

Bathymetric variations in a reach of Po River (Northern Italy) during channelization works

Historical analysis (1919-1946) of the reach including the confluences of River Taro and River Crostolo with Po River

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The paper describes the used method for analysis of fluvial historical dynamics and of evolutionary trend induced by hard in-channel structures affecting riverbed of River Po (northern Italy, fig. 1). The study was carried out using a morphological-sedimentary approach (Tacconi, 1990; 1994) and Geographic Information Systems (Neteler & Mitasova, 2002). Such approach starting from the natural characteristics of the stream, analyses the present conditions, considers the effects on the equilibrium of riverbed due to river in-channel structures and allows the definition of the evolutionary trend. All this with the goal of resolve the problems related to the equilibrium of the riverbed, defining the possible technical solutions. The paper is limited to discussion of a representative reach of the river Po.

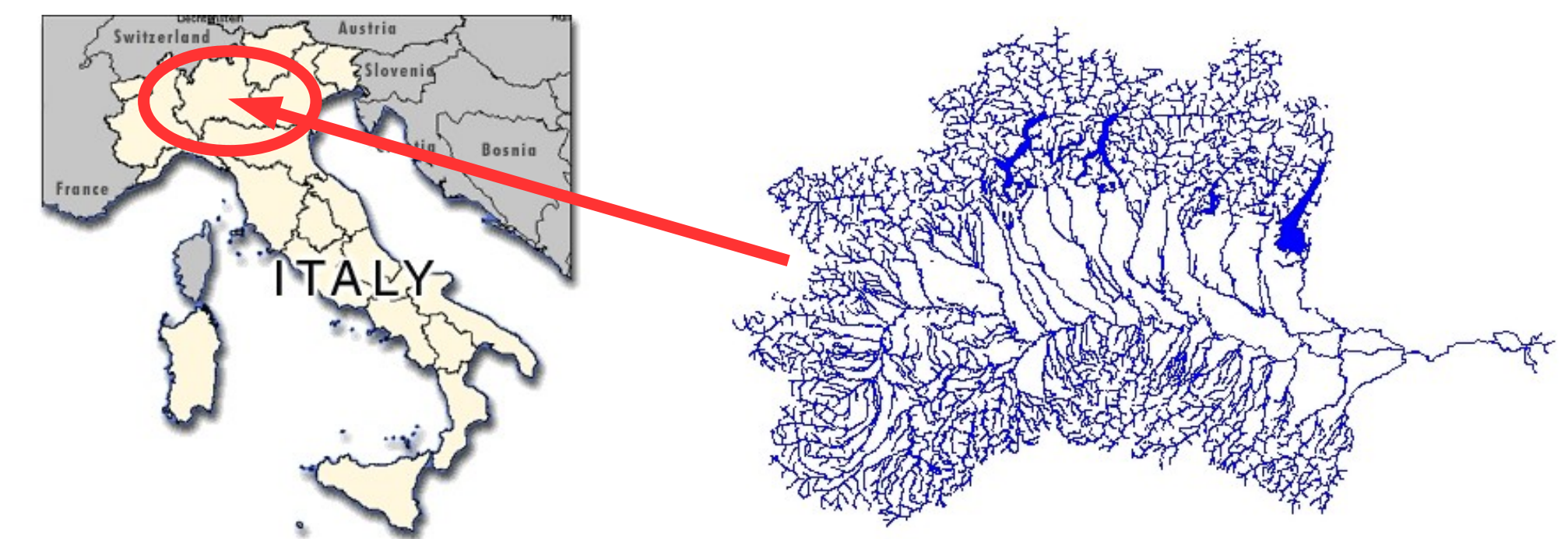


Fig. 1 – Location of Po basin.

GEOGRAPHIC CHARACTERISTICS

The Po basin is the greatest of Italian peninsula, with an area of 70,700 sq. kms. The boundaries of the basin are represented by Alps and Apennines Chains; the maximum elevation is represented by Mt. Bianco (4,810 m asl). The river mouth is in Adriatic Sea, with a broad delta, after a trace of 673 kms. The average discharge is 1,470 cubic metres per second, while the discharge of return period of 100 years is 11,600 cubic metres per second. The climate is temperate, with an average annual temperature of 15°C and average annual rainfalls of 1,100 mm.

NATURAL CONDITIONS OF RIVERBED

At present the riverbed is not under natural conditions, because some important hard structures was realised in the past. Such very large works conditioned morphological-sedimentary characteristics of the riverbed and its evolutionary trend. The natural characteristics of riverbed were defined through the researches carried out in some cartographic archives (figg. 2, 3, 4), and through the photointerpretation of aerial photo. The riverbed of River Po in natural conditions should present a very dynamic bed, with braided segments alternating themselves with broad meanders and with zones where the two features of sinuosity and braiding cohabit. The considered reach is just a one where at the concomitant presence of sinuosity and braiding, corresponds a strong mobility of the riverbed and the presence of many active bars (with the prevalence of the longitudinal ones).

MAIN DIRECT INTERVENTIONS IN CHANNEL MANAGEMENT

In the considered reach, as well as in other large portions of the riverbed, the main direct interventions affecting directly the riverbed, in time order were:
 the building of levees, started from various centuries ago;
 the channelization of low discharge riverbed, started in 1919 and closed in the 80ties;
 the intense quarrying activity, with the extraction of gravel from the active channel, for its utilization for concrete, started in 60ties and interrupted in 90ties.
 The effects of the first ones (building of levees) on the fluvial dynamics were not important. In fact such levees, usually, were built outside of the area affected by mobility of the riverbed.
 The effect of quarrying into the riverbed reached large proportions since the end of 50ties until recent times; it affected many portions of the active channel and it was not well controlled, without possibility to know the real quantities of extracted materials. The coarse sediments present in the channel (gravel and coarse sand) were extracted. Certainly this activity was and it is the most important responsible of the lowering of the riverbed in the last decades (Ministero dell'Agricoltura – Consorzio per il canale emiliano-romagnolo, 1990). At the present time the quarrying activity is not permitted.

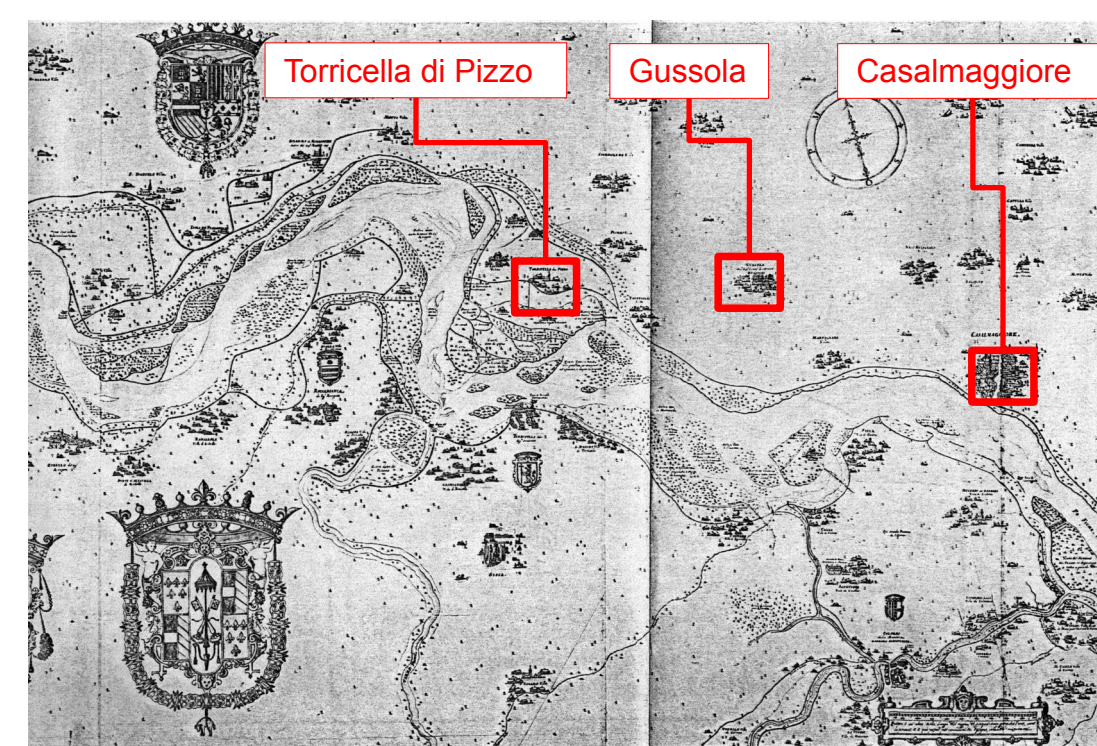


Fig. 2 - Map of a part of the studied reach (1588).



Fig. 3 - Map of a part of the studied reach (1703).

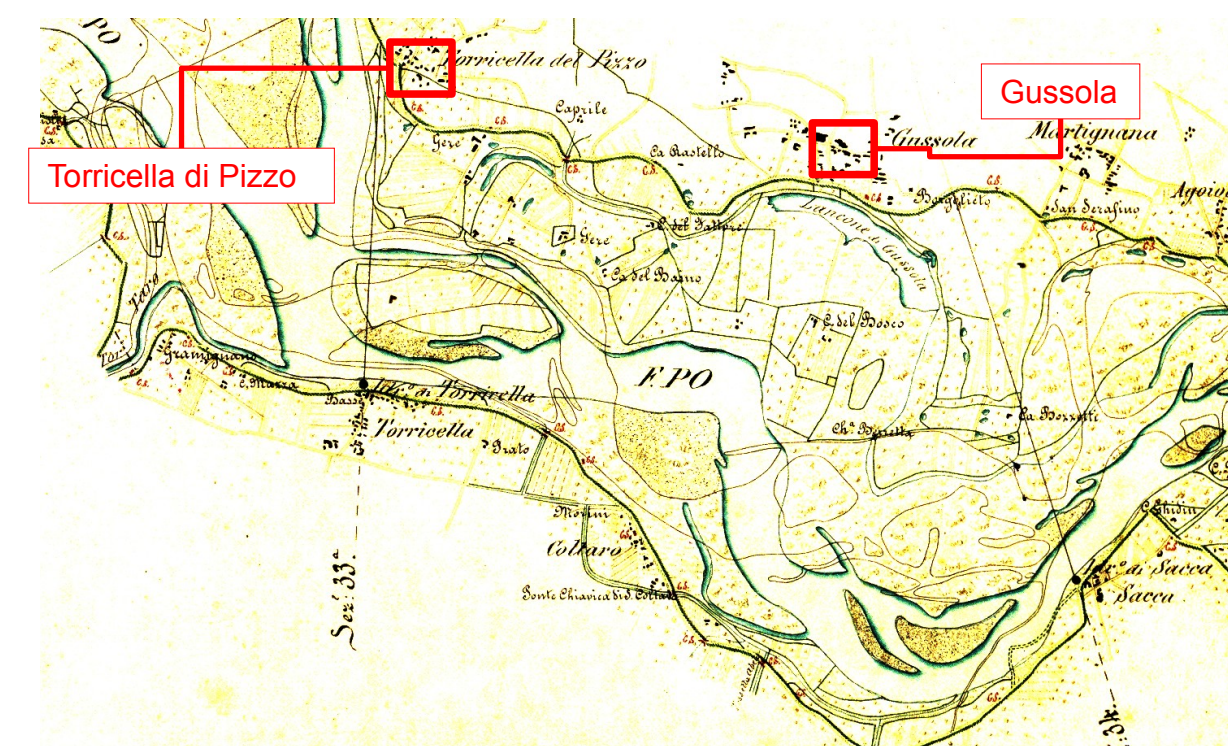


Fig. 4 - Map of a part of the studied reach (1873).

The effect of riverbed channelization or of the river bank fixation is very interesting. The channelization was planned in the first years of the XX century with the aim of favouring the navigability of the river. The project was carried out by means of the realization of a fixed low flow channel inside the active riverbed (which, in normal conditions, showed a intense mobility). The channel was planned for a discharge of 400 cubic metres per second, allowing the greater discharges to flood the other parts of the active riverbed. The planned tracing was constituted by a continuous series of parabolic curves, joined by means of flexus points, so that the same sinuosity of the natural low flow channel could be conserved. The constraints (i.e. towns, bridges etc.) required the movement of the tracing until 1,000 metres away from the original one. The expense for the earth movements due to the building of the new tracing would have been very large and for this reason they decided to use the river flow energy for eroding the river banks which would have had to be moved, to reach the new position, towards the external side of the curves which would have had to be moved, to reach the new position, towards the low flow channel. This goal was achieved with the progressive realization of works (rip rap, baffles) that at the same time deviated the current towards the zones that would have had to be eroded and protected the river banks (Cati, 1981). It was a very advanced plan for the time (first years of XX century), and we think it is important to analyse its effects by means of the consultation and the processing of historical cartographic documents at disposal (fig. 5).

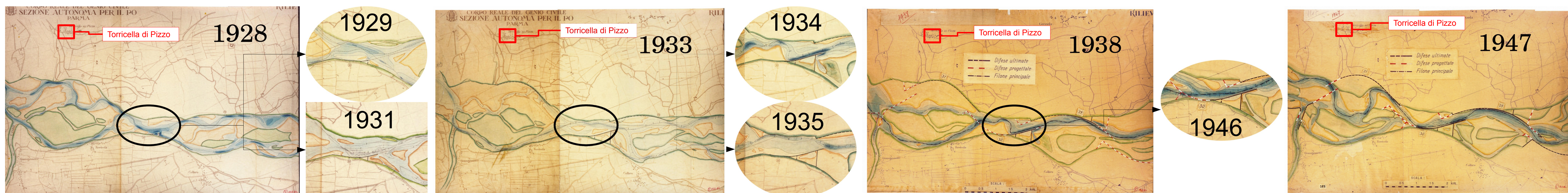


Fig. 5 - A maps sequence of the same river segment during the period 1919-1947. The detail of a baffle construction is shown

Indeed the project was continuously monitored and a lot of bathymetric maps of the river were created, in the period 1919-1946, for a 40 km reach length. By using this technical cartography we have digitised (for 1919, 1929, 1935 and 1946) the main morphological characters of the river (bars, channel, banks), and the same was done for the bathymetric lines. These lines have been interpolated to build a bathymetric raster model of the river in each analysed year (fig. 8). All data was processed by means of a Open Source GIS (GRASS-GIS, Neteler & Mitasova, 2002).

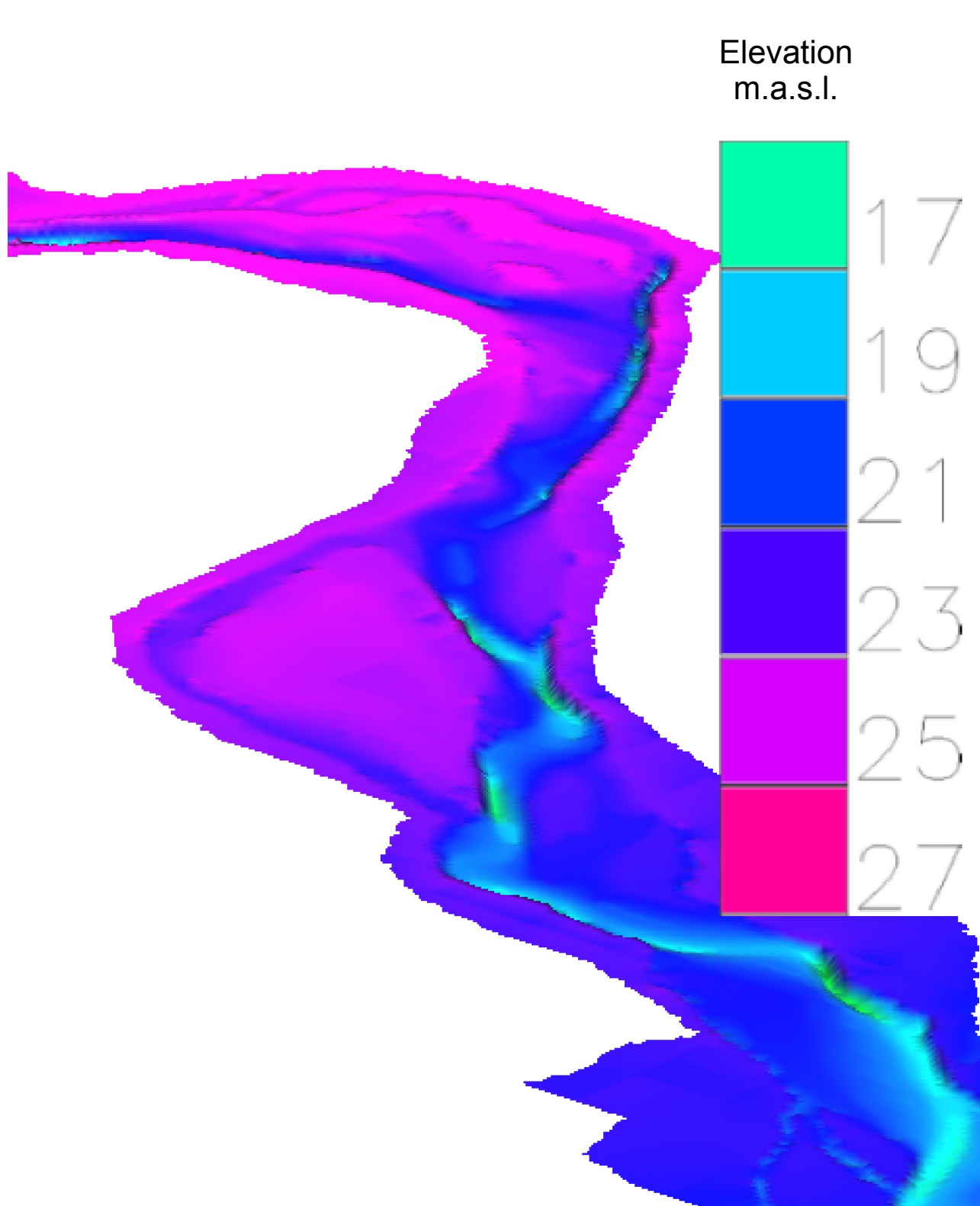


Fig. 6 - An example of a Digital Terrain Model of the channels bottom

Using streamflow stage measurements data it was then possible to estimate the water surface slope and to convert the bathymetric model to a Digital Terrain Model (where elevation is in terms of metres above sea level) of the channels bottom (fig. 6).

The obtained data was used to measure the thalweg elevation of the riverbed for each year and to analyse the volume of eroded material in the channels. Looking at the graph of thalweg elevation (fig. 7) and at the tables of volume of eroded material (tabs. 1, 2) it is important to consider that the 1919 maps only cover half the length other 3 analysed periods.

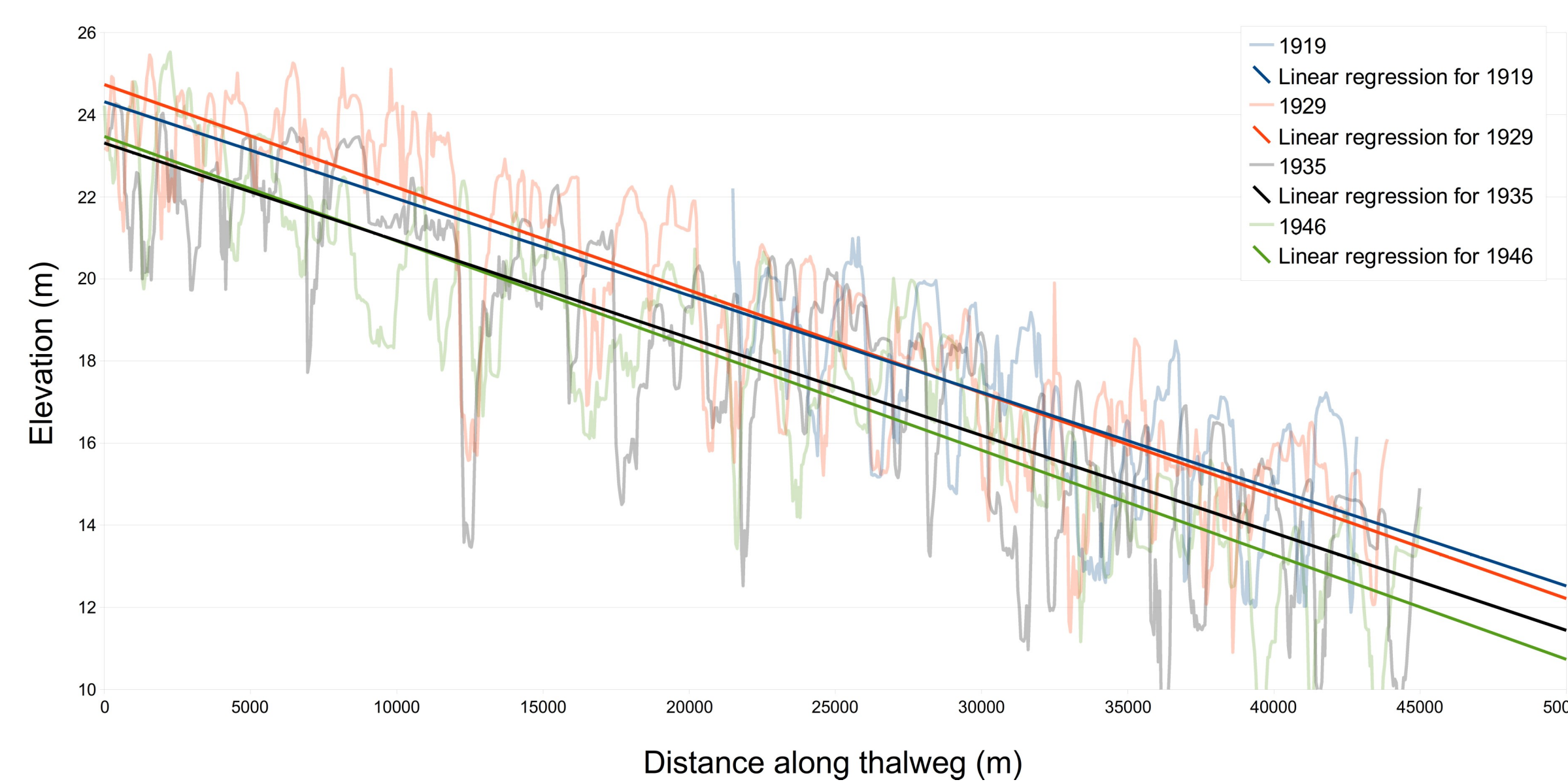


Fig. 7 - Thalweg profile of the studied reach of Po river for 4 different years. The regression lines are shown. Please note that the regression line for 1919, in the first half of the reach, is only extrapolated. It is clear the progressive lowering of the thalweg profile.

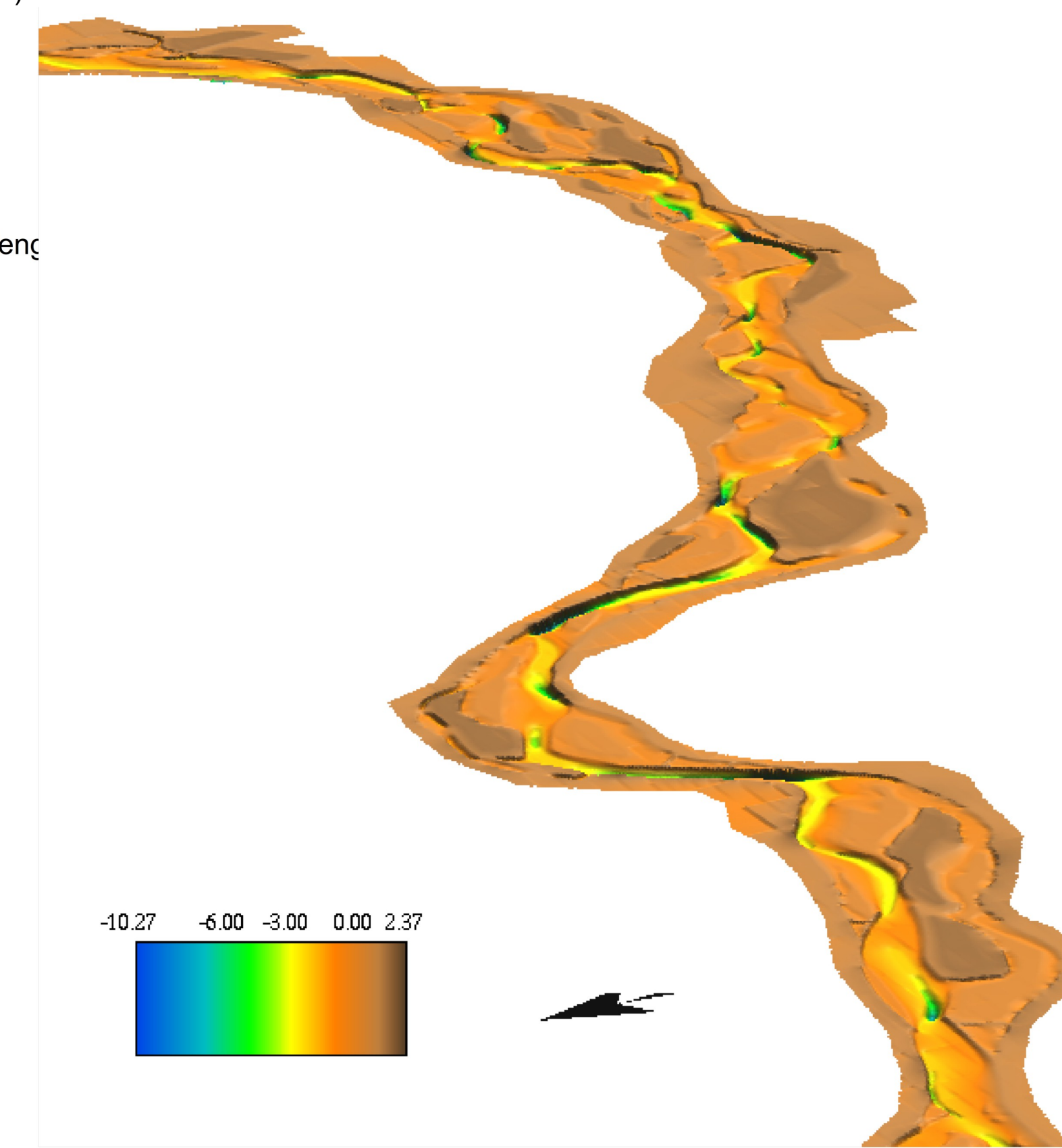


Fig. 8 - An example of a bathymetric raster model.

period	mean thalweg length (m)	volume increment under a common flow stage (mc)	years increment	erosion rate (mc/(km ² y))
1929-1935	44428.5	13592479	6	50990.09
1935-1946	45003	9347206	11	18881.99

Tab. 1 - Erosion rate in the whole studied reach for the periods 1929-1935 e 1935-1946

period	mean thalweg length (m)	volume increment under a common flow stage (mc)	years increment	erosion rate (mc/(km ² y))
1919-1929	21895.5	2407915	10	10997.31
1929-1935	22772.5	7228946	6	52906.99
1935-1946	21548.5	5043860	11	21279.1

Tab. 2 - Erosion rate in the second half of the reach for the periods 1919-1929, 1929-1935 and 1935-1946

The main effect (to improve the navigability of the river) was reached by means of establishing the low flow channel and a better continuity of the thalweg (figg. 9-10).

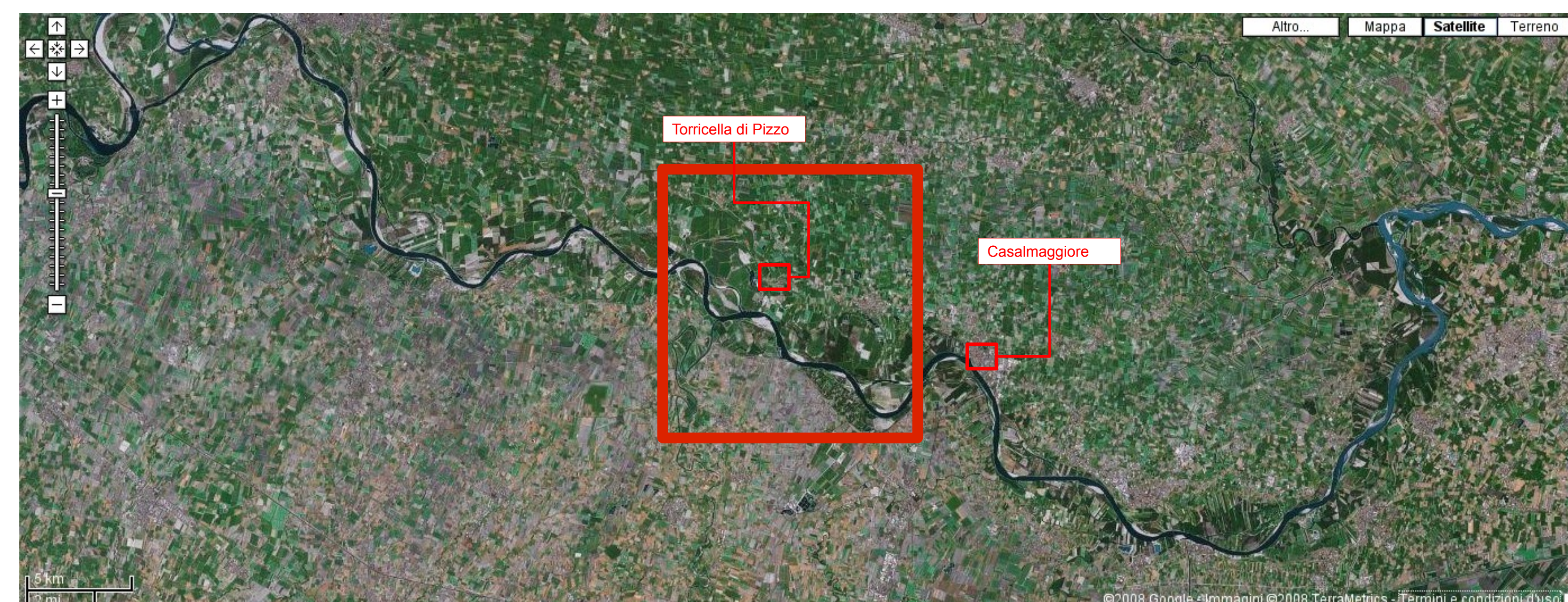


Fig. 9 - The whole studied reach in a satellite image by Google Map. In the red square the partial reach of fig. 10 is represented.

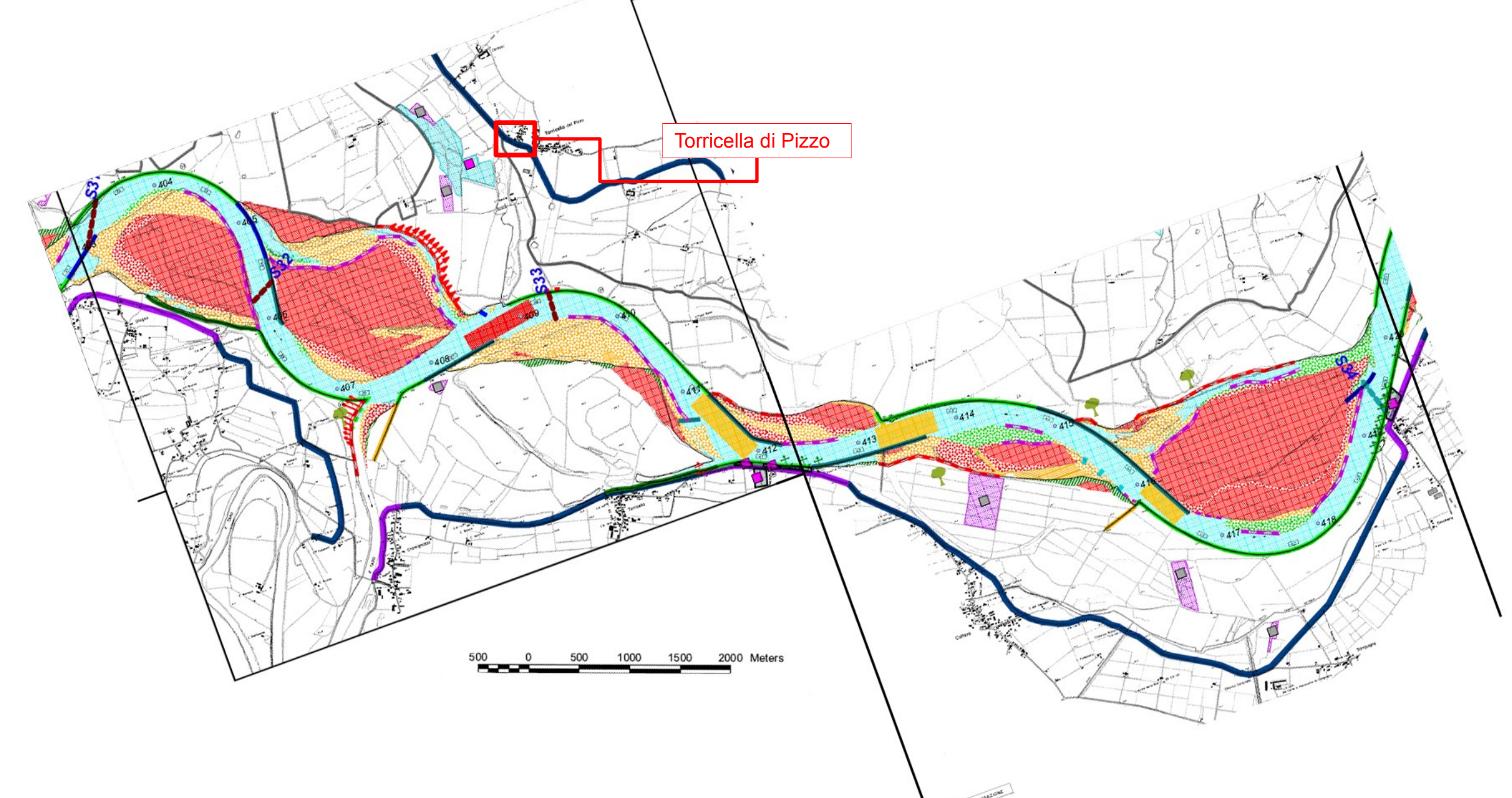


Fig. 10 - Geomorphological map of the riverbed (Autorità di Bacino del Fiume Po, 2007).

EVOLUTIONARY TREND AND PLANNED IN-CHANNEL HARD STRUCTURES

Other undesired effects was obtained by the direct interventions in channel management. An excess of the transport capability of the flow in the fixed channel occurred, and it produced an intense erosion of the channel, perhaps also due to the residual effects of the past intense quarrying activity. At the moment the channel allows a discharge until 800 cubic metres per second, in place of the discharge in the plan (400 cubic metres per second). Such relevant increase of discharge, and then of transport capability, increase further the tendency to erosional processes and alters the river bank stability. In order to contrast such excess of erosion in the channel, it is planned the realization of a series of run-off river power stations, with the goal of fixing the local base level, stabilizing the previously realised in-channel hard structures, improving the navigability of the river and permitting the production of hydroelectric power with water flowing systems that will use the potential energy drop produced by the dams. The building of the planned power stations, considered the elevation drops and the present slopes, will produce a relevant influence on the dynamics of the riverbed, presumably the trend towards erosional processes in the channel will stop and, on the contrary, the riverbed will be affected by sedimentation of material and aggradation.

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