Predictive model to determine the volume of water flooded reservoir with the slope of the bottom topography that is not part of mounds or depressions

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Abstract. The predictive model for determining of water volume depending on the level of flooding based in the article proposed. The model includes the coastal zone and part of the intermediate zone between the depressions and the mounds of the bottom. The model makes it possible to outpace the potential danger of a hydrological emergency in terms of water volume, depending on a small number of parameters.

1. Introduction
One of the most important global problems of the last decades has been the global climate change. The imbalance of natural systems has led to temperature anomalies, changes in precipitation patterns and an increase in such phenomena as hurricanes, floods, earthquakes and droughts. According to the United Nations, the damage caused by natural disasters, including floods has only increased over the years. Flooding is one of the most dangerous and frequent destructive disasters in terms of area of distribution, average annual material damage and the number of victims.

Currently, there are no uniform rules for accounting, collection and storage of information on waters that occurred in different regions, a single system of damage assessment and a single system of complex multi-factor flood risk assessment. In Russia, 40-70 major floods occur annually, of which 70-80% floods and floods. The average annual damage from such flooding is more than 40 billion rubles [1]. In Russia there are more than 30 thousand reservoirs, which are operated without reconstruction for more than 50 years and are in disrepair.

Numerous studies by European scientists show that due to climate change, the socio-economic development of infrastructure in Europe could double the risk of flooding by 2050. Currently, catastrophic flooding in Europe occurs every 16 years. Floods in 2000-2012 cost the European Union more than 50 billion euros, and by 2050 these losses could reach 25 billion euros per year.

Thus, the problem of management of the hydrological situation of the area is quite relevant, because there is a danger of hydrodynamic accidents.
2. Materials and methods
To ensure the successful implementation of measures to reduce damage from floods, it is necessary to forecast the development of floods on the basis of mathematical modeling of the flooding process, which provides adequate forecast values of the main characteristics of flooding of the territory necessary for the development of effective measures to minimize damage from them. A special interest of applied nature is the problem of modeling the slopes of the bottom relief, which are not part of the mounds or depressions. These slopes include the coastal zone, as well as part of the intermediate zone between depressions and mounds [2].

For land topography these areas include Dingle, sole, gully, precipice, part of the valley etc. These sites will be modeled by defining equations of a plane.

3. Results and discussions
The main result of the study was the problem of modeling the slopes of the bottom relief that are not part of the mounds or depressions. These slopes include the coastal zone, as well as part of the intermediate zone between depressions and mounds [2].

For land topography these areas include Dingle, sole, gully, precipice, part of the valley etc. The sites were modeled by defining equations of a plane bounded by the point’s spot soundings (figure 1).

Figure 1. Part of the terrain, limited by the points spot soundings. The figure shows the plot of terrain with averaged empirical level lines that define the convex parts for submarine and surface (shore) of the bottom topography and boundaries of the depressions between them. The points were located on two contours of an imaginary topographic map (with approximately equal spacing between the points on one contour).

Let \( M(x, y, z) \) be a variable point on the plane \( (abkm) \) (figure 2). In this case, the coordinates of the points: \( a(x_1, y_1, 0), b(x_2, y_2, 0), c(x_3, y_3, 0), d(x_4, y_4, 0), m(x_3, y_3, -h), k(x_4, y_4, -h) \).
Figure 2. Part of the simulated terrain. The figure shows an image of a part of the simulated relief with a variable point on the plane by the coordinates \((abkm)\) of the depth measurements of the underwater and surface (land) terrain for the conditions of the coplanar vector product.

Thus, the practical solution was determined by the fact that the equation of this plane was obtained from the condition of complementarity of vectors in the form of a mixed product \((aM, bM, mM) = 0\).

Calculating the following determinant

\[
\begin{vmatrix}
  x - x_1 & y - y_1 & z \\
  x - x_2 & y - y_2 & z \\
  x - x_3 & y - y_3 & z + h \\
\end{vmatrix} = 0
\]

get the equation of the plane

\[
z = p(x, y) = x \frac{h(y_2 - y_1)}{d} + y \frac{h(x_1 - x_2)}{d} + \frac{h(x_1y_2 - y_1x_2)}{d}.
\] (1)

The relief area with the support in the form of a quadrangle \(p = (abcd)\) was modeled by the equation (1), limited acting on the carrier:

\[p(x, y) \times x_p(x, y),\]

here \(x_p(x, y)\) the indicator function of the rectangle:

\[
x_p(x, y) = \begin{cases} 
0, & \text{если } (x, y) \notin P, \\
1, & \text{если } (x, y) \in P.
\end{cases}
\]

Summing up all such sections, we obtain a functional description of areas of the relief described in this paragraph.
\[ \sum p_j(x, y) \times x p_j(x, y). \]

Similar modeling captures also cases with a flat bottom or a plateau (figure 3).

**Figure 3.** Schematic representation of the relief with a flat bottom and a plateau. The schematically image of a relief with a flat bottom and the plateau is submitted that visually describes modeling not being a part of hillocks and hollows. Characterizes similar modeling for the overland (coastal) land relief determined by the topographic map.

Practical solution the main task of modeling the flooded surface is to predict the volume of water caused by natural or climatic weather conditions [3-18].

It is desirable to have a model with certain and small set of parameters that characterize the volume of water [19-23]. Let's denote the depth value on the level line corresponding to the rectangle \( D_j \) (for example in point \((x_{(up)}, y_{(up)})\)) through \( h_{D_j} \).

Let the function defined by the formula (2) for the given medium be - \( f_j(x, y) \). The center of the substrate – at the point \((x_j, y_j)\) and the depth of the measurement at this point is - \( h(x_j, y_j) \).

Then the volume of liquid concentrated on this rectangle for the underwater hill is equal to:

\[ \Pi D_j = h_{D_j} \times S_{D_j} + v_j^+ \times \left[ \mu \int f_j(x, y) \chi_{D_j}(x, y) \, dx \, dy \right], \]  

(2)

where \( \mu = -1, v_j^+ = \left[ h_{D_j} - h(x_j, y_j) \right] \), the indicator function of \( \chi_{D_j}(x, y) = 1 \), for \((x, y) \in D_i\), and zero otherwise.

The volume of fluid centered on that rectangle for underwater depressions equal:

\[ \Pi D_j = h_{D_j} \times S_{D_j} + v_j^- \times \left[ \mu \int f_j(x, y) \chi_{D_j}(x, y) \, dx \, dy \right], \]  

(3)

where \( \mu = +1, v_j^- = \left[ h(x_j, y_j) - h_{D_j} \right] \).

The total volume of the underwater part of the flooded relief consists of all local volumes calculated for depressions and mounds (2, 4), plus the volume concentrated on the parts of the bottom relief modeled by planes:

\[ \Pi_{(waterpart)} = \sum \Pi_{D_j} + \sum \int p_j(x, y) \, dx \, dy, \]  

(4)
In fact, we obtain a predictive model that depends on a small number of parameters. So, if the water level rises to a height $h_{level}$ the new volume of water is calculated by two terms:

1) the first term is associated with the relief within the boundaries of the former reservoir. To the volume of water calculated by formulas (2)-(4) the summand is added:

$$\Pi_{level} = h_{level} \times S(water),$$

here $S(water)$ the surface area of the reservoir, which is easy to determine on the map;

2) the second term is connected with the flooded relief of the earlier coastal plots [19-25]. The volume of water in this area is calculated according to the same scheme by formulas (8)-(10). In this case, to determine the media - $\hat{D}_j$ and $\hat{P}_j$ land relief is used (figure 4). Let us denote it:

$$\Pi_{(overlandpart)} = \sum_j \Pi_{\hat{D}_j} + \sum_j \int \int \hat{p}_j(x,y)dx dy,$$

The final formula is as follows:

$$\Pi(h_{level}) = \Pi_{(waterpart)} + h_{level} \times S(water) \times \Pi_{(overlandpart)}. \tag{5}$$

![Figure 4](image)

**Figure 4.** Schematically full predictive model of flooding of the area in borders of a reservoir of a surface and underwater part of a relief is presented. For accounting of hollows and hillocks of a relief, both coastal, and underwater it is possible and it is necessary to model by means of the equations of the plane using the topographic map of the area with the put lines of level.

### 4. Conclusion

Thus, as a result of the study on a fundamentally new basis, a predictive model for determining the volume of water in a flooded reservoir is obtained. This model actually has one control parameter - $h_{level}$. Of course, taking into account the factor that its value affects the shape of the newly flooded, therefore, the land part of the relief of the territory. They are defined in a similar way. In model dynamics of process is not considered, however it is simple to carry out calculation of, a new configuration of flooding at change of water level with high frequency. Note that at the current level to determine the level line and the shape of the aquifer media can be using sonars. Based on the proposed model have been carried out the calculation of the probability of occurrence of accidents at low intakes of the Voronezh region. The conducted research allowed to establish the number of small water intakes that are in an emergency condition and to determine the initial level of development of hydrological emergencies necessary to create a predictive model of flooding.
References

[1] Puchkov V A, Akimov V A, Sokolov Y I Disasters and sustainable development in the context of globalization: a popular Science publication 2013 (Moscow Institute GOCHS) p 328
[2] Arifullin E Z 2014 Bulletin of the Voronezh state technical University 10 10-12
[3] Semenova O M 2008 Analysis and modeling of runoff formation in poorly studied basins (on the example of the Lena river basin) (candidate dissertations of technical Sciences) (St. Petersburg, St. Petersburg) p 216
[4] Eitrich G, Hardy A, Bojang L, Cross D 2017 Remote Sensing of Environment 217 506-522
[5] Hu R, Fang F, Salinas P, Pain C 2018 Journal of Hydrology 560 354-363
[6] Abebe Y A, Ghorbani A, Nikolic I, Vojinovic Z, Sanchez A 2019 Environmental Modeling & Software 111 483-492
[7] Mignot E, Li X, Dewals B 2019 Journal of Hydrology 568 334-342
[8] Zischg A P, Mosimann M, Bernet D B, Röthlisberger V 2018 Journal of Hydrology 557 350-361
[9] Molinari D, De Bruijn K M, Jesica T, Rodriguez C, Giuseppe T, Laurens A, Bouwer M 2018 International Journal of Disaster Risk Reduction, In press, corrected proof, Available online 1 5 2-24
[10] Munoz D H, Constantinescu G 2018 Advances in Water Resources 122 148-165
[11] Wang Y, Chen S A, Fu G, Djordjevic S, Zhang C, Dragan A 2018 Environmental Modelling & Software 107 85-95
[12] Coles D, Yu D, Wilby R L, Green D, Herring Z 2017 Journal of Hydrology 546 419-436
[13] Liu Z, Merwade V 2018 Journal of Hydrology, 565, 138-149
[14] Jamal B, Löwe R, Bach P M, Urich C, Arnbjerg-Nielsen K, Deletic A 2018 Journal of Hydrology 564 1085-1098
[15] Andreas P Z, Hofer P, Mosimann M, Röthlisberger V, Jorge A, Keiler R M, Weingartner R, Zischg A P 2018 Science of The Total Environment 639 195-207
[16] K. Kim, P. Pant, E. Yamashita 2018 International Journal of Disaster Risk Reduction, 31 1177-1186
[17] Chaumillon E, Bertin X, Fortunato A B, Bajo M, Schneider J-L, Dezileau L, Walsh J P, Michelot A, Chauveau E, Créach A, Hénaff A, Sauzeau T, Waeles B, Gervais B, Jan G, Baumann J, Breilh J-F, Pedreros R 2017 Earth-Science Reviews 165 151-184
[18] Tanaka T, Tachikawa Y, Ichikawa Y, Yorozu K 2017 Journal of Hydrology 554 370-382
[19] Hartnett M, Nash S Water Science and Engineering 201 175-183
[20] Chang C T 2017 Journal of Environmental Management 200 1-5
[21] Teng J, Jakeman A J, Vaze J, Croke B W, Dütta D, Kim S 2017 Environmental Modeling& Software 90 201-216
[22] Stripling S, Panzeri M, Blanco B, Rossington K, Sayers P, Borthwick 2017 Coastal Engineering 121, 129-144
[23] Fewtrell T, Bates P Horritt D M, Hunter N 2008 Hydrol. Process. Int. 22 5107–511