Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.34910/MCE.101.10

Flood events dynamics estimation methodology in a GIS environment

A. Nikonorov*, V.L. Badenko
Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
** E-mail: coolhabit@yandex.ru*

Keywords: river basins, floods, flood protection, self-regulated dams, GIS environment

Abstract. Hard floods of rare frequency can cause significant damage to the ecosystem of the river basin, as well as to settlements and infrastructure. Therefore, the urgent task is to develop sustainable measures of minimization of the dangerous effects of these phenomena. One of the feasible technical measure is the construction of a self-regulating flood control dams with temporarily filled reservoirs system in the river basin. This article proposes an improved technique for flood events modeling, taking into account the proposed measures. The proposed method is based on the modeling in a GIS environment coupled with hydrologic simulation software. GIS modeling is preceded by the development of the digital elevation model. According to the results of the research, the requirements for the input data were formulated. An algorithm for creating models was given, as well as examples of already created models. The viability of this technique is shown, together with the limitations identified during the simulation.

1. Introduction

Hard floods of a rare occurrence annually take place in Russia. The average annual flood damage is estimated at about 40 billion rubles [1]. Flood damage assessment is a multi-criteria task of calculating the integral risk, which includes technological, economic, environmental and social risks [2].

From the often-recurring nature of flood events, it is obviously necessary to take timely and accurate measures to prevent and minimize damage from these phenomena [3, 4]. Flood protection measures are divided into operational (urgent) and technical (preventive) [5]. Operational measures include timely forecasting of maximum flood levels, timely notification of possible dangerous levels, organization of evacuation of the population and material assets, etc. [2]

Technical measures are precautionary in nature, and their implementation requires the advance construction of special engineering structures with the expenditure of significant material and financial resources. The complex of technical measures distinguishes between active and passive methods of protection (Fig. 1).

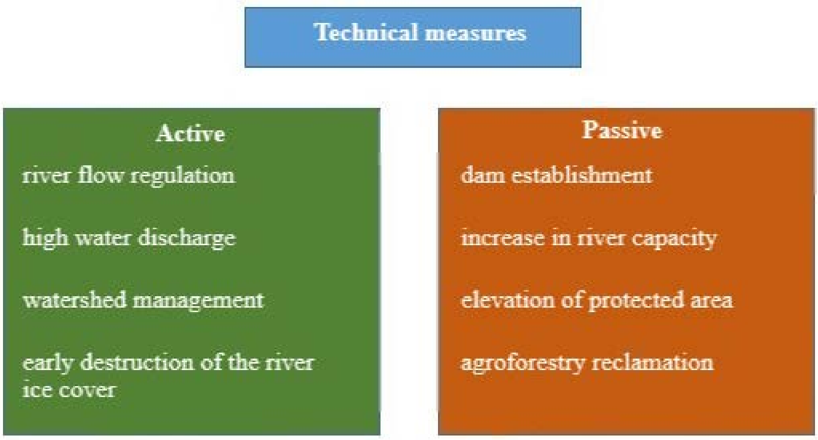

Figure 1. Technical flood protection measures.

Nikonorov, A., Badenko, V.L. Flood events dynamics estimation methodology in a GIS environment. Magazine of Civil Engineering. 2021. 101(1). Article No. 10110. DOI: 10.34910/MCE.101.10

The choice of method for protecting flooded areas depends on many factors, such as the hydraulic regime of the watercourse, terrain, engineering-geological and hydrogeological conditions, the presence of engineering structures in the riverbed and floodplain (dams, reservoirs, bridges, roads, water intakes, dams), the presence of an agricultural facilities located in the flooded zone, etc.

Nowadays, research on the prevention and minimization of flood consequences is also being conducted in the direction of flood events modeling on river basin modified by different engineering solutions appliance [6].

Geoinformational modeling (GIS modeling) of river basins is the most demanded area of practical application of digital elevation models (DEM). Recently, not a single hydrological and geomorphological study has been complete without such modeling. The DEM allocation technology for the hydrographic network and river basins was tested on the example of the territory of Switzerland near the city of Waldkirch [7]. As a result of modeling watercourses in the ArcGIS software package and visual stereo decryption in the DSP PHOTOMOD images to the corresponding territory, a map of the hydrographic network was created. A map of catchment areas was built. The main advantage of the modeling procedure compared to visual stereo decryption was the automation of the process and, as a result, the shorter execution time [8, 9].

Another interesting model example in terms of the research is the HiResFlood-UCI. It was developed by coupling the NWS's hydrologic model (HL-RDHM) with the hydraulic model (BreZo) for flash flood modeling at decameter resolutions [10]. The coupled model uses HL-RDHM as a rainfall-runoff generator and replaces the routing scheme of HL-RDHM with the 2D hydraulic model (BreZo) in order to predict localized flood depths and velocities. A semi-automated technique of unstructured mesh generation was developed to cluster an adequate density of computational cells along river channels such that numerical errors are negligible compared with other sources of error, while ensuring that computational costs of the hydraulic model are kept to a bare minimum [11, 12].

In conditions of aggravation of the flood situation in Russia and in the world, information support for managerial decision-making is of particular importance. Therefore, executive authorities are in demand to obtain the results of GIS modeling of floods based on remote sensing data [7, 9].

An interesting modern technical flood protection passive measure for the problem solution is the creation of a distributed network of self-regulated flood dams (SRFD) with temporarily filled reservoirs on river basin to minimize the consequences of flood events [13]. The study [14, 15] considers the issue of finding the parameters of a system that includes a hydroelectric power station (cascade of hydroelectric power stations) for complex purposes (electricity generation, flood control) on the main river with minimal reference mark and capacity for regulating maximum flow. An algorithm was developed and mathematical programs were implemented with the mathematical models of operating modes of a channel hydropower plant and flood control measures on the side tributaries. Authors of this article propose the improvement of the multicriteria selection technique for the distributed network of reservoirs location determination.

The developed method was designed to research the changes in the flood situation in the river basin with different options for the location of SRFD with various parameters. This will justify the location of the SRFD system with certain parameters in the river basin and evaluate the impact of the SRFD on ecosystems in the river basin. Proposed method is based on the GIS modeling with the DEM usage.

The design of self-regulatory flood dams is a multi-criteria task, and the final decision should be determined taking into account technological, economic, environmental and social factors.

Previous studies have shown the feasibility of flood control measures in the form of temporarily filled self-regulated flood dams with temporary filled reservoirs [16, 17]. The aperture of the dam is designed with an unregulated spillway without the use of gates, which increases the reliability of the operation and reduces the cost of maintenance. During the period of accumulation of flood discharge, the bed of such a reservoir is flooded for a short time, and after self-emptying until the next flood, it remains in its natural state without any changing of natural discharge.

The aims and tasks of the current research, presented in the article, were:

1. Confirmation of the relevance of the problem of flash floods and review of the modern state of an its consequences minimization question.

2. Proposal of a modern technical flood protection passive measure for the problem solution – system of SRFD with temporary-filled reservoirs.

3. Theoretical description of the method, definition of the demanded initial data.

4. Practical example of the developed method usage – the creation of a model according to the detailed algorithm.

5. Conclusion based on the results of the modeling, determination of the advantages, disadvantages and limitation of the proposed method.

2. Materials and Methods

2.1. Prerequisites of the modeling

The study of the environmental aspect of managerial decision-making when taking flood control measures is very relevant in our time, as evidenced by numerous publications of works by researchers-hydrologists, limnologists, ecologists, bio-, geochemists, hydrogeologists, etc. [18], engaged in studies of the current environmental situation on water bodies of our country. The strongest pollution of water bodies is observed, which leads not only to unsuitability of water for consumption, but also to the death of aquatic flora and fauna. This also fully applies to small-scale water bodies (small rivers) [13].

Changes in the hydrological regime of water bodies located in protected areas, due to a decrease or complete loss of the regulatory capacity of hydraulic structures, have a negative impact on both aquatic and terrestrial ecosystems [19]. It is also important to pay attention to the environmental aspect when directly implementing flood control measures. If you analyze the territorial planning schemes, you can see the protected areas or others, in which any construction and activities are prohibited in principle. This imposes a certain restriction on the choice of a place for flood control measures. Also, engineering decisions that can be made can affect the environment, for example, when creating hydropower facilities with reservoirs, even temporary ones, it is possible to cause irreparable damage to the natural environment, therefore it is necessary to correctly analyze the proposed places for flood control measures in order to identify restrictions, primarily on the environmental aspect [20].

The main parameter under consideration is the dynamic boundary of the water level (the territory covered by water) – It is for this purpose that the usage of GIS is necessary (Fig. 2) [11].

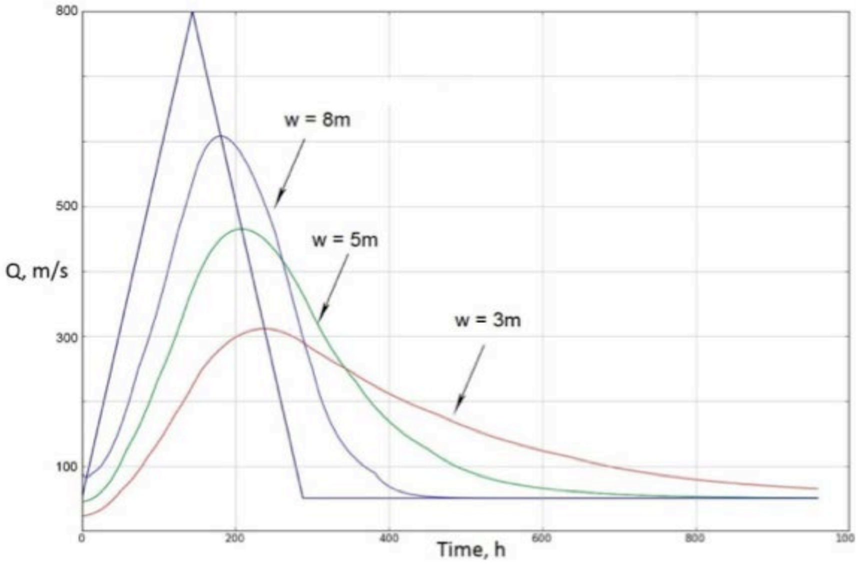

Figure 2. Hydrograph in the downstream of self-regulated flood dam, with different widths of the aperture.

Obtaining data on the dynamic boundary of the water level, it is possible to determine which ecosystems (or their parts) could be flooded as well as the timing of these events. In accordance with these facts, it is possible to choose the location of the proposed network of structures on the watercourse taking into account specific criteria, primarily ecological. The remaining parameters (the width of apertures of dams, as well as the cross-sectional area of watercourse at the selected locations) are set in a simplified form, theirs values are not calculated in method proposed. The main criterion for choosing (comparing) the location of the SRFD is the level of environmental impact – which territory can be flooded in the temporarily filled reservoir and for how long. More details about the method could be found in the previous works of the authors [10, 11].

2.2. Computational basis of the modeling

There are a large number of hydrological modeling systems based on GIS for water management [21−25]. Based on the results of the comparative analysis [26−29], it was decided to conduct modeling in the HEC-RAS software package, using the HEC-GeoRAS module to work with a digital elevation model in ArcGIS or QGIS [30]. Currently, HEC-RAS is able to perform one-dimensional calculations of the water surface profile for a steady, gradually changing flow in natural or constructed channels (Fig. 3) [31]. Water surface profiles with subcritical, supercritical, and mixed flow patterns can be calculated. The calculation model of the complex is based on the calculation of water surface profiles.

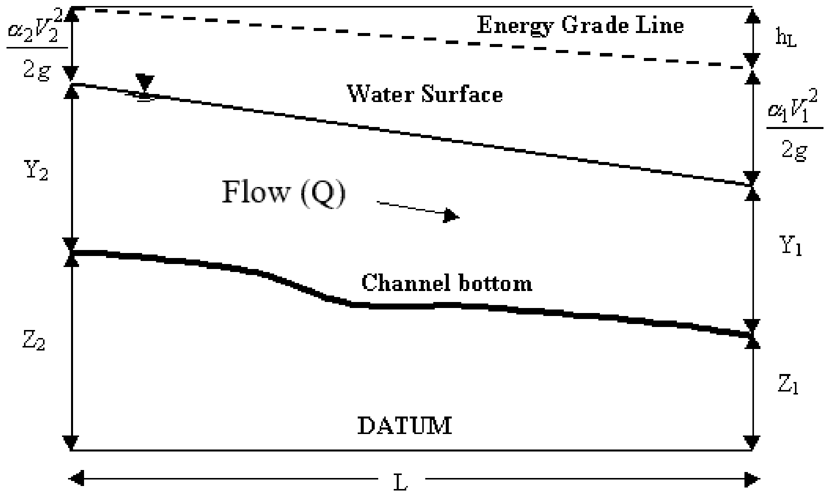

Figure 3. Method diagram.

Water surface profiles are calculated from one section to another by solving the Bernoulli equation with an iterative procedure, the so-called standard step method. The Bernoulli equation is the energy conservation law for two neighboring sections and is written as follows:

$$Z_2 + Y_2 + \frac{\alpha_1 * \upsilon_1^2}{2g} + h_e \tag{1}$$

where: Z_1, Z_2 are heights at points of the main channel taken at the center of gravity; Y_1, Y_2 are water depth in cross sections; V_1, V_2 are average velocities; a_1, a_2 are weighting coefficients for velocities; g is gravity accelerations; h_e is head losses.

The equation for head losses used in HEC is as follows:

$$h_e = L\overline{S_f} + C\left|\frac{\alpha_2 * \upsilon_2^2}{2g} - \frac{\alpha_1 * \upsilon_1^2}{2g}\right| \tag{2}$$

where: L is weighted average element length; $\overline{S_f}$ is characteristic hydraulic slope between two sections; C is compression ratio or expansion loss.

For the velocity of surface runoff under assumption that the Manning equation can be used the following equation is used:

$$\upsilon = k_r H^{2/3}\sqrt{I} \tag{3}$$

where k_r is roughness (according land use), I is a slope, H is a depth of water at a soil surface. For a pulse inflow, outflow peaks after a time given by the time lag, and then decays exponentially as follow:

$$Q_0 = (1 - x/(dt/K))Q_i; x = 1 - e^{(-dt/K)} \tag{4}$$

where Q_0 is outflow, dt is a time step, Q_i is inflow, K is a delay parameter.

The calculation of the flood volume $V_S(t)$ that could be potentially accumulated in a system of reservoirs at a specific time is calculated using balance method:

$$V_S(t) = V_S(t-1) + (Q_i(t) - Q_0(t))dt \tag{5}$$

where $Q_i(t)$ is inflow to SRFD, $Q_0(t)$ is outflow through the aperture of SRFD, dt is time step.

2.3. Initial data

The construction of a model of a section of the river basin for determining the alignment for the erection of the SRFD in each case begins with the collection of initial data. The most important source of up-to-date environmental information for various layers of GIS database are remote sensing data [32]. The concept of a GIS model for hydrological systems should include the following actions (Fig. 4):

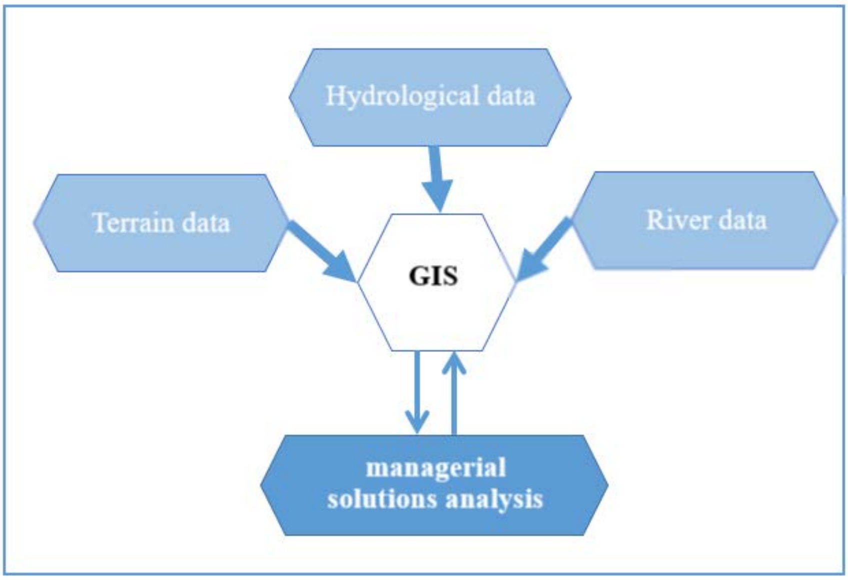

Figure 4. GIS-based model for building a hydrological system.

2.2.1 Terrain data

The terrain data is represented by the digital elevation model (DEM) (Fig. 5). The use of digital photogrammetric stations (DFS) for the creation of DEM by remote sensing is a successfully established method. DFS are a set of software and hardware designed to analyze data from space and aerial photography. It is possible to extract terrain data using special stereo processing tools both in automatic and in manual mode [22]. Based on such compiled DEMs, with the help of GIS software packages, it is possible to obtain important geometric, morphometric, hydrological, and other relief characteristics for simulated river basins [23].

During the processing of a DEM with GIS tools, geoinformation modeling of the hydrographic network, catchment areas and flood areas is implemented, which in turn provides the necessary basis for building more complex databases: floods and their consequences [31].

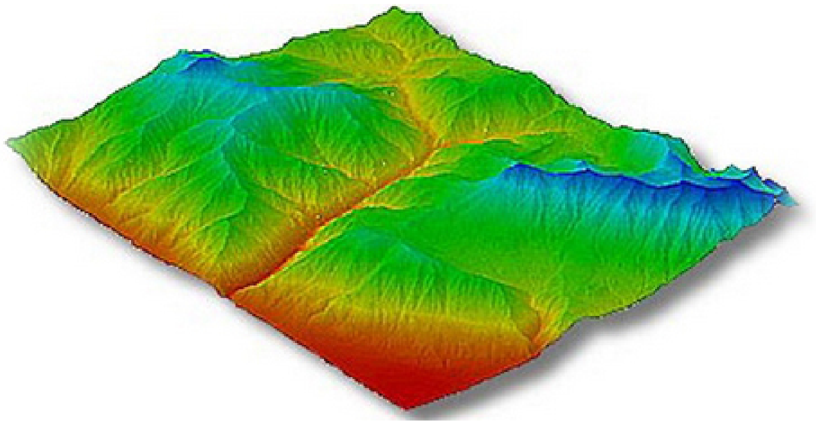

Figure 5. Terrain data example.

2.2.2 Hydrological data

Characteristics of river flow, including maximum flow rates and water levels in representative river basins, periods and duration of high water standoff, and other data can be found in the following sources:

- map materials (Fig. 6);
- Data from hydrological posts (Table 1);

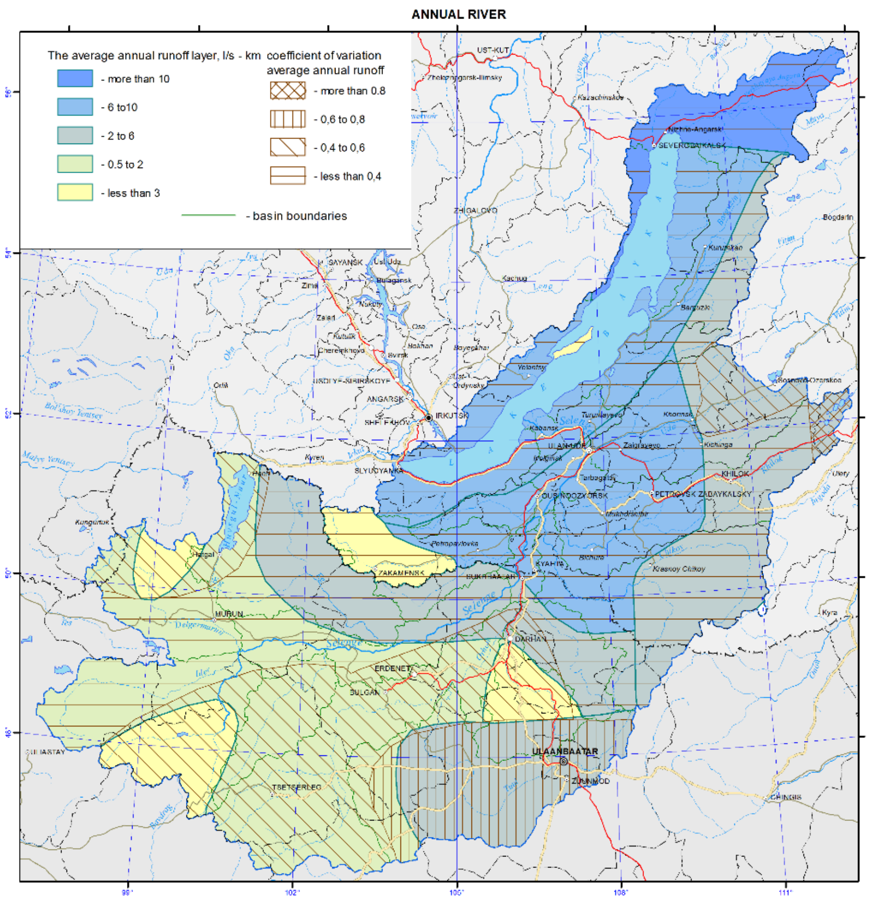

Figure 6. Annual river runoff map example.

Table 1. Hydrological post data example.

Post code	Name	Water object code	Distance from estuary, km	Drainage area, km^2	Zero level, m	Average level
6362	Met.station Selemdzha	118103384	544	1660	0	0
6363	s.Ekimchan	118103384	449	11600	480.29	0
6364	s.Stoyba	118103384	326	19600	339.66	0
6365	s.Selemdzhinsko e	118103384	262	20700	279.52	0
6367	s.Vissynskoe	118103384	197	27900	259.24	0
6369	city Norsk	118103384	134	46500	200.49	0
6370	v.Ulanochka	118103384	108	48800	190.12	0

2.2.3 River data

During the modeling process the time of a water standing at a certain level could be obtained, with a particular hydrograph and the SRFD configuration characteristics. Accordingly, the river data for the certain area of the river basin should be obtained, in order to have an appropriate solution of the problem in terms of environmental criteria. With the use of abovementioned data, so as with the land cover and land use data, the possible affection of SRFD to the environment could be estimated. This could help to understand, is it possible to build a SRFD at this section of the watercourse at all without or with any restrictions to the configuration.

3. Results and Discussions

For the assessment of the proposed method, a hypothetical river basin was considered. The work of creating a model consists of the following steps:

- modeling inside the ArcGIS software package with the HEC-GeoRAS module for working with terrain and creating river networks and cross-sections;
- direct work in the HEC-RAS software package [28], where editing of river sections and objects on them, and determining the hydrological properties of the watercourse itself;
- creation of the required model [27, 29−30], both static and dynamic (by setting hydrographs in a specific site).

Based on the data of remote sensing, a river network, a coastline are laid, and the direction of the river flow could be also indicated. Next, cross sections should be created. When calculating flood zones, HEC uses the constructed cross sections in accordance with the abovementioned and other formulas. They can be set automatically, with a defined interval and width, as well as manually. The software package analyzes data taking into account distances and elevations of the terrain and creates a file for export to HEC-RAS. At the next stage, using the tools of the HEC-RAS software package, the imported data from ArcGIS are processed and the hydrological conditions are set. After creating a separate project within the framework of HEC-RAS, modeling begins with the Geometric Data tab. Here it is possible to edit each cross section, reduce the number of points on which it is built, or smooth the alignment, if it is impossible to work with the original channel due to software limitations. Such restrictions arise due to the possible appearance of the «false channel» effect. If there are large differences in elevation of the relief, the program can identify them as independent channels, and this will cause an error in the calculation.

Also, the Manning coefficient is set in the Geometric Data tab, the characteristics of the river network are changed. In addition, any hydrological structures could be specified at a certain site (an easy adjustment of the cross sections was carried out and a synthetic roughness coefficient was set. The next step should be either SteadyFlow Data or UnsteadyFlow Data, depending on the type of a demanded model. As a result, the analysis of the given data was carried out using the SteadyFlow Analysis module and we obtain a model of the flood zone of a specific section of the river basin. The obtained data can be exported to ArcGIS to create a visual map. Modeling process at its various stages can be seen in Fig. 7−10.

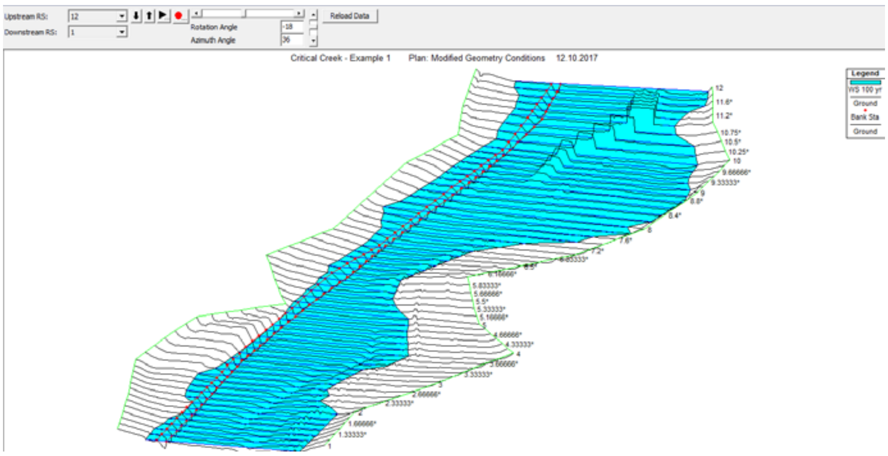

Figure 7. The modeling result without SRFD.

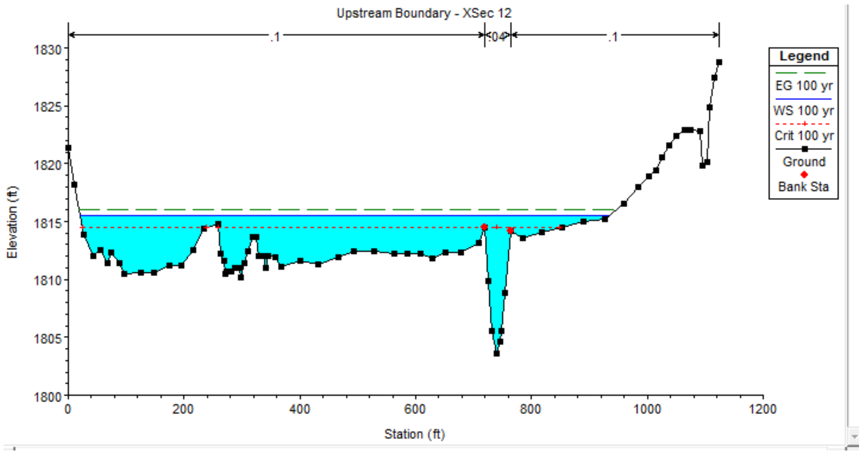

Figure 8. Cross-section without SRFD.

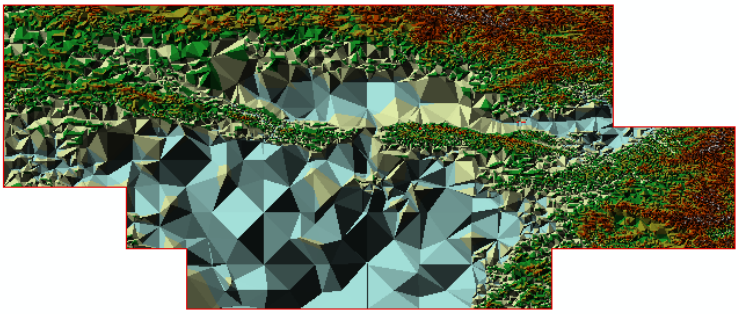

Figure 9. DEM with a specific rendering error.

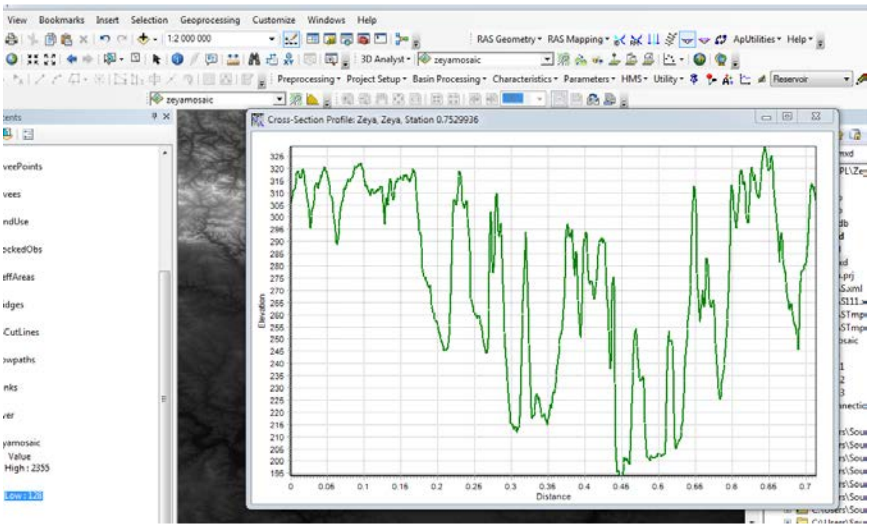

Figure 10. Cross-section with a "false channel" effect.

As we can see, there is a problem of source data related to DEM. Correct modeling is possible only if the terrain model is in the TIN format. When working with a raster image (obtained using SRTM), or with a model generated from a raster, incorrect data may be obtained. This is due to the specifics of the SRTM method [7, 8] (a general map is created from square tiles, each pixel has its own height, but error situations may occur at the junction of the squares), as well as due to incorrect terrain generation from the raster in the GIS environment (the terrain is generated triangular polygons). This problem seems to be a significant limitation, since fairly accurate initial data are required, otherwise there is a need to create synthetic river networks in which there will be no false channels and other deviations, but the modeling accuracy will suffer, the output model will differ significantly from the real one situation [32].

4. Conclusion

1. In the context of an increase in anthropogenic impact on the environment and the global economic crisis, a system of self-regulating flood control facilities with temporarily-filled reservoirs in the river basin is an appropriate measure to reduce the risk of floods. In this case, the regulatory capacity from flooding can be distributed evenly, while it is possible to protect large areas both in the floodplain of the river and in its upper tributaries, and on the side tributaries, from the harmful effects of flood waters.

2. In the course of the research, a flood modeling technique was formulated based on the use of GIS-based software systems, requirements for the initial data and the main algorithm of actions were formulated. The results of the study convincingly show that thanks to the created models of flooding the territories with the use of technical means of protection (in the form of a network of SRFD and temporarily filled reservoirs), it is possible to analyze both flood floods that have already occurred and to simulate possible floods of a given coverage. Based on such models, management decisions regarding flood control measures are possible. The advantage of the proposed methodology is the ability to justify the location of the proposed technical measures (systems of SRFD with certain parameters in the river basin), taking into account the assessment of the impact on ecosystems in the river basin. The disadvantage of this method is the extreme degree of dependence on the source data regarding the DEM, as well as the need for powerful personal computer to create a model for large sections of river basins, since due to the peculiarities of the GIS-systems operation, loading the generated model on weak computers takes considerable time.

3. The following areas of development in this research area can be distinguished:

- Updating cartographic information on modern infrastructure in river basins – the boundaries of settlements in the flood zone, roads, linear structures, as well as on the configuration of river channels.
- Obtaining information about the relief of river basins. For these purposes, DEMs obtained on the basis of highly detailed space and aircraft images are preferred.
- Calibration and verification of hydrodynamic models based on information about the boundaries of flooding from satellite images.

References

1. Danilov-Danilyan, V.I., Gelfan, A.N., Motovilov, Y.G., Kalugin, A.S. Disastrous flood of 2013 in the Amur basin: Genesis, recurrence assessment, simulation results. Water Resources. 2014. 41(2). Pp. 115–125. DOI: 10.1134/S0097807814020055
2. Abt, S.R., Wittier, R.J., Taylor, A., Love, D.J. HUMAN STABILITY IN A HIGH FLOOD HAZARD ZONE. JAWRA Journal of the American Water Resources Association. 1989. DOI: 10.1111/j.1752-1688.1989.tb05404.x
3. Aronica, G.T., Candela, A., Fabio, P., Santoro, M. Estimation of flood inundation probabilities using global hazard indexes based on hydrodynamic variables. Physics and Chemistry of the Earth. 2012. DOI: 10.1016/j.pce.2011.04.001
4. Evans, E., Hall, J., Penning-Rowsell, E., Sayers, P., Thorne, C., Watkinson, A. Future flood risk management in the UK. Proceedings of the Institution of Civil Engineers: Water Management. 2006. DOI: 10.1680/wama.2006.159.1.53
5. Apel, H., Thieken, A.H., Merz, B., Blöschl, G. Flood risk assessment and associated uncertainty. Natural Hazards and Earth System Science. 2004. DOI: 10.5194/nhess-4-295-2004
6. Habersack, H., Hein, T., Stanica, A., Liska, I., Mair, R., Jäger, E., Hauer, C., Bradley, C. Challenges of river basin management: Current status of, and prospects for, the River Danube from a river engineering perspective. Science of the Total Environment. 2016. DOI: 10.1016/j.scitotenv.2015.10.123
7. Aref'ev, N.V., Badenko, V.L., Osipov, G.K. Basin-landscape approach to the organization of environmental monitoring of hydropower complexes on the basis of geographical information technologies. Power Technology and Engineering. 1998.
8. Nogueira Vilanova, M.R., Perrella Balestieri, J.A. Energy and hydraulic efficiency in conventional water supply systems. 2014.
9. Merkuryeva, G., Merkuryev, Y., Sokolov, B. V., Potryasaev, S., Zelentsov, V.A., Lektauers, A. Advanced river flood monitoring, modelling and forecasting. Journal of Computational Science. 2015. DOI: 10.1016/j.jocs.2014.10.004
10. Rafieeinasab, A., Norouzi, A., Kim, S., Habibi, H., Nazari, B., Seo, D.J., Lee, H., Cosgrove, B., Cui, Z. Toward high-resolution flash flood prediction in large urban areas – Analysis of sensitivity to spatiotemporal resolution of rainfall input and hydrologic modeling. Journal of Hydrology. 2015. DOI: 10.1016/j.jhydrol.2015.08.045
11. Mirsaidov, M.M., Toshmatov, E.S. Spatial stress state and dynamic characteristics of earth dams. Magazine of Civil Engineering. 2019. DOI: 10.18720/MCE.89.1
12. Kantardgi, I.G., Zheleznyak, M.I., Anshakov, A.S. Numerical modeling of nonlinear hydrodynamics of the coastal areas. Magazine of Civil Engineering. 2019. DOI: 10.18720/MCE.87.7
13. Fedorov, M.P., Maslikov, V.I., Badenko, V.L., Chusov, A.N., Molodtsov, D.V. Reducing the Risk of Flooding by Using Hydro Complexes Distributed on the Drainage Basin. Power Technology and Engineering. 2017. DOI: 10.1007/s10749-017-0840-x
14. Chusov, A., Maslikov, V., Molodtsov, D., Manukhina, O. Determination of Environmental Impact Factors of Flood Control Hydrosystems with Temporarily Filled Self-regulating Reservoirs. Advances in Intelligent Systems and Computing. 2018. DOI: 10.1007/978-3-319-70987-1_113
15. Davydov, R., Antonov, V., Molodtsov, D., Cheremisin, A., Korablev, V. The simulation model for a flood management by flood control facilities. MATEC Web of Conferences. 2018. DOI: 10.1051/matecconf/201824515002
16. Nikonorov, A., Badenko, V., Terleev, V., Togo, I., Volkova, Y., Skvortsova, O., Nikonova, O., Pavlov, S., Mirschel, W. Use of GIS-environment under the Analysis of the Managerial Solutions for Flood Events Protection Measures. Procedia Engineering. 2016. DOI: 10.1016/j.proeng.2016.11.916
17. Nikonorov, A., Terleev, V., Badenko, V., Mirschel, W., Abakumov, E., Ginevsky, R., Lazarev, V., Togo, I., Volkova, Y., Melnichuk, A., Dunaieva, I., Akimov, L. Modeling the hydrophysical soil properties as a part of self-regulated flood dams projection in gis-environment for sustainable urban development. IOP Conference Series: Earth and Environmental Science. 2017. DOI: 10.1088/1755-1315/90/1/012109
18. Ahmad, S., Simonovic, S.P. System dynamics modeling of reservoir operations for flood management. Journal of Computing in Civil Engineering. 2000. DOI: 10.1061/(ASCE)0887-3801(2000)14:3(190)
19. Kaspersen, B.S., Jacobsen, T.V., Butts, M.B., Boegh, E., Müller, H.G., Stutter, M., Fredenslund, A.M., Kjaer, T. Integrating climate change mitigation into river basin management planning for the Water Framework Directive – A Danish case. Environmental Science and Policy. 2016. DOI: 10.1016/j.envsci.2015.10.002
20. Molina-Navarro, E., Hallack-Alegría, M., Martínez-Pérez, S., Ramírez-Hernández, J., Mungaray-Moctezuma, A., Sastre-Merlín, A. Hydrological modeling and climate change impacts in an agricultural semiarid region. Case study: Guadalupe River basin, Mexico. Agricultural Water Management. 2016. DOI: 10.1016/j.agwat.2015.10.029
21. Sanders, B.F. Evaluation of on-line DEMs for flood inundation modeling. Advances in Water Resources. 2007. DOI: 10.1016/j.advwatres.2007.02.005
22. Motovilov, Y.G., Danilov-Danilyan, V.I., Dod, E.V., Kalugin, A.S. Assessing the flood control effect of the existing and projected reservoirs in the middle amur basin by physically—based hydrological models. Water Resources. 2015. DOI: 10.1134/S0097807815030124.
23. Meert, P., Pereira, F., Willems, P. Computationally efficient modelling of tidal rivers using conceptual reservoir-type models. Environmental Modelling and Software. 2016. DOI: 10.1016/j.envsoft.2015.11.010
24. Sainov, M.P., Soroka, V.B. Ultra-high rockfill dam with combination of the reinforced concrete face and clay-cement diaphragm. Magazine of Civil Engineering. 2018. DOI: 10.18720/MCE.81.14
25. Bazarov, D.R., Mavlyanova, D.A. Numerical studies of long-wave processes in the reaches of hydrosystems and reservoirs. Magazine of Civil Engineering. 2019. DOI: 10.18720/MCE.87.10
26. Prakash, M., Rothauge, K., Cleary, P.W. Modelling the impact of dam failure scenarios on flood inundation using SPH. Applied Mathematical Modelling. 2014. DOI: 10.1016/j.apm.2014.03.011

27. Papathanasiou, C., Makropoulos, C., Mimikou, M. Hydrological modelling for flood forecasting: Calibrating the post-fire initial conditions. Journal of Hydrology. 2015. DOI: 10.1016/j.jhydrol.2015.07.038
28. Zazo, S., Molina, J.L., Rodríguez-Gonzálvez, P. Analysis of flood modeling through innovative geomatic methods. Journal of Hydrology. 2015. DOI: 10.1016/j.jhydrol.2015.03.011
29. Saleh, A.M., Belal, A.B., Mohamed, E.S. Land resources assessment of El-Galaba basin, South Egypt for the potentiality of agriculture expansion using remote sensing and GIS techniques. Egyptian Journal of Remote Sensing and Space Science. 2015. DOI: 10.1016/j.ejrs.2015.06.006
30. Halwatura, D., Najim, M.M.M. Application of the HEC-HMS model for runoff simulation in a tropical catchment. Environmental Modelling and Software. 2013. DOI: 10.1016/j.envsoft.2013.03.006
31. Mohammadi, S.A., Nazariha, M., Mehrdadi, N. Flood damage estimate (quantity), using HEC-FDA model. Case study: The Neka river. Procedia Engineering. 2014. DOI: 10.1016/j.proeng.2014.02.130
32. Arefiev, N., Nikonova, O., Badenko, N., Ivanov, T., Oleshko, V. Development of automated approaches for hydropowerpotential estimations and prospective hydropower plants siting. Vide. Tehnologija. Resursi – Environment, Technology, Resources. 2015. DOI: 10.17770/etr2015vol2.260

Contacts:

Aleksandr Nikonorov, coolhabit@yandex.ru
Vladimir Badenko, vbadenko@gmail.com