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1-D Mathematical Modelling of Flood Wave Propagation

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According to the monitoring data number of floods in habitat areas is constantly growing. Thus, it is required to develop tools for flood prediction and prevention. Current paper presents a research of 1-D mathematical modeling of flood wave propagation application in Krasnodar region of Russian Federation. The modelling is based on the Saint-Venant equations. The modeling has been processed in MIKE 11 by DHI software. The results of the modeling prove a series of actions that have to be identified and realized in order to eliminate floods and flood aftermaths. The results of the modelling have proved that constant reservoir bed clearing but not liquidation of the reservoir is necessary

1. Introduction

There are several types of floods, such as coastal floods due to earthquakes, river floods due to seasonal rainfalls, floods due to dam breaches and flash floods resulted from sudden intense rainfall. Analyze of data records of the past 70 years (Figure. 1) shows that total number of registered floods is on the rise. The major reason for this is not the increase of peak discharges, but a new buildings construction in flood plains, that were forbidden for development before (Abhas K. Jha, 2012, Halbert er al, 2016*)*. Bloeschl et al. (2015) in their large review paper have made an interesting finding of such long term analyses that floods tended not to occur evenly distributed throughout history but in clusters of periods that were particularly prone to flooding resulting in flood rich and poor periods.

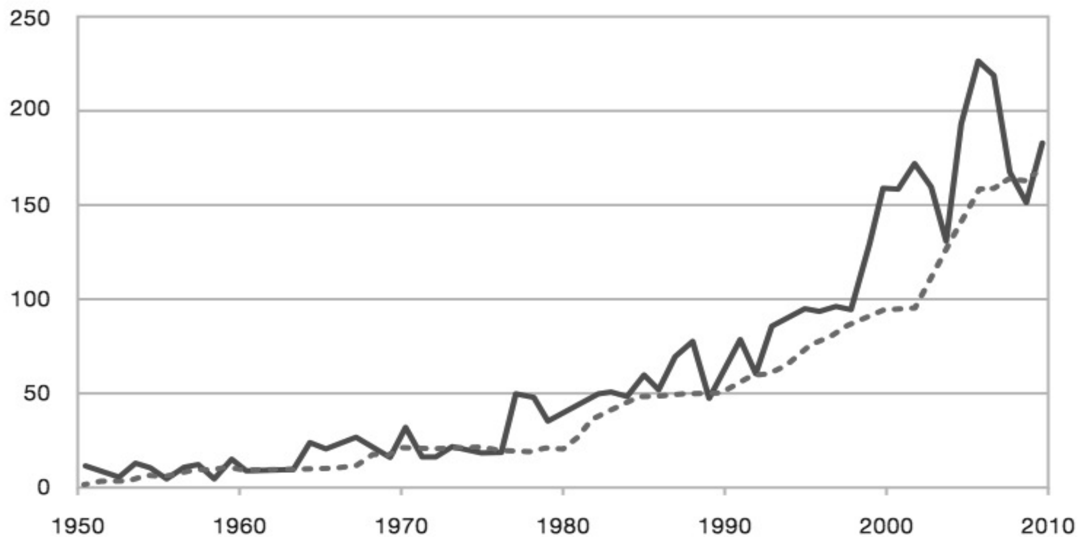

Figure 1: Increase in the number of registered floods. Solid line – occurencies; dashed line – median value over 10 years.

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Seasonal flood flows and accidents at hydraulic engineering works are reasons of floods in 90% of cases. In particular, these two accident development scenarios were investigated during building of mathematical model of a flood in the territory of the Krasnodarskoe reservoir tail race.
Evaluation of flood consequences was the investigation purpose. In order to achieve the purpose it was necessary to resolve the following problems:

- Accumulation of necessary data on the current state of the reservoir and tail race territory;
- Analysis of vulnerable areas of the hydraulic engineering work;
- Generation of accident scenarios development;
- Building and calibration of mathematical models under accident scenarios;
- Evaluation of flooding areas boundaries;
- Provision of recommendations on damage mitigation.

2. Description of the water reservoir

The water reservoir is called Krasnodarskoe reservoir and located on the south-west of Russia near Krasnodar city. The reservoir is the start of the flow of Kuban river, which eventually falls in Azov sea. It was constructed over 40 years ago. At the moment the reservoir under study is in disrepair. Considerable silting through accretion of silt from the upper reaches of the Kuban River and formation of natural organic layer out of the reservoir biomass represent a very serious problem. Thus useful capacity of the reservoir has decreased from 2,126 million. m^3 down to 1,606 million m^3; average depth has reduced for more than a meter from 7,0 to 4,7 meters and shallow water areas has increased fourfold. This indicates that constant reservoir bed clearing but not liquidation of the reservoir is necessary.
Engineering survey of the hydraulic engineering work has demonstrated that in the dam body there are no damages, which can lead to ground failure and washout occurrence.

3. Mathematical modelling

At the moment there are 3 main methods of liquid flow simulation (Nikishov, 2007):

1) One-dimensional simulation;
   Is widely used as it is fast in computation, however, due to complicated modelling and necessity to choose optimal modeling scheme. Also, this method does not allow to model transverse water flow velocity. (Czech, In press).
2) Finite element method;
   Is the most popular method. However, it requires splitting water flow into finite elements. This drastically increases calculation time for vast analyzed territories.
3) Particle method.
   The most precise method. In this case behaviour of each particle is modeled. However, the existing computing capacities do not allow to perform modeling of vast areas.

Besides there are other specific methods, such as geomatic (S. Zazo et al, 2015). A suitable assessment and management of the exposure level to natural flood risks necessarily requires an exhaustive knowledge of the terrain. Other uncertainties in the water level-discharge relation are describe by Halbert (2015). This paper shows that modeling strategy should consist in improving the description of the river bed geometry using topographic and bathymetric measurements.
We have chosen one-dimensional mathematical simulation method because it requires minimum input data and gives an opportunity to make relatively quick calculations that is a considerable advantage of the method. However regardless of all positive performance one-dimensional simulation method does not consider transverse velocity of flow and significantly complicates building of a model itself. Thus, usage of 3D model allows significant increase in the knowledge of hydraulic variables in natural waterways.
Saint-Venant equation in one-dimensional schematization is included into mathematical tools of the method:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$
$$\frac{\partial Q}{\partial t} + \alpha \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial h}{\partial x} + gAS_0 - gAS_f \tag{1}$$

where:

Q (x, t) – water discharge;

A (x, t) – free section area of the waterway;
t – time;
x – coordinate along the length of waterway;
g – acceleration of gravity;
h (x, t) – depth;
S_0 – initial flow friction slope;
S_f – final flow friction slope;
α - friction coefficient.

As we mentioned before, seasonal flood flows are the most common prerequisites of floods. Two accident development scenarios are considered in the current paper:

1) 0.01% probable flood (scenario 1, the least believable and the most serious one);
2) 5% probable flood (scenario 2).

The model computational scheme is presented in Figure 2.

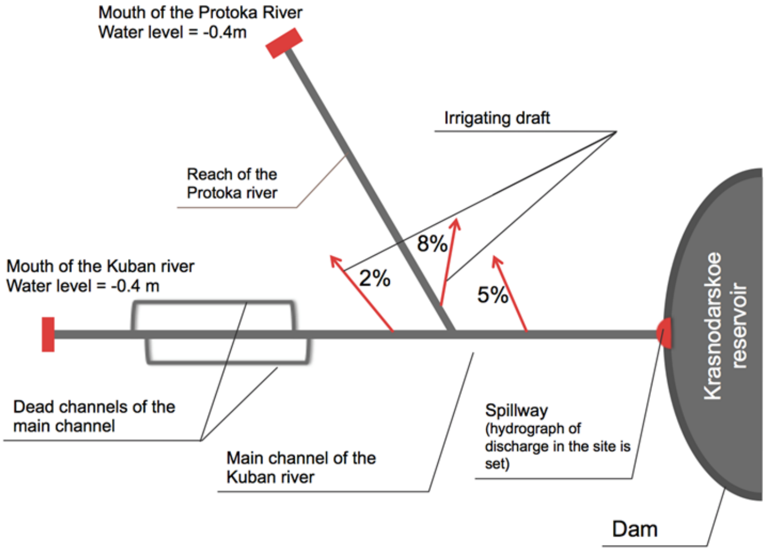

Figure 2: Computational scheme.

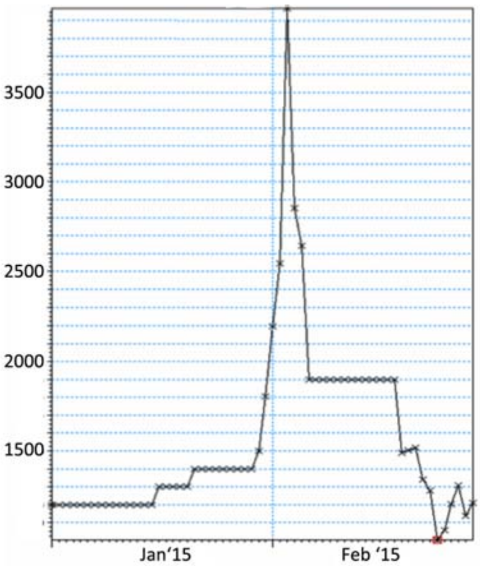

Figure 3. Hydrograph of 0.01% probable flood. X–axis: monthes of the year. Y–axis: water discharge, m^3/h

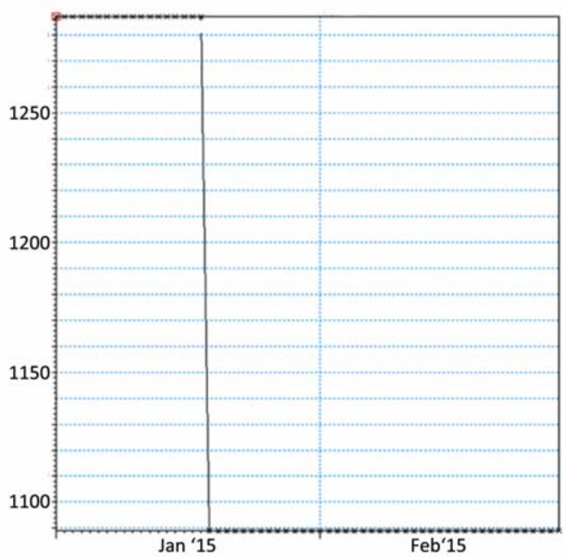

Figure 4. Hydrograph of 5% probable flood. X–axis: monthes of the year. Y–axis: water discharge, m^3/h

Initially determined discharge hydrograph corresponding to willful destruction of gates to preserve dam body and to pass uncontrolled flood through is set in figure 3. Discharge hydrograph of 5% probable flood is set in figure 4.
Lower reach of the Kuban River is characterized by a great many of dead channels, which are described in the model as additional lateral channels. This turns to be possible because bulkheads remain along the river, but there are places where the bulkheads were dismantled. In the model such places are indicated as forks of lateral channels.
Water level is the final boundary condition of the main river channel. Because river flows into the sea, we can assume that the water level in this place always equals to 0.

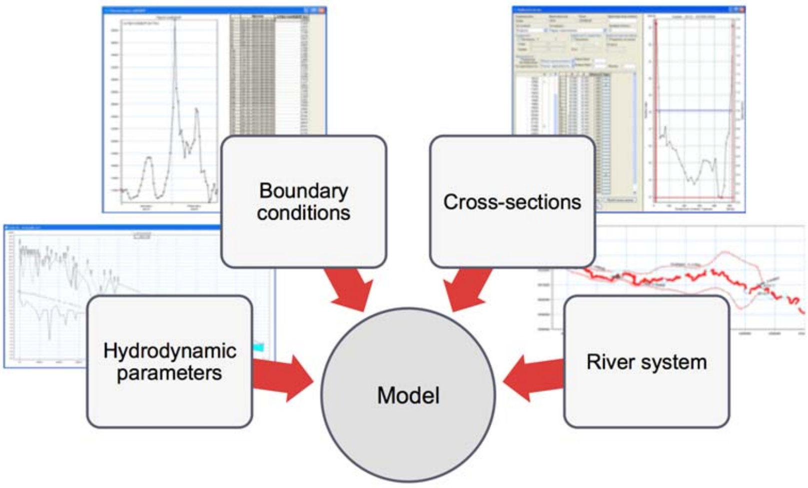

Figure 5. Simulation input data

All data are recorded in tables of different types (Figure 5):

- data on river system location;
- boundary conditions for outermost dam sites consisting of discharge hydrographs or water level;
- hydrodynamic characteristics, which include information on bed roughness and initial conditions of simulation;
- composition of the river and adjacent flood plain channels cross-sections.

Model calibration is performed mainly by variation of roughness factor. The calibration is performed until discrepancy is less than 1/6 of flood wave. The calibration has been implemented for two water discharges: 80 m^3/s and 1500 m^3/s.

4. Results and Discussion

As a result of calculation, maps of potentially flooded areas have been created (Figure 6 and 7). They show the possible flooded areas, progress of flood wave and change of water depth along the flooded area. Figures 6 and 7 show that there are flooded areas of the territory. In case of catastrophic discharge of 0.01% probability flooded area covers 169 human settlements, in 50 of them, depth is less than 1.5 meter (Figure 6).
In scenario with 5% probable flood flooded area is much less; it covers only 47 human settlements (Figure 7).
We propose the following efforts to contract boundaries of the flooded areas:

- recover and upgrade bulkheads along the whole river;
- take measures for recovery of the reservoir design capacity;
- take measures for cleaning of the Kuban River channel in tail race of the reservoir.

However, developed model can be significantly improved. This requires improving the description of the river bed geometry using topographic and bathymetric measurements and correction of the friction coefficients in the river bed and the flood plain through the assimilation of in situ water level measurements.

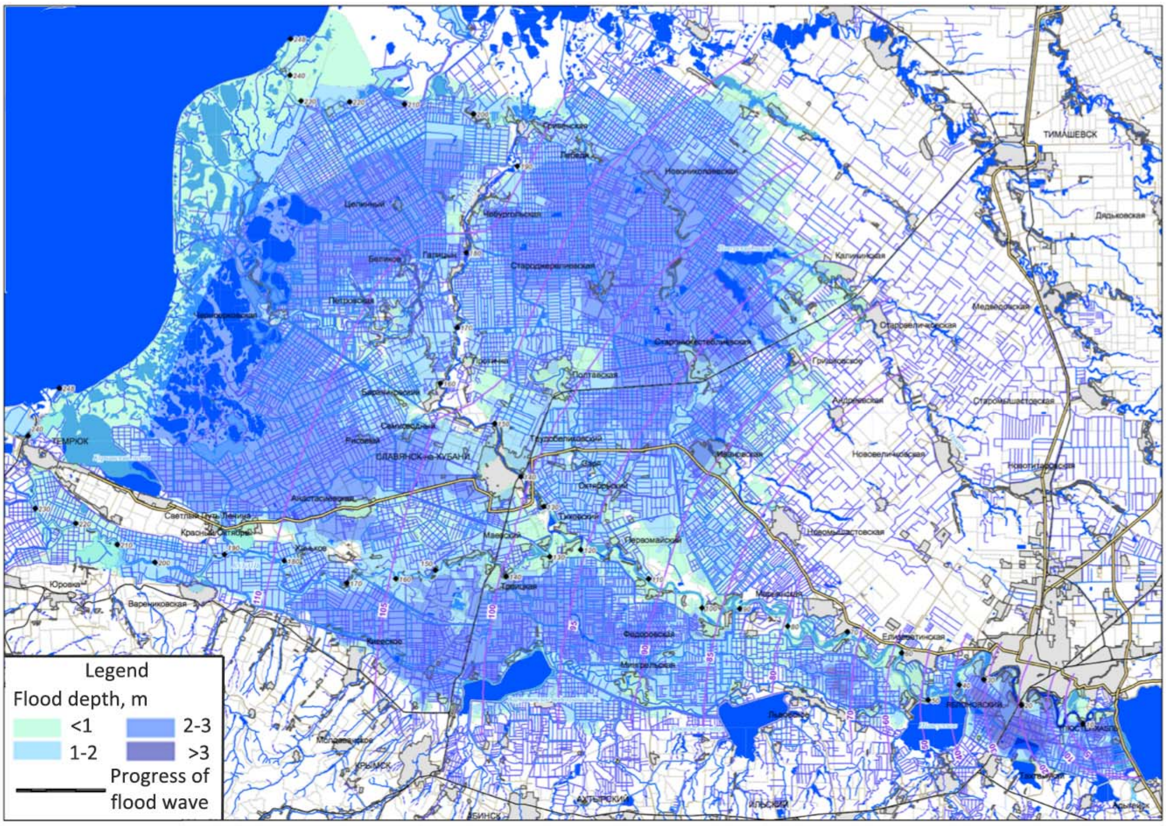

Figure 6. Flooded area under scenario 1

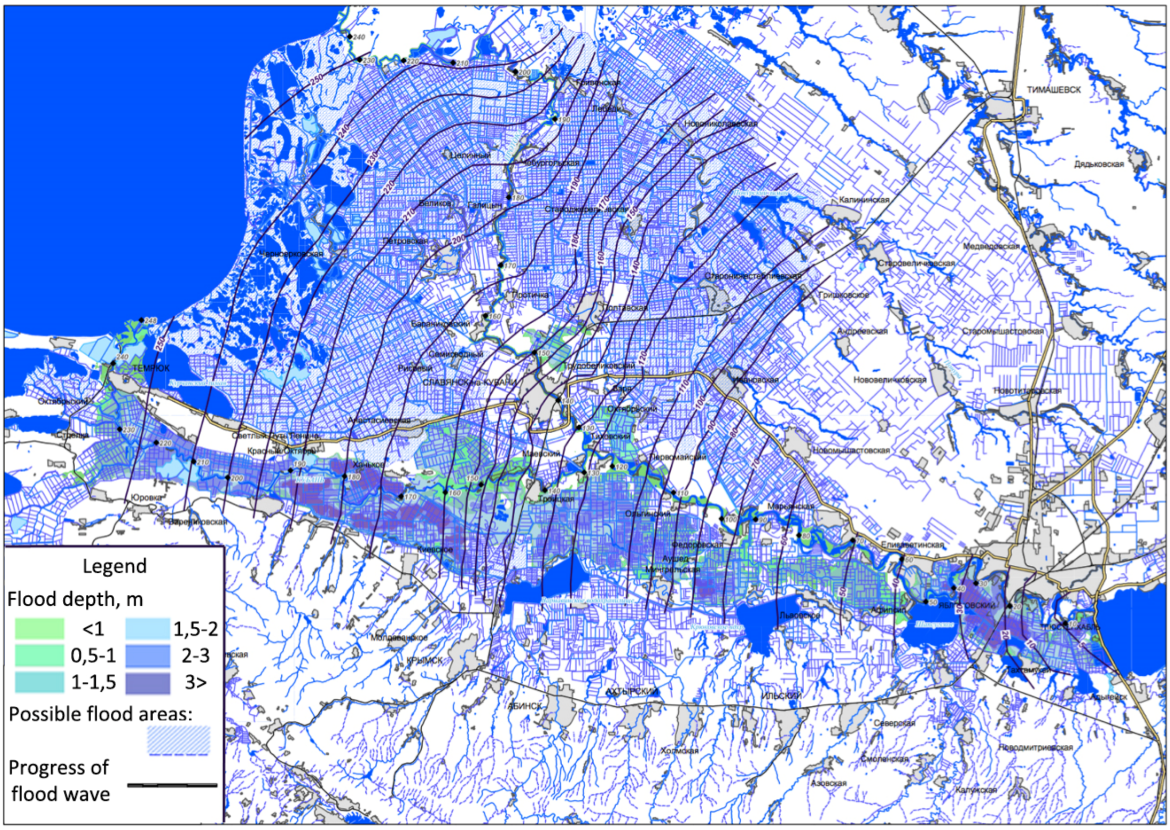

Figure 7. Flooded area under scenario 2

5. Conclusions

This paper shows an importance of people's awareness of possible floods in habitat areas and their aftermaths. An example was provided on a real case that could happen in Krasnodar region of Russian Federation. This example was done by 1-D modelling in Mike by DHI software and has shown that an ordinary river in case of In case of catastrophic discharge of 0.01% probability would cover 169 human settlements flooded, while 50 of them will be 1,5 meters under water. In the most probable flood scenario 47 human settlements would be flooded. This obviously proves the necessity of development of a series of measures and activities of people's flood awareness enhancement, flood prevention and mitigation techniques and others.

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