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# RECONSTRUCTION OF BOG LAKE WATER LEVEL FLUCTUATIONS USING METHOD OF SIMPLE MODELLING: A CASE STUDY ON LAKE RĖKYVA

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**Abstract.** Considering lack of observations and meteorological data, the article analyses the reconstruction of bog lake water level fluctuations. The main issue of using advanced methods for determining water level fluctuations and balance can be lack of verified data. The proposed method uses only a variable length period of precipitation amount data series. Bog lake Rėkyva can be distinguished from other bog lakes due to its large area, and therefore has been chosen for this case study. The main conclusion is that the proposed method is suitable for determining trends towards water level fluctuation over long time periods.

**Keywords:** modelling lake water level, hydrology of bog lakes.

## Introduction

The largest bog lake in Lithuania is Lake Rėkyva. Changes in the water level of it have remained the subject of many discussions during the recent years. Considering the above introduced information, the lake was chosen as an example for this study. There is an opinion that the water level in the lake is decreasing due to nearby peat-bog exploitation, and thus a threat to recreational resources and fragile environment appears. The obtained data on water level fluctuations helps with identifying the state of botanical-zoological values because changes in water levels create problems concerning lakeside botanical-zoological values as defined by hydro-biologists (Rėkyvos… 1999). However, there is another opinion suggesting that the artificially maintained water level of the lake is too high and destroys its peaty banks. The lake shallows and sandy segments of the littoral are covered with organic sediments and overgrown by water plants. The evaluation of changes in water levels in the lake and causes affecting the existing situation need the reconstruction and analysis of long-term water level fluctuations.

The observations of lake water levels were started in 1926. Since then, 35 different stations have been used. However, there are only 6 lake water level observation time series (Tauragnas, Totoriškės, Plateliai, Sartai, Dusia, Žuvintas lakes) which reach more than 30 years. Therefore, water level fluctuations in the majority of lakes have to be determined using other indirect methods. Consequently, connections between water level fluctuations and other parameters having more observed data are analyzed and the results are used to reconstruct long-term water level fluctuations.

The main purposes of this study are to reconstruct lake water level fluctuations and determine the normal water level applying simple methods and data on meteorological observation. The reconstruction of water level fluctuations helps with a better understanding of the water balance of lakes with such unique catchment mainly consisting of mire areas. Hence, this knowledge gives opportunities to avoid mistakes in planning, changing and managing similar types of basins using water resources of the lake.

## Study Area

Lake Rėkyva is situated in the northern part of Lithuania on the divide between the catchments of Nemunas and Lielupė rivers and is the largest one situated in the drainage divide area of Lithuania. The lake surface area makes 11.8 km², whereas its catchment counts only 7.1 km² (Rėkyvos… 2008). The lake is surrounded by the large areas of mire (Bumblauskis 1983) (Fig. 1) the drainage and exploitation of which started at the end of the 19th century. The catchment area, in comparison to the one in the middle of the 20th century, has decreased by 10 km² due to lowering surface watershed because of the drainage of the large areas of mire surrounding the lake. The peatland (Rėkyvos… 1962) on the southern bank of the lake is currently intensively exploited. The


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bogs remain pristine only on the western bank of the lake where a reservation was established. Such a complex use of the lake and its catchment causes conflicts related to nature. Finding a solution needs objective studies of the lake state and evaluation of various factors influencing changes.

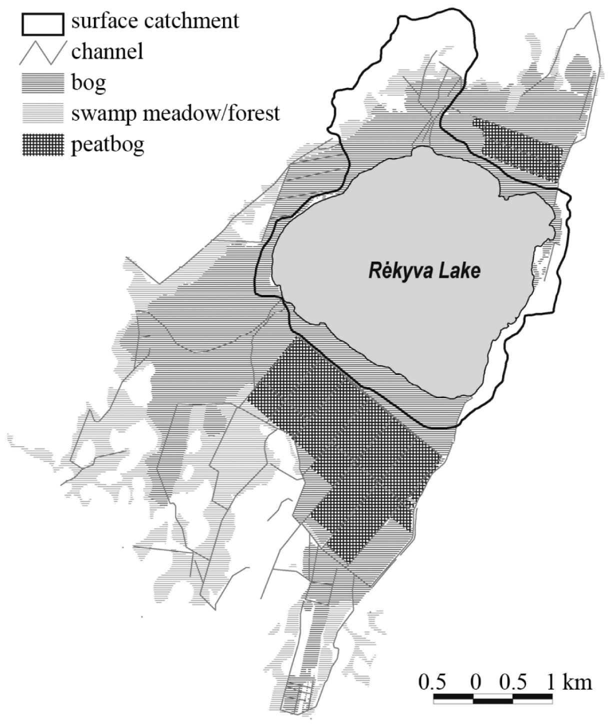


**Fig. 1.** The catchment and surrounding mires of Lake Rėkyva

Rėkyva is a shallow lake. The maximal depth is 4.8 m and an average depth is 2.04 m. The lake has no tributaries except some small drainage canals. The effluent on the south-west bank of the lake has been blocked. An artificial rivulet connecting the lake with the catchment of the Lielupė River flows out of the north-eastern part of Lake Rėkyva. The runoff of this rivulet is limited by a fixed height spillway. The type of the spillway located in the rivulet determines different conditions of rivulet runoff. When the water level is high, it spills over the top of the spillway and the lake water level is determined by the baseflow and the amount of water spilling over the top of the above mentioned spillway. However, when the water level is low, there is a stable runoff (~30 *l*/s) through the pipe at the bottom of the spillway (Rėkyvos… 2008) and the lake water level depends on the ratio of precipitation and evaporation. Therefore, when the lake water level is low, it is mainly determined by climatological factors. Hence, Lake Rėkyva the water level of which directly depends on precipitation and mire water regime can be considered to be a part of the wetland complex, i.e. a bog lake. The main elements of the water balance of the lake include precipitation, evaporation from the surface of the lake and evapotranspiration from the catchment.

**Data and Methods Used**

The method of the dependence of the water level for the variable length period of precipitation amount was chosen for modelling the water level of Lake Rėkyva. This method was accepted because in this case, the main part of simple methods using the variability of the same parameter (Altunkaynak *et al.* 2003) and autocorrelation ignore the amount of precipitation as an important parameter. Many other models where the amount of precipitation is the main input (for example Tennessee Valley Authority model, Snyder 1963) are not suitable for this particular case because of the peculiarities of Lake Rėkyva catchment where precipitation flow to the lake in the mire catchment is differently delayed. Models and methods that require more input data like Thornthwaite-Mather (Steenhuis 1986) or even more complex arrangements including atmospheric circulation patterns (Rodionov 1994) are not useful in this case because significant results can be obtained examining precipitation only, so there is no need to include other parameters making no difference for the results.

The study was carried out in several stages:

- the analysis of relations between the average monthly lake water level and the past period precipitation sum;
- the compilation of the simplest available model for calculating monthly and annual averages of the lake water level;
- modelling the average annual lake water level and comparing the received results with the available data on the measurement of the lake water level.

Data on precipitation was taken from Šiauliai meteorological station situated 7 km north from Lake Rėkyva. Potential evapotranspiration (PET) was calculated using data on air temperature observation from the same meteorological station (Thornthwaite 1948).

Data on observing the water level of Lake Rėkyva was taken from three sources: 1) hydrological yearbooks recorded in 1950–1964 (Гидрологический… 1954–1964) containing data on observing daily water level from the water measuring station kept in operation at that time; 2) reports on the year 1979 embracing data on observing the annual average and maximal and minimal water level in Rėkyva thermal power plant outflow canal in 1965–1978; 3) and data on daily (working days) water level observations carried out in the outflow canal by JSC Šiaulių vandenys in 2006 08–2007 12.

The relations between the calculated monthly average on Lake Rėkyva water level and a variable length (1 to 15 months) period of precipitation amount were analyzed using data on the water level of Lake Rėkyva and precipitation amount for periods 1950–1963 and 2006–2007. The essential correlation coefficients or factor loadings are distinguished according to the below formula (Смирнов 1980):

$$\left|r_p\right| = t_{p,f} \Big/ \left(t_{p,f}^2 + N - 2\right)^{1/2}, \quad (1)$$

where $t_{p,f}$ is the critical value of Student distribution with $f = N - 2$ degrees of freedom and the significance level $p$ chosen from statistical tables.

The significance level ($p$-level) represents the probability of error (for example, the significance level of 0.05 points to 5 % probabilities showing the accidental relation between the variables). The significance level of 0.05 is a borderline acceptable error level. Significant results at level $p \leq 0.01$ are considered statistically significant and at levels $p \leq 0.005$ or $p \leq 0.001$ – highly significant (Смирнов 1980).

As a result, two matrixes with three different calculation variants of the correlation between precipitation and Rėkyva Lake water level each were developed. Calculation variants differ on the criterion that was the basis for the precipitation summing period (Table 1). All chosen criteria for precipitation summing periods varied between 1 and 15 months.

**Table 1.** The matrixes of the correlation between the water level and precipitation amount

| Data period | 1950–1963 | 1950–1963, 2006–2007 | Criterion of precipitation summing period selection |
|---|---|---|---|
| Variant | A | A' | Fixed period beginning – September |
| | B | B' | Shortest period with sufficient significance level |
| | C | C' | Highest correlation coefficient |

Annual average water level changes in Lake Rėkyva during the period of 1925–2007 were modelled using data on observing precipitation obtained by Šiauliai meteorological station during the period from 1925 to 2007. The average annual water level was calculated using the modelled average monthly water level. Model validation was carried out comparing the results received in the periods of 1964–1978 and 2006–2007 with the data of the same period on observing the water level.

## Dependence of the Water Level on Precipitation Amount

The analysis of relations between the water level of Lake Rėkyva and precipitation amount showed that their correlation varied between – 0.596 and 0.962. Yet it is possible to select a length period of past precipitation for every month when the correlation between the average monthly water level and precipitation amount can be considered not less than significant ($0.05 \geq p \geq 0.01$). For this reason, it can be stated there is a close connection between the specified length period precipitation amount and the average monthly water level of Lake Rėkyva.

The identified dependences for the first half and remaining months of the year differed notably while analyzing relations between the average monthly water level and the past specified length period precipitation amount. The significance level of the correlation between the average monthly water level for the first six months and the precipitation amount of the specified length period coefficients in A, B and C variants varied between 0.01 and 0.001 and those of the remaining months between 0.05 and 0.01. A connection between the average water level for March and the precipitation amount of the period from December to March (4 months) was extremely close (B variant $r = 0.947$). This case shows that the average water level for March has been greatly influenced by the amount of water accumulated in snow and frozen soil layer during the winter. Another high correlation coefficient is between the average water level for April and the precipitation amount of the period from October to April (7 months) as well as the average water level for May and the precipitation amount of the period from November to May (7 months). This group of close connections between the average monthly water level and the specified length period precipitation amount can be expanded by the average monthly water levels for January, February and June and the fixed periods of precipitation summing (accordingly 12, 11 and 9 months). The connection between the water level for the first half of the year and precipitation amount fallen after the end of the intensive evaporation season becomes more evident.

However, the water level for the months in the second half of the year is less dependent on the precipitation amount of the past period and the lake water level depends on the precipitation amount of 12–15 months length period. The water level for these months is more influenced by intensive evaporation and probable water suppression till the end of the summer in the dried peaty catchment of Lake Rėkyva.

Correlation was highly significant ($p \leq 0.001$) for more months including July, August, September, October, November and December while using variant A' for calculations.

While analyzing the correlation between the average monthly water level and the shortest past period length with a sufficient level of significance, precipitation amount (B, B') for January, February, March, May, June and July differs from the period length used in variants A and A'. The period length of precipitation summing for calculating correlation with the average monthly water level for June, August, September, October, November and December while choosing the period length of the highest correlation coefficient (C, C') does not differ from the period length in variants A and A', when the period length of precipitation summing was counted from past September (Table 2).

The average monthly water level of Lake Rėkyva measured in 2006-08–2007-12 was compared to the same period modelled using different variants (A, A', B, B', C, C') water level (Fig. 2). The measured water level is lower than that for most of the months. The least difference between the modelled and measured average monthly water level values was in variant C'. The graph produced on the basis of calculating variant C' was used for model validation.

Validation was performed by calculating the average difference between the measured and modelled lake water levels in the period from 2006–08 to 2007–12 adding (subtracting if difference is negative) it to the equation.

**Table 2.** The correlation between the average monthly water level and the precipitation amount of the past period

| Month | Period (length in months) | *r* | | Period (length in months) | *R* | | Period (length in months) | *r* | |
|---|---|---|---|---|---|---|---|---|---|
| | | A | A' | | B | B' | | C | C' |
| January | 5 | 0.865 | 0.83 | 12 | 0.904 | 0.892 | 14 | 0.917 | 0.912 |
| February | 6 | 0.884 | 0.846 | 11 | 0.902 | 0.889 | 15 | 0.924 | 0.917 |
| March | 7 | 0.943 | 0.943 | 4 | 0.947 | 0.942 | 15 | 0.959 | 0.950 |
| April | 8 | 0.962 | 0.938 | 8 | 0.962 | 0.938 | 8 | 0.962 | 0.938 |
| May | 9 | 0.936 | 0.93 | 8 | 0.907 | 0.909 | 9 | 0.936 | 0.930 |
| June | 10 | 0.962 | 0.953 | 9 | 0.898 | 0.898 | 10 | 0.962 | 0.953 |
| July | 11 | 0.807 | 0.957 | 14 | 0.764 | 0.946 | 11 | 0.807 | 0.957 |
| August | 12 | 0.811 | 0.944 | 12 | 0.811 | 0.944 | 12 | 0.811 | 0.944 |
| September | 13 | 0.819 | 0.944 | 13 | 0.819 | 0.944 | 13 | 0.819 | 0.944 |
| October | 14 | 0.870 | 0.942 | 14 | 0.870 | 0.942 | 14 | 0.870 | 0.942 |
| November | 15 | 0.761 | 0.926 | 15 | 0.761 | 0.926 | 15 | 0.761 | 0.926 |
| December | 15 | 0.804 | 0.947 | 15 | 0.804 | 0.947 | 15 | 0.804 | 0.947 |

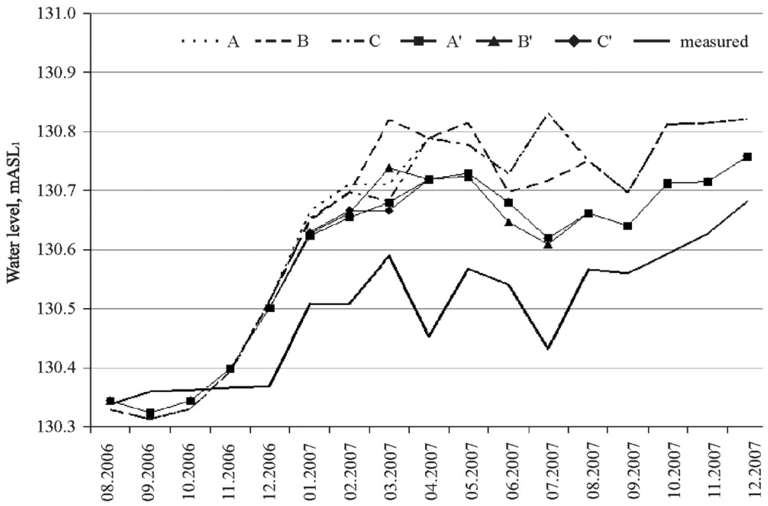


**Fig. 2.** The average monthly water level of Lake Rėkyva measured and modelled using different variants

## The Water Level of Lake Rėkyva Modelled in 1926–2007

For modelling the average annual water level of Lake Rėkyva in 1926–2007, the precipitation amount of the past period was used. The length of the period having the highest correlation and the longest data row was chosen (C'). For most of the years, the measured water level was lower than the modelled one (Fig. 3).

The biggest difference in the measured water level that was significantly lower than the modelled one was established in 1960–1961 and 1971–1973. The difference was mostly influenced by anthropogenic actions: mire drainage, runoff from lake regulation and the use of lake water resources for industrial and household needs. For this reason, it can be considered that hydrological conditions for the catchment influencing fluctuations in the level of lake water had been relatively natural until 1955. Later, the individual water balance components of Lake Rėkyva were significantly influenced by anthropogenic activity.

The modelled average annual level of lake water matches the relatively natural water balance of Lake Rėkyva influenced by changes in climate (precipitation). A trend towards increasing water level dominated in the period between 1976 and 1997. However, the situation has been changing since 1998 following a trend towards decreasing water level. Both trends can be clearly seen in data on the modelled water level as well as in the measurement data sets. Data on measuring the water level of Lake Rėkyva during the period of 2006–2007 is quite similar to the modelled data. Therefore, it can be taken into account that the present water level of Lake Rėkyva is close to the natural one.

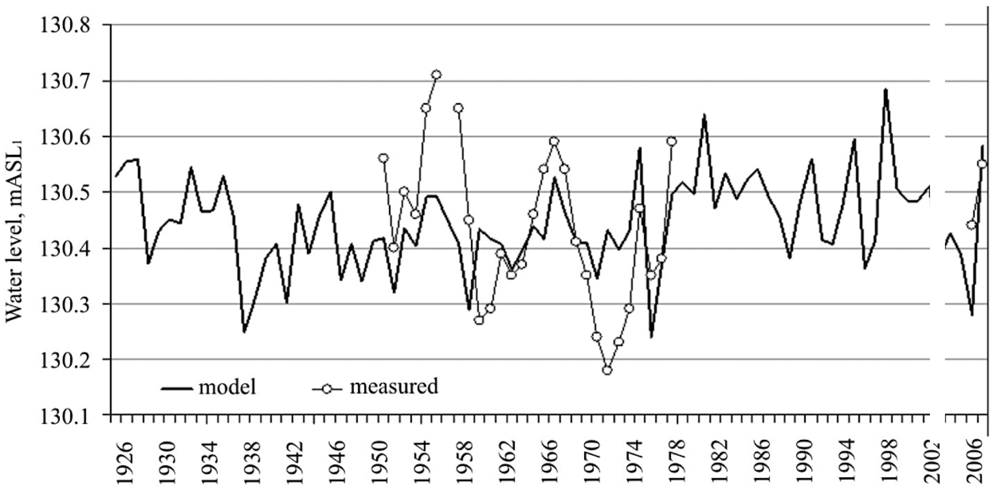


**Fig. 3.** The measured and modelled average annual water levels of Lake Rėkyva

The norm of the average annual water level calculated from the modelled results makes 130.44 m above the sea level (ASL). The same norm was calculated using data on measurement. The modelled average annual water level of Lake Rėkyva was little changed by anthropogenic activities done in the period from 1926 to 1955 and made 130.43 m ASL. The water level significantly changed by anthropogenic activities in 1956–1975 was 130.42 m ASL and its fluctuation amplitude was 0.34 m. The highest modelled lake water level was in 1977–1998 (average 130.48 m ASL) and the average water level in 1999–2007 was close to normal.

## Conclusions

1. The analysis of connections between the fixed monthly water level and the precipitation sum of the past period showed that the length of the precipitation summing period when the correlation between precipitation amount and the average monthly water level is at least sufficient ($0.05 \geq p \geq 0.01$), can be found for each month of the year.

2. Correlations between the average monthly water level for March, April, May and June and the precipitation amount of several past months have the highest significance ($p \leq 0.001$).

3. The annual water level modelled using precipitation matched best with the measurements of the water level from the periods with no anthropogenic influence (until 1955) and with a fixed height spillway (since 1975).

4. Comparing the modelled average monthly water level for the period of 2006–2007 with the corresponding measurements of the water level showed that the modelled water level differed from 16 to 3 cm. This difference accounts for 5–28 % of the average long-term water level fluctuation amplitude. The average water level modelled using this method yields a quite significant error. However, the correlation coefficient between the modelled and measured average annual water levels during the period without natural outflow from the lake (until 1955 and after 1975) is high and makes 0.765 ($p \geq 0.01$). Hence, the use of this method is suitable for identifying trends towards fluctuation in the water level for a long period.

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## PELKINIŲ EŽERŲ PRAEITIES VANDENS LYGIO KAITOS REKONSTRUKCIJA PAPRASTO MODELIAVIMO METODU. RĖKYVOS EŽERO PAVYZDYS


**J. Taminskas, A. Mažeikis, R. Linkevičienė**



Santrauka

Paviršinių vandens telkinių vandens lygio kaitos tyrimai yra vienas iš metodų klimato kaitai tirti ir vertinti. Straipsnyje siūlomas metodas rekonstruoti pelkinių ežerų vandens lygio kaitą naudojant minimalų meteorologinių duomenų rinkinį, kuris yra statistiškai patikimas ir tinkamas ilgo laikotarpio vandens lygio kaitos rekonstrukcijai. Tiriamojo Rėkyvos ežero atveju patvirtintas itin glaudus ryšys tarp skirtingos trukmės praeities periodo kritulių kiekio sumos ir vandens lygio kaitos, todėl naudojant paprasčiausią regresiją priklausomybė išreikšta lygtimis, kuriomis galima nustatyti vandens lygio kaitą tuo laikotarpiu, kai nėra stebėjimų, bet yra kritulių kiekio duomenys.



**Reikšminiai žodžiai**: vandens lygis, modeliavimas, pelkiniai ežerai, hidrologija.