

A Set of GRASS GIS-Based Shell Scripts for the Calculation and Graphical Display of the Main Morphometric Parameters of a River Channel

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Abstract

For the analysis of river evolution, the use of quantitative parameters can be quite useful in order to assess changes in the channel planform. Among the several parameters proposed by different authors in a number of papers, channel length and width, braiding and sinuosity indexes, and channel lateral shifting are proved to be the most effective ones for a quantitative analysis of river changes. However, the calculation of these parameters is time-consuming, tedious and error-prone, even where made in a GIS environment. This work describes four shell scripts that perform fast and automatic calculation of the morphometric parameters and draw curves showing the variation of the calculated parameters along the entire channel development. The scripts are based on commands of the GRASS GIS free and open source software and, as input, they require a simple vector map containing the essential features of a river channel, *i.e.* bankfull channel limits and longitudinal and lateral bars.

Keywords

GRASS GIS, Shell Script, River Morphometry

1. Introduction

In a recent paper [1], the morphological evolution of the unconfined reach of the Taro River (Italian Northern Apennines) in the last two centuries (1828-2011) has been evaluated. The river features as of nine different dates (1828, 1881, 1958, 1976, 1999, 2003, 2006, 2008 and 2011) were surveyed based on old historical maps and re-

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cent orthophotos. The analysis of the morphological changes was conducted on a quantitative basis by comparing the values of the morphometric parameters commonly used to define the planform characteristics of a river unconfined reach, *i.e.* channel length and width, braiding and sinuosity indexes, and channel lateral shifting. As the calculation of these parameters requires a long and repetitive sequence of operations, even when carried out in a GIS environment, a set of shell scripts was created, mainly based on the commands of GRASS (Geographical Analysis Support System), a free and open source GIS [2] [3]. A first script defines, for the channel as of a specific date, the channel centreline, computes the channel length and width, and the braiding and sinuosity indexes. A second script evaluates the lateral shifting of the channel centreline between two dates.

Other two scripts construct graphics, in Postscript format, showing the curves of the values of the computed parameters along the entire channel centreline. More precisely, the first one draws the curves of width, braiding and sinuosity as of a specific date and shifting over a specific time interval. The second one draws the curves of a single parameter as of several dates in a single graph, allowing punctual evaluation of the parameter changes over time.

The use of these shell scripts allows fast and automatic calculation of the main morphological parameters and the drawing of graphs which detail the continuous parameters variation along the entire channel development. In this paper, the characteristics of the four implemented shell scripts are described.

2. Channel Centreline Definition and Parameters Calculation

2.1. Input Data

The input data for the first script consist in a vector map containing the bankfull channel limits and the limits of longitudinal and lateral bars. The area between the bankfull limits, with the exclusion of the areas occupied by bars, defines the active subchannels (**Figure 1**).

In order to have fixed reference points, in space and time, which the channel characteristics and changes from date to date refer to, a set of ground points along both borders of the channel must also be collected. These points, which can be digitized on a reliable map or acquired by GPS on the field, are projected perpendicularly to the channel centreline and reported along the x-axis of the graphics with their distances from one another and their cumulative distances from the origin.

2.2. Centreline Extraction

In most works, the channel centreline, *i.e.* the line whose points are equidistant from the two limits of the channel, is traced manually. In a few works, specific algorithms have been proposed to automatically derive this feature by thinning a channel raster map pixel by pixel [4] [5] or to extract it from the bank lines in vector form

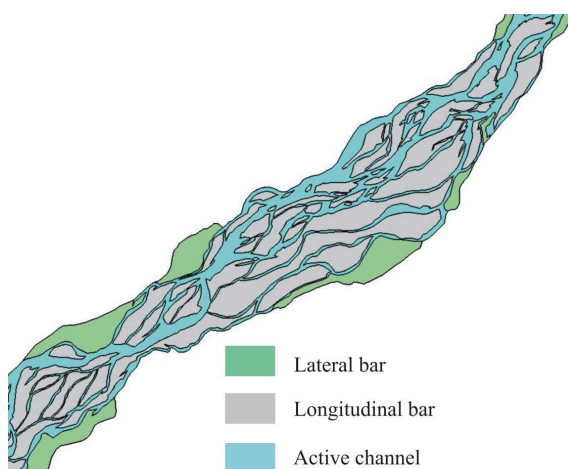


Figure 1. Portion of the vector map showing the limits of the bankfull channel and of longitudinal and lateral bars, which is the input map for the calculation of morphometric parameters.

using Delaunay triangulation principle [6]. In [7] the centreline has been defined by joining a set of evenly-spaced points along the river channel, whose equidistance from the two banks has been determined by successive approximations. In GRASS, a specific module (v. centerline) is proposed to define a line that represents an approximation of the central tendency of a series of input lines, all of which with similar trajectories and, therefore, that can be used also to define the centreline of a channel represented by its two sides. However, the module gives good results when the lines are approximately parallel to each other. Moreover, it may give unreliable results when two reaches of the channel are very close to each other, as can happen at the neck of a meander.

In this work, a different approach is adopted and the centreline is extracted from the vector map containing the bankfull channel limits, mainly by using the GRASS module that traces lines parallel to existing features. Starting from the bankfull channel margins, pairs of lines parallel to the channel banks are repeatedly traced out toward the channel centre. Since each of the two parallels traced out at each iteration is equidistant from the pertaining bank line, the intersection of the two parallels defines points that are equidistant from the banks (**Figure 2(a1)-(a8)**). The line joining these intersection points defines the channel centreline (**Figure 2(b)**). The length of the centreline is assumed as the length of the channel.

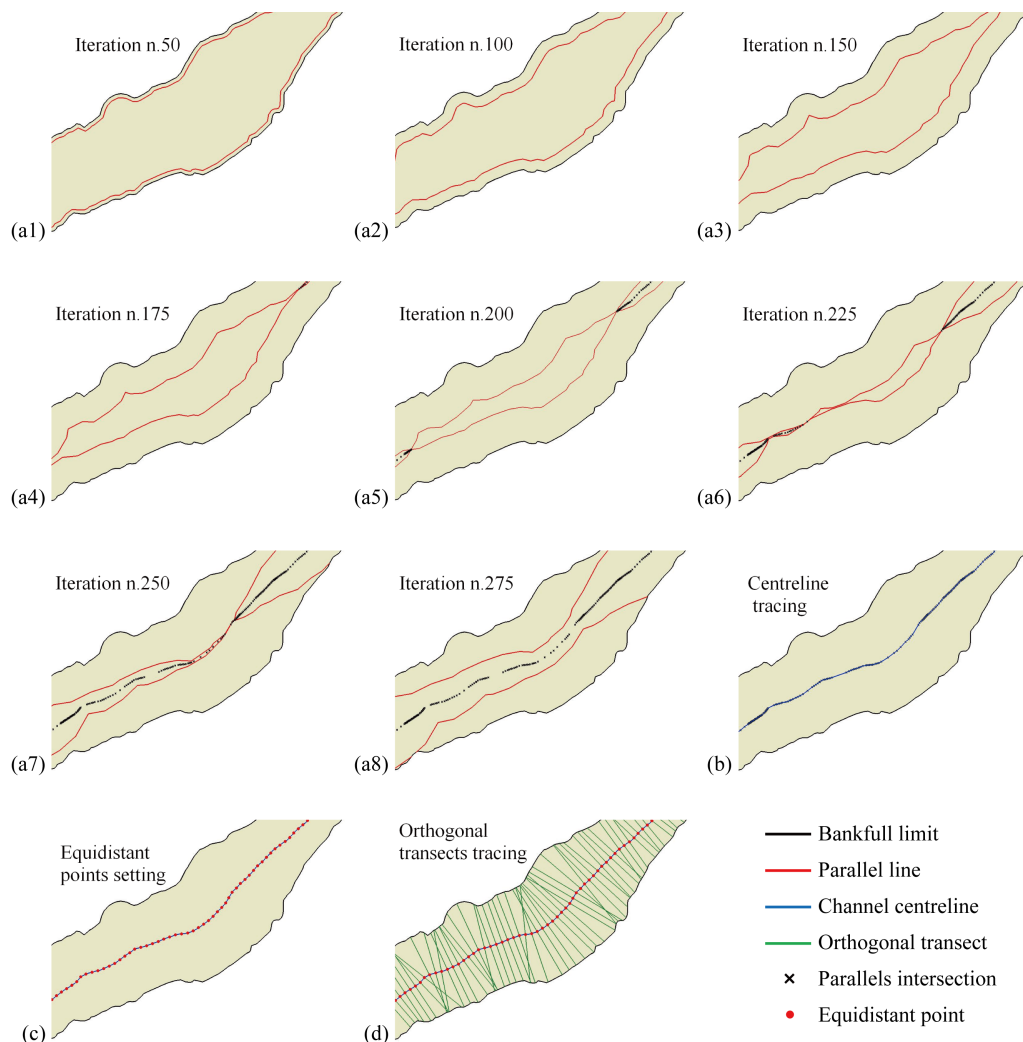


Figure 2. Procedure for channel centreline definition and channel transects tracing. (a1)-(a8) Iterative tracing toward the center of the channel of the lines parallel to the limits of the bankfull channel. (b) Tracing of the channel centreline by joining the intersections of the parallel lines. (c) Location of equally spaced points along the channel centreline. (d) Tracing of transects orthogonal to the centreline at the equally-spaced points.

2.3. Width Calculation

The channel width is commonly defined as the length of the line from bank to bank orthogonal to the channel centreline. In the above mentioned algorithms [4] [5], channel width is automatically computed along the lines orthogonal to the pixels forming the computed raster centreline. In [8], a Python script is described for the calculation of channel width at regularly-spaced transects orthogonal to the channel centreline. The same procedure is adopted in the script described in this work (Figure 2(c), Figure 2(d)).

2.4. Braiding Calculation

Many different indexes have been proposed by various authors to express the degree of braiding of a river [9]. Among them, the so-called Channel count index [10] is the most commonly used one, since it is simple to calculate and is the least sensitive to river-stage effects [11]. It is simply expressed as the number of active sub-channels along a channel transect.

Similarly to what is reported in the above cited paper [8], in the script described herein this index is computed by simply counting the number of active channels along the same transects where the channel width is defined.

2.5. Sinuosity Calculation

In its classical formulation, the sinuosity index is defined as the ratio of channel length to valley length [12]. It requires prior subdivision of the river valley into rectilinear segments. Then, the length of the channel centreline encompassed in the valley segment is divided by the length of the valley segment. The valley segmentation introduces a certain degree of subjectivity, especially where the valley shows a curvilinear path. To reduce the degree of subjectivity, in [8] a fixed length value is used for the valley segmentation. In this work, to further reduce subjectivity and obtain a more detailed assessment of sinuosity along the entire channel course, the river valley is ignored and only the channel centreline is used. More precisely, sinuosity is calculated by considering a portion of the channel centreline with fixed length, progressively shifted downstream by a constant distance. Sinuosity is obtained by dividing the fixed length of the centreline tract by the straight-line between its endpoints. The computed sinuosity value is assigned to the midpoint of the centreline tract (Figure 3).

2.6. Output

The output of the first script consists of:

- 1) A screenshot of three simple graphs which allow a first rough check of the results (Figures 4(a)-(c)).
- 2) A vector map containing the channel centreline.

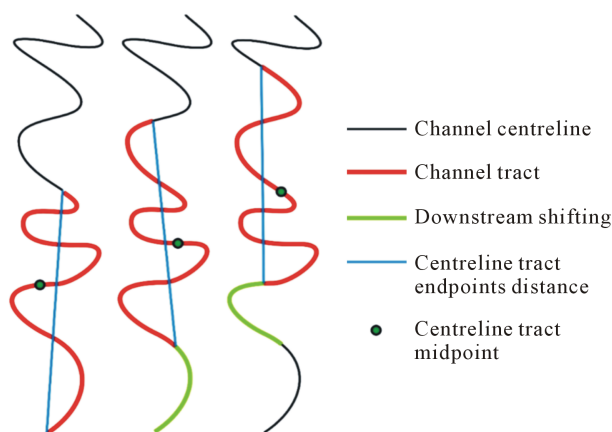


Figure 3. Procedure for sinuosity calculation by dividing the fixed length of a centreline tract by the distance between its endpoints. The centreline tract is progressively shifted downstream by a fixed length along the entire centreline and the computed sinuosity value is assigned to the midpoint of the tract.

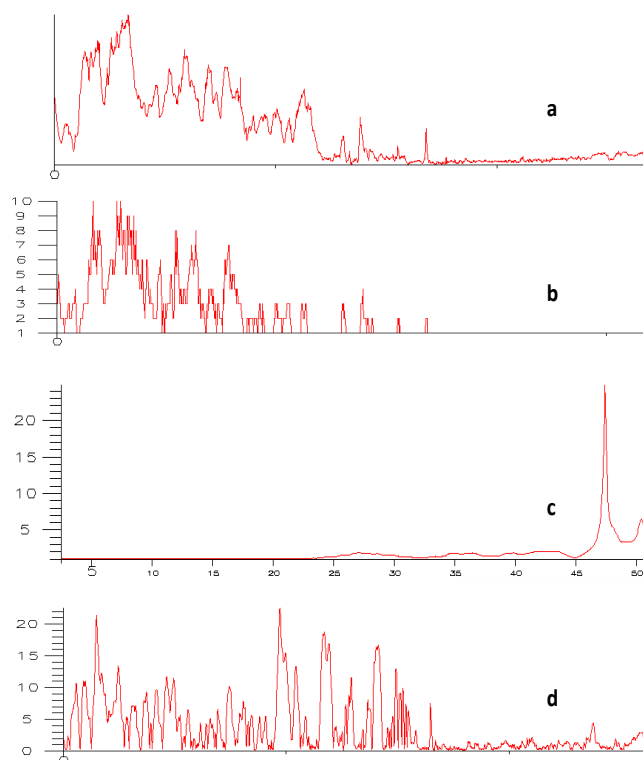


Figure 4. Example of screenshot of simple graphs of the computed width (a), braiding (b), sinuosity (c) and lateral shifting (d).

3) A report containing the main computed statistics (**Table 1**).

4) Three text files containing the values of width, braiding and sinuosity. In each file, the first column reports the progressive number of each measure, the second reports the distance from the origin and the third reports the parameter value (**Table 2**).

2.7. Lateral Shifting Calculation

The second script computes the channel centreline lateral shifting between two dates. As it requires the preemptive construction of the channel centrelines as of the two dates by the previously described shell script, a specific shell script has been constructed. The script, starting from a vector map containing the channel centrelines as of the two dates, computes the lateral shifting using a procedure similar to the previously described one adopted to define the centreline between the two channel banks. Indeed, the parallels to the two centrelines are traced out and their intersection joined by a line that represents the line equidistant from the two centrelines. The distances between the two centrelines are then computed along lines orthogonal to the computed axis at regular intervals and are assumed as the channel centreline shifting between the two dates (**Figure 5**).

The output consists of a report (**Table 3**) and of a text file with the shifting values at regular interval along the computed centreline axis (**Table 2**). A rough simple graph is also displayed on the screen (**Figure 4(d)**).

3. Graphs Construction

For the creation of graphs showing the variations of the parameters along the river channel, two scripts were built. The first one constructs graphs of the four calculated parameters (width, braiding, sinuosity and lateral shifting) as of a specific date. The input includes the vector map containing the channel centreline, the vector map containing the reference points and the four text files containing the parameters previously computed by the first script. In addition to the curves of the original computed values, curves of simple moving average of various orders can also be drawn. Obviously, vertical and horizontal scales, size and colours of the lines and characters can be defined by the user. Examples of the curves of the four parameters are given in **Figure 6**.

Table 1. Example of output report containing the main computed statistics.

JOB NAME: Taro 1976
 INPUT FILE:
 Vector map with banks and bars: vect_topo1976_2013_mod
 JOB PARAMETERS:
 Distance (m) between transects for width and braiding calculation: 20
 Length (m) of channel tracts for sinuosity calculation: 5000
 Distance (m) between points where sinuosity values are located: 50
 OUTPUT FILES:
 Channel centreline vector map: centreline_taro_1976
 File with width values: width_1976
 File with braiding values: braid_1976
 File with sinuosity values: sinuos_1976
 COMPUTED CHARACTERISTICS
 Channel area A (sq m) = 11761798.6185508
 Centreline length L (m) = 53728.982242
 Mean width (m) A/L = 218.91^a
 Total sinuosity = 1.4664^c
 Minimum width (m) = 34.325062 (Section n. 1723)
 Maximum width (m) = 869.590516 (Section n. 335)
 Mean transect width (m) = 220.081^b
 Minimum sinuosity = 1.015797 (Progressive point n. 168)
 Maximum sinuosity = 24.890106 (Progressive point n. 899)
 Mean sinuosity = 1.75954^d
 Minimum braiding = 1
 Maximum braiding = 10
 Mean braiding = 2.14732

^aRatio of the channel area to the centreline length; ^bMean of the width values computed at the transects orthogonal to the centerline; ^cRatio of the centreline length to the distance between centreline endpoints; ^dMean of the sinuosity values computed at the fixed length tracts along the centreline.

Table 2. Example of text files with the computed values of channel parameters (only the first and last 10 values of each file are reported).

Width ^a			Braiding ^a			Sinuosity ^b			Shifting ^a		
1	0.0	464.201	1	0.0	3	1	2500	1.0242	1	0.0	10.4793
2	19.9959	424.4595	2	19.9959	5	2	2550	1.0230	2	19.9990	12.2521
3	39.9917	433.1364	3	39.9917	5	3	2600	1.0229	3	39.9981	14.3268
4	59.9876	411.3395	4	59.9876	5	4	2650	1.0224	4	59.9971	17.3037
5	79.9835	398.4922	5	79.9835	5	5	2700	1.0213	5	79.9962	17.5562
6	99.9794	400.4545	6	99.9794	3	6	2750	1.0206	6	99.9953	15.1635
7	119.9753	375.6974	7	119.9753	4	7	2800	1.0206	7	119.9943	12.0381
8	139.9712	368.1004	8	139.9712	4	8	2850	1.0215	8	139.9934	8.8488
9	159.9671	347.6836	9	159.9671	5	9	2900	1.0216	9	159.9924	5.0606
10	179.9630	336.4495	10	179.9630	5	10	2950	1.0215	10	179.9915	4.2401
.....				
2679	53,549.0191	74.3096	2679	53,549.0191	1	966	50,750	4.3445	2640	52,777.5195	43.0162
2680	53,569.0150	76.8547	2680	53,569.0150	1	967	50,800	4.0159	2641	52,797.5186	43.5175
2681	53,589.0109	79.5911	2681	53,589.0109	1	968	50,850	3.7258	2642	52,817.5176	44.0586
2682	53,609.0068	81.8723	2682	53,609.0068	1	969	50,900	3.4727	2643	52,837.5167	43.3405
2683	53,629.0027	84.0832	2683	53,629.0027	1	970	50,950	3.2508	2644	52,857.5158	43.5645
2684	53,648.9986	86.3211	2684	53,648.9986	1	971	51,000	3.0603	2645	52,877.5148	43.3423
2685	53,668.9945	93.5090	2685	53,668.9945	1	972	51,050	2.8984	2646	52,897.5139	43.5656
2686	53,688.9904	107.6350	2686	53,688.9904	1	973	51,100	2.7517	2647	52,917.5129	43.7866
2687	53,708.9863	108.5434	2687	53,708.9863	1	974	51,150	2.6187	2648	52,937.5120	43.6764
2688	53,728.9822	109.7612	2688	53,728.9822	1	975	51,200	2.4960	2649	52,957.5111	43.9825

^aValues are computed along transects 20 m-spaced (automatically recalculated at 19.9959 to ensure equal distance between points along the centreline); ^bValues are computed for centreline tracts 5000 m long and shifted 50 m downstream.

Table 3. Example of an output report resulting from the centreline lateral shifting calculation between two dates (the example refers to the time interval 1958-1976 in [1]).

JOB NAME: Centreline shifting Taro 1958-1976
 INPUT VECTOR MAP: asse_taro_1958_1976_patch
 JOB PARAMETERS:
 Distance (m) between transects for lateral shifting calculation: 20
 OUTPUT FILES:
 Mean centreline vector map: asse_spostamento_taro_1958_1976
 File with shifting values: spostamento_centrelines_1958_1976
 COMPUTED CHARACTERISTICS
 Between centrelines area A (sq m) = 1952141.90903244
 Centrelines axis length L (m) = 52957.51111
 Mean shifting (m) A/L = 36.8624
 Minimum shifting (m) = 0.791423 (Section n. 861)
 Maximum shifting (m) = 225.443272 (Section n. 972)
 Mean shifting along sections (m) = 36.889

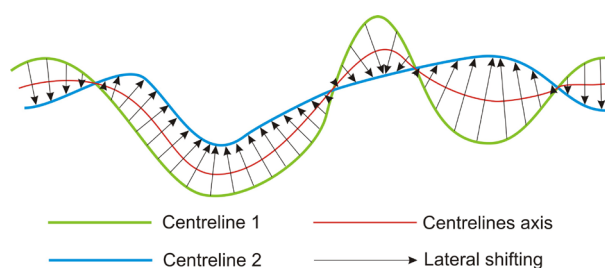


Figure 5. Procedure for lateral shifting calculation. The axis of the centreline position as of the two dates is calculated and the distance along the lines orthogonal to the axis is assumed as the shifting value.

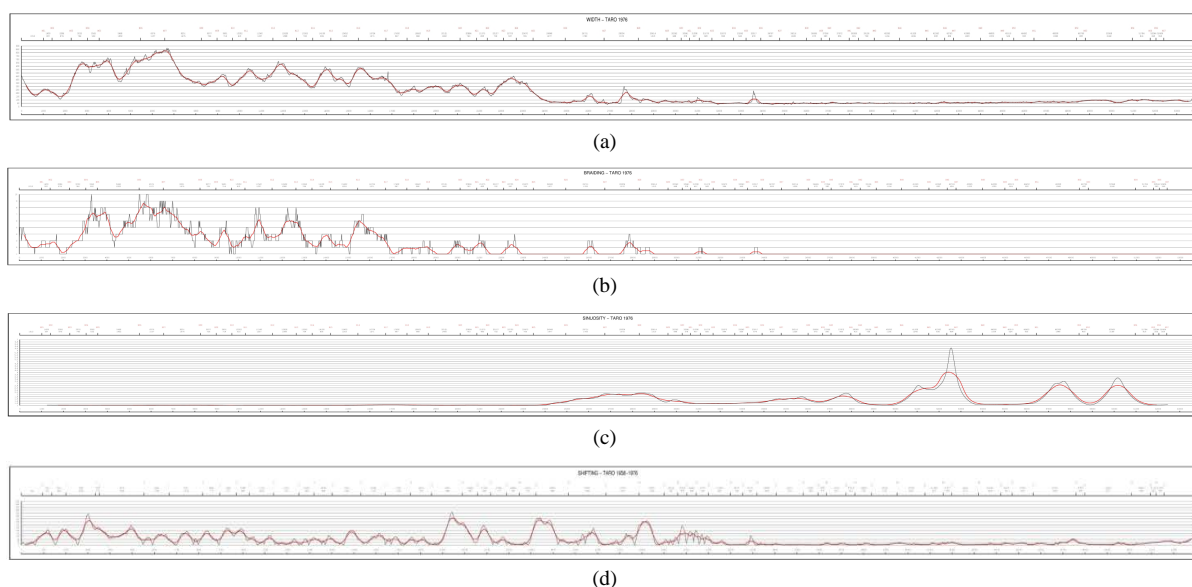


Figure 6. Examples of the curves of the four channel parameters: width (a), braiding (b), sinuosity (c) refer to the 1976 date, shifting (d) to the time interval 1958-1976 [1]. 57 reference points were collected. In addition to the curves of the original values, the moving average curves of 21 terms are traced (thicker red lines). In the lower x-axis the progressive distances (in meters) from the origin are reported. On the upper x-axis the positions of the reference points (numbered from R01 to R57) projected on the channel centreline are reported, together with their partial and cumulative distances. The parameter value is on the y-axis (for high resolution images, click: (a) <http://www.cler.unipr.it/IJG/fig6a1.jpg>; (b) <http://www.cler.unipr.it/IJG/fig6b1.jpg>; (c) <http://www.cler.unipr.it/IJG/fig6c1.jpg>; (d) <http://www.cler.unipr.it/IJG/fig6d1.jpg>).

The second script draws the curves of each single parameter as of several dates in a single graphic, allowing an overview of the progressive variations of each parameter over time. If many dates are considered and/or the differences among the curves are small, the graph proves easier to read and interpret if only the moving average curves are traced. An example showing moving average curves of the channel width as of several dates is reported in **Figure 7**.

The input and output of the four shell scripts are schematically summarized in **Table 4**.

4. Conclusion

The use of shell scripts based on the GRASS GIS commands allows fast and automatic calculation of the main morphological parameters and the drawing of graphs which detail the continuous parameters variation along the

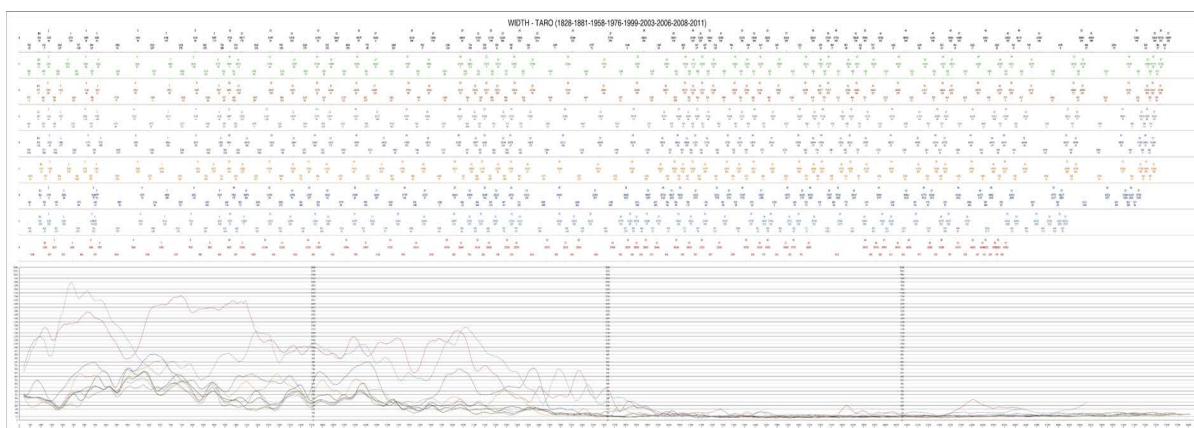


Figure 7. Example of multiple dates graphic. Curves refer to the channel width as of the nine dates from 1821 to 2011 considered in [1]. For simplicity, the curves of the original width values have been omitted and only the moving average curves of 21 terms have been traced. In the lower x-axis, the progressive distances from the origin are reported. On the upper x-axes, the positions of 57 reference points (R1-57) projected onto each channel centreline are reported, together with their partial and cumulative distances. Since the channel length changes from date to date, the projections of the reference points change their positions along each x-axis. The difference in distance between each couple of reference points from one date to the previous one, which is a measure of the change in channel length, is reported on each axis. The different dates are marked with different colours, for both the curves and the axes of the upper part of the graph, proceeding from the oldest (1828), in red, to the most recent (2011), in black. The channel width value is on the y-axis. All values are in meters. For a high resolution image, click <http://www.cler.unipr.it/IJG/fig7.jpg>.

Table 4. Input and output for the four shell scripts used for the calculation and graphical representation of the channel characteristics.

	Input	Output
Script 1	<ol style="list-style-type: none"> 1) Vector map with the limits of bankfull channel and bars (Figure 1) 2) Vector map with reference points 	<ol style="list-style-type: none"> 1) Vector map with the channel centreline (Figure 2) 2) Report with the main computed statistics (Table 1) 3) Text files with width, braiding and sinuosity values (Table 2)
Script 2	<ol style="list-style-type: none"> 1) Vector map with two dates centrelines 	<ol style="list-style-type: none"> 1) Vector map with the axis of two dates centrelines (Figure 5) 2) Report with the main computed statistics (Table 3) 3) Text file with shifting values (Table 2)
Script 3	<ol style="list-style-type: none"> 1) Channel centreline as of a single date 2) Axis as of two dates centrelines 3) Text files with width, braiding, sinuosity and shifting values 	<ol style="list-style-type: none"> 1) Curves for width, braiding and sinuosity for a single date (Figure 6(a), Figure 6(b), Figure 6(c)) 2) Curve for shifting between a couple of dates (Figure 6(d))
Script 4	<ol style="list-style-type: none"> 1) Vector map with the centrelines of several dates 2) Text file with width or braiding or sinuosity or shifting values of several dates. 	<ol style="list-style-type: none"> 1) Curves of a single parameter for several dates (Figure 7)

entire channel development and a punctual evaluation of the river planimetric changes in space and time. Furthermore, the methodology here adopted reduces the possibility of errors and, most of all, makes the common and very subjective practice of prior channel segmentation unnecessary. The scripts here described simply require digitization of the bankfull channel limits, of the longitudinal and lateral bars and of a number of reference points.

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