Investigation of channel pattern evolution of experimental rivers

PhD dissertation

Author:
KINGA KISS
Doctoral School of Earth Sciences
Department of Cartography and Geoinformatics

Doctoral Supervisor:
DR. TITUSZ BUGYA
Department of Cartography and Geoinformatics

Head of Doctoral School:
PROF. DR. ISTVÁN GERESDI
Department of Geology and Meteorology

University of Pécs

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Chapter 1

Introduction and Objectives

The term river channel pattern describes the general shape of a river reach which can be straight, sinuous or meandering, wandering, braided or anabranching. These types, however, cannot be clearly categorized into homogeneous classes, as prevailingly transitional patterns are found in nature. Nonetheless, rivers are constantly changing, therefore, the actual channel pattern is only a snapshot of the channel evolution process. Rivers give various responses to the external impacts, which are manifested in diverse channel patterns. Hence, channel patterns ultimately are the result of changes and processes that occur along the course of the river

Processes that influence the evolution of river channel patterns have been concerning fluvial morphologists for a long period of time and many processes, responsible for channel development, are poorly understood. In general river planform evolution is controlled by both anthropogenic and natural factors simultaneously. However, their relative importance differs for each river channel. Natural processes include channel roughness, slope, channel petrology, bedload type and depth, land use type, sinuosity and river competence. However, the intensity and impact of these factors on channel evolution is different. Therefore, a question is may raised: which external and internal processes form each pattern and how their intensity enhances the evolutionary processes?

Today, anthropogenic effects are increasingly influencing channel patterns and geomorphic characteristics of rivers and greatly influence the processes, landforms and planforms of fluvial systems. Such anthropogenic effects include the construction of dams, levees and other flood prevention structures, coastal protection and regulation systems or changes in land use along the river. These changes in land use may affect runoff conditions generating marked channel pattern changes.

One way to understand the intensity of these factors is the use of physical models, like flumes, to model the natural processes.

Therefore, we aimed at identifying factors that are responsible for channel pattern formation. Our specific goals were the following:

1. To determine similarity between river planforms and channel patterns formed under natural processes and flumes;
2. To examine if river channel patterns can be reproduced as demonstrated in former literature using similar parameters;
3. To reproduce sinuous or meandering patterns under laboratory conditions;
4. To determine the indices – used for describing channel characteristics – most suitable for the classification of channel patterns for both experimental and natural rivers;

5. To analyze correlation between the above-mentioned indices and channel patterns formed in the flume;

6. To investigate how channel patterns formed in the flume differ from patterns formed in natural rivers.

Chapter 2

Materials and Methods

The flume at the University of Pécs was used to simulate channel and planform evolution as a function of slope, discharge and texture.
The flume tests were carried out using the PTETHYS (Project for Tectonical and Hydrological Simulations) flume at the University of Pécs. The flume can be adjusted and tilted both around its longitudinal (7.5°) and transversal axes (up to 10°) and has adjustable push-blades both vertically and horizontally. Six sections can be moved vertically and it has 4 push-blades which allows lateral deformation. These adjustments enable the execution of various experiments including tectonic and morphological processes. These motions are controlled by computer-governed electro-engines. Thus water and sediment could leave the flume only through a sink in its downstream part.
The experimental area is 4.4×2.3 m, which can hold up to 2500 kg of sediment. For modeling purposes a 1 m wide section of the entire flume was used where the bottom was made of plexiglass and for the lateral constrains of the flow wooden boards were used. The bottom of the flume was also secured using plexiglass to prevent the infiltration. Discharge was measured and

regulated by a flow meter.
The material used in these experiments is color-coded; the colors of grains indicate grain size. Coarse grains are grey ground basalt (1.0 mm) and black andesite (0.8 mm). The 0.6 mm diameter grains are of red marble and the 0.2 mm diameter are of beige limestone.
At low gradients, flow and sediment mobility was too low or remained below the threshold of motion. Therefore, compared to natural river gradients, relatively steep slopes (from 1° to 5°) were used in the flume experiments. This allowed the onset of sediment transport and resulted in active morphodynamics and the development of river planforms. During the gradual change of input parameters (gradient, discharge and texture), phenomena, typical for natural rivers, was observed.
During the flume tests, images of actual planforms were taken in every 60 seconds using 8 Canon EOS 1100D (4 Samyang 16 mm f/2,2 and 4 Sigma 24 mm f/1,4 objectives) cameras installed on a system of cantilevers above the experimental area. Cameras were connected to a computer with USB ports, hence images were taken concurrently with each camera. Pictures were taken with a horizontal overlap of 80%, enabling the calculation of the 3D models of the planforms. Ten markers (ground control points) of known spatial coordinates were used as references in the experimental. Their coordinates were measured with a Sokkia total station in a local coordinate system. As a result, all obtained 3D models were in the same coordinate system allowing the measurement of distances and volumes in the model space.
Agisoft Metashape 1.5.3 was used for image processing and the calculation of digital elevation models using synchronous images. Digital elevation models were processed in ArcGIS Pro. Based on the obtained 3D models, channel planform changes were analysed by the cross-sectional profiles of the channels and their im-

mediate vicinity.
To determine channel patterns, indices, developed by different authors, were used. Sinuosity and braiding indices were calculated for the channels formed during the flume experiments.
The digitized layers used for calculating these indices can be examined in Figures 2.1 and 2.2.

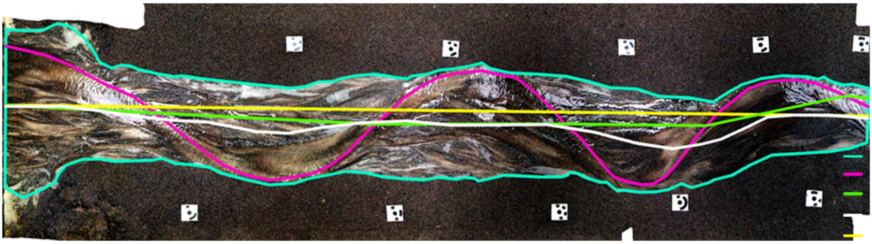

Figure 2.1: Vector layers digitized for calculating sinuosity indices.

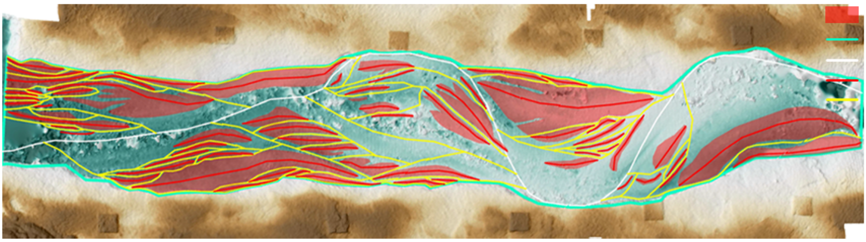

Figure 2.2: Vector layers digitized for calculating braiding indices.

Chapter 3

Summary

Our experiments were typical examples of river channel patterns formed under humid and semihumid climates. Over the course of our research, the 3 studied factors (gradient, discharge and texture) were systematically changed in order to determine their effect on planform formation. The large number of repeated experiments were suitable for identifying trends without a large number of comprehensive statistical analyses. According to our findings, the following conclusions have been drawn:

1. The flume experiments validated that planforms and processes observed in nature can be reproduced under laboratory conditions. The modelled planforms can be used as starting points for further research and by refining them they may provide an opportunity for comprehensive statistical analysis.

2. Our experiments were carried out using a slightly higher slope than in the previous, classic (e.g. Schumm, Khan) research. Although by changing this parameter it was found that planforms of rivers change indeed in a similar way. Experiments of higher gradient were

needed to obtain channel networks similar to natural ones. These findings verified the research of Schumm, Khan (évszám).

3.Meander evolution was found to be greatly influenced by bank strength. Although sinuous thalwegs were formed during all experiments, meandering channel pattern was not obtained. This is explained by the reduced bank strength due to the low coherence of the medium used during the flume experiments. This finding is in correspondence with the results of (Hiuvatkozás).

4. Sinuosity and braiding indices were applicable to quantitatively compare and analyse channel patterns and assess sinuosity and the properties of anastomosing and braided features of the channel networks. These indices were found applicable for the analysis of both natural and laboratory channels. Both the degree of sinuosity and braiding indices showed a relatively low variability during the experiments. These indices therefore provided a basis for the quantitative comparison of natural rivers and rivers created in laboratory conditions.

5.Gradient markedly influenced the degree of braiding. Braiding featured were formed more rapidly on steep gradients (closer to 5°) than on low gradients (closer to 1°). Inverse relationship was revealed between sinuosity and braiding in the used range of gradient (1 to 5°). We observed that the morphology of braided and anabranching channels are very similar to their natural counterparts and they are shaped by similar processes. Orthophotos were found to be suitable for the identification of channel forms and the calculation of sinuosity and braiding indices.

6.. The morphology of braided and anabranching channels were similar to their natural counterparts, i.e. flume experiments properly reproduced natural channel features. When upscaled, the active channels of the modelled braided and anabranching rivers migrated at similar rate to natural channels with increasing time of channel evolution. Hence the lateral migration history of the main channels can be reproduced under laboratory environments. We also found that in a linear relationship with braiding, channel length increased during the flume experiments. We found that the formation of these patterns is closely related to partial avulsion processes, channel migrations and to the changes in sinuosity, which in fact forms the entire braided-anabranching river planform. The total length of channels of these planforms gradually increase, which can be supported by the calculated values of brading indices. We found that the formation of these patterns is closely related to partial avulsion processes, channel migrations and to the changes in sinuosity, which in fact forms the entire braided-anabranching river planform. The rate of avulsion processes can be reduced by strengthening riverbanks, which is achieved by creating a small valley in the experimental medium prior to the onset of the experiment. This way formation of planforms with braided-anabranching channels can be reduced, forming wandering channels with sinuous thalwegs and point bars. The structure, shape and relative size of the point bars were similar to those of found in nature.

Publications

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VIII. Halmai Ákos, Gradwohl-Valkay Alexandra, Czigány Szabolcs, Ficsor Johanna, Liptay Zoltán Árpád, **Kiss Kinga**, Lóczy Dénes, Pirkhoffer Ervin Applicability of a Recreational-Grade Interferometric Sonar for the Bathymetric Survey and Monitoring of the Drava River *International Journal of Geo-Information 9(3):149* (SJR: Q1)

IX. Marcin Słowik, **Kinga Kiss** ✉, Szabolcs Czigány, Alexandra Gradwohl-Valkay, József Dezső, Ákos Halmai, Adam Marciniak, Remigiusz Tritt, Ervin Pirkhoffer The influence of changes in flow regime caused by dam closure on channel planform evolution: Insights from flume experiments *Environmental Earth Sciences 80, 165 (2021).* (SJR: Q2)

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