Reconstructing ground-water level fluctuations in 20th century in the forested catchment of Drwinka (Niepołomice Forest, S. Poland)

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Introduction

The stream of Drwinka along with its tributaries drains part of the Niepołomice Forest which is situated in the vicinity of the Nowa Huta steel complex, one of the largest industrial enterprises of this type in Poland built in the early 1950's (Fig. 1). Extensive industrial emissions over the last 50 years are influencing the condition of the forest environment. The magnitude of this influence and the resulting destruction have been investigated by many forest-ecology teams (*Resources*… 1981, Grodziński, Weiner, Maycock 1984, Weiner et al. 1998). The ground-water table, alongside industrial emissions, has the potential to influence the state of the forest. Information on ground-water levels before and after the opening of a steel complex should make an assessment possible as to what extent the ground-water table fluctuations have been influencing the state of the forest environment, and to what extent its destruction has resulted from industrial emissions.

The paper aims to reconstruct the ground-water fluctuations in the Drwinka forested catchment for the period 1901-1960, having available the ground-water table data for 1961-2000 and meteorological data for the whole of the 20th century.

Physiography of the Drwinka catchment area

The Niepołomice Forest and the Drwinka catchment are situated in the Vistula River valley, between the Vistula and its tributary – the Raba River. Elevation is between 190 and 214 m a s l. The dominant bedrock is Pleistocene sand, clay and gravel of glacifluvial and fluvial origin covering deeper Miocene silt and clay. Part of the sands is wind-transformed and forms chains of dunes. The ground-water table depth is usually between 1-4 m except glacifluvial hills and dunes, where it locally exceeds 8-10 m. The dominant plant communities are coniferous fresh and wet mixed forests - ca 50%, deciduous forests - 24% and fresh and wet mixed forests - 20% (*Resources*… 1981).

Available data and method of reconstruction of ground-water fluctuations

There was only one ground-water monitoring post (Poszyna) in the Niepołomice Forest (see fig. 1). There the ground-water levels were measured on a weekly basis since 1953, although reliable data without major gaps only cover 1961-2000. Other posts distributed in the surroundings of the Niepołomice Forest were operating irregularly and just for short periods. Long-term meteorological data are available for Kraków (20 km to the west, the Jagiellonian University meteorological station). The data series (air temperature and precipitation) cover the period since the middle of 18th century. Assuming the relationship between the meteorological and ground-water variables and having available meteorological data for 1901-2000 (Kraków) and the ground-water

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table data for 1961-2000 (Poszyna), an attempt was made to build a neural-network model of ground-water fluctuations for Poszyna, to reconstruct ground-water table fluctuations before 1961. The monthly means of the ground-water levels and air temperature, and monthly totals of precipitation were used for model calibration.

Neural network modelling procedure

A predictor concept was applied to solve the issue of ground-water level modelling based on artificial neural networks (Masters 1996, Ossowski 1996, Tadeusiewicz 1998). The predictor is a conversion of a past series of data into a simulated present value. The method of learning artificial neural networks is a classical algorithm of back-propagation with momentum, mixed with pruning by optimal brain surgery (Ossowski 1996, Stork, Hassibi 1993).

There are two modelling tasks. The first gives an answer to the question: how useful for ground-water level modelling at Poszyna are the meteorological data from Kraków. The series of both meteorological data and the ground-water level are the model inputs. The results are satisfactory. For the independent test set the error measures are: mean error = 8.2 cm, standard deviation = 6.7cm, linear correlation coefficient = 0.95. The pruning method gives us small networks, which are easily interpreted.

The goal of the second task is the construction of a model that can be used to find a relationship between the ground-water level in Poszyna and the Kraków meteorological data. For the independent test set the error measures are: mean error = 17.6 cm, standard deviation = 14.3cm, linear correlation coefficient = 0.72. Although the results are not as good as in the previous case they are still useful in obtaining values close to the real ones. This model was used to perform a full conversion of the Kraków meteorological data into the Proszyna water level series. The obtained series conform to the forest behaviour at the time of measurements in the learning set.

Assigning ground-water fluctuations in different parts of the catchment area

Both, reconstructed and observed ground-water levels at Poszyna mirror the periods of dry, medium and wet years. Having the ground-water levels for Poszyna for the whole of the 20th century, the next step of the procedure was to reconstruct ground-water table fluctuations in other parts of the catchment area. In order to find the relationship between ground-water fluctuations at Poszyna and other parts of the catchment, nine piezometric wells were established in different parts of the forest, and then used for a one-year-long (May 1999-April 2000) monitoring, which was simultaneous with the one at Poszyna (fig. 2). The wells were located in, at least 100-year-old tree stands, to make possible future studies on the relationship between ground-water levels and annual tree-ring increments.

The one-year-long series of measurements has shown a well expressed linear relationship between water levels in the piezometric wells and Poszyna. This relationship was used for calculation of the ground-water levels at the monitoring sites for the whole of the 20th century. As the linear relationship between the Poszyna and piezometric wells was based on a one-year-long series of observations, the question arises whether this relationship is valuable for the whole of the 20th century. One of the factors to consider is the changing age of the tree stands and resulting changes in transpiration efficiency influencing ground-water levels over the period studied.

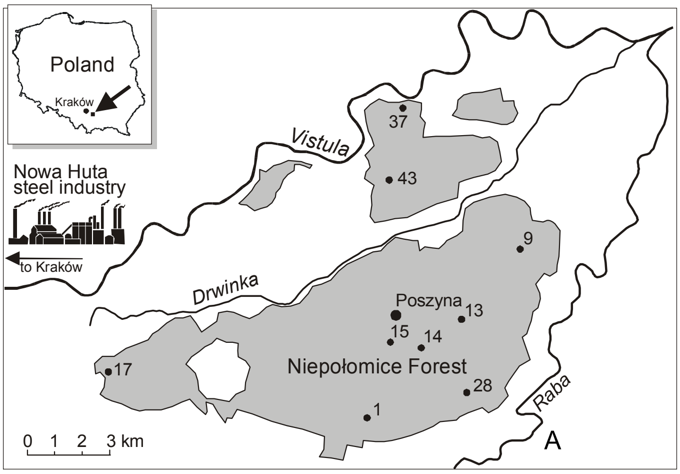


Figure 1. Location of the Niepołomice Forest with ground-water monitoring sites.

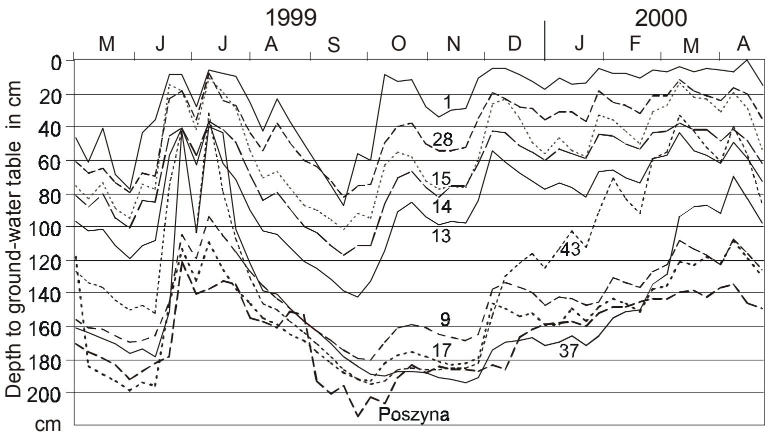


Figure 2. Ground-water levels at Poszyna and piezometric wells in 1999/2000.

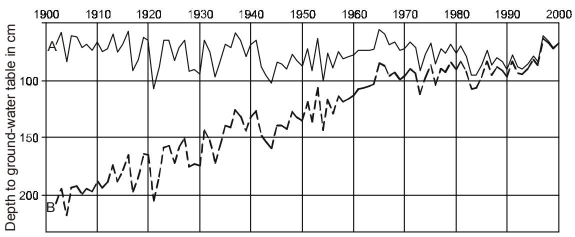
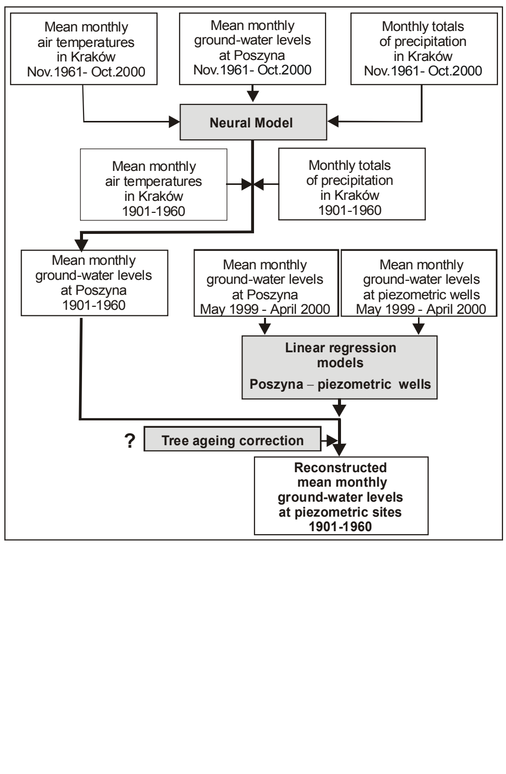


Figure 3. Ground-water levels at piezometric well 15 unadjusted (A) and adjusted (B) for tree ageing effect.



The trial approach to the problem was made using the formula of Suliński (1990) showing the dependence between the mean depth to a ground-water table H [m], a stands age A [years], and the coefficient of filtration of water bearing deposits K [10^{-5} m/s] and:

$$H_A = 40{,}05\ K^{0{,}198}\ A^{0{,}278}\ e^{-0{,}020A} \qquad [1]$$

Fig. 3 shows the ground-water levels for the 140-year-old pine stand (*Molinio-Pinetum*) at site 15; one without the correction for tree age (A), and another – with the correction based on the formula [1]. The doubts connected with use of the formula arise due to the unknown effect of the tree ageing at the Poszyna post, which is situated in a woodland glade, surrounded by forest of unknown effect on the ground-water level at the monitoring site. The whole reconstruction procedure is shown in fig 4.

Conclusions

Neural networks are a useful tool for ground-water level modelling based on meteorological variables. Linear regression between ground-water levels in different sites can be used for the spatial extrapolation of data. Further studies are needed to assess the tree ageing influence on the long-term tendency of ground-water levels.

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