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Development of Channel Processes and the Need to Forecast Deformations of the Stryi Riverbed

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ABSTRACT

Deformations of the channel are a consequence of the development of denudation processes in the basin area, increase in the volume of solid runoff and deposition of debris of the rock, its fractional redistribution in the channels, which especially increase during floods and flooding. They cause changes in the hydrological regime and structure of the river system, the destruction of residential and commercial buildings, as well as the infrastructure in the floodplain. Trends, magnitudes and intensity of deformations of riverbeds are formed by a complex of natural and man-made factors. Neglecting the planned and high-altitude displacements of riverbeds often leads to unpredictable consequences. Washing the shore can cause a gas or oil pipeline to rupture, leading to a strong explosion and fire, as well as oil pollution and environmental damage. Channel processes are associated with the washing of bridge piers, power lines, significant material losses and even human casualties during floods and flooding. The aim of the work is to analyze the development of channel processes in the basin of the river Stryi and forecast the deformation of its channel. The results of the analysis show that the riverbeds of Prykarpattia are very unstable and are characterized by intense erosion of the banks and bottom, which is caused by the influence of various factors. It is a man-made activity that includes the development of gravel quarries in floodplains and riverbeds and their straightening, runoff regulation, changes in forestry and land use. Natural factors, such as climate change and water runoff, etc., are also affected. It was found that the bed of the river Stryi does not have a stable shape, significantly changed the configuration, significantly reduced multi-sleeved and increased its straightness, and in some places the river changed its position by 60–80 meters. Restoration works carried out in some parts of the riverbed during this period were not effective enough. Water in different parts of the riverbed washes the shores, which causes dangerous landslides that occur directly near the riverbed. In these areas, it is necessary to more effectively carry out measures to regulate runoff and restore shore protection.

Keywords: mountain rivers, surface waters, channel processes, shore protection, deformation of riverbeds, denudation processes.

INTRODUCTION

Numerous problems can arise during the design, construction, operation of buildings on rivers, which depend on local natural conditions and features of structures and types of buildings. Sometimes buildings have to be designed in places with clearly unfavorable conditions. This can be caused by environmental, strategic and economic conditions. There are always four main questions that must be answered, namely the choice of optimal locations for the building, the basic requirements for its construction, protection measures and environmental safety.The answer to these four questions forms the content of the forecast of the channel process. It is necessary to anticipate the process of deformation for a period determined by the standard duration of operation of the designed structure. For such types of structures as crossings of power lines, pipelines for various purposes, cable lines, water intakes and wastewater discharges, these terms are usually from 30 to 50 years. These are so-called passive structures that are affected by the channel process, but do not have a significant impact on its development and can only lead to local deformations, often not even covering the entire width of the channel.

For active structures, ie the presence of which can make significant changes in the development of deformations of riverbeds and floodplains (dams, bridges, embankment dams, etc.), the duration of their work can be calculated for centuries. Active are also structures that are not only in the channel, but also in the catchment. In this case, they affect the channel processes of rivers indirectly by influencing the factors of channel formation. In particular, they include anti-erosion, which affect the flow of water and sediments, agroforestry and other measures. For active structures, it is usually necessary to assess the development trends of deformations of riverbeds and floodplains not only for sections of long rivers on which they are located, but also for the network of tributaries falling into the area of influence of these structures. In this case, the forecast is based on the assessment of changes in channel formation factors and already on this basis assess how the changed channel formation factors will affect the channel process and its changes. The forecast for tens and hundreds of years ahead is usually probabilistic. In addition to hydromorphological analysis, hydraulic calculation methods are often used as the basis for channel process forecasts for passive structures.

It should be noted that channel processes react most quickly and sharply to anthropogenic impact. The degree of this influence can now be so great that radically changes the channel process not only in the watercourse, but also in the water intake.

MATERIALS AND METHODS

The Stryi River is the largest right tributary of the Dniester in the upper reaches, over 230 km long and with a basin area of about 3055 km^2. The sources of the river are located at an altitude of 1123 m at the confluence of several streams on the northwestern slopes of Mount Yavirnyk of Verkhovyna watershed, near the source of its largest right tributary of the Opir River (Fig. 1). The river flows through a wide valley in a rather unstable, gravel bed with high values of the runoff modulus up to 20–21 l/s. The banks of the channel are in most cases steep, often rocky, in

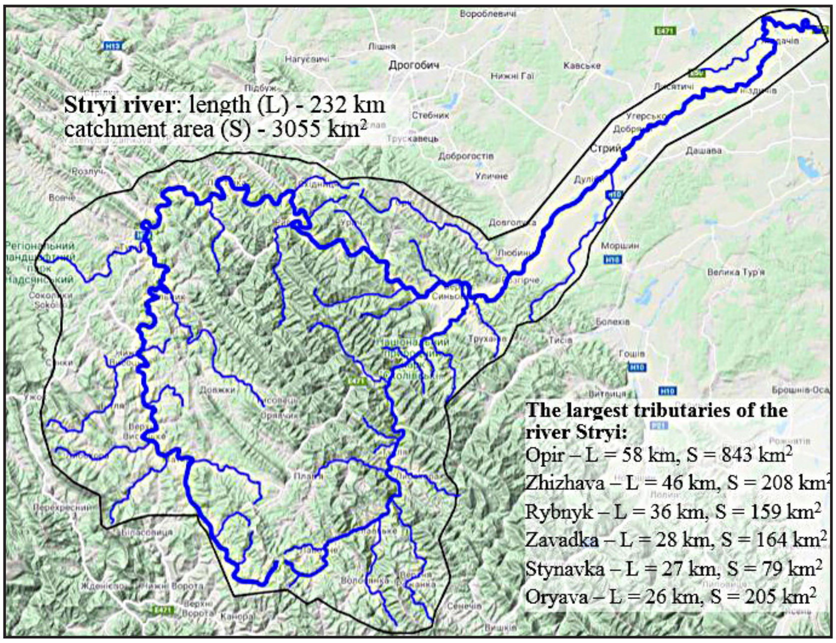

Fig. 1. The catchment area of the river Stryi with the spatial location of its sources and the right tributary of the river Opir near the mountain Yavirnyk of the Verkhovyna watershed

the upper reaches up to 40 m. The river is characterized by high variability of the level regime (Khilchevsky et al., 2013). The mouth of the river is located near the town of Zhydachiv and the village of Zalisky in the Pre-Carpathian plain at the level of 239 m. Taking into account the total length, sources and estuaries, the average slope of the river is 3.2 m/km. Most of the basin (75%) is located in the Carpathians and only 25% in the Precarpathians. The river network of the mountainous part of the Stryi river basin has a lattice structure. The largest rivers Stryi and Opir flow along the lines of tectonic faults and these areas are characterized by consecutive valleys, and their tributaries pass in rocks that are easily eroded and characterized by subsequent valleys. In the basin of the Stryi River, 31 first-order tributaries are hydrographically distinguished, among which the largest are the Opir, Zhyzhava, Rybnyk, Zavadka, Yablunka, and Stynavka rivers (Nazaruk, 2018; Matolych et al., 2009). The hydrological feature of the Stryi River is that at the confluence its length and area of the basin is greater than the Dniester River. Significant humidity of the mountainous part of the basin in combination with geological and orographic features of the territory cause a significant branching of the hydrographic network of the river basin of the river Stryi. It is characterized by a dense network of permanent watercourses of about 1–1.2 km/km^2 and maximum values up to 1.5 km/km^2 (Jacik, 1991).

The rivers of the basin have a typical mountain character with significant slopes within the hydrodynamically active area, fast flow, insignificant depths and a large reserve of alluvial deposits of floodplains and floodplain terraces. Hydrodynamic-passive sections are characterized by greater depths and slow flow. The upper reaches of the river have a variable width, mainly 20–40 m, and in the middle reaches it expands to 80 m. Within the Precarpathian Plain, the density of the river network decreases from average values of 0.3–0.5 km / km^2 to a maximum of 0.7 km. / km^2. In the lower reaches, the width of the channel is 150 meters (Buffington et al., 2013). The valley of the river Stryi in the upper and middle part in the areas with fast flow is V-shaped, mainly erosive, and in case of slowing down the flow is U-shaped, erosive-accumulative. In the lower reaches, the valley of the Stryi River becomes only accumulative, with a slight slope and wide floodplain terraces. Due to the long-standing system of hydrological monitoring, the hydrological parameters of the river network of the Stryi River are among the most fully studied in the Dniester River basin. In different periods, a total of 15 hydrological posts and observation points for the hydrological regime of the rivers of this basin operated here. Today, 11 of them are operating and one is a hydrological station «Stryi». System hydrological observations allow us to identify the most important features of the Stryi river basin, namely the patterns of changes in the state of the hydraulic system over time, which depend mainly on climatic conditions (Borutska et al., 2015).

Undissolved minerals and rocks that are suspended or transportable by water flow are carried away by it and form the volume of solid river runoff. The magnitude and regime of solid runoff depend on the flow levels, slope, lithological composition of root and quaternary sediments, relief features, as well as precipitation intensity, forest and soil cover, transverse and longitudinal profile of the river valley. Solid runoff in our river basin differs significantly in mountainous and plain areas. Differences in the values of solid runoff in the mountainous and flat parts of the basin indicate the influence of the hydrodynamic regime of different sections of the flow. During periods of floods and flooding, debris is deposited and its fractional redistribution occurs. If we take into account the processes of landslides and linear erosion, the value of total denudation is about 1.5–3.0 mm / year, which is proportional to the intensity of tectonic movements within the Skibovy Carpathians and Precarpathians (Kravchuk, 2005 and 1999).

Studies in hydromorphology have shown that riverbeds change their planned and altitude position over time. Depending on the type of river, in 50–100 years it can shift to a value that significantly exceeds the width of the channel, new channels, branches appear and the configuration of the channel changes. This should be taken into account in the design and construction of hydraulic facilities, power lines during the crossing of rivers, laying gas and oil networks and other work related to channel processes. The influence of channel displacements is important for ecological processes, especially for determining the areas of flooding and the extent of destruction after floods or flooding (Burshtynska et al., 2019;

Hajdukiewicz et al., 2016). Deformations of the channel are a consequence of the development of denudation processes in the basin area, increase in the volume of solid runoff and deposition of debris of the rock, its fractional redistribution in the channels, which especially increase during floods. They cause changes in the hydrological regime and structure of the river system, the destruction of residential and commercial buildings, as well as the infrastructure in the floodplain. Trends, magnitudes and intensity of deformations of riverbeds are formed by a complex of natural and man-made factors (Kovalchuk et al., 2013; Mykhnovych and Pylypovych, 2017). Neglecting the planned and high-altitude displacements of riverbeds often leads to unpredictable consequences. Washing the shore can cause a gas or oil pipeline to rupture, leading to a strong explosion and fire, as well as oil pollution and environmental damage. The washing of bridges, power lines, significant material losses and even human casualties during floods and flooding are associated with channel processes (Watson and Basher, 2005; Hu et al., 2017; Peggy, 2006).

The purpose of the paper is research of hydrodynamic and channel processes, development of recommendations for protection of territories from floods and reduction of anthropogenic influence. To achieve this goal, the following tasks are solved: to analyze the development of channel processes in the basin of the river Stryi; to forecast deformations of the Stryi riverbed and to develop recommendations for protection of adjacent territories from floods and flooding.

RESULTS AND DISCUSSION

The study of channel and floodplain areas in the Carpathian region was started in 1960 and took into account the results of previous significant geomorphological and hydrographic studies. Horizontal deformations of the Opir riverbed were analyzed in 2000, and some studies for the reconstruction of the Druzhba oil pipeline and to protect the river banks on the tributaries of the Dniester river of the Carpathians were conducted in 2005 (Mykhnovych and Pylypovych, 2017).

The results of the analysis show that the riverbeds of the Prykarpattia are very unstable and are characterized by intense erosion of the banks and bottom. The average value of bottom erosion is in the range from 1 to 60 mm/year for the last 20–30 years. Coastal erosion ranges from a few centimeters to 1.5–3.7 meters per year. The changes that were detected as a result of the analysis of longitudinal profiles showed that they were caused by various factors. It is a man-made activity that includes the development of gravel quarries in floodplains and riverbeds and their straightening, runoff regulation, changes in forestry and land use. Natural factors, such as climate change and water runoff, etc., are also affected. In the Precarpathian parts of rivers, alluvium accumulation processes are observed at the same time, but erosion processes predominate (Allan and Castillo, 2007; Richards et al., 2002).

The maximum intensity of erosion is observed in such rivers as Rozhanka (near the village of Rozhanka, 45 mm/year), Slavska (near the town of Slavske, 35 mm/year) and Stryi (town of V. Synyovydne, 31.25 mm/year). Intensive lowering of the bottom of the Stryi riverbed due to regressive erosion was confirmed by the results of field research conducted in 1997–2010. And the same studies in 2010–2015 showed intense erosion and incision of channels in the river systems of Yablunka, Oryava and Opir (Mykhnovych and Pylypovych, 2017). The main reasons for the intensification of erosion processes in the basin of the Stryi River and its tributaries are the extraction of gravel from the riverbed near the town of Stryi and the increase in water runoff during floods, which is reflected in the longitudinal profiles of the analyzed rivers. This conclusion is also confirmed by the nature of the spread and development of vertical deformations in other river systems of the Ukrainian Carpathians (Fig. 2) (Kovalchuk et al., 2013).

Extraction of gravel and pebble material and straightening of riverbeds are characteristic of almost all river systems of the upper part of the Dniester basin. The presence of sand-gravel mixtures on the channel territory encourages their extraction, which is often unauthorized, which causes deformation processes of the riverbed and its banks (Fig. 3). Soils that are light in mechanical composition are eroded, especially during floods. This causes the development of erosion processes in the riverbeds and adjacent areas (Snitynskyi et al., 2019).

Significant increases of extraction in sand and gravel quarries in mountain riverbeds are discrete in nature and vary in length. The leveling of the river bottom is further carried out by floods and discharge, which are considered to be

Fig. 2. Significant vertical deformations of the Stryi riverbed caused by the gravel-pebble mixture extraction and floods of the past periods

Fig. 3. Unauthorized quarrying in the Stryi riverbed (Snitynskyi et al., 2019)

channel-forming. Extraction of gravel and pebble deposits is very often carried out under the pretext of clearing channels, elimination of sediments and islands to prevent the negative impact of floods, not always environmentally sound. As a result, such activities not only lead to a decrease in the local base of erosion, destruction of shores and deterioration of water quality, but also negatively affect spawning migration and spawning of fish in the Stryi river basin (Snitynskyi et al., 2019; Hooke, 2006). Most unorganized landfills for solid waste have also emerged within the quarries, which greatly complicates the problem of their disposal. The organizers of such repositories often mistakenly believe that quarries are already helping to protect against environmental pollution. However, even clay quarries do not guarantee the environmental safety of such landfills. Very often floods and flooding erode these reservoirs, which leads to the removal of their contents into the watercourses of rivers.

The paper (Burshtynska et al., 2017) published the results of experimental studies of changes in the Stryi riverbed near city of Stryi and the settlements of Myrtyuky and Duliby, where topographic plans of different years were used and were analyzed of changes in the Stryi riverbed in this area during 1992–2009. In Fig. 4 shows a comparative image of the Stryi riverbed in the specified area. Comparison of satellite images from 1979, 2000, 2009 with topographic plans in 1992 and 2008 showed that changes in the cannel of the Stryi River take place along its entire length. In the study area there is a tendency to shift the channel to the left and erosion of the coastal part, as well as its greater straightening and simplification of the initial configuration, the emergence of new and disappearing islands, which were observed in 1992 in different parts of the channel. Based on the obtained results, it was concluded that the change in the shape of the channel, which was observed during the analysis, is a consequence of severe floods. It was assumed that the floods in 1997, 1998, 2001, 2004 and especially in 2008 were the cause of this phenomenon, as well as substantiated the impact of anthropogenic activity, which is expressed in the riverside construction and extraction of gravel and sand materials (Burshtynska et al., 2017). Analysis of the data of engineering and geodetic works in the Stryi riverbed allows us to conclude that over a five-year period it has significantly changed its configuration, in particular, the multi-sleeveness has decreased and the straightness of the riverbed has increased. In some areas, the river changed its course by 50–60 meters from the position of the riverbed in 2003. The state enterprise «Zakhidgeodeskartografiya» in 2010 observed the river Stryi after the flood in summer 2010 and obtained interesting and unexpected results.

The appearance of the riverbed in 2008 indicates a decrease in the sleeve, a more stable shape, and data from 2010 confirm the increase in its multi-sleeveless and significant change in shape in the area of the road bridge, as well as in the area between road and railway bridges. Analysis of the results of satellite imagery and engineering and geodetic works in 2010, indicate that the channel does not have a stable shape and requires effective shore protection hydraulic works (Burshtynska et al., 2017). In scientific works (Burshtynska et al., 2017; Burshtynska et al., 2018) the Stryi river was monitored for a 128-year period from the village of Dovhe, Stryi district, to the city of Zhydachiv, Lviv region. It is conditionally divided into mountain, foothill and plain part. The length of the foothills of the river, which is located from the town V. Synyovydne of Skole district to the village of Gnizdychiv, Stryi district, Lviv region, is 50 km away. It is characterized by significant multi-sleeveless river (Fig. 5). In 1886, the maximum width of multi-sleeveless was up to 1.5 km, the river was divided into 3–4 sleeve. After almost 100 years (1989), the width between the extreme sleeves decreased to 500 m, but in the satellite image of 2000 there is a significant interweaving of the channel, and in the image (2014) the riverbed in this area is single-sleeved, which indicates to reduce the

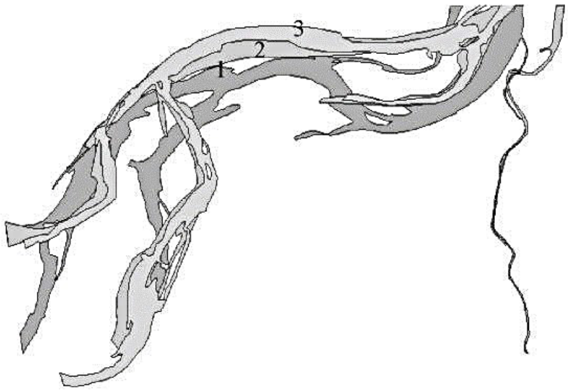

Fig. 4. Comparison of the positions of the Stryi riverbed for the period 1992–2009 (1 and 2 - 1 and 2 - respectively according to the topoplans of 1992 and 2008, 3 - according to the satellite image, 2009) (Burshtynska et al., 2017)

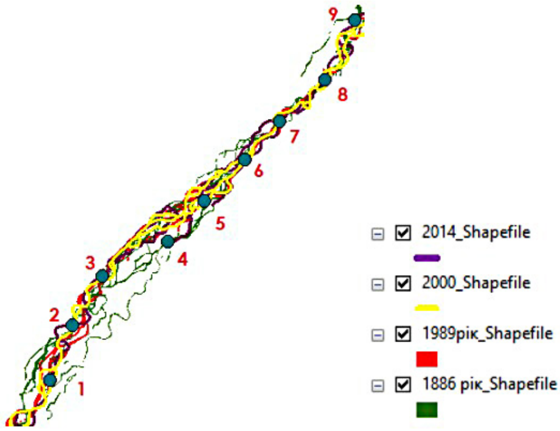

Fig. 5. General view of the channels of the foothills of the Stryi River (Burshtynska et al., 2018)

water content of the river. In the foothills, the channel shifts in the north-western direction and poses a threat of flooding of the Kyiv-Chop highway of international importance. It is indicated that the reason for the change in the nature of the channels is a significant influence of anthropogenic factors, namely the extraction of gravel-sand materials (Burshtynska et al., 2018; Rudko and Petryshyn, 2014).

In our research, an analysis of the distribution of the intensity and magnitude of the development of channel deformations, as well as risk assessment in the Stryi river basin. In fig. 6 shows the change in the course of the Stryi River from 2002–2017 near the city of Stryi and the village of Verchany, where we observe a shift of the channel towards the city of Stryi, but the presence of a dam protects the city from floods and flooding. There are signs of flooding of the earth dam in the area of the bypass road, so measures are needed to restore it. In December 2017, with a significant increase in river runoff, the river flowed with the destruction of the lower slope of the dam, as well as flooded the old channels in the area of the village Verchani (Fig. 6). During the study period 2002–2017 the main channel of the river has shifted by 98 m towards the town of Stryi, which will probably contribute to further washing of the banks and the fortification dam during floods and flooding.

The results of the study of channel processes near the village Hirne showed that in general the channel shifts in the western direction with the washing of the left bank along the river and causes the threat of washing the Kyiv-Chop highway (Fig. 7). In high-water periods the stream passes through the sleeves of the old channels towards the village Bratkivtsi, which helps to increase the flow rate of wells in the Stryi water intake.The biggest changes in the channel process and water regime occur in the section of the river that flows through the flat part of the area from the village Gnizdychiv of Stryi district before the confluence with the Dniester River near the city of Zhydachiv, Lviv region. The length of the plain part of the Stryi River is 18 km with a very winding channel, a significant number of meanders and old channel of river. The river makes the most interesting meanders near the village of Rybnyk and the town of Zhydachiv, where it flows for several kilometers in several different directions. This part of the riverbed mostly depends on the geomorphological structure, which is characteristic of the Precarpathian depression. Passing through sections of rocks of different hardness, the river forms valleys of different types, from narrow with no terraces to wide at the intersection of soft rocks (Burshtynska et al., 2018). Intensive extraction of gravel and sand from the riverbeds of the studied basin, as well as the development

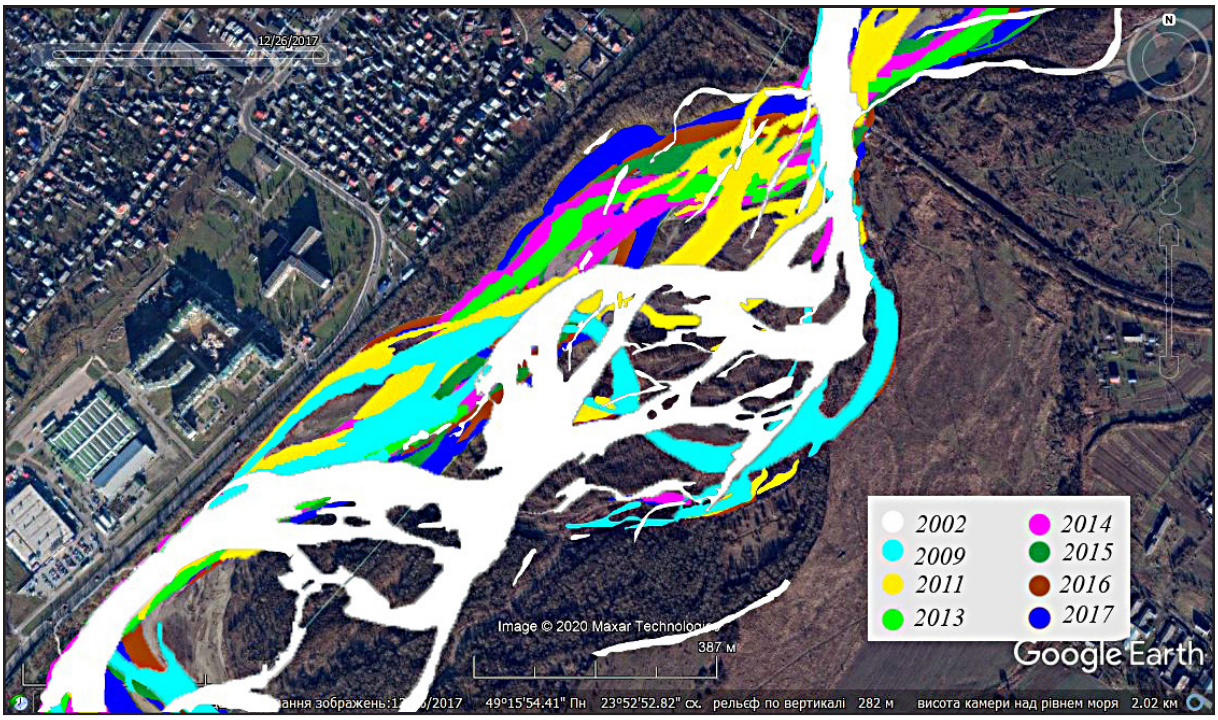

Fig. 6. Change of positions of the Stryi riverbed near the town of Stryi for the period 2002–2017

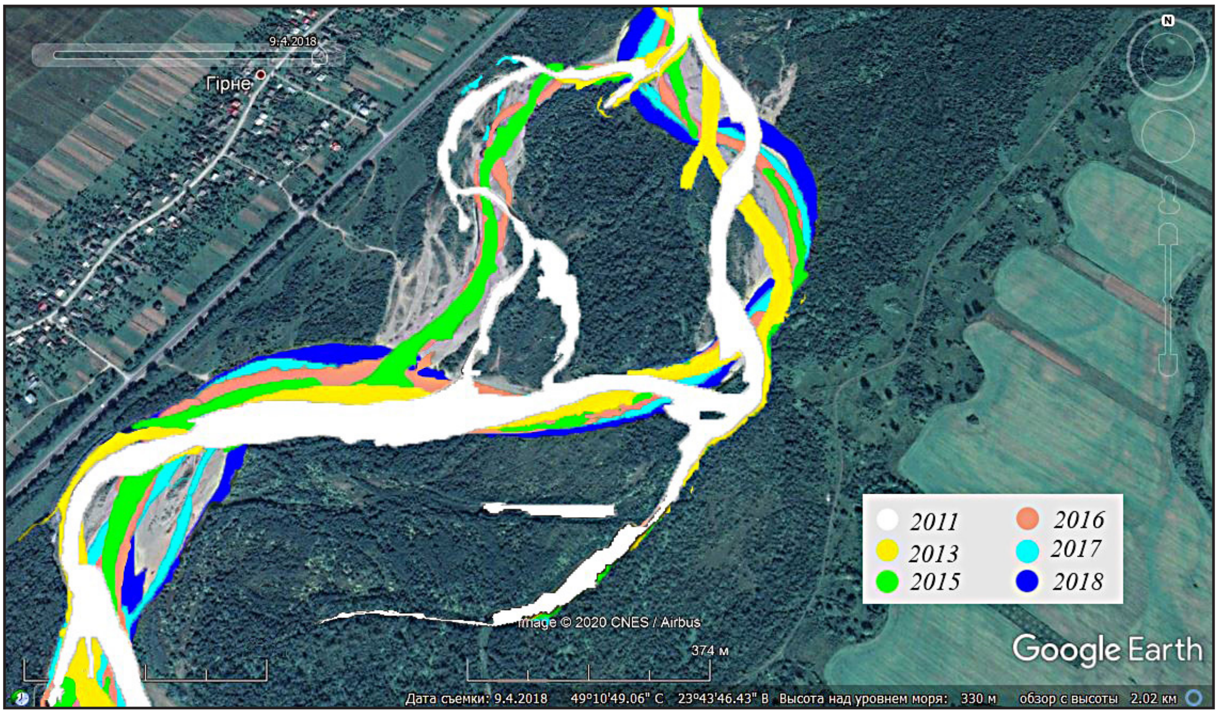

Fig. 7. Development of channel processes in the Stryi River near the village of Hirne for 2011–2018

of boulder-gravel-sand deposits in the mountain rivers Stryi and Opir in the Lviv region has a negative impact on the ecological state of the environment (Rudko and Petryshyn, 2014).

CONCLUSIONS

The results of research conducted for the period 2002–2018 show that the channel does not have a stable shape, significantly changed its configuration, significantly reduced multi-sleeved and increased its straightness, and in some places the river changed its position by 60–80 meters. Restoration works carried out in some parts of the riverbed during this period were not effective enough. Water in different parts of the riverbed washes the shores, which causes dangerous landslides that occur directly near the riverbed. In these areas, it is necessary to more effectively carry out measures to regulate runoff and restore bank protecting structures.

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