Calculation of the maximum levels of lakes in the north-west Russia in the absence of hydrometric observation data

E V Davydenko and A V Sikan

Russian State Hydrometeorological University (RSHU), Russia
davydenko091@gmail.com*, sikan07@yandex.ru

Abstract. The methodology for calculation the maximum water levels of unexplored lakes is examined in the article. This methodology is based on the generalization of all available information about the lakes’ regime in the North-West of the Russian Federation. The dependence of the standard deviation of the upper water level on the average long-term upper level is revealed for medium and small lakes with a specific drainage area of less than 100. The recommendations for calculation of the parameters of the probability curve of maximum levels of unexplored lakes of the North-West of Russia and of the Southern part of the Kola Peninsula are developed. It is proposed to determine the probability curve of maximum water levels of an unexplored lake not with accordance to the similar water tank, but on the basis of regional generalizations, which integrates all available information about the lake regime of the studied area.

1. Introduction

Lakes are unique water bodies. They hold an important economic and environmental significance. There are more than two million of lakes in Russia with a total area above 350 thousand square kilometres, and mainly those are small and very small lakes with the average area of a one square kilometre. However, less than 1% of the water bodies have been covered by hydrometric observations so far. Therefore, the task of calculation of the lake levels in the absence of observation data is persisting.

In the valid regulatory normative document ‘SR 33-101-2003’ the following formula for calculation the maximum levels of unexplored flowing lakes is recommended:

\[ \Delta H = \beta (A/\Omega)^{0.5} \]

In equation (1) \( \Delta H \) – average long-term spring-summer rise in the water level in the lake above the runoff threshold, cm; \( A \) – catchment area of a lake basin, km\(^2\); \( \Omega \) – lake mirror area, km\(^2\); \( \beta \) – coefficient determined from observation data at neighbouring lakes with close ratios of morphometric characteristics and a flow regime from a water tank.

The values of the coefficient of variation (Cv) and the ratio of the coefficient of variation to the coefficient of asymmetry (Cs/Cv) are recommended to be determined from an observational data of neighbouring lakes that are explored.

In practice these recommendations are difficult to work with because:
- this methodology can be used only for ‘flow-through’ types of lakes;
- a threshold of lake drainage is not always reliably measured in the course of the field surveys;
- for the correct calculation it is necessary to know not only the runoff threshold of an unexplored lake, but also of an analogue lake, because the coefficient of variation depends on the level of zero of gauge;
- in some areas it is difficult to find an analogue lake;
- when using only one analogue, the error $\beta$ can be significant.

Taking into account the given arguments, this article puts forward the following proposals:

1. As an actual zero point of graph of an unexplored lake it is recommended to use the elevation of the average long-term minimum level of summer low water ($H_{\text{min}}$) instead of a runoff threshold. This mark may be determined at the summer runoff flow with acceptable accuracy during field surveys. Additional information can be obtained with help from local residents. Also, in most cases, this mark is close to the lake water-mark, which is plotted on topographic maps. See related publication [2].

![Figure 1. Scheme of lake’s hydrological posts on the North-West of the Russian Federation.](image-url)
2. Instead of a code of variability, consider using for standard deviation a characteristic of the variability of the maximum level of a lake. It is justifiable because it doesn’t depend on a zero of a graph of a water gauge station.

3. The parameters of the probability curves of maximum water levels of an unexplored lake should be determined not with reliance to one analogue, but on the basis of geography-specific generalizations, using all available information about the regime of lakes within a studied area.

2. Materials and methods

The research is conducted for the area of The North-West of Russian Federation including the Republic of Karelia and the Southern part of the Kola Peninsula.

Data on 42 lakes with water surface areas from 2 to 2613 km$^2$ is used for the research. The scheme of location of the lakes is shown in figure 1.

According to work [3], three regions have been identified on the territory under the scrutiny: 1 – Kola segment; 2 – Karelian segment; 3 – North-Western part of the Russian plate – all are affected by the Valdai glaciation. These regions were covered by the last Valdai glaciation, which ended only about 10,000 years ago. These are territories of wide distribution of lakes of glacial origin, adjacent to water bodies of river, organogenic, tectonic and karst origin. See related publication [4, 5, 6, 7, 8, 9].

The lakes with a normalized catchment area ($\frac{A}{\Omega}$) more than 100 km were excluded when justifying the research methodology. The remaining lakes were divided into two groups. The first group embraced only small and medium-sized lakes [10], with a surface area less than 100 km$^2$. The second group embraced all lakes [11].

3. Results

For the first group of the lakes it was revealed that there is a stable dependence of the average maximum water level above $H_{max}$ on the indicator ($\frac{A}{\Omega}$)$^{0.5}$ for the entire territory of the investigation (figure 2):

$$H_{max} = 21\left(\frac{A}{\Omega}\right)^{0.5}$$  \hspace{1cm} (2)

![Figure 2. Dependence of the average maximum lake level on the indicator ($\frac{A}{\Omega}$)$^{0.5}$ for the territory of the North-West of the Russian Federation.](image)
The multiple regression equation was obtained for the second group of the lakes. It includes the lake surface area, the lake drainage area, and their combination in the form of an indicator \((A/\Omega)^{0.5}\) as predictors:

\[
\bar{H}_{\text{max}} = 22(A/\Omega)^{0.5} - 0.049\Omega + 0.0032A
\]  

(3)

The absolute term in the equation has turned out to be statistically insignificant [12], therefore the parameters of the equation (3) were obtained with a zero-absolute term (table 1). The graph of the correlation between the empirical and maximum levels calculated by the formula (3) is shown in the figure 3.

![Figure 3](image)

**Figure 3.** The dependency graph between the empirical and calculated by the formula (3) average maximum water levels for the lakes of the North-West of the Russian Federation.

**Table 1.** The parameters of the equation of a multiple linear regression for the dependence (3).

| Characteristic          | Coefficient | Standard error | Student Statistics |
|-------------------------|-------------|----------------|-------------------|
| Absolute term           | 0           | –              | –                 |
| Water surface area, \(\Omega\) | -0.049      | 0.015          | -3.23             |
| Catchment basin, \(A\)  | 0.0032      | 0.00054        | 5.93              |
| \((A/\Omega)^{0.5}\)   | 22.0        | 1.04           | 21.2              |

The relative error of calculation by formula (2) was 20%, the maximum - 44%. The relative error of calculation by formula (3) was 20%, the maximum - 48%.

The dependence of the standard deviation of the upper water level on the average long-term upper level is revealed for medium and small lakes with a specific drainage area of less than 100 (figure 4). When constructing the graph, the lakes which are used as reservoirs of seasonal regulation, were excluded.

The dependence is approximated by the exponential expression:

\[
\sigma_{H_{\text{max}}} = \bar{H}_{\text{max}}^{0.7}
\]  

(4)

The relative calculation error, estimated with the formula (4), was 20%, the maximum was 66%.

The \(Cs/Cv\) ratio is taken as the average within the identified areas: area 1 – \(Cs/Cv = 0\); area 2 – \(Cs/Cv = 0.5\); area 3 – \(Cs/Cv = 1.0\).
Figure 4. The dependency graph between the average maximum water level and the standard deviation for medium and small lakes in the North-West of the Russian Federation.

4. Conclusion

The methodology for calculation of the maximum water levels of unexplored lakes has been explained. It is based on the generalization of all available information about the lakes’ regime of the explored area.

It is proposed to use the elevation of the average long-term minimum level of summer low water as the zero of graphs of unexplored lakes. It will make possible the application of a unified approach, when calculating the maximum levels of not only the lakes that are flowing, but also of those which are with outlets or terminal.

Recommendations for calculation of the parameters of probability curves of the maximum levels of unexplored lakes in the North-West of the Russian Federation and the southern part of the Kola Peninsula are developed.

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