Development perspectives of channel processes in the Sylva River basin (the Kama basin) in the XXI century

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Abstract. According to some well-established connections between air temperatures and atmospheric precipitation for the entire period of instrumental observations, it is concluded that the modern values of humidification in the Sylva River basin (the Kama basin) will be preserved until the end of the XXI century. When determining the trend in the development of channel processes, results of forecasts of relative changes in the annual runoff calculated for the East-European Plain with an ensemble of 7 CMIP3 models are used. The range of fluctuations is 0.9–1.1. The development of channel processes in the territory under study will not undergo significant changes in its orientation and activity until the end of the XXI century.

1. Introduction
Study of the nature and direction of the development of fluvial processes in river channels is a necessary and important part of research in the design of dredging and straightening work in navigable sections of rivers, during the construction of bridge crossings and other engineering structures in the coastal zone [1, 2]. The results of such surveys play a significant role in identifying space-time stability of floodplain-channel landscape complexes in river valleys. Stable position of these geosystems determines the safety and comfort of people living on the banks of rivers that it is a limiting condition for the existence of coastal settlements in many regions of the world in the era of global climate change [3]. There is already a practice of using channel pattern analysis of the current channel environment in the development of forecasts of the activity of channel processes, as shows an analysis of publications devoted to the results of special surveys in river valleys [4, 5].

Conducting research only based on knowledge of the modern situation in the development of channel processes cannot fully satisfy the requirements for the set and detail of input information for long-term forecasting. The question of reliable data on the speed and direction of channel processes as a means of providing the necessary data on the geodynamic stability of the river coast cannot be considered solved today. The main problem is forecasts based on the current information but not considering the peculiarities (trends) in the development of channel processes in the past. The absence of such materials from studies of the historical period cannot guarantee the objectivity of forecasts of the development of channel processes or the emergence of crisis situations during the restructuring of the channel in the bottoms of river valleys. The results of a study of restructuring of the channels of some rivers from the Late Pleistocene to the present are presented in [5–7]. They note that the morphological pattern of traces of ancient channels and the nature of the microrelief of the river valleys in Central and Eastern Europe indicate the presence of several large cycles of their formation over the past 13–18 thousand years [8]. Less information is provided on the development of the channel situation in the historical period. The source of such data is usually cartographic materials, which made it possible to determine the timelines for changing the activity and/or direction of channel processes in some sections of rivers [9–11].

A few examples available today of studying the morphodynamic river channel of the Perm Region cannot yet satisfy the increased scientific and practical interests in the problem of variability in the development of channel processes over time. The solution of the question of their activity in the region requires a significant expansion of the geography of research and the use of old maps and any other cartographic sources for which the morphological features of river channels are identified with acceptable reliability. This approach can allow one to investigate the past of the river valleys of the
Middle Kama basin using the example of even a small number of rivers for centuries. Considering the current situation, it becomes possible to predict the direction of formation of floodplain-channel landscape complexes in the future based on channel pattern analysis.

2. Object of research

The object of studying the development of channel processes in the recent past was the downstream of the Babka River which is a tributary of the Sylva River, one of the largest rivers in Predural'e (Figure 1). The object of research is highlighted according to the results of an analysis of cartographic sources. The section of the river is located at the Northern end of the Ufa Plateau crossing it in the direction from north-west to south-east. The valley slopes are cut into the Perm sediments at a depth of 50–60 m and are composed of Irene limestones and gypsum whose karst is sometimes observed in the places. The river valley and the slopes of the watersheds adjacent to it are today one of the centers of concentration of rural settlements, bridge crossings, and industrial infrastructure in the south-eastern part of the Perm region.

In contrast to the middle course of the river, which is characterized by a broad-bottomed riverbed with a two-sided floodplain, in the lower course there is a narrowing of the valley to 400–800 m with an average width of a one-sided floodplain of 100–150 m. The main morphodynamical type is a meandering channel. Confining bends of the river are sometimes interrupted by short sections of the straight braided or unbraided channel. The economic development of the valley is significant. Three relatively large settlements (Kylasovo, Kazaev, Ergach) and several dozen small villages and villages are located on the fluvial terrace above the floodplain. The valley is crossed by main gas pipelines, automobile and pedestrian bridges. The railway tracks connecting the cities of Perm and Yekaterinburg are along the right (indigenous) bank of the river valley.

![Figure 1. Location of the study area of the Babka River (highlighted by a dashed line).](image-url)
3. Research materials and methods

The source of information about the morphological structure of the riverbed and its morphodynamical changes over time includes cartographic materials of the XVIII-XX centuries: a general survey map of the Kungursky uyezd of the Perm province [12] (Figure 2), modern topographic maps of different scales, and satellite images. A comparison of the planned position of the river channel in different periods of its development by overlaying the planned outlines of the channel with reduction to one scale allowed us to draw certain conclusions about the direction of the channel process in time. The study of the direction of development of the channel was carried out mainly by using remote research methods for a period limited to the last decades. These included calculating the morphological–morphometric characteristics for each of the periods. The channel tortuosity coefficient, the radiuses of bends, and the degree of development of "young" bends within the emerging new floodplain which are now at the initial stage of their development was carried out. The rate of bank erosion in the reference areas was measured by using semi-instrumental methods.

![Image](image_url)

**Figure 2.** Fragment of a general survey map of the Kungursky uyezd.

4. Research result

The study of the change in the nature of development of channel processes of the Babka River using cartographic sources was based on an analysis of changes in the planned outlines of the channel in 8 sections of different lengths from the village of Kylasovo to the river mouth from the end of XVIII century until now (Figure 3). It has been established that to date the channel tortuosity coefficient has changed. Moreover, in some areas the main trend of changes was an increase, the channel length increased, while in the others a decrease was observed, the channel length decreased (Table 1). A combination of channel plans of different development times showed that the increase in the meandering values is mainly associated with the formation of free meanders within the “young” generation of the floodplain; for example, area 4 changed from 1.54 to 1.73 (Figure 4). The development of meandering judging by the structure of the floodplain-channel complexes and their display on a space image took place relatively recently, and today it is confined to a narrow zone along the modern channel. For this reason, young bends, which are much smaller in size than the “main”
(confined) bends, mainly develop in areas where relatively straight sections of the channel are located and can be considered bends of the second (modern) stage of the floodplain development.

![Figure 3: Location of the areas.](image)

**Table 1.** Channel tortuosity coefficient of the Babka River from late XVIII to early XXI century.

| N/no | Channel tortuosity coefficient (XVIII century) | Channel tortuosity coefficient (XXI century) | Channel tortuosity coefficient of relatively straight sections of the channel within the “young” floodplain |
|------|-----------------------------------------------|---------------------------------------------|----------------------------------------------------------------------------------|
| 1    | 1.68                                          | 1.58                                        | 1.11                                                                              |
| 2    | 1.25                                          | 1.17                                        | 1.17                                                                              |
| 3    | 2.23                                          | 1.46                                        | 1.06                                                                              |
| 4    | 1.54                                          | 1.73                                        | 1.19                                                                              |
| 5    | 2.10                                          | 1.42                                        | 1.15                                                                              |
| 6    | 1.91                                          | 1.72                                        | 1.14                                                                              |
| 7    | 1.47                                          | 1.70                                        | 1.15                                                                              |
| 8    | 1.38                                          | 1.52                                        | 1.09                                                                              |
Figure 4. Formation of a “young” floodplain on the sections of the braided channel: 1 – formation bend of the braided channel; 2 – straightening of the channel in the XIX–XX centuries; 3 – straightening of the channel in time before the end of the XVIII century.

Figure 5. Straightening of the bends though the spur: 1 – river channel at the end of the XVIII century; 2 – straightening though the spur in the XIX–XX centuries.

The reason for a decrease in the channel tortuosity coefficient in some areas was straightening between the neighboring bends (Figure 5); for example, in area 3 from 2.23 to 1.46. The vast majority of cut-off meanders formed by the end of the XVIII century were drop-shaped or finger-shaped with a radius of their tops of about 150–180 m downstream the Babka River. The development of bend necks was limited to ledges of the first fluvial terrace above the floodplain (or the second fluvial terrace above the floodplain at present) and the root slopes of the river valley before their break. Bends that
have avoided spur straightening are now typical confined bends with minimal lateral planform changes.

Judging by the width of the fragments of the young generation of the floodplain at the tops of loop-shaped and segmental bends, the average rate of their deformation is limited to the first centimeters per year in modern conditions. The exception is the local manifestations of channel erosion activity in the channel sections that were previously referred to straight sections. Stationary observations at the village Zhilino (area 7) recorded a significant (up to 5.1 m/year) change in the edge of the high bank of the fluvial terrace above the floodplain (the average speed over 6 years was 2.6 m/year), which led to a partial destruction of the adjacent buildings and movement of the house from a strip of potential destruction as a result. In other areas, the rates of planned changes were in the range from 0.0 to 3.0 m/year, with average values of 0.1–0.3 m/year.

The contours of the old channels are of great importance in getting information on the morphodynamic of the river channel. Together with the geosystems displayed on the space image and modern topographic maps at a scale of 1: 25000, materials from the XVIII century indicate the nature and development of the channel processes in the periods preceding the time of creation of the general survey map. The small size of the old channels (radius of bends: 50–100 m) and their location on the first fluvial terrace above the floodplain almost throughout the width of the valley bottom indicate the existence of floodplains with a freely meandering channel here in the XVIII century.

5. Discussion of results and conclusions

Based on the entire set of data on the morphodynamic of the Babka River channel, it becomes obvious that throughout the last Millennium the channel formation conditions have repeatedly changed. This was reflected in the restructuring of the geomorphological elements of the river valley. For a short time spanning only a few decades at the end of the XVIII – in the first half of the XIX century, there was a transformation of the broad floodplain into a fluvial terrace above the floodplain. From that moment on, the planned channel planform changes were already limited by the ledges of the new first fluvial terrace above the floodplain, thus forming a new young floodplain.

An explanation of these changes is the entire previous history of development of floodplain-channel landscape complexes on the East-European Plain in the historical period. As you know, this time is characterized by alternation of cycles with the predominance of erosion or accumulation in the channel processes. Climatic and meteorological conditions played a leading role in the change in the direction and rate of development of the river valley morpholithogenesis, which usually determine the features of the formation of streamflow volumes and its regime. River flow is the main and active factor in channel processes. The climate of the East-European Plain during this period was characterized by a high degree of instability of the hydrological and climatic conditions [13]. From the XIV to the XVII centuries, during the period of global relative cooling («Little Ice Age»/LIA), there was a noticeable decrease in the amount of precipitation and a decrease in the length of the seasons in which precipitation could directly affect the development of fluvial processes. Harsher and longer winters were interrupted by short and relatively cool seasons with positive temperatures [14]. A decrease in the stream discharge with a simultaneous increase in the meandering channel became the main difference between this period and the previous and subsequent eras. Ancient channel formations with a radius of bends much smaller than those of the bends of the XVIII century are identified on a space image and the general survey map within the fluvial terrace above the floodplain of the Babka River.

At the end of LIA, the direction of development of the channel processes responsive to the amount and regime of precipitation reacted quite quickly to the overall increase in humidification. For almost the entire territory of the European part of Russia and Western Siberia, at the end of the XVII century there was a long period of large amount of precipitation, which then repeated in the second half of the XVIII century and at the end of the XIX century [9]. An increase in the water flow and the duration of the impact of effective discharge in the Babka River valley led to the straightening of bends and a reduction in the meandering channel length. Subsequently, achievement of effective discharge that
operates at water levels below the channel edges [15] led to the development of a young floodplain with a segment-shaped meander.

The temporary morphodynamical variants of the channel situation in the Babka River are distinguished according to the morphological and morphometric characteristics of the channel. On their basis, a certain sequence of stages of their development and evolution of the floodplain-channel landscape complex was constructed (Figure 6).

Figure 6. Stages of development of morphodynamical types of the Babka River channel in the XIV–XXI centuries and modern geomorphological position of the evolved floodplain-channel landscape complexes: A – the second fluvial terrace above the floodplain; B – the first fluvial terrace above the floodplain; C – floodplain: 1 – alternation of incised macrobends with sections of a meandering confined channel and relatively straight inserts; 2 – wide-floodplain meandering channel with longitudinal and longitudinal-transverse movement; 3 – wide-floodplain meandering channel with longitudinal-transverse planform changes and cut-off meanders; 4 – wide-floodplain meandering channel.

The period preceding the LIA refers to the time of development of a wide-flooded meandering channel that formed the second fluvial terrace above the floodplain. The traces of a loop-shaped channel are seen extremely rarely and fuzzy due to overlapping of the surface with soil erosion products. The stage relating to the time of the LIA (XIV–XVII centuries) is represented by a wide-flooded meandering channel with longitudinal and longitudinal-transverse movements within the modern first fluvial terrace above the floodplain (floodplain at that time). A change in the climatic conditions at the end of the LIA provoked an increase in the streamflow and the onset of a period of sharp increase in the activity of the fluvial processes. As a result, the formation of a meandering channel with larger bends occurred within a short time. At the last stages of its development, the channel was already characterized by longitudinal-transverse movement and a breakthrough of spurs. The beginning of the last period can be attributed to the second half of the XIX century when, as conditions “accumulated” for the next higher level of activity of the channel processes, a planned pattern of the modern Babka River channel was formed. Its morphodynamic version fixed in space images can be defined as alternation of incised macrobends with sections of a meandering confined channel and relatively rectilinear inserts.

The change in the activity of the channel processes in the historical period, in addition to its connection with climate change, can be explained by the location downstream in the area of karst. In such areas, the “usual” formation of geomorphological levels characteristic of river valleys cut into terrigenous rocks is disturbed by an under-channel karst. Depending on the extent of their localization, the geomorphological structure of the river valley floor is complicated (rapid formation of a new
microrelief stage) or simplified (convergence of the levels of fluvial terraces above the floodplain) [16, 17].

As one of the reasons that radically changed the course of the channel processes at certain stages of historical time in the downstream of the Babka River, it is necessary to take into account the anthropogenic component in the formation of the valley bottom relief. It is highly probable that in the XVIII–XIX centuries rapid evolution of the floodplain into a fluvial terrace above the floodplain was provoked by climate changes, the impact of the karst processes, and activation of the accumulative processes of anthropogenic origin (for example, plowing up of flat interfluves and their slopes). The processes of accelerated erosion that have covered the south-eastern uyezds of the Perm province over the past 200 years have contributed to the movement of a large amount of sediment into the valley bottoms. As a result, during this period the traces of the old river channels were partially or completely buried where today agricultural land and settlements are located. According to some data, the rates of overlapping of microforms below the surface level by sediments in the river floodplains of the newly developed territories reached 15 cm/year [18], which led to a rapid transformation of the floodplains of small and even medium rivers into fluvial terraces above the floodplain in the first half of the XIX century.

Considering the prospects for the development of channel processes soon, it should be noted that the very discussion of this issue is possible only at the condition of a clear understanding of the direction of climate change. Climate change is the leading regulator of erosion activity and largely controls the activity of karst-suffusion and anthropogenic processes that have already played a role in the formation of the river valley topography. A conclusion was made on the preservation of modern humidification values (with a prospect of a slight increase) for the Sylva River basin (with the Babka River basin) by the presence of established connections between the air temperatures and the atmospheric precipitation in the entire observation period [19]. This can be confirmed and illustrated by observations of cases of shower in the Perm region in 1979–2015. The number of such rains (≥ 50 mm/12 hour) increased from 1.6 to 3.5 cases per year during this period. At the same time, the number of showers (≥ 30 mm/1 hour) throughout this period does not change and amounts to 2–3 cases per year [20]. Another characteristic example of an increase in the atmospheric precipitation with increasing temperatures is a positive trend over 40 years (1962–2002), which was recorded in the dynamics of the water equivalent of snow accumulation in winter [21].

The increase in water content during the low-water periods can be considered as the main feature of the modern climate-related changes in the streamflow with a natural regime [19]. However, the data on the increase in spring streamflow in the Sylva River basin are of the greatest interest in relation to prospects for maintaining the current activity of the channel processes in the future. The increase in the section of the Podkamennoe village (Sylva River) is from 1430 m³/s (up to 1978) to 1580 m³/s (1978–2009). This is 10% [22]. In general, the increase in the annual runoff in the basin in 1981–2004 compared to the period of 1930–1980 is 25%. The largest increase in the streamflow values occurred in recent years [19].

When determining the development of channel processes in the Babka River valley, we can rely on the results of forecasts of relative changes in the annual runoff calculated for the Eastern European Plain using an ensemble of 7 CMIP3 models. The main conclusion based on the results of the calculations is that no significant changes in the streamflow both in the middle and at the end of the XXI century are expected for the Sylva River basin. The range of fluctuations from the modern values will be 0.9–1.1 [19]. The main conclusion is that the development of channel processes in the downstream of the Babka River soon will not undergo significant changes in its direction and activity in relation to the current situation. This is indirectly indicated by the data on the approximate duration of the last three stages in the development of morphodynamical variants of its channel in the XIV–XXI centuries (Figure 5). The erosion of the fluvial terraces above the floodplain will continue in the concavities of large incised bends locally. The main tendency of the planform channel changes within the boundaries of a young floodplain will be a longitudinal movement with the formation of flat adapted bends within relatively straight parts of the channel between the incised bends.
Using the forecast of the development of channel processes in the valley of the Babka River, which is considered as a river with a typical direction of development of channel processes characteristic of the region, it can be concluded that the morphodynamics of river channels and floodplain-channel landscape complexes in the valleys of the Sylva River basin will remain at the current level until the end of the XXI century. There is no reason to expect cardinal changes in the activity of the fluvial processes.

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