldian trough is not convincing.

3 Concluding Remarks

In order to understand the spatial processes better, the spreading of salty water in sheet dolomite was modelled by the concept of cellular machines. The model validates the results of time series analysis and simulates the movement of wasted water.

0,05	**0,2**	**0,05**
0,05	**0,4**	**0**
0,2	**0,05**	**0**

Fig. 6: The used Moore-raster

The spreading of the known yearly amount of deposited waste brine was simulated with the help of the above represented Moore-raster (Fig. 6). FINKENWIRTH AND FRITSCHE IN (DVWK, 1993) notice a spreading velocity between the control wells Friedewald and Weisenborn (distance 2.7 km) of nearly 450 m per year. This velocity itself reflects nearly by distance of raster of 500 x 500 m. In this raster field the movement was simulated. Programming can be done on an EXCEL table page.

40 per cent of the salty water remains in a raster cell after one simulation step, as one can see. Another part moves correspondingly Fig. 6 into the neighbour cells.

A weak salt load spreads relatively quick over the entire area, as the simulation results prove. Amounts of salt of more than 10 t per raster cell remain much longer around the disposal wells and spread slowly, like the definition of the Moore-cells, underground. The non-linear spreading of the main front of the waste brine body is simulated well with the help of the model.

The arriving front of salty sewage water between Gerstungen and Widdershausen in 1940 is a reference point of the model-plausibility. A diffuse ascending of salty water was also reported at this time (HOPPE, 1962) .

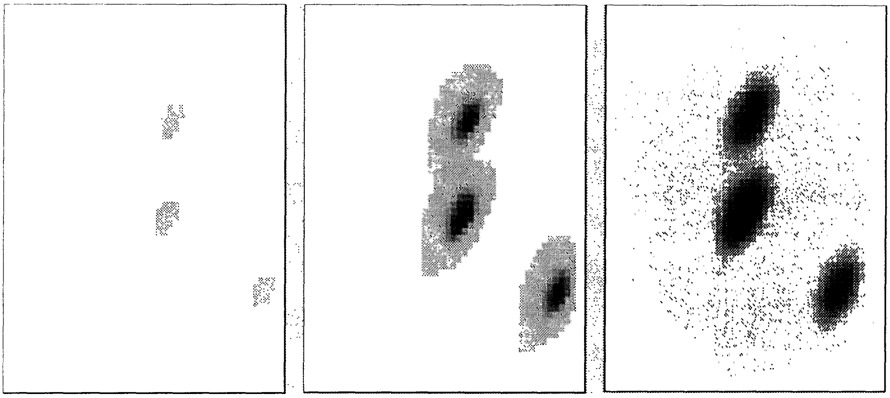

Fig. 7: two-dimensional spreading model of underground-deposite salty water in the Werra-potash district. Model works with Moore-neighbours (cell-distance 500x500 m = spreading in yearly steps). Dark areas past time-steps of 2 years, 12 years and 35 years are the most salt-loaded reaches.

References

AURADA, K.-D. (1992a): Prolegomenon einer Ökologistik Angewandter Geographie. In: Petermanns Geographische Mitteilungen 136 (2+3/1992), p. 81-91.

AURADA, K.-D. (1992b): Auswirkungen der Salzabwässereinleitungen und -deponien im Südharz- und Werra-Kalirevier... . In: Neue Bergbautechnik 22 (6/1992), p. 203-212.

DVWK (1993): Salz in Werra und Weser. DVWK, Bonn, 1993.

HOPPE, W. (1962): Grundlagen, Auswirkungen und Aussichten der Kaliabwasserversenkung im Werra-Kaligebiet. In: Geologie 11 (1962/9), p. 1059-1086.

SCHÖNWIESE, C.-D. (1992): Praktische Statistik für Meteorologen und Geowissenschaftler. Berlin, Stuttgart, 1992.

RÖDEL, R. (1997): Zeitreihenanalyse von aufsteigendem Salzabwasser im Werra-Kalirevier. In: Wasser & Boden 12/1997, p. 27-30.