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Morphodynamics of low-order floodplains in the Crasna drainage basin during extreme hydrological events.

Abstract of the doctoral thesis

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CONTENTS

KEYWORDS

Fluvial systems, morphodynamics of the floodplains, small catchments, stream power, bank resistance, normal discharge, bankfull discharge, extreme hydrological events, experimental research, Crasna river.

ABSTRACT

The present thesis starts form the premise that in the context of a considerable progress registered in the last decades in the fluvial morphodynamics a more thoroughly research on related issues is possible. This can be done by focussing the research, at an intermediate level scale and a micro-scale, on mechanisms and processes that define the structure, the functionality and the morphology of the fluvial (sub) systems.

The main aim of the thesis was the design of models on the evolution of floodplains from varied geomorphogenetic contexts. These models are to show the correlations between morphodynamics and geological, geomorphological, climatic, hydrological, biogeographical and anthropic factors. The models are to be designed based mainly on the results obtained from field research and experiments. Once we get to know the quantitative characteristics of the normal flow and of the extreme flows, as well as the evolution and dynamics of the fluvial systems, that achieve their role in the transport of energy and matter, we can predict the answer the river is giving. Most of the studies on the floodplain dynamics have been done at macro-scale, mainly focussing on issues related to the influence climatic and hydrological factors have on the entire drainage basin and less on their correlation with hydrological and morphological parameters, internal to the floodplain systems. An alternative to such an approach would be an analysis of the floodplains within their local landscape, with a focus on the river specificity, seen as a capacity to store and channel energy and matter flows.

A research in the low-order floodplain morphodynamics was done through quantitative and qualitative analyses at the level of the whole drainage basin and at the level of the floodplain. Stream power, circularity index, slope, depth and density of relief fragmentation are the characteristics analyzed at the level of the whole drainage basin. The parameters analyzed at the level of the floodplain were: floodplain gradient, hydraulic radius, rugosity index, bank cohesiveness and stream power on length unit and on active section of the flow. The analysis of the power of erosion the rivers have correlated with their capacity to answer in different locations and at different times permitted the identification of the dominant floodplain processes in the formation of the floodplains.

The present study is done on Crasna River drainage basin and is based on understanding and explaining the correlations between the morphological characteristics of

the low-order drainage basins and the present processes of floodplain erosion. These correlations are done in the present day local geological and hydrological setting. The present land use is also considered, as it is an extension of the anthropic influence. The selection and the delineation of the areas to be researched was the baseline for the design of the models of floodplain evolution. The low-order basins for the study cases have been chosen considering the relief morphology (high, mountainous areas and low, hill-type areas), the base level (upstream and downstream of Vârşolţ reservoir) and anthropic activities (forestry and agricultural type of lands).

Crasna River drainage basin is located in the Northern part of Apuseni Mountains, with an area of 2139.48 km^2 . Crasna River is a 1^{st} order tributary of Tisa and has its sources at 577 m, in Pria Hillock (Meseş Mountains). The origin and the territorial development of the drainage basin is defined by its position within the Apuseni Mountains and by the movements of the Transylvanian-Pannonian Micro-plate that generated a series of movements of the areas of subsidence in the lower courses of the rivers from the Eastern part of the Pannonian Basin and, implicitly, in the lower course of Crasna River.

Crasna basin was the focus of numerous studies, of geographic and geologic type, either being considered as a sole entity of study or as a part of the Western Hills and Western Plain. From the monographic studies authored by Petri Mor (1901-1906) and published in Budapest, over the time, other integrative studies or studies that focused on certain components of the landscape have analyzed Crasna basin from a historical, evolution-related and functional perspective.

The issue of researching and designing models for fluvial processes is old and therefore, over the time, as new information was gathered, concepts have been redefined and the big picture concerning the morphology of the valley and the complex processes rivers determined has been changed. The major role rivers have in shaping the earth determined the creation of a distinct subject matter, named Fluvial Geomorphology. It is a recognized science, part of Geomorphology and it researches the fluvial system in various locations within the floodplain, at different scales of the drainage basin. The periods of time that are under analysis vary from short duration (a single flood) to a whole morphoclimatic cycle (glacial-interglacial variations). The fluvial geomorphology studies focus in detail on the explanation of the relationships between the physical properties of runoff, sediment transport and floodplain morphology, at various fluvial levels.

Drawing up the research methods and implementing them meant putting in practice the principles of general scientific methods and instruments and also of those that are specific for Geography. The focus was on choosing and implementing a methodology that is suitable for this type of research that works with experiments.

In drawing up the methodology, we complied with what “scientific method” means in achieving the aim we had and using the resources available. We complied with the research principles. They formed the basis for the operational methodological categories that have been established, namely: methods, procedures, techniques and means of research. The definition of the concepts was done step by step, as they were being implemented in research. There were cases when several variants of the concepts have been presented. Mainly two methods have been used: the experiment, implemented in the field research and the comparison method, used to analyze the variations, in space and time, within low-order floodplains systems.

The experiments involved having a measurements plan beforehand in order to do the experimental measurements in the field. We measured: water discharge in order to evaluate the fluvial processes that show the capacity the river has to erode, transport sediments and deposit them elsewhere. We repeated the measures in cross-section areas established beforehand, at short intervals (24-48 hours), in order to observe the processes within the river channel and at medium intervals (3-4 months), in order to research the stability of the floodplain.

The analysis of the morphodynamic evolution of low-order floodplains was done through an assessment of the floodplain processes and landforms, at three territorial levels that reflect different levels of organization the drainage systems have. A first longitudinal level is precisely the longitudinal sections that have been analyzed. They reflect the limits and the dynamic processes at the level of the whole basin. Another level studied is the horizontal one within which an analysis of the planform dynamics was done, with a focus on the specificity of the floodplain dynamics, within the three courses: upper, middle, lower.

The characteristics of flow and of the deposits play an important role within this level. The third level is the cross-section in which the shape of the floodplain section was analyzed, as a result of the interaction between flow processes and the morphological answer of the bedrock.

These levels have been integrated in a temporal dimension of the river dynamics by interpreting the floodplain processes in three different periods: at minimum discharge, normal discharge and at bankfull discharge.

The morphohydrological system is functioning by integrating the slope, floodplains, floodplain sectors, sub-basins sub-systems in the upper, medium and lower basin sub-systems. One of the major qualities of the morphohydrographical basins is the *feed-back,* an action that determines a continuous auto-regulation of the basin aiming to achieve a dynamic equilibrium (F. Grecu, 2008). The variations within the functioning of a morphohydrographic system determine fluctuations in the flow process. At bankfull and low flow, the flow processes have medium values, while in a stationary state, if a perturbation is slow downed, the system goes back to the no perturbation state.

The variation of the energetic flow in different points of the floodplain represents the main control factor of the dynamics of the riverbed. This variation is controlled by various parameters of the morphohydrological system: discharge, slope and the resistance of the deposits. The morphology and internal changes of the morphohydrographic system, which in this case is represented by the floodplains, represent an answer the landform gives to the inputs and outputs variability. The changes in the energetic flow entering the system determine changes in the flow dynamics, which determine morphological adjustments, as an effort the river makes to go back to a state of equilibrium.

There are numerous attempts to define in an exact way the concept of extreme hydrological event in geomorphological and hydrological research. Usually, it is associated with the concept of flood. The present study considers the concept of extreme hydrological event as a hydrological event that determines extreme answers from floodplain morphology and refers to a significant increase of the level of waters in the floodplains, being synonymous with flash flood. According to several opinions, the flood appears when the level of the river goes over its banks and overflows in the surrounding area, the flow reaches the level of the floodplains. For practical purposes, a specific stage for different levels is established, namely the flood level. From this level the water overflows over its banks. We say that when close to this point, the river reached its bankfull level, yet the water is still within river channel limits. The increase of the river level to its maximum point followed then by a gradual decrease in the water level is called the flash flood wave hydrograph, usually known as flash flood wave. This is made up of an extreme increase and decrease of the discharge during a very short period of time.

Usually, the main change the river experiences during floods is an increase of the water level, followed by an overflow in the floodplain area. Yet, important changes are taking place in the river channel, too, even though they are less visible. The channel deepens due to erosion and the sediment deposits fill this depth at the same time, as a consequence of the changes occurred in the river capacity to transport its load. The capacity to transport the bedload increases three or four times the value of the speed. If during a flood, the river speed doubles, the capacity to transport the bedload increases to eight-sixteen times.

Therefore, catastrophic changes take place within the floodplain during floods and significant increases of the discharge in the floodplain.

The analysis of such a complex system the floodplain is can not work with a low number of variables. The present research needed some synthetic variables, which to indicate the trends of evolution of the floodplains and, at the same time, to describe their behaviour during extreme events.

In conformity with some approaches from scientific literature (Nanson and Croke, 1992), we chose to measure the energies from the river channel, up to the bank level. These energies were compared to the flow capacity and the morphological resistance of the floodplain. The two above –mentioned authors do a classification of the floodplains in three major categories of floodplains in connection to the energy in the floodplain, determined as a function of the stream power and the characteristics of the deposits. They enumerate high energy non-cohesive floodplains (their landforms are in disequilibrium, as they are totally or partially eroded, following rare extreme events); medium-energy non-cohesive floodplains (they are in a dynamic equilibrium with the annual and multi-annual flow regime; usually, they are not affected by extreme phenomena; the main mechanism by which the floodplain is formed being lateral accretion of sandbars or vertical accretion in braided-river floodplain) and low-energy cohesive floodplains (associated with a lateral stability of the river channel; there is only one channel, in an anastomosing process).

The present study operated with these three classes of energetic floodplains, evaluated at extreme events flows, considering the flow power at bankfull, for the monitored floodplain sectors. Floodplain dynamics in between banks was also evaluated through measurements done in established cross-sections within the monitored areas. The aim was to define specific energetic conditions imposed by the flow regime, which depends on rainfall regime. Variations in space of the runoff in connection to the characteristics of the drainage basin have also been analyzed. The stream power and bank resistance were relevant in the study of the morphodynamics of low-order floodplains.

The stream power measures its capacity to transport sediments as bedload or in suspension. Our measurements showed major differences between the two. The stream power on length unit, at bankfull was 6586 W/m (Tagu River) and 3950 W/m (Ragu River), in the mountainous area and 243 W/m (Corhani River) and 470 W/m (Poiaş river). The measurements done at normal discharge register similar differences. The conclusion would be that rivers at high altitude, when faced with high discharge, succeed to take along coarse-grained sediments and erode the river channel through intense processes, of lateral and vertical incision. Low-altitude rivers, within which suspension-type of transport dominates, evolve through processes of transportation and accumulation of fine-grained sediments within the floodplains, developing anastomosing trends.

The power with which these rivers act is though conditioned by the bank resistance and the sediments they transport. The resistance of the deposits (non-cohesive coarse-grained sediments, in high-altitude rivers and cohesive, fine-grained sediments, low-altitude areas) differs and determines a different morphological answer imposing different morphodynamic trends to low-order floodplains from Crasna River drainage basin. Ragu and Tagu rivers evolve by deepening towards a straight type of river channel and tend to destroy their floodplains at extreme hydrological events as there is a weak resistance of floodplains. River at low altitudes evolve through processes of lateral migration and tend to overflow in the floodplain determining an aggradation through floodplain accumulations. These rivers have cohesive banks, resistant to erosion.

The evolution trends of the floodplains have been evaluated based on the researche done on the longitudinal sectors of the floodplains. These trends are based on the behaviour of the floodplains in each position of the long profile, as an answer to the specific flow conditions in each sector. Morphodynamic processes do not work isolated but in association, therefore floodplain morphology is the result of complex genetic mechanisms. Floodplain profiles in cross-sections emphasized specific incision and accumulation processes, even at short intervals, in the case of high altitude rivers, as they are functioning in a dynamic disequilibrium. The profiles were less relevant in the case of low-altitude rivers as they are in dynamic equilibrium.

Specific stream power is a parameter measured on wetted perimeter of river channel section indicating the power available for erosion or aggradation in cross-sectional areas. Correlating this parameter with the floodplain processes, which have been seen during the monitoring or on the succession of long profiles, the genetic mechanisms of the floodplain morphodynamics could be established. By comparing these genetic mechanisms of each floodplain sector with the mechanisms of the genetic classification, done on energetic criteria by Nanson and Croke (1992), we succeeded to validate the former, both concerning the energetic values and the resulted landforms.

High-energy morphogenetic environments, evaluated at bankfull discharge, specific for high-altitude rivers, determine the formation of high-energy non-cohesive floodplains with specific stream power between 300 and over 1000 W/m^2. These types of values are registered in the case of the two sub-basins located in forestry areas, the variations being connected to local specificities.

Sub-basins located in the piedmont, agricultural areas registered lower energetic values (specific for a medium-energy morphogenetic environment) in the upper course, at bankfull. Despite these low values, the planform is straight, no meandering. Corhani and Poiaş rivers are characterized by medium-energy 50-200 W/m^2, the floodplains evolving through incision and lateral accretion of non-cohesive deposits. The two rivers have a sinuous sector within the middle course, within a medium-energy morphogenetic environment. Energy is increased by the increase of basin surface as it receives tributaries. Corhani River is characterized by a low-energy morphogenetic environment within its lower course and develops an anastomosed sector, with vertical accretion in its river channel. Extreme events determine an overflow onto the floodplain and vertical accretion of fine-grained deposits. Poiaş River experiences variations of its base level following overflow from Vârşolţ reservoir. Its evolution trend is a typical one, of vertical incision and the formation of the floodplain through suspension.

The results obtained facilitated the drawing up of evolution models for low-order floodplains in Crasna basin, through a functional and comparative type of approach.

Two evolution models have been created and they describe the specificity of the morphohydrographic basin of Crasna River. These models are: one characterizing the low-order floodplains from hydrographic sub-basins located in forestry areas, at the contact between the metamorphic-structured mountains and the piedmonts. This model is represented by Ragu and Tagu rivers. The second one is specific for hydrographic sub-basins located in agricultural areas, at the contact between the piedmonts and low altitude areas, characterizing Corhani and Poiaş rivers.

Fluvial modelling within low-order floodplains has several similitudes with fluvial modelling at high-order floodplains, concerning the structure of the floodplain system and genetic mechanisms. Low-order basins, in comparison with high-order ones, are characterized by simpler type of runoff pattern, as the runoff is dominated by fluvial processes with extreme materializations which mainly affect the components of the floodplain. Major morphologic features of low-order rivers (bank configuration, the floodplain planform) are generated during extreme runoff conditions, as within normal flow conditions there are only rearrangements of the deposits in the river channel.

The conclusion of the present study on the morphodynamics of the low-order floodplains is that the floodplain is a transitional state between torrent erosion (temporary mophohydrographical systems) and high-order morpho-fluvial systems (permanent mophohydrographical systems). The lack of flow uniformity confers a superior dynamics to floodplain landform for low-order rivers. These rivers pass rapidly from low discharge to normal flow and then to high discharge, determining a spasmodic flow, thus they are similar to torrential type of erosion. The main cause of this accelerated dynamics is the small contribution of base runoff from the infiltration of rainfall. As the river gathers more waters, its discharge and flow regime is regulated through an extension of the basin, thus becoming a high-order river.

Sub-basins located in forestry areas at high altitudes in the upper course of Crasna basin (Tagu şi Ragu) develop in high –energy morphogenetic environments and present a high level of instability at all floodplain sectors. Upper and middle courses instability is determined by the relief energy and is intensified during extreme events. The morphodynamics of low-order floodplains oscillates between degradation and aggradation, in connection with the evolution of their discharge and the slope, yet the degree of cohesiveness of the deposits controls the rhythm of the processes. The succession of the meandering and braided–type of sectors along the long profile is supported by the antagonism of the incision and accretion processes within cross-section, where the river channel and the floodplain adjust one another. This balance is visible in planform. It rapidly passes from a straight course into a meandering one (high-energy non cohesive floodplains, with vertical accretion), in the upper course of the forestry area rivers; or from a braided course to a meandering one (medium-energy non-cohesive floodplains, unconstraint by vertical accretion), in the middle course of these rivers. The stability of the lower course increases as the basin expands (in the case of Ragu River) or the forest extends (Tagu River). Stability is maintained within the lower course even during extreme events. This indicates the existence of autoregulation mechanisms at the level of the floodplains (in the case of Ragu River) or at the level of the morphohydrographical basin (Tagu River). The morphodynamics of the two basins is controlled by climate.

Sub-basins in low-altitude, agricultural areas of Crasna basin (Poiaş and Corhani) evolve in medium and low-energy environments and their operation in a state of equilibrium confers them high morphodynamic stability, both at normal flow and extreme events. Instability within these systems is related to the introduction of additional energies through anthropic activities. Agriculture determines torrent-type of processes in the upper course and water exploit determines variation of base level destroying the equilibrium of the rivers. High stability in all sectors is determined firstly by the low relief energy and also by the wide floodplains, which allow the rivers to adjust their flow through an overflow into the floodplains during extreme events.

The stability of such morphohydrographical systems that evolve in low-energy morphogenetic environments is perturbed by anthropic activities. Research showed that low-order floodplains, downstream Vârşolţ reservoir, are affected by vertical incision processes, of regressive nature, following the overflow that changed local base level. This difference in evolution of the basins in the piedmont, agricultural area prove that the reservoir represents the local base level for the upstream floodplains, yet it also influences the downstream floodplains. The morphodynamics of low-order floodplains from agricultural areas in Crasna basin shows that man becomes an important control factor and, along with climate, introduces major perturbations in the operation of morphohydrographic systems.

Low-order floodplains are the proof of the fundamental instability in the dynamics of a fluvial system which can be seen in the processes of vertical accretion and incision of the bedrock and the ones of lateral accretion and incision of the banks. The four processes are closely linked in the mechanism of floodplain genesis. The most probable scenario is that the causes of this instability are answers of the morphodynamic system given to climate, the main factor that controls the inputs in the system. Yet, lately, this answer is given to the anthropic factor in a greater degree.

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