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CHANGE OF THE FLOODPLAIN AREAS ALONG SOME RIVERS OF THE VOLGA RIVER BASIN

ABSTRACT. The estimation of the area of the territories which are under the threat of flooding is of great importance. The technique, based on a principle of conformity of the area of a floodplain massif, averaged within the part of the river with a particular order, to this order has been proposed. The stream order, according to the Scheidegger scheme, were calculated for the mouths of 9907 rivers in the Volga river basin. For 96 rivers of the Volga basin, which has length of more than 200 km, changes of stream order within the entire extent were calculated and a map was compiled using the obtained results.

For several rivers in the Volga river basin, change of the average floodplain areas along the rivers was estimated. It allowed establishing dependences between the average floodplain areas and the stream order, with higher order corresponding to bigger floodplain areas.

KEY WORDS: Volga; floodplain areas; water regime.

INTRODUCTION

Spring high water period is a hydrological season of a year with a greater risk to hydroecological safety of the population and economy. River floods can cause considerable social, economic, and ecological damage. The loss increases with greater frequency, depth, and duration of flooding [Taratunin, 2000]. It also increases with growing population, settling area in valleys of the rivers, and growing cost of basic assets [Dobrovolsky, Istomina, 2007]. Though the territory of the Volga river basin includes the zones with rather small risk of flooding, annual damages from this dangerous natural and social phenomenon in the Volga river basin can reach 200 million Russian roubles and more.

FREQUENCY OF FLOODS IN THE VOLGA RIVER BASIN

Let us assume that, at some water level H_m, flooding of a river segment with the initial H_p water level starts. At $H_{mn} \leqslant H < H_p$, the water stream is limited with the low-water period level and is not a danger for the population and the social and industrial objects located on the floodplain. Difference $H_m - H_{mn} = \Delta H$ characterizes a natural range of change of water levels on the river segment. It depends on the size of the river (its rank N_{Sh}) [Nesterenko, Kositsky, 2010] and the watershed area F. In the Oka river basin, for example, at $F < 15\,000$ км^2, this difference is (in cm) $\Delta H = 0{,}04F + 160$ [Samokhin, 2006].

The value of ΔH depends on a geomorphological type of a river channel (broad-floodplain, altered, or incised). In the Volga river basin, there prevail (80%) broad-floodplain river channels, for which periodic or annual flooding of the both sides of the river is characteristic. The rivers with altered channels usually have a floodplain on one side (on the opposite bank, there is usually a slope composed of solid rocks). In the Volga river basin, altered segments of rivers occupy about 5% of the river network. Within the watershed area F = const and in the floodplain zones, ΔH of broad-floodplain and altered river channels changes slightly. Approximately 15% of the Volga basin channel network belongs to the extended incised channel type with a very small or completely absent floodplain. For the incised channels, there is no danger of flooding of the area because the slopes of such rivers are abrupt, and banks are high and can contain seasonal maxima of water levels that can cause flooding.

The type of water regime of the Volga basin (according to V.D. Zajkov) does not significantly influence the spatial change of ΔH because the overwhelming majority of the rivers of this basin have identical type of the intra-annual distribution of the river flow (East European type). Small- and medium-size rivers in the south and the southeast of the territory represent the exception; there, the water regime belongs to the Kazakhstan type. The intra-annual distribution of river flow defines, to a greater degree, the frequency and duration of water discharge and water levels at which flooding occurs on a high floodplain. According to the data [Morphology and dynamics..., 1999], the duration of flooding of the Volga basin floodplains does not exceed 50 days (Fig. 1).

For the most parts of the basin, short flooding of the floodplains (on average, it proceeds for less than 10 days) is characteristic. In the Kaluga, Kirov, Moscow, Ryazan, and Tver regions, the Perm territory, Republic of Bashkortostan, Tatarstan, Udmurtiya, and Chuvashiya, this period is longer (10–30 days). Only occasionally floodplains of some rivers (Vetluga, Mologa) are flooded for more than

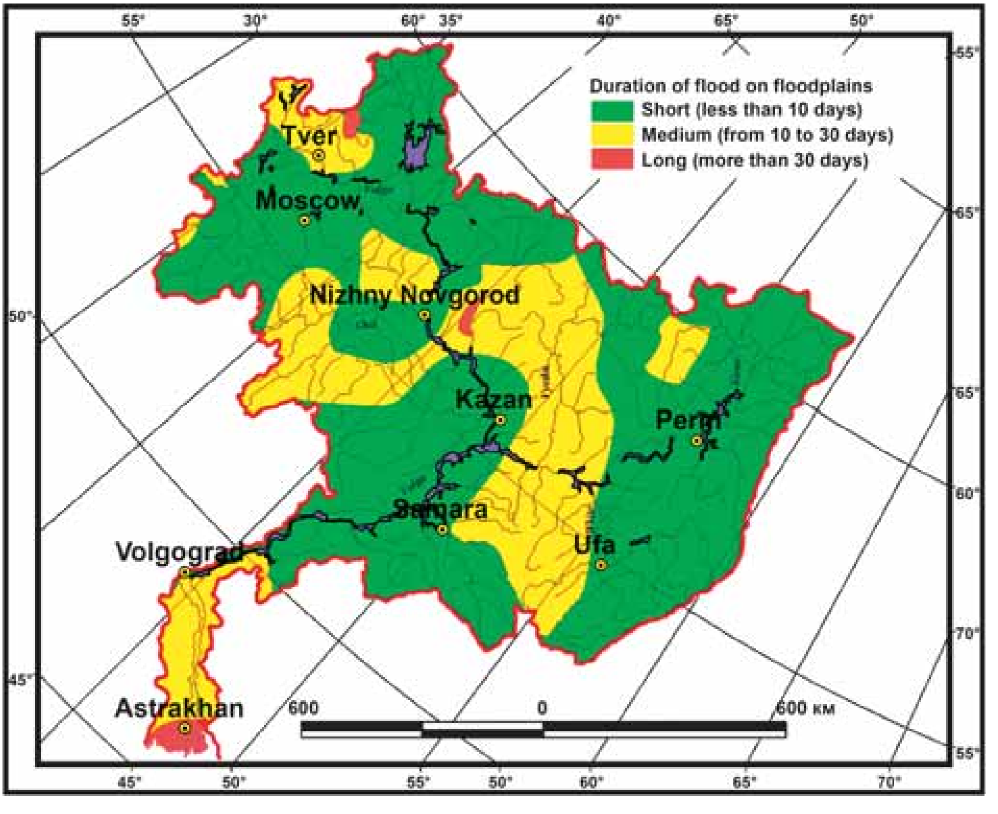

Fig. 1. The map of the duration of floodplain flooding in the Volga River basin

30 days. Floodplains of some small rivers in the Volgograd and the Samara regions are very seldom flooded in a high water periods or are not affected by flooding in the modern hydro-climatic conditions. The mountain and semi-mountain rivers of the western slope of the Ural Mountains have no floodplains or they are fragmentary, which allows considering them as rivers with no risk of flooding.

The frequency of flooding of the Volga basin floodplains can be estimated only for the territories with the hydrological posts. Only in this case it is possible to evaluate daily water discharge (long-term average) for conditions of steady flooding of a floodplain. This frequency corresponds to the highest interval of channel-forming water discharges Q_{bff} [Vlasov, Chalov, 1991], which, in long-term, is most objectively characterizes the regime of its flooding. Value of Q_{bff} is connected with the size of the river (its area, stream order N_{Sh}) by the power equation (Fig. 2):

$$Q_{bff} = 2^{1.76 N_{Sh}^{0.72}} .$$

Recurrence of the water discharge Q_{bff} and corresponding duration of the phenomenon characterizes average (for the long-term period) duration of flooding of floodplains. Data processing on 132 posts in river Volga basin in period from 1877 to 1980 has shown that duration of flooding of floodplains doesn't exceed 27 days. Recurrence of water discharges Q_{bff} varies from 0,01 % to 7,5 % [Vlasov, Chalov, 1991]. The maximal value of this parameter is characteristic for the rivers

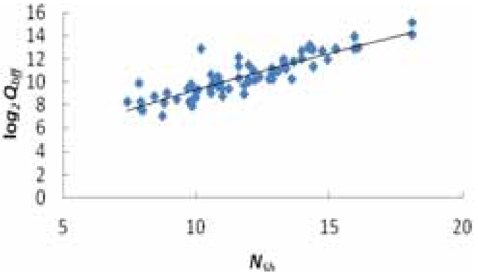

Fig. 2. Dependence of the size of the top interval of channel-forming water discharges Q_{bff} on stream order (N_{Sh}) in the Volga river basin

in the upper courses of the rivers White, Vyatka, Oka, and Kama. With an increase in the size (stream order) of the frequency of river water discharges, Q_{bff} increases somewhat. The frequency is much greater on broad-floodplain channels compared to adapted and incised channels.

THE CHANNEL NETWORK IN THE VOLGA RIVER BASIN

The information on the area of flooding F_f in the river valleys is of high importance for the evaluation of flooding damage. Such data allow estimating potential damage and economic efficiency of the investments necessary for flooding control. Other things being equal, the increase in this area is associated with a linear (or nonlinear) increase of social and economic damages. Nowadays, there are no methods of defining this important characteristic for large territories located in the valleys of small, average, and large rivers.

The problem analysis shows that for this purpose, it is necessary to identify regional (or basin) dependences between the area of floodplains F_f and the stream order. The existence of consistent dependences between the parameters (average area of floodplain for a river segment with N_{Sh} = const and the corresponding value N_{Sh}) and between the distribution of the rivers within the territory and their size (length, stream order) make it possible to identify potentially flooded parts of floodplain areas within the Russian Federation regions or individual river basins (and potential damages from this dangerous hydrological phenomenon).

In order to test this statement, we used the data on the number of tributaries shorter than 10 km in the Volga basin river network [The Hydrological scrutiny, 1966]. We estimated the stream order (according to A. Scheidegger scheme) using formula:

$$N_{Sh} = 1 + \log_2 S,$$

where S is the total number of the tributaries shorter than 10 km.

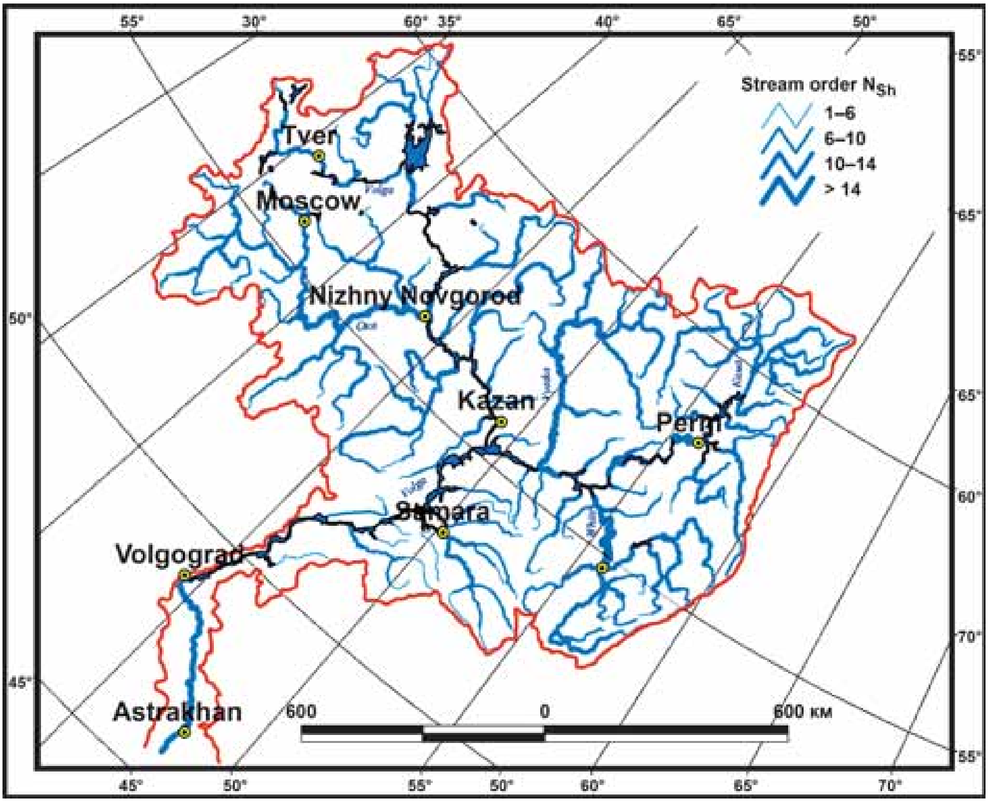

Fig. 3. The map of stream order in the Volga River basin

This procedure was conducted for the mouths of 9907 rivers in the Volga basin to estimate their hydrographic similarity.

For 96 largest rivers of the Volga basin (longer than 200 km), we estimated changes of the stream order (Fig. 3). The changes are associated with an increase of the

Table 1. Distribution of the rivers (according to the value of stream order in the mouth) in the Volga River basin

Value of stream order N_{Sh} in the mouth	Number of the rivers with the corresponding value of N_{Sh}	Value of stream order N_{Sh} in the mouth	Number of the rivers with the corresponding value of N_{Sh}
>18	1	8–9	158
17–18	1	7–8	384
16–17	0	6–7	695
15–16	2	5–6	1312
14–15	2	4–5	1918
13–14	5	3–4	1898
12–13	9	2–3	1282
11–12	23	1–2	698
10–11	41	1	573
9–10	89	Data is not available	816

majority of hydrological parameters of the rivers from their beginnings to mouths because of inflowing tributaries. Discharge through river branches is characteristic of the Volgo-Ahtubinskaya floodplain and the Volga delta. For the majority of the river mouths in the Volga basin, rank N_{Sh} does not exceed 7 (Table 1). The maximal number of the rivers have $N_{Sh} = 3 \cdot 5$. The number of the rivers with $N_{Sh} > 11$ does not exceeded 10.

FLOODPLAIN AREAS ALONG SOME RIVERS

For the calculation of the floodplain areas for segments of the rivers with changing size (stream order), 67 topographic maps, 1:50 000 scale, for the Oka river basin territory were used. The calculation was carried out using a software program AcrView GIS 3.2. In the program, the raster image (topographic map) was georeferenced to the geographical coordinates, then, according to characteristic features – relief, borders of settlements, and character of vegetation, the floodplain areas were delineated and the area was calculated automatically by the program.

The estimates of the floodplain areas of the tributaries of the Volga river depending on their length (the rivers Moskva, Pahra, and Oka) were obtained. If the stream order of the rivers for which the floodplain areas were defined, changed within unity (for example, from 5,1 to 5,7 or from 12,2 to 12,6), their average value was defined. It was compared according to the stream order (e.g., 5 or 12) (Fig. 4).

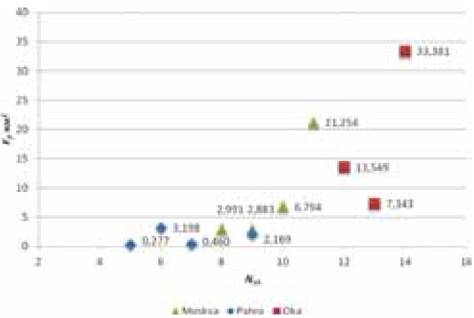

Fig. 4. Relation between the average area F_f of floodplains of the Volga basin rivers and their stream order N_{Sh}

Change of the average areas of the floodplains depends on the stream order and is described by nonlinear increasing function. Fig. 4 indicates that the increase of the average floodplain area coincides with the increase in the stream order. The existing dispersion of the points specifies the dependence of the floodplain area on the morphological features of the river valleys and geomorphological type of the river-segment channels. For example, the average area of the Oka river floodplain at N_{Sh} =12 is equal to 13,5 km^2, and for N_{Sh} = 13, is equal to 7,3 km^2, which is due to the change of the channel type.

CONCLUSION

The established dependency between the average areas of the floodplains and the stream order of the rivers opens prospects for defining the F_f for the unstudied parts of the river valleys with hydrographic information and data on the river channel geomorphological type. Using dependence $F_f = f(N_{Sh})$ it would be possible to estimate the areas of man-altered territories in the river valleys potentially affected by flooding. It is possible to objectively plan flood-control actions in different parts of the Volga river basin through assessing the frequency of floodplain flooding and potential damage considering the value of basic assets and the population in the areas of flooding risk.

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