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Sediment delivery at sea by the Magra River, Northern Italy

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Abstract:
The present paper describes the geological, geomorphological and hydrological characteristics of the catchment area of the Magra River, providing an estimate of the bed load sediment deliver through two methodological approaches: the first one is based on the results of field measurements conducted between 1999 and 2000 by the local authorities of Massa Carrara; the second one is based on the application of available empirical formulations. The range of the obtained results is between 35×10^3 and 68.5×10^3 m^3/y which are comparable to previous investigation of WL DELFT HYDRAULICS (2006) and CAVAZZA (1977) and are higher compare to estimation derived from field measurements carried out at the Calamazza section in the upper part of the basin.
Keywords: Bed load transport, Sediment delivery, ICZM, Natural capital.

1. Introduction

The estimate of sediment delivery from rivers is a critical issue for the economic development of the Apuan-Versilia coast, which is subject to intense erosion processes (CIPRIANI *et al*., 2001; PRANZINI, 2004), strongly influenced by anthropogenic impacts (AMINTI *et al*., 2002; CAPPUCCI *et al*., 2011). The analysis of the evolutionary trend of the coastal system requires investigating sedimentary processes at the scale of the Physiographic Unit (WL DELFT HYDRAULICS, 2006) and Catchment area (RINALDI & SURIAN, 2005), including reservoirs (ONORI *et al*., 2006; PIEGAY & RINALDI, 2006).

The sediment delivery of the Magra River was previously investigated by:

1) CAVAZZA (1977), which estimated the value between 72×10^3 m^3/y and 338×10^3 m^3/y.
2) The River Basin Authority (2005), which had monitored the values at the mouth as a result of a flood event of November of 1999, calculating the volumetric changes occurred at the river bed.

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3) The Dutch institute WL DELFT HYDRAULICS (2006) which identified in the River Magra a major source of sediment input calculating that, until 1930s bedload transport was about 70-130×10^3 m^3/y, and decreased trough time due to intense excavation for the aggregates needed to build the embankments of highways.

2. Study area

The Magra River has a length of about 62 km and flows with an average slope of 2% into the Tyrrhenian Sea following a dendritic pattern. During the time interval 1965-2000, the water level measurements have showed an increase in the average annual water discharge varying from 54.4 to 73.83 m^3/s (UFFICIO DEL GENIO CIVILE DI MASSA CARRARA, 2000); its catchment area is ~1.720 km^2 (Fig. 1) and three artificial barriers (Giaredo, Rocchetta and S. Margherita di Vara) entrapped ~5,5 million m^3 of sediment. Limestone, sandstone and limited outcrops of massive rocks, where erosion is active, characterise the river valley and the morphological changes of the riverbed are related to variations in water discharge (RINALDI & SIMONCINI, 2006).

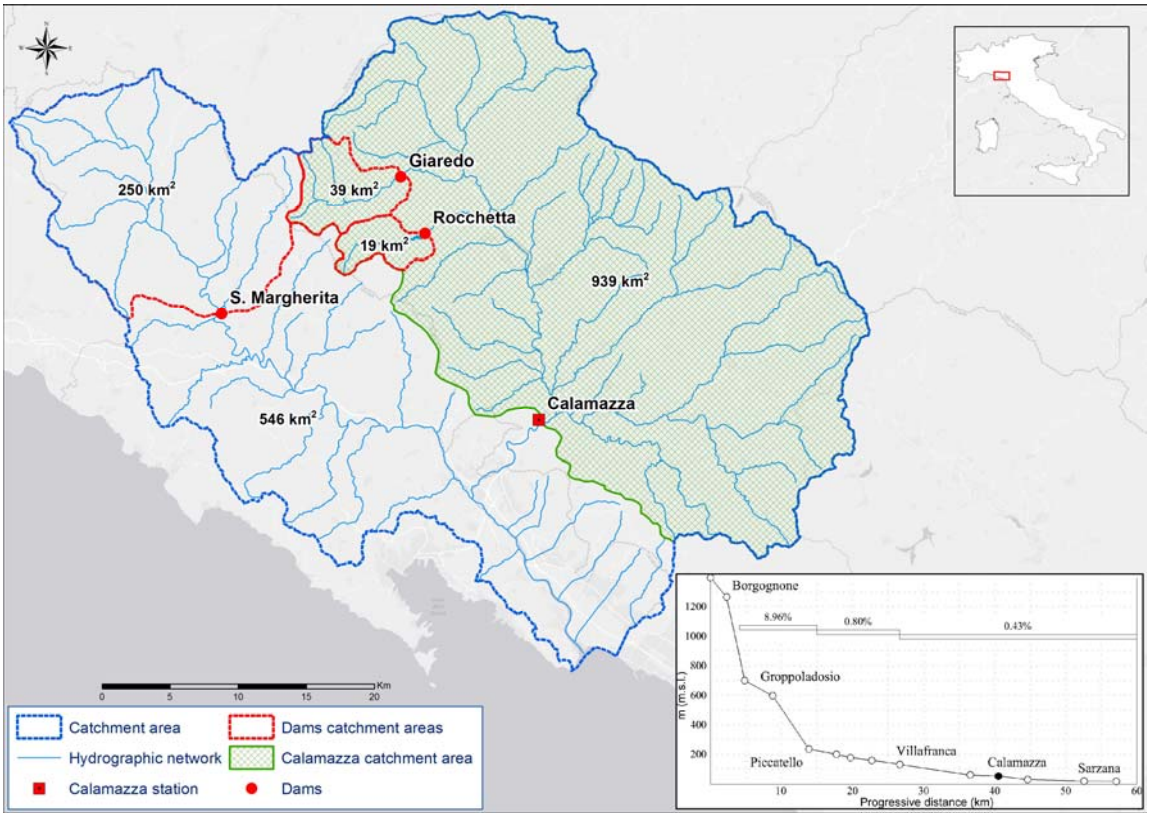

Figure 1. Magra River catchment area at Calamazza station (939 km^2) and location of rainfall and hydrometric stations along the river cross-section.

Thirty rainfall stations, which have been operative since 1925, measured an average precipitation rate of about 1700 mm/y and an annual runoff coefficient of 0.75

(D'AQUINO, 1989). Based on the lithological and hydrological characteristics of the river it can be assumed that sediment transport is relevant, especially for larger size fractions, occurring mostly only during major hydrometric events (BASIN AUTHORITY, 2000; 2005).

3. Materials and methods

The bed-load sediment transport of the Magra River was estimated, based on field measurements and the application of available empirical formulations.

In situ measures collected from March 1999 to October 2000 at Calamazza station, located 22 km far from the River mount (Figure 1), were used (Ufficio del Genio Civile di Massa Carrara, 2000). In particular, water level and water discharge time-series as well as sampling of bottom sediments (six samples collected during each field campaign by deploying an Halley Smith-trap), were preliminary analyzed. The most significant information obtained by this dataset are reported in Table 1.

Given the hourly time series of water level Y (m) and an average width of river section of 50 m, the following linear relationship between the water discharge (Q in m^3/s) and the associated bed-load transport (P in kg) per unit width across the river section was found:

$P=0.0004*Q \qquad (r^2=0.99)$

Thus, given the rating curve $Y=0.3445*Q^{0.3386}$, an estimation of the average annual bed-load is obtained by hourly time-series of the water discharge and the related measured of bedload transport.

In addition, to better estimate the solid volumetric flow rate per unit width across the river section ($m^3/s/m$), three empirical formulations were applied: (1) MEYER-PETER & MULLER-MPM (1948); (2) SCHOKLITSCH (1962); (3) SMART & JAEGGI (1983). These formulations allow estimating the bed-load sediment transport (expressed in m^3/y) as a function of the sediment proprieties of the river bed and of hydrological and morphological parameters derived by field data.

In this case, the rating curve was discretized in a daily time-series and related daily flow-rate values were obtained. Then, daily bed-load sediment transport values were estimated by the application of selected empirical formulations. The mean bedload annual value of was finally calculated as the amount of all daily estimated contributions.

In particular, in order to estimate the bed-load transport at the Calamazza station, the sediment grain size (D_{50}), based on grain size analysis, was imposed equal to 1 cm, the weight of the unit volume (γs) equal to 2.7 t / m^3 and the slope of the river bed equal to 0.4%. While, sensivity analysis were performed to define the most appropriate values of the dimensional and adimensional coefficients in the formulations, based on ranges resulting from a specific literature review.

The bed-load sediment at the mouth of the Magra River was then calculated by relating the whole catchment area of the Magra River (1720 km^2) with the catchment area at the

Calamazza station (939 km^2), both considering and not the contribution of the catchment areas of the S.M. Vara's dam.

Table 1. Field campaigns, average value of water discharge, derived from water level, and weight of samples (UFFICIO DEL GENIO CIVILE DI MASSA CARRARA, 2000).

Field campain	*Discharge (m^3/s)*	*Weight (g)*	*Field campain*	*Discharge (m^3/s)*	*Weight (g)*
08/05/1999	*28*	*29.05*	*28/10/1999*	*42*	*79.05*
11/06/1999	*8*	*19.08*	*12/01/2000*	*25*	*26.03*
10/08/1999	*3*	*14.02*	*29/03/2000*	*415*	*836.08*

4. Results

Results of bed-load sediment transport obtained at Calamazza station and at the mouth of the Magra River, are reported in Table 2 (from field surveys) and Table 3 (from empirical formulas considering (*) or not (**) the contribution of the catchment areas of the S.M. Vara's dam.

Table 2. Values of bedload transport estimated at Calamazza from in situ sampling and at the mouth of Magra River.

Station	*Calamazza*	*River mouth*	
Basin extention (km^2)	*939*	*1720 **	*1470 ***
Bedload transport (m^3/y)	*$22.6 \cdot 10^3$*	*$42.4 \cdot 10^3$*	*$34.9 \cdot 10^3$*

Table 3. Values of bedload transport estimated through empirical equations.

Station	*Calamazza*	*River mouth*	
Basin (km^2)	*939*	*1720 **	*1470 ***
Used equation	***Bedload Transport (m^3/y)***		
Schoklitsch (K=5000)	*$43.8 \cdot 10^3$*	*$80.2 \cdot 10^3$*	*$68.5 \cdot 10^3$*
Meyer-Peter and Muller-MPM	*$40.9 \cdot 10^3$*	*$76.6 \cdot 10^3$*	*$63.1 \cdot 10^3$*
Smart and Jaeggi	*$43.5 \cdot 10^3$*	*$81.4 \cdot 10^3$*	*$67.0 \cdot 10^3$*
Average values	*$42.7 \cdot 10^3$*	*$79.4 \cdot 10^3$*	*$66.2 \cdot 10^3$*

5. Conclusion

The application of empirical formulas for estimating the river sediment transport requires the use of parameters that, due to various limitations, can provide results that differ from the real sediment delivery. However, in the present paper, by virtue of particular lithological and hydrological behaviour of Magra River, the results obtained by the application of empirical formulations (63.1**-80.2*$\times 10^3$ m^3/y) are comparable to previous investigation of WL DELFT HYDRAULICS (2006; 70-130$\times 10^3$ m^3/y) and

CAVAZZA (1977) and are ~150% higher compare to estimation derived from field measurements carried out during water discharge (34.9-42.4×10^3 m^3/y).

It is observed that the lower values of bedload sediment transport, estimated by relating the water discharge time-series with field measurements of bottom sediments, can be due to: (a) the reduced river flow rate (varying from 3 m^3/s to 415 m^3/s) occurred during the short time interval (03/1999-4/2000) of measurements; (b) to the absence of sediment samples in the central part of river cross-section at Calamazza station and (c) the real transport capacity of the river sand in the section between Calamazza and Magra River mouth, where processes of deposition are known and under investigation

To notice that out of the three formulas tested, only the MPM is strictly speaking applicable to the geomorphological context of the Magra in the lower course. Although the other two formulas were tested, they are more appropriate for rivers with steep beds and narrow alluvial plains.

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