River channel planform changes based on successive cartographic data. A methodological approach.

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Abstract

The boost in the national and international research on the centennial and multicentennial-scale changes in the configuration of river channels has led to a need for standardization of database acquisition methods, so that the final results may be accurately compared regardless of the size of the analyzed river and its physical environment. This paper introduces: the working materials needed for such studies (sources available in Romania and their preparation); landmarks necessary for the delimitation of the study area, typological classification of the channels, delineation of the representative channel sectors; methods for acquiring morphometric data (planform). The literature (with illustrative case studies cited in this paper) provides examples on how the results can be processed and interpreted in order to obtain valuable indicators of the trends in channel changes and the stages in the evolution of their configuration. Moreover, they may also indirectly deliver information on the historical changes in the controlling factors (i.e. climate variation or anthropogenic interventions) which generate changes in the morphology and morphometry of river channels.

Cuvinte cheie: river channels, historical maps, aerial photos/orthophotos, planform morphometric methods, Romanian examples

1. Introduction

The recent amplification of scientific interest regarding the centennial-scale changes in river channels, both nationally (Dumitriu, 2007; Canciu, 2008; Feier & Rădoane, 2008; Ioana-Toroimac, 2009; Perșoiu, 2010; Rădoane et al., 2010; Cristea, 2010; Floroiu, 2011; Perșoiu & Rădoane, 2011; Chiriloaei, 2012; Zaharia et al., 2011), but more so internationally (e.g. Winterbottom, 2000; Gurnell et al., 2003; Surian & Rinaldi, 2003; Rinaldi, 2003; Liébault & Piégay, 2001, 2002; Surian and Cisotto, 2007; Wyżga, 2008; Zawiejska and Wyżga, 2010; Swanson et al, 2011; Zilliani and Surian, 2012) compels us to grant special attention to the matter of necessary resources and research methods.

The present study aims at approaching this matter, such that the quantitative investigations of channel planform changes in Romanian rivers may have a common ground for comparison. Furthermore, this database could be compared with corresponding continental-scale databases or even broader.

The results obtained thus far (on rivers pertaining to Siret drainage basin - Rădoane et al., 2010; Cristea, 2011; Chiriloaei, 2012, Prut basin - Rădoane et al., 2008, Prahova basin - Ioana-Toroimac, 2009; and Someș drainage basin - Perșoiu, 2010) were not the product of unitary methods, such that the deriving information on the behavior of rivers during the past 100-150 years may be unequivocal. By the intended outcome of this work we wish to provide a framework for
researchers, master and doctoral students, and anyone who is interested in measuring planform changes in river channels over variable periods of time. Moreover, the resulting database could be conceived as patrimony for synthetic analyses.

The approach is focused on two major parts: the working materials (available sources and their preparation), the preparation for the measurements (ranging from selecting the channel corridor and the reach to segmentation of the channel), and the actual morphometric measurement methods (various techniques for acquiring morphometric data from historical maps).

2. Materials for river channel geomorphometry research

The materials necessary for such studies are historical documents, mainly maps and aerial photos/orthophotos, which have recorded certain configurations of the river channel. We will focus, as expected, on records of the Romanian territory which are available to the academic community. For comparison, a comprehensive paper summarizing the nature and diversity of historical materials currently used internationally in such investigations was published by Kondolf and Piegay (2003).

2.1. Cartographic sources available in Romania

In order to properly identify the documents and historical maps instrumental to the study of rivers it is necessary to appeal to the history of Romanian cartography through works such as the guide by Popescu-Spineni (1978), but also more recent papers (Osaci-Costache, 2001, 2006) and dedicated websites (www.geo-spatial.org).

Fig. 1. Reaches with different typology according to successive cartographic documents.
The sequence of cartographic documents used to study the changes in the channel of Someşu Mic river over a time period of 145 years (Perşoiu, 2010) is shown in Fig. 1. This series of images readily illustrates the dynamic potential of river channels. The sinuous sector of the river in 1860 (though clearly maintaining two generations of meanders within the floodplain from an earlier period) has morphed into a channel with straight reaches in 2005 (under anthropogenical intervention); a highly meandering sector in 1860 has evolved into a sinuous channel in 2005; an anastomosed reach in 1860 developed into a sinuous, unitary channel in 2005 (also, by undergoing significant anthropogenic intervention).

The main historical maps of the Romanian territories which have been used up to date in relevant studies of fluvial geomorphology are shown in Tables 1 and 2 (comprised all the data provided by the authors of the papers).

Table 1. Historical documents and maps employed for the analysis of planform changes in river channels from southeastern Romania (Ioana-Toroimac, 2009; Cristea, 2011)

<table>
<thead>
<tr>
<th>Source name</th>
<th>Century, year</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical documents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Documente privind Istoria Românilor, Documenta Romaniae Historicae, Documente tecucene, Documente putnene (pentru câmpia joasă a Siretului)</td>
<td>XV, 1423-1495</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XVI, 1514-1589</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XVII, 1642 – 1677, 1677-1688</td>
<td></td>
</tr>
<tr>
<td>Historical maps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harta lui N.Sanson</td>
<td>1655</td>
<td></td>
</tr>
<tr>
<td>Harta lui C.Cantacuzino</td>
<td>1700</td>
<td></td>
</tr>
<tr>
<td>Harta lui Dimitrie Cantemir</td>
<td>1737</td>
<td></td>
</tr>
<tr>
<td>Harta lui von Bawr</td>
<td>1770</td>
<td>1:288000</td>
</tr>
<tr>
<td>Harta lui von Otzellowitz</td>
<td>1790</td>
<td>1:28000</td>
</tr>
<tr>
<td>Harta lui Specht</td>
<td>1790-1791</td>
<td>1:57600</td>
</tr>
<tr>
<td>Harta rusă</td>
<td>1835-1853</td>
<td>1:420000</td>
</tr>
<tr>
<td>Harta Satmari</td>
<td>1855-1857</td>
<td>1:57600</td>
</tr>
<tr>
<td>Planuri directoare de tragere, proiectie Lambert</td>
<td>1897-1902</td>
<td>1:20000</td>
</tr>
</tbody>
</table>

Table 2. Cartographic documents employed for the analysis of the planform shape of Someşu Mic channel (Perşoiu, 2010)

<table>
<thead>
<tr>
<th>Name of the map</th>
<th>Date of the survey</th>
<th>Publishing year</th>
<th>Scale</th>
<th>Projection</th>
<th>Institution</th>
<th>Resolution</th>
<th>Year referenced in the text</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Austro-Hungarian military surveying</td>
<td>1763-1773 1785 / 1787*</td>
<td>1787*</td>
<td>1:28.800</td>
<td>No projection</td>
<td>Institutul de Geografie Militara, Viena</td>
<td>No geo-referenced</td>
<td>1764</td>
</tr>
<tr>
<td>Third Austro-Hungarian military surveying</td>
<td>1869 - 1884</td>
<td>1890 – 1910</td>
<td>1:25.000</td>
<td>Proiecție stereografică Tg Mureș pe elipsoid Besel 1841</td>
<td>Institutul de Geografie Militara, Viena</td>
<td>2m/pixel</td>
<td>1884</td>
</tr>
<tr>
<td>Topographi maps</td>
<td>1940*</td>
<td>1943</td>
<td>1:50.000</td>
<td>Proiecție stereografică Tg Mureș</td>
<td>UNGARIA</td>
<td>No geo-referenced</td>
<td>1940</td>
</tr>
</tbody>
</table>
| Topographical maps | Updated: 1968  
|--------------------|----------------|-------|----------|-----------------------------------------------|-----------------------------------|------------|------|
| Topographical plans | Aerial photography: 1968-1976  
Field: 1970-1977 | 1971-1979 | 1:5.000 | Proiecție stereografică Stereo 70 Elipsoid Krasovski | IGFCOT | 0.4 m/pixel | 1970 |
| Orthophoto | 2005 | - | 1:5.000 | Proiecție stereografică Stereo 70 Elipsoid Krasovski | ANCPI | 0.5 m/pixel | 2005 |

Notă: * Uncertain data or incomplete; IGFCOT = Institutul de Geodezie, Fotogrammetrie, Cartografie și Organizarea Teritoriului; DTM = Direcția Topografică Militară; ANCPI = Agentia Nationala de Cadastru și Publicitate Imobiliara.

2.2. Preparation of the materials

This section is dedicated to some practical aspects regarding the proper manner in which to analyze each cartographic document and the necessary know-how for this operation, as well as the risks to the quality of the measurements posed by a superficial approach of this stage (i.e. “preparation of the materials”). Specifically, it involves scanning the available cartographic materials, georeferencing in the Stereo 70 projection or establishing map location based on control points, and a statistical estimation of the errors generated by georeferencing.

2.2.1. Scanning / acquiring the available cartographic materials

Scanning the source materials, i.e. transferring the data from analog to digital format, is a mandatory step in the graphic processing of the data by using a specialized software. Furthermore, the quality of the scan contributes to establishing the mapping scale; e.g., when scanning a 25,000 scale topo map at 300 dpi (dots per inch), the resulting resolution of the pixel after georeferencing the map will be approx. 2.1 m (according to the calculation shown below). Scanning the map at 150 dpi will generate a pixel resolution of approx. 4.2 m, thus a generalization. While these differences do not interfere with the degree of accuracy of the original map, they will, however, influence the quality (scale) of vectorization of some elements (banks, thalwegs, etc.).

\[
\frac{1}{300} \text{ (dpi)} = 0.003; \quad 0.003 \times 25000 \text{ (map scale)} = 83.33; \quad 83.33 \times 2.54 \text{ (conversion of inch to cm)} = 211.66 \text{ cm (pixel resolution after georeferencing, 2.11 m)}
\]

Considering the fact that military and cadastral maps, with relatively restricted accessibility, are the most commonly employed cartographical documents for such purposes, the access to such data in analog format is rather difficult. Moreover, the movement of maps and survey plans is considerably facilitated when they are in digital format (e.g., the Austrian maps dating back to the 18th and 19th centuries – distributed by ARCANUM, Timar et. al., 2010, Planurile Directoare – distributed by www.geospatial.org, Crăciunescu et. al., 2011), and the user is unable to intervene on the scanning settings. However, we believe it is pertinent to highlight the quality of the digital materials employed in the analysis (i.e. the resolution) in order to accurately assess the vectorization errors.

2.2.2. Georeferencing and statistical estimation of georeferencing errors
Through the georeferencing process, cartographic materials published in different chronological stages and projections are assigned geographical coordinates by means of a specialized software in order to achieve an accurate positioning on the Globe as a basis for comparative analysis.

The information necessary in this stage (name of the projection and datum, the known geographical or rectangular coordinates of several points – considered control points during this process) is commonly printed on the map sheet, including the year/period when it was elaborated. However, this data is lacking in older maps; therefore, in these situations, the georeferencing process needs to be carried out based on previous cartographical studies comprising information regarding the coordinate system used for that particular generation of maps or plans, or, ultimately, by identifying pairs of common points (whose position has not been altered over time – e.g., buildings, crossroads, bridges, etc.) on old cartographic materials and the more recent ones, which have already been georeferenced.

The accuracy of the process requires the materials to be georeferenced in their original projections and to subsequently be re-projected in a different coordinate system, as needed. This matter is of particular importance in historical change analyses, considering the fact that several types of projection systems have been employed for the Romanian territory over time, each with distinctive types of errors. Aside from the projection systems used on a regional scale, it can be noted (Table 3) that the entire Romanian territory has been covered during the 19th century by maps made in either conical, azimuthal or cylindrical projection, each with different parameters and degree of distortion of distances and areas.

**Table 3.** Characteristics of projections and ellipsoids used in different chronological stages for the elaboration of maps covering the entire territory of Romania

<table>
<thead>
<tr>
<th>Characteristics of Map Projections</th>
<th>Lambert-Cholensky*</th>
<th>Stereo 70</th>
<th>Gauss - Krueger</th>
<th>U.T.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central meridian</td>
<td>Conic projection (conformal)</td>
<td>Azimuthal projection on a secant plane (conformal oblique stereographic / double stereographic **)</td>
<td>Transverse cylindrical projection (conformal)</td>
<td>Transverse cylindrical projection (conformal)</td>
</tr>
<tr>
<td>Origin latitude</td>
<td>24°18'44.99&quot; E (24.31249722 E)</td>
<td>25° E</td>
<td>21° E</td>
<td>Zona 4</td>
</tr>
<tr>
<td>Scale factor</td>
<td>45°02'29.21&quot; N (45.04144889 N)</td>
<td>46° N</td>
<td>0°</td>
<td>Zona 5</td>
</tr>
<tr>
<td>Datum</td>
<td>0.99844674</td>
<td>0.999750</td>
<td>1.00000</td>
<td>Zona 34</td>
</tr>
<tr>
<td>Datum</td>
<td>504599.11</td>
<td>500000</td>
<td>500000</td>
<td>Zona 35</td>
</tr>
<tr>
<td>Datum</td>
<td>NA</td>
<td>Dealul Piscului 1970</td>
<td>Pulkovo 1942 (S-42 Romania)</td>
<td>WGS 1984</td>
</tr>
<tr>
<td>Ellipsoid</td>
<td>Clarke 1880</td>
<td>Krasovski 1940</td>
<td>Krasovski 1940</td>
<td>WGS 1984</td>
</tr>
<tr>
<td>Semi-major axis</td>
<td>6378249.2 m</td>
<td>6378245.0 m</td>
<td>6378245.0 m</td>
<td>6378137.00 m</td>
</tr>
<tr>
<td>Semi-minor axis</td>
<td>6356515.00 m</td>
<td>6356863.02 m</td>
<td>6356863.02 m</td>
<td>6356752.31 m</td>
</tr>
<tr>
<td>Inverse Flattening</td>
<td>293.47</td>
<td>298.30</td>
<td>298.30</td>
<td>298.26</td>
</tr>
</tbody>
</table>

*Rus et. al. (2009) **ESRI software

The official cartographic projection currently used in Romania is Stereo 70 (datum Dealul Piscului 1970); consequently, most databases were built up in this coordinate system. Thus, old cartographic materials are georeferenced and then re-projected in this system in order to ensure the homogeneity of the subsequent analysis. However, the precision of map overlay is influenced in
some instances not only by the accuracy of the coordinate conversion from a different projection system, but also by a number of parameters related to the geocentric conversion between the ellipsoids employed (in terms of datum). In the case of the data re-projected from Gauss-Krüger to Stereo 70 no transformation of the geodetic datum is required (as they are referenced to the same ellipsoid), whereas the re-projection from WGS 84 to Stereo 1970 would result in planform differences between the point positions ranging up to 125 m in the absence of transformation parameters. The accuracy of the transformation parameters depends on the method employed to generate them (i.e. their number - 3, according to the Molodenski method, and 7, according to the Bursa-Wolfe method). Thus, it is considered that in the case of the most commonly used WGS84 – Dealul Piscului 1970 transformation, with three translation parameters of the coordinates (ΔX= -28 m, ΔY= 121 m, ΔZ= 77 m), the position errors can amount to approx. 5 – 10 m (Bănică et. al., 2008).

The information regarding the coordinate systems employed in cartographic materials created over the past 50 years and the transformation parameters for their datum is rather common knowledge, therefore these materials generally allow for an analysis of channel planform changes with relatively small errors. However, the matter is considerably more complex in the case of older maps; e.g., for an approx. 33 km-long sector of Buzău valley (Vernești – Găvănești), Planurile Directoare de Tragere, georeferenced according to the parameters shown in Table 3 and re-projected to Stereo 70 (the maps are available online as part of the eHarta project, on www.geospatial.org; Crăciunescu et. al., 2011).

![Fig. 2](image-url)

**Fig. 2.** Differences in the position of several fixed points (churches) on *Planurile directoare* georeferenced within the *eHarta* project (background), sc. 1:20000 (1895 – 1900) and on *Topographic Map of R.S.R* (*Harta topografică a R.S.R.*), sc. 1:25000 (cca. 1980) – both re-projected to Stereo 1970.
In order to evaluate the precision of the overlay of *Planurile directoare* and the 25,000 military topographic map (edition 1980) we assessed the differences in the positioning of several fixed points (churches) appearing in both sets of maps. A total of 22 unevenly distributed pairs of such points, according to the degree of humanization of the territory, were identified on the 4 sheets comprising the channel sector under study (fig. 2).

By comparing the two datasets (pairs of points) we were able to identify deviations ranging from 50 to 110 m, with the majority of the deviations ranging from 60 to 90 m (70% of the instances) (fig. 3). By analyzing the orientation of vectors (generated by the pairs of coordinates from both maps), it became apparent that approx. 80% of the occurring differences were generated by a southward deviation of *Planurile directoare* compared to the more recent maps. This could be explained by an insufficient knowledge of the transformation parameters for older maps datum in the course of re-projection.

![Fig. 3. Magnitude of difference-vectors and their orientation (azimuth).](image)

Map overlay errors are significant to the analysis of river channel dynamics, thus, it is necessary to make corrections of the geographical location of older maps. This can be achieved by repeating the georeferencing process by using the common elements in both maps – e.g., churches. Human settlements are commonly located along the floodplains of large rivers, therefore the identification of such pairs of points is relatively facile. Although this method based on unevenly distributed control points does not necessarily guarantee an increase in the overall map overlay precision, it can, however, provide a more accurate frame of analysis of the floodplain.

Thus, in the case of the aforementioned valley sector, the repositioning of the old map sheets according to the newer edition based on the 22 control points (churches), ensued by an analysis of the residual values resulted from the adjustment of the coordinates and the elimination of the ones far exceeding the average, have greatly contributed to the increase in the overlay precision (<30 m). This is influenced by the type of conversion of the images used within the georeferencing software (which may include translation, rotation, uniform scaling – image-wide, or uneven scaling – local, by distorting the image), and the degree of accuracy of repositioning of the control points can be assessed by the RMS total error.

3. Preamble to the morphometric investigation of river channels

3.1. Typological classification of river channels under review
Any quantitative or qualitative approach to river channel analysis should be preceded by the typological classification of the planform configuration of the river, as the type of channel is the criterion which determines the ensuing steps: the sectorisation and segmentation of rivers, the actual morphometric measurements and determining the planform migration of river channels. The geomorphological classification of channel types is relevant because it contributes to a better understanding of the relationships between processes, forms and stability.

The progresses made in classifying channel planform shapes resulted in some changes in this regard compared to the earliest classifications made by Leopold and Wolman (1957) or Schumm (1981, 1985). The recent typology published by Rinaldi et al (2011) combines the latest developments in terms of the classification of channel planform configurations (fig. 4). The transition of channels from one type to another can occur along the same river without any obvious delineating thresholds, as the type of underlying sediment and the stability of the channel changes (Thorne, 1998). The types of channel assembled in Fig. 4 are characteristic for the Romanian geographical environment and are based exclusively on the channel planform shapes observed in the field, on historical maps or orthophotos (e.g., fig. 1).

A brief description of the main types of channel illustrated in Fig. 4 is as follows:

The **straight** (*R*) type is extremely rare in nature. It depicts straight channels with relatively uniform widths, low sediment loads, low slope gradients and stable banks which are usually shaped in deposits with high contents of silt and clay. The sinuosity index (*Is*) ranges from 1 to 1.05, whereas the anastomosis index (*Ia*) is below 1.5.

The **sinuous** (*S*) type describes a channel with an *Is* ranging from 1.05 to 1.5 carrying a mixed solid load (suspended and dragged), which contains small bars positioned alternately in the context of a sinuous thalweg, indicating that accumulation on the bank will be ensued by erosion due to the upstream migration of the bar.

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**Fig. 4.** Diagram of fluvial morphology and relative areas of variability of the planform morphological indices (Sinuosity index, *Is*, Braiding index, *Im*, Anastomosis index, *Ia*) (Rinaldi et al., 2011)
The **meandering (M)** type describes a whole array of meandering channels (Is equal to or above 1.5) ranging between two extreme situations: a) channels with high sinuosity where the suspended solid load is prevalent, which have high dynamic stability and their typical evolution is towards meander cutoff, and b) less stable meandering channels, due to the mixed solid load with increasing dragged sediments content. The channel width is greater within the meanders. Processes such as meander migration and meander cutoff are characteristic for this subtype of channel.

The **sinuous** type with alternating bars (SBA) and the **wandering (W)** type are transitional from meandering to braided channels. The solid loads carried by the channels in this class are typically high, comprising mainly of sand, gravel and boulders. The channel width is relatively high in relation to the depth. Alluvial banks and bars commonly develop within the channel bed, which play an important role in localizing bank erosion. The distinction between the two types of channels is provided by the braiding index ($Im \sim 1$ for SBA and $Im < 1.5$ for W).

The **braided (AI)** type is a category of channels commonly occurring in cases where the rivers have a significant dragged sediment load, braided channels enclosing rhomboidal bars, high slope gradients and highly unstable channel, which, in some cases, may lead to avulsion (sudden abandonment of the previous channel).

The **anastomosing (A)** type includes channels comprising of branches divided by islands covered with vegetation, low slope gradients and cohesive banks, and are typically more stable due to the prevalence of suspended solid load.

### 3.2. Delimitation of the study area

The selection of the study area in the field of river channels must take into account several considerations (listed below) in order to ensure the representativeness of the results in terms of the historical evolution of channels (approx. 150 years for Romanian rivers):

a) **The selection of the entire river or a certain reach displaying particular traits according to the position within the fluvial geomorphological system.**

In both cases, it should be taken into consideration that a river has certain characteristics imposed by the dominant control factors according to the position within the fluvial geomorphological system (fig. 5).

**Fig. 5.** Generalized scheme of a fluvial system (Schumm, 1977). The particularization of the investigations on the fluvial system varies according to the objectives pursued. A geologist or a geomorphologist may be interested in the river basin or the drainage area (zone A) over a long geomorphological time (at least 1 mln. years); a geomorphologist or a hydrologist can be interested in a reach (B) over a time frame ranging from tens to thousands of years; a sole meander (C) may be the focus of a geomorphologist or a hydraulic engineer over a period of merely a few years; the formation of a bar within the channel and the distribution of the sediments fall under the scope of the sedimentologist (D; E) (after Ichim et al., 1989).
Thus, the study area can be either located in the 1st zone of the fluvial system (where the organization and the evolution of the river network is mainly under the control of valley slope processes), in the 2nd zone of the fluvial system (the domain with the highest complexity of the water + sediment transport), or in the 3rd zone (where the sedimentation of the products originating upstream generate specific terminal morphologies).

The 2nd zone of the fluvial system is the area where the most typologically complex river channels commonly develop, which has prompted Schumm (1977) to define this as the fluvial zone. It is, thus, inherent that within the 2nd zone, a river can include all the morphological types of channel described in the previous chapter. However, this does not imply the absence of river channels in the 1st and 3rd zone, but their presence is not as representative as in the case of the 2nd zone.

Identifying and observing these zones will enable us to move on to the following methodological stage, namely the delimitation of study sectors.

b) Delineation of representative reaches along the investigated river

According to the definition of fluvial geomorphology, the reach describes a unit of the natural channel whereby the length is the wavelength of a meander (in the case of sinuous, meandering or wandering channels), the distance between two successive pools or riffles (in straight channels), or the distance between two consecutive braiding nodes (in braided channels). These lengths can be derived based on the channel width; e.g., for a channel below 1 m wide, the length of the reach can amount to 5-7 m; a channel width of 200 m commonly results in a length of the reach of approx. 1.5 km (Leopold et al., 1964).

We believe that, in the context of the research on the historical dynamics of Romanian river channels, the selection of the reach length according to the aforementioned criterion is restrictive. A reach of 5 – 7 x bankfull channel width can be illustrative of the changes in the micromorphology and the subsequent fluvial processes over a relatively short period (i.e. a flood event, a season, or changes occurring over several years). However, a broader approach in terms of the reach length is required in order to document the historical-scale changes in a river channel. Therefore, the length of the reach suitable for this type of approach has been extended to the order of tens of kilometres. We also took into account the recommendations of Surian et al., (2009) or Rapp şi Abbe (2003), who suggested that the reach length should be of 10 to 14 fold the width of the channel, or 10 to 20 fold, respectively. We ensured that in no instance did the length of the reaches in the river channels under analysis fall below the length recommended in the literature, but, on the contrary, it exceeded this limit (Table 4). In the case of rivers shown as example in table 4, the length of the reaches ranges from 136 km (approx. 85% of the total length of the river) to 35 km (11.5% of the total river length).

Table 4. General data on the study reaches in Romania in terms of the contemporary and historical evolution

<table>
<thead>
<tr>
<th>River</th>
<th>Drainage basin area A (km²)</th>
<th>River length L (km)</th>
<th>Reach name</th>
<th>Reach length Ls (km)</th>
<th>Percentage of analyzed reach (%)</th>
<th>General slope gradient Ig (m/1000 m)</th>
<th>Drainage basin area, Upstream Aam (km²)</th>
<th>Discharge Qmean annual (m³/s)</th>
<th>Suspended load Qmean annual (g/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Someşul Mic</td>
<td>3595</td>
<td>176,8*</td>
<td>Gilău – Dej</td>
<td>105</td>
<td>59.4</td>
<td></td>
<td></td>
<td>22.5</td>
<td>9,5</td>
</tr>
<tr>
<td>Buzău</td>
<td>5238</td>
<td>303.4</td>
<td>Cândeşti - Săgeata</td>
<td>35</td>
<td>11.54</td>
<td>0.002</td>
<td>2783,2</td>
<td>3871,8</td>
<td>27.7</td>
</tr>
<tr>
<td>Putna</td>
<td>2518</td>
<td>160.3</td>
<td>Lepsa – confl. Siret</td>
<td>136</td>
<td>84.8</td>
<td>0.004</td>
<td>149</td>
<td>2518</td>
<td>16.1</td>
</tr>
</tbody>
</table>
c) Establishing the confinement degree of the channel

Regardless of its planform, the channel can be influenced in terms of its evolution by the degree of limitation of lateral migration by various obstacles (e.g., the contact with the hillslope). This aspect is assessed quantitatively by means of the degree of confinement (Gc) (fig. 6).

![Fig. 6](image)

Fig. 6. A. The degree of confinement and the size of the river course in various zones of the fluvial system; B. Illustration of the method of measurement of the degree of confinement, Gc, of the channel (processing after Rinaldi et al., 2011, Brierley & Fryirs, 2005, Church, 1992).

This parameter assesses the degree of lateral confinement of the channel along the river at reach- and subreach-scale. It represents a ratio between the length of the banks (Lm_sum) which are in direct contact with valley slopes, terrace scarps, etc., and the total length of the banks within the study reach (Ltm) and is estimated as a percentage value. The sectors where the degree of confinement (Gc) is above 90% are considered reaches with confined channels, whereas a Gc >10%-<90% indicates a semi-confined channel, and a Gc <10% indicates a reach with a non-confined channel.

In addition, the index of confinement (Ic) evaluates the degree of confinement within a measured cross section, as opposed to the Gc, which is a longitudinal approach of the confinement along the reach. This index represents the ratio between the width of the floodplain (including floodplain terraces) and the bankfull channel width. The value of the confinement index is 1.0 (when the floodplain is lacking). In order to measure it, we use the cross sections delimiting the reach. In turn, the confinement index allows for a subdivision of the reaches in the following classes:

- high confinement, index ranging from 1 to 1.5
- medium confinement, index ranging from 1.5 to n
- low confinement, index > n
The \( n \) value, which is designed to distinguish between medium and low confinement is also related to certain types of channel (Rinaldi et al, 2011), as follows:
- \( n = 5 \) for single channels and *sinuous with alternating bars* transitional channels
- \( n = 2 \) for braided channels and *wandering* transitional channels.

Based on the values of these two indices, reaches can be divided into 3 classes: confined, semi-confined and non-confined.

### 3.3. Delineation of typologically distinctive channel subreaches

The delineation of *channel subreaches* implies identifying abrupt changes in the width and sinuosity of the channel, its morphology and lateral dynamics (stability vs meandering, avulsion) occurring prior to potential significant human interventions. The actual delineation is performed on the most representative set of maps available and requires a good knowledge of the study area, particularly in instances when the control factors, such as geology, by means of structure and tectonics, and the sediment input from the tributaries, result in changes of the channel typology. A brief description of the respective subreaches is required, including the criteria used for the delineation. Whenever possible, the validation in the field of this delineation should be undertaken.

Subsequent detailed morphometric measurements, regardless of the historical set of maps used, will take into account these subreaches. The model for the selection of subreaches is the one proposed by Schumm et al (1995) when investigating the historical dynamics of the Mississippi (fig. 7).

![Fig. 7. Model of segmentation of a reach for the study of the historical dynamics of the channel (the case of a channel with a succession of types ranging from straight to sinuous and meandering) (Schumm et al., 1995).](image)

The delineation of subreaches was performed on survey maps dating back prior to large-scale meander rectifications (i.e. before 1915). It was established that the length of the subreaches is...
uneven, as they delineate a meander wavelength (e.g., segments 9 or 13, fig. 7), a straight (segment 10) or anastomosing channel (segment 11). Thus, it is recommended that subreach delineation is made on accurate maps preceding large anthropogenic interventions on the fluvial systems under study. For example, in the case of Someșu Mic (Perșoiu, 2010), the non-georeferenced maps (1764 and 1940 editions) served a consultatory function, whereas the maps from 1869 – 1870, assisted by those published in 1890 – 1910, served as the map base for reach delineation and performing morphometric measurements.

To illustrate the case of a braided and wandering channel, we present the method of subreach delineation used for Moldova river. The most representative set of cartographic documents used for this purpose were the orthophotos from 2004 - 2006. Several factors were taken into account, such as the degree of confinement, the detail geomorphology of the channel, potential discontinuities along the channel, the extent of sedimentation zones, the position of nodes, etc. The result is shown in fig. 8, wherein the 110 km-long river was divided into 9 relatively uniform reaches.

![Fig. 8. Diagram of the channel reaches along a wandering and braided river (the case of Moldova river between Gura Humorului and Roman) (Chirilă, 2012).](image)

4. Methods for measuring the planform changes of the channel under investigation

Several methods are currently used to investigate the spatial behavior of the channel during a given time frame or in successive time frames, by manually or automatically (GIS applications) determining the morphometric parameters of the river. Opting for one or more such methods depends on the degree of coverage of the territory with detailed maps, the type of channel under investigation, etc.
After the database is generated, the researcher can either opt for an analysis on the temporal and spatial variations of the detail values, or an analysis on the mean values determined for the channel reaches defined according to Figures 7 and 8.

Below we briefly present three of the methods used to investigate planform changes, as applied in the cases of rivers Someșu Mic, Prut, Putna, Buzau (fig. 9) and Moldova: successive cross section measurements of the floodplain; measurements along the central axis of the bankfull channel (single channel or main drainage channel); surface morphometric measurements.

4.1. Cross section measurements on the bankfull channel and floodplain

The morphometric variables subject to measurements are summarized in Table 5, where each variable is accompanied by a review on the manner of extraction from historical maps. These variables were determined and used in the morphometric analysis of Romanian rivers and do not
exclude other viewpoints. However, these parameters are essential for the quantitative assessment of the planform dynamics of the channel.

Table 5. Examples of morphometric variables which can be determined using the floodplain cross section measurement method, for each time frame

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method of extraction of the parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floodplain width (including floodplain terraces, alluvial plain), (L_{am}), m</td>
<td>Length of the floodplain cross sections, perpendicular to its central axis, at even intervals of 100... 1000 m. It has a fixed value for the entire analyzed period.</td>
</tr>
<tr>
<td>Bankfull channel width, (L_a), m</td>
<td>Measurements perpendicular to the axis of the channel, in the points of intersection of the cross sections with the central axis of the river (single channel/main drainage channel). It is determined for each time frame.</td>
</tr>
<tr>
<td>Width of the active discharge strip, (L_{fa}), m a) Sinuous or meandering channel b) Wandering or braided channel c) Anastomosing channel</td>
<td>Measurements perpendicular to the axis of the channel, in the points of intersection of the cross sections with the central axis of the river (single channel/main drainage channel). It is determined for each time frame.</td>
</tr>
<tr>
<td>Number of channels, (N_c) a) Unorganized meandering channel or braided channel b) Anastomosing channel</td>
<td>Measurements perpendicular to the axis of the channel, in the points of intersection of the cross sections with the central axis of the river (single channel/main drainage channel). It is determined for each time frame.</td>
</tr>
<tr>
<td>Braiding index, (I_m), / Anastomosing index, (I_a) (after Ashmore, 1991)</td>
<td>Average value of the intersecting channels in floodplain cross sections, within the investigated reach.</td>
</tr>
<tr>
<td>Channel length, (L), m a) Sinuous or meandering channel b) Unorganized meandering channel or braided channel c) Anastomosing channel</td>
<td>Channel length along its central axis (single channel/main drainage channel) between two floodplain cross sections. It is determined for each time frame.</td>
</tr>
<tr>
<td>Sinuosity index, (I_s)</td>
<td>Ratio between the length of the single/main drainage channel along its central axis and the length of the aerial distance between two floodplain cross sections. It is determined for each time frame.</td>
</tr>
<tr>
<td>Position of the channel within the floodplain</td>
<td>Measurements in the point of intersection of the floodplain cross sections with the central axis of the single/main drainage channel or the channel banks. It is determined for each time frame.</td>
</tr>
<tr>
<td>Rate of lateral migration, (R_m), m/yr</td>
<td>The difference between the positions of the channel within the floodplain in two consecutive time frames. The ratio between the value and the number of years between the two moments reflect the annual rate of lateral migration.</td>
</tr>
</tbody>
</table>

The morphological and morphometric variables must be defined clearly (some need annotations) in order to eliminate confusions when performing measurements.

The floodplain or alluvial plain (figs. 9, 10) surport the same genetic significance. The matter of these terms was discussed by Ichim et al. (1989) and he concluded with the following definition: the floodplain is the relatively smooth surface adjacent to the channel, formed during the last period of geological time (last Glacial - Holocene) through the prevalence of vertical and lateral accretion, delimited by structural scarps (often directly by terrace scarps developing on each side of the valley and interfering with the lateral migration of the river). Other steps (1 - 2 m, 3 - 4 m) can occur within this relatively smooth surface which do not interfere with the lateral migration of the channel, thus they were included in the floodplain. The alluvial steps with relative elevation higher than 5 – 7 m were not included (as they can constitute obstacles in the way of free migration of the river).
Fig. 10. A. Components of a braided channel and the relation with the dimensional elements of the floodplain and channel; B. Floodplain cross sections perpendicular to its central axis, equally spaced at 100 m – the morphometric measurements on the channel / active drainage strip are performed next to each floodplain cross section: e.g., Moldova river channel (Chiriloei, 2012); C. Sample of morphometric parameters determined in the cross section, along Someșu Mic river (sequence of meandering and anastomosing channel): XY, YZ - linear distance between the extremities of consecutive reaches; HH’ – width of the anastomosis active strip; A-B/A’-B’, E-F/E’-F’ - distance to the left/right from the edge of the floodplain to the left/right bank of the channel (single/main drainage channel) (Perșoiu, 2010).

**Bankfull channel width.** The channel (fig. 10) (the elongated concavity within the terrain topography which provides the natural drainage with the free surface of water) is shaped predominantly by the bankfull discharge or dominant discharge. Their recurrence periods range to 1.5 years (in the mid part of the USA), 1.85 years (Australia), 0.45 years (England and Wales), 0.7 – 5.3. years (Belgium) (Malavoi and Bravard, 2010). Following the initiation of the channel, throughout its length, its entire geometry, be it the channel planform or the hydraulic geometry, is governed by the same laws, and any assessment on causality relations between the vast majority of the processes and subsequent geomorphology and nature of transiting deposits is referenced to the state of the channel at bankfull discharge. Therefore, these discharges are highly significant in terms of morphogenetic impact. Identifying the width of the bankfull channel on survey maps, satellite images and orthophotos should take into account the principle of the bankfull channel. The images from Fig. 11 are illustrative of this phenomenon. The bankfull discharge value of 68 m³/s recorded in july 2010 on Moldova river had maximum efficiency in terms of shaping the cross section, whereas the extremely low discharge value of 5.62 m³/s from july 2012 left uncovered the
largest part of the channel, which is no longer shaped by the water discharge for a certain period of time.

![Image](image1.png)

Fig. 11. Moldova river in sections Gura Humorului (top) and Praxia (below), bankfull channel (left) and minimum discharge (right) (photos N. Rădoane).

The **width of the active belt** (figs. 9, 10) (also called low floodplain) where the river migrates unimpeded depends on the type and size of channel. In the case of meandering channels, the active belt approximately equals the maximum amplitude of the meanders and includes both abandoned meanders and active ones. In braided channels, the active belt equals the width of the bankfull channel, whereas in anastomosing rivers all the channels need to be taken into account in delimiting the active belt. Several researchers established a direct relationship between the width of the active belt and the floodplain width as follows: the floodplain width is approximately tenfold the width of the active belt (Bridge and Leeder, 1976) and even up to 20 times the width of the active belt (Bridge, 2003).

The **sinuosity index** (fig. 12 I). The sinuosity of the channel within a given reach is described by the ratio between 2 lengths: the distance between the extremities of the reach measured along the axis of the main channel, and the length measured along the axis of the valley. Unlike the braiding index, which is applied in evenly distanced cross sections, sinuosity can be quantized on reaches of varying lengths, according to the morphology of the channel (also see fig. 7). Fig. 12 I illustrates the method to measure and calculate the sinuosity index by reach.

Cross section morphometric measurements on the bankfull channel and floodplain are performed in sections perpendicular to the central axis of the floodplain and are equally distanced. The measurements for each time frame are made in the points of intersection of the respective cross sections with the river and its central axis, in accordance with the morphometric parameters.
considered (fig. 8). The measuring interval is determined according to the level of detail required and the size of the investigated river/reach. For example, in the rivers listed in Table 4, the intervals of the cross sections ranged between 100 m and 250 m. Once established, the floodplain cross sections remain fixed throughout the entire period under investigation, regardless of how many sets of historical maps and satellite images are employed.

\[
I_m = \frac{l_{1a}}{l_1 + l_2 + l_3 + l_4}
\]

**Fig. 12.** I. Measuring the sinuosity within a reach between points A and B, with variations of the path axis (\(l_{1a}\) - length measured along the channel axis; \(l_1 + ... + l_4\): length measured along the axis of the planform path) (Surian et al., 2009); II. Method for measuring the braiding index (Egozi and Ashmore, 2008)

Establishing the location of the cross sections must be made according to the following aspects:

a) the state of the channel at bankfull discharge must be considered;

b) the channel is not always represented at bankfull discharge on historical maps and satellite images. Thus, it is necessary to follow in each case the morphological step delineating the channel within the floodplain, regardless of the depicted width of the riverbed. Moreover, special attention needs to be granted in this regard to braided and wandering channels, whereby the bankfull channel width comprises multiple channels (fig. 8).

The braiding index has been the subject of numerous calculation formulas, albeit it was concluded (Thorne, 1997; Egozi & Ashmore, 2008) that the fewest errors are obtained by totaling the number of channels (links) transected by the cross section instead of measuring the length of channels or bars (e.g., Brice, 1964). Therefore, we propose that the most reliable method of calculation is the one illustrated in fig. 12 II, according to Egozi and Ashmore (2008):

\[
I_m = \text{number of transected channels (mean values obtained/number of cross sections considered)}
\]

The **rate of migration of the channel** is determined based on the position of the channel at a given time within the floodplain. In order to compute the temporal mobility of the channel, a reference point is required. The model shown in Fig. 13 illustrates how such measurements are performed in the case of Moldova river. The same cross sections used for measuring the braiding index are employed here, but it is also necessary to know the position of each channel bank compared to a fixed point in 1910, 1960, 1985 and in 2006.
In this case, we established the fringe of the floodplain (the contact of the valley slopes with the terrace scarps over 5 – 7 m elevation) as the fixed benchmark. The method used for meandering or anastomosing channels is illustrated in Fig. 10C. Once the distances in meters from the fixed benchmark to the right bank were measured, the values obtained were recorded in a data table. The value measured for the following reference year are also recorded in the table. The difference between the two consecutive positions of the channel, in meters, indicate the migration of the channel (by erosion or accumulation, which can be quantized by dividing the migration distance by the number of years elapsed between the two positions.

4.2. Measurements on the morphometry of sinuous, meandering and anastomosing channels (sinuous or meandering channels)

This type of measurements refers to the morphometry of sinuous channels, namely of meanders as they were first introduced by Leopold and Wolman (1957, 1960), Langbein and Leopold (1966). The knowledge of these methods comes to support the indirect determination of bankfull flow of paleomeanders (Dury, 1977; Rotnicki, 1991) and can provide information for the millenial-scale reconstruction of channel dynamics.

In the analysis of a sinuous channel the basic morphometrical unit is the channel loop or meander loop. The planform of a meander loop can be described by the following elements (shown in Fig. 14): the meander loop length (c), corresponding to the length of the meander loop chord (in Fig. 14 are indicated the two meander loop chords by c1 and c2); the meander loop height (h), measured on the perpendicular line uniting the center of the chord and the intersection with the axis of the channel (at medium discharge values) and corresponding to the meander loop axis; the mean radius of the meander loop (r c), i.e. the radius of the arc of circle circumscribing the meander loop; the meander loop flattening, defined as the ratio between the length and the height of the meander loop (c/h); the meander loop sinuosity, as the ratio between the channel length measured along the river course between the points of intersection of the chord (lc) and the length of the chord (c1+c2); the meander loop orientation, or the azimuth of the meander loop axis, which indicates the direction of migration of the meander; the meander loop apex, is the point of
intersection between the meander loop height and the concave bank; the *inflection point* is the spot on the channel axis where the *riffle* is located. Two consecutive meander loops form a *meander*. Depending on the context, the elements of meander loop morphometry also include: the *wavelength* ($\lambda$), which measures the distance between the ends of the two successive loops; the *meander amplitude* ($A$) is the distance measured perpendicular to the meander length, between the apices of the two meander loops or on the centroid, and provides an insight on the active meandering strip.

![Diagram](image)

**Fig. 14.** The main components of meander geometry (*Leopold et al.*, 1964; *Selby*, 1985). Further explanations in the text.

The delimitation of each meander loop is based on the curvature radius, taking into account that the adjacent arcs are linked to them by straight line segments. For a channel sector to be considered a meander loop, the chord of the loop has to be larger than the radius and not more than sevenfold the channel width. The loops may occur individually and are not necessarily combined in meander formations. In this case, we can distinguish between *simple symmetrical loops* (have only one constant curvature segment); *simple asymmetrical loops* (have only constant curvature segments, but the length of the segment of one of them is larger than the radius); *composite loops*.

When highly detailed satellite images are available (e.g., Corona KH7), numerous elements of micromorphology can be identified (chute bars, bars, old channels whose age can be deduced based on the vegetation) and detail measurements can be applied (*Cristea*, 2012).

This method of investigation was employed by Cristea (2010) on Putna river, as follows: for each set of images the axis of the channel was extracted in ArcGIS, and further on the circle circumscribed to the two points of the segment and the point of maximum inflection was generated for each meander loop. Generating the circles based on the three points can be easily achieved in ArcView 3.x, with the extensions Polytools and Trace MS. The center of each circle marks the radius of the meander in the respective sector. Tracing the movement of the loops can is based on the differences occurring in the central points, as pairs, of the circumscribed circles from each historical stage, both in terms of distance and azimuth (fig. 15).
Fig. 15. Method for determining the dynamics of meander loops based on the dynamics of the centroids of the circumscribed circles; the magnitude of the movements of the meander loops in the analyzed reach, and the preferential directions of movement of meanders are shown on a polar diagram (Cristea, 2012).

4.3. Surface morphometric measurements

Whenever highly detailed cartographic materials in terms of the channel and floodplain morphology are available, the method of surface morphometric measurements can be applied in order to investigate the spatial and temporal behaviour of several elements of interest, summarized in Table 6.

Table 6. Examples of elements of interest along the channel, active discharge strip and floodplain which can be measured by using the polygon method in GIS

<table>
<thead>
<tr>
<th>1. Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active channel (sinuous or meandering river course)</td>
</tr>
<tr>
<td>Active channels (unorganized meandering river course, braided or anastomosing river course)</td>
</tr>
<tr>
<td>Riverbank surface</td>
</tr>
<tr>
<td>Bars</td>
</tr>
<tr>
<td>Islands</td>
</tr>
<tr>
<td>Chute bars</td>
</tr>
<tr>
<td>Areas with vegetation within the channel (trees, shrubs, herbaceous vegetation)</td>
</tr>
</tbody>
</table>
2. Meandering active strip
Meander scrolls
Natural levees
Riparian vegetation (trees, shrubs, herbaceous vegetation)

3. Abandoned strip, Floodplain
Paleomeanders
Wetland, other than paleomeanders
Terrains with various agricultural uses
Areas affected by relatively isolated constructions (e.g., buildings, airport, etc.)
Perimeters with archaeological findings
Built-up area
Landfills
Perimeters affected by gravel mining
Hydrotechnical works (lakes, reservoirs, drainage channels, levees)
Roads, railways

Depending on the nature of the investigation (i.e. the purpose), the data generated for each considered time frame can be used for: a) characterizing the channel, the active discharge strip or the floodplain at a certain time (e.g., the percentage value of the elements of interest within the investigated area); b) analyzing the spatial dynamics of the elements of interest (repositioning, narrowing, broadening), by overlaying /intersecting the polygons corresponding to different time frames (this type of investigation allows for prediction analyses of future trends in the spatial dynamics of the channel, such as narrowing/broadening, lateral migration, chute bar development, bar/island dynamics, changes in the riparian land cover); c) analyzing the temporal dynamics of the elements of interest by statistical analysis of the variations in the surface values of the delineated elements (e.g., variations along the river, statistics on the variations of the mean and total values).

To exemplify, we selected an analysis of the evolution of riparian vegetation types along a channel reach on Moldova river between 1960-2005 (Chiriloei, 2012). The available historical maps have enabled us to delineate the boundaries of the vegetation within the channel, as well as outside the channel (marginal vegetation, Comiti et al., 2011). Also, we were able to distinguish between herbaceous vegetation with shrubs and arborescent vegetation. Furthermore, orthophotos proved to be even richer in information, allowing for detailed visualization of the vegetation within the fluvial corridor, and thus enabling us to add other classes of vegetation to our analysis). The result is shown in fig. 16, which illustrates how the areas with various types of vegetation changed over time. The ArcGIS 9.3 software can assist in obtaining the quantitative data of the element subject to measurement. In this case, we are referring to the area (in hectares) of the terrains covered by certain types of vegetation in successive time frames (table 7). These quantitative elements further allow us to conduct detailed analyses on the evolution of the investigated phenomenon.

Tabel 7. Synthesis of the changes in the vegetation cover in reach 1 on Moldova river (ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total area</th>
<th>Active unvegetated area</th>
<th>Islands with herbaceous vegetation</th>
<th>Islands with arborescent vegetation</th>
<th>Marginal herbaceous vegetation</th>
<th>Marginal arborescent vegetation</th>
<th>Agricultural terrains</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>620,17</td>
<td>271,69</td>
<td>94,89</td>
<td>36,68</td>
<td>105,1</td>
<td>111,81</td>
<td>-</td>
</tr>
<tr>
<td>1980</td>
<td>620,17</td>
<td>190,28</td>
<td>96,02</td>
<td>38,6</td>
<td>254,62</td>
<td>40,79</td>
<td>-</td>
</tr>
<tr>
<td>2005</td>
<td>620,17</td>
<td>168,6</td>
<td>38,7</td>
<td>49,39</td>
<td>178,45</td>
<td>30,25</td>
<td>154,78</td>
</tr>
</tbody>
</table>
5. Conclusions

The availability of a series of cartographic materials published during the past 250 – 150 years (depending on the geographical area) enables researchers to conduct analyses on the spatial and temporal variability river channels. This topic of geomorphological research is significant for understanding the natural dynamics and current trends in the behaviour of rivers in the context of high anthropogenic stress and global climate changes. Such investigations have been conducted for at least 4 – 5 decades, but the great difficulty that faced the authors was the lack of comparable data generated by the analysis, due to the fact that the elements of interest (e.g., the morphometric parameters of the river) were represented at different scales and measured/assessed by different methods.

The vigorous development of GIS applications and their massive penetration of geography has generated a tremendous boost for such studies by allowing the overlay and visualization at the same scale various cartographic and topographic materials which originally had different scales and projections. Modern methods of investigation assimilated classical methods (e.g., measurements along the central axis of the channel on meander loops and meanders) and further diversified (floodplain cross section method, surface measurement method), resulting in the possibility to generate a considerably larger amount of data at much higher resolutions than previously obtained.

Currently, depending on the nature of the study, the level of detail, the quality of available maps and georeferencing errors, the type of investigated channel and mechanisms, the available time and the amount of work required, or the possibility or lack thereof to automatically determine the relevant morphometric parameters, a method or a combination of methods can be chosen.
provided that there is unity in the use of working methods in order to be able to generalize the conclusions of the studies.

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