

From geotechnical and hydraulic researches to use of natural materials in mitigation works for river embankments: a case study

S. Amoroso, M. Leopardi & G. Totani

*Department of Structural, Water and Geotechnical Engineering,
University of L'Aquila, Italy*

Abstract

In rivers, a hydraulic hazard is the result of natural or human factors, or both. The first step in addressing the problem is to establish hydraulic security measures; the work undertaken must allow for improving hydraulic characteristics of the river in order to create a section compatible with the maximum predictable height and flow. The logic of the mitigation works for the hydraulic hazard usually doesn't coincide with river redevelopment measures because some actions are obviously conflicting. These questions are faced with a geotechnical and hydraulic research and with the use of natural materials in mitigation works. The study consists of a diagnosis about the conditions of functionality of the fluvial embankments (in particular in the urban section), to suggest guidelines for measures with low environmental impact and with a "friend of nature" engineering approach. In this paper the geotechnical and hydraulic problem of the existing embankments is analysed in two areas that are particularly important to the Aterno River (L'Aquila, Italy). The aims of the studies are to find the most suitable solutions of correction and restoration works. This paper illustrates the methodology to define the map of hydraulic hazard and to determine the maximum heights of the flow. Moreover, it shows the results of many in-situ tests by flat dilatometer (DMT) and laboratory geotechnical tests performed in the river alluvium soils in order to perform a stability analysis of embankments and for settlements prediction. Finally, it gives guidelines for measures with low environmental impact and with an eco-friendly engineering approach.

Keywords: hydraulic hazard, soil properties, mitigation works, environmental impact.



1 Introduction

During recent years in the suburbs of L'Aquila the agricultural lands have been subjected to infiltration by civil and industrial structures and facilities, and the buildings have extended into the valley bottom, affecting the fluvial processes within the Aterno River, fig. 1. Today it is necessary to check the appropriateness of the existing defence works, to hold account of the aforesaid modification of the use of the territory, particularly where the river is embanked. In this article we describe the conservative-functional solutions in order to keep the morphologic and structural layout of the fluvial section unchanged, using adjustment measures of the transversal sections, reinforcing longitudinal defence works and recovering naturalistic characteristics of the river bed and of its closed areas.

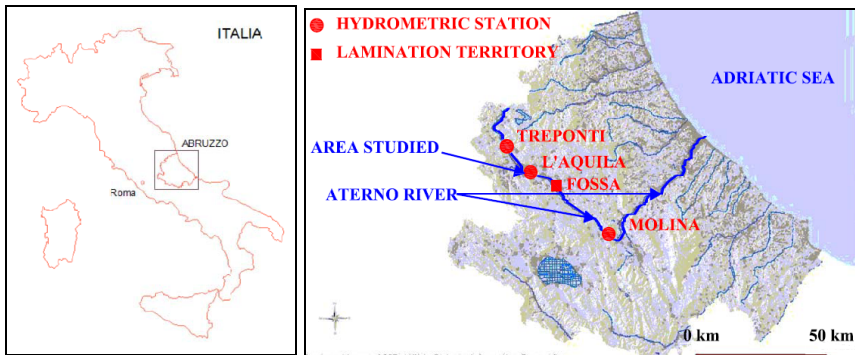


Figure 1: Aterno River and L'Aquila in Abruzzo's regional map.

2 Geological setting

The L'Aquila basin, fig. 2, extending in direction NW – SE, is a wide depression of tectonics origin enclosed between high mountains formed mostly by carbonatic rocks and, subordinately, sandstones of the Meso-Cenozoic period.

The bottom of the depression was filled in the Pleistocene period with continental environment deposits. Currently it holds immense plains of recent (Holocene) alluvial filling from the Aterno River and Raio Stream, with the main affluent on the right-hand side.

The most ancient continental deposits form wide level areas, placed at several heights on the valley-bottom plains of the two watercourses. Finally, inside the basin, mountains of modest height emerge constituted by rocky outcrops of the Meso-Cenozoic basement.

The alluvial sediments, emerging in the valley-bottom plains of Aterno R. and Raio S., are constituted by gravel that variously alternates to lens and levels of sand, sandy and/or clay silt, silty clay of dark color; the thickness reaches 10–12 m.

In the Aterno and Raio plain. The deposits support, according to surfaces of variously modeled erosion, on several continental sediments or bed-rock. The basic geology of L'Aquila basin is illustrated in figure 2.

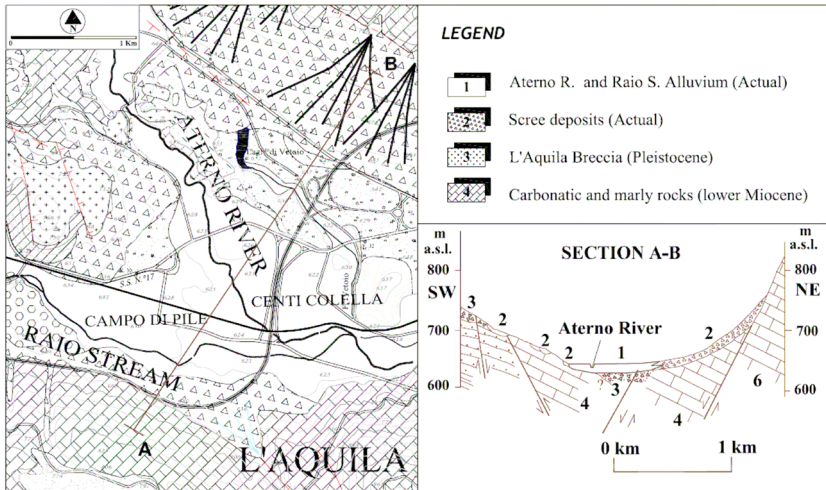


Figure 2: Geologic aspect of L'Aquila basin.

3 Hydrologic and hydraulic studies

The Aterno River rises in Gran Sasso-Monti della Laga's National Park and flows in Velino-Sirente's Regional Park; from Capo Cancelli Mountain, the river's source, it receives along its course contributions from tributaries that come from sources in carbonatic rocks. From the initial medium flow, that is about 24 l/s (estimated value in some decades of observation), the flow increases mostly in L'Aquila basin, fig. 3, thanks to the Vetoio, Raio and Vera Rivers. The global flow is characterized by a normal regime of variability during all the hydrologic year. However, in the past (the last event happened in December 1999) some floods are registered, sometimes with considerable damage and risks for public and private safety.

In L'Aquila basin the Aterno River is completely canalized and it is embanked along extended stretches of the river because of ancient hydraulic works (1880–1950). During this period some old mills with intake constructions were built for productive activities.

From 1952 the urbanization process marks the decrease of traditional activities, like fragmented and widespread farming. It engraves the territory with infrastructures, preventing the chances to access and use the river belt and determining the social-cultural detachment from the city and the consequent degradation and deflection.

Today, admitting the role the river belt, fig. 4, can have in the ecologic valorisation and in the use of free time in L'Aquila basin, geotechnical and hydraulic researches are necessary to design and to build defence works with an eco-friendly engineering approach.

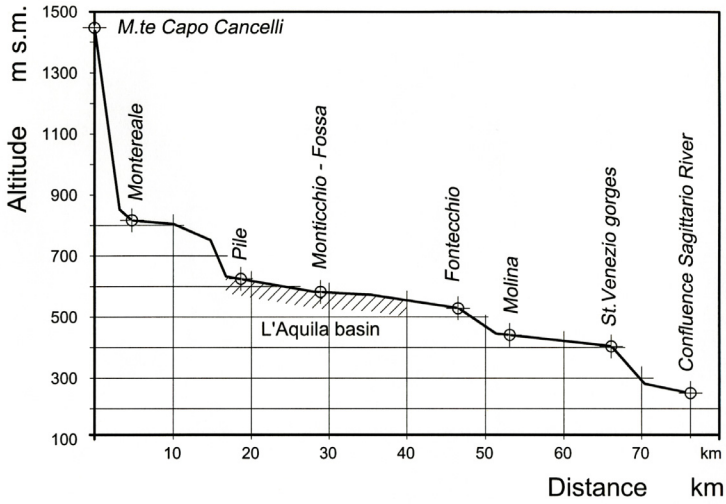


Figure 3: Longitudinal profile of Aterno River.

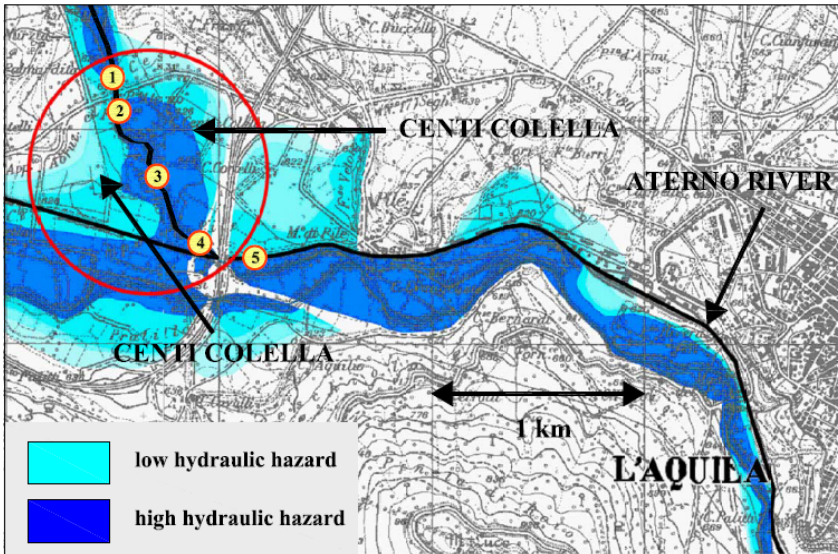


Figure 4: Map of hydraulic hazard of Aterno River and section of study.

3.1 Hydrological characteristics of Aterno River

The data of the Hydrographic Service describe the hydrologic characteristics of the Aterno River that underline a paucity of superficial flow, with an annual medium rainfall of 900 mm and with an extension of the basin of about 1342 km². This aspect is related to the high permeability of the basin.



At the scope to determinate the maximum high flow, the direct measures of flow have been used in three stations distributed along the Aterno River: Treponti, L'Aquila and Molina, table 1.

Table 1: Characteristics of the hydrometric stations.

Hydrometric stations	Area of the basin (km ²)	Basin permeability (%)	Medium altitude (m)	Hydrometric zero (m)
Treponti	114	34	1026	760.00
L'Aquila	531	46	1105	640.00
Molina	1303	60	1120	435.00

3.2 The plan of hydraulic and environmental compatibility with the municipality projects

According to statistics of the maximum value observed, one procedure is the elaboration of the probability distribution of maximum flow values, for a fixed recurrence time ($T = 200$ years), $Q(T)$, with reference to the function of Gumbel's distribution EV1. In addition to this procedure, the function $Q(T)$ is acquired either with the statistical method of the moments or with the statistical method of the maximum verisimilitude. In table 2 the results obtained in the stations using the various methodologies are summarized:

Table 2: Values of the maximum flow and the specific flow with $T = 200$ years.

Measure stations	Method of the maximum observed value		Method of the moments		Method of maximum verisimilitude	
	Q_{200} (m ³ /s)	q_{200} (m ³ /s/km ²)	Q_{200} (m ³ /s)	q_{200} (m ³ /s/km ²)	Q_{200} (m ³ /s)	q_{200} (m ³ /s/km ²)
Treponti	73	0.64	71	0.62	60	0.52
L'Aquila	329	0.62	319	0.60	354	0.66
Molina	124	0.09	121	0.09	109	0.08

The check of the reliability of the adaptability of Gumbel's law to the series of values of the flows has been conducted with the Method of the Fiduciary Bands (Kolmogorov-Smirnov): this method allows the retention of the hypothesis to choose the function of Gumbel's distribution in order to interpret the three statistics series.

From the analysis of the stations' values of flow at their fullest it is pointed out that for the Molina station, contrary to what is expected, the flows are clearly inferior compared to that of the L'Aquila's station, although the subtended basin is more than double. The cause is to be sought out in the lamination effect produced by the overflow of Aterno R. in Fossa's Territory.

Assuming that the specific flow equals $0.64 \text{ m}^3/\text{s}/\text{km}^2$ and the area of the basin subtended by Aterno R. in the concerning tract equals 276 km^2 , the design maximum flow is approximately $177 \text{ m}^3/\text{s}$.

From the examination of the planimetric river course, fig. 4, and the longitudinal profile of the river bed there is a quite homogenous course with



uniform slopes ($i = 0.0046$). Subdividing the watercourse in homogenous tracts, five meaningful sections have been found. From their examination it can be deduced that the modeling of the river bed, or of “bank full”, generally corresponds to the ordinary high flow, with the flow estimated near to the mainly embedded part of the transversal sections.

In figure 5(a) the current section 5 is shown with the relative heights of uniform flow, calculated for the modeling flow and for the maximum high flow (177 m³/s), and critical height for the last one (the same results come out from the other sections).

A planning solution, in order to contain the overflow in the area concerned has been the realization of embankments for delimiting and centralizing the riverbed of “bank full” with flood beds, fig. 5(b), 8.

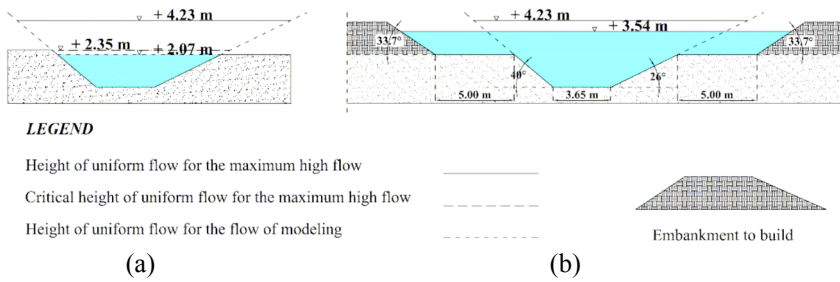


Figure 5: Section 5. (a) Current section with heights of uniform flow and critical heights for the maximum high flow; (b) design solution.

4 Soil properties

In the area located before the confluence of Raio S. in Aterno R. (zone of Campo di Pile, Centi Colella) an extended geotechnical investigation was carried out by boreholes, fig. 7, and in situ and laboratory tests. The flat dilatometer (DMT) test, Marchetti [3], Marchetti *et al.* [4], has been extensively used with both penetrometer (20 tons) and torpedo-system probe. Numerous SPT tests (gravel-sand layers) have been executed and numerous samples (silt-clay layers) have been collected for laboratory tests. The coefficient of permeability of the soil layers has been determined by in situ permeability tests (direct determination) and/or by DMTA dissipation tests (indirect determinations), Marchetti *et al.* [4],

Table 3: Geotechnical parameters and typical soil layers underlying the embankments in locality Campo di Pile.

Stratigraphy	z (m)	Soil	γ (kN/m ³)	M (MPa)	OCR	Cu (kPa)	C' (kPa)	ϕ' (°)	k (cm/s)
	0 ÷ 3	silty sand	21.0	44 ÷ 66	12	-	0	33 ÷ 38	$5 \cdot 10^{-4}$
	3 ÷ 8	sandy gravel	22.0	170 ÷ 210	11	-	0	46.5 ÷ 48.5	1
	9 ÷ 26	silty clay	18.8	55 ÷ 64	10	200 ÷ 300	0 ÷ 10	27 ÷ 30	$2 \cdot 10^{-8}$

Totani *et al.* [5]. In table 3 and in figures 6(a), 6(b), 7 the more meaningful data related to geotechnical parameters, stratigraphy, permeability and physical-mechanics properties have been presented. The ground water level is located 2 m below the ground level.

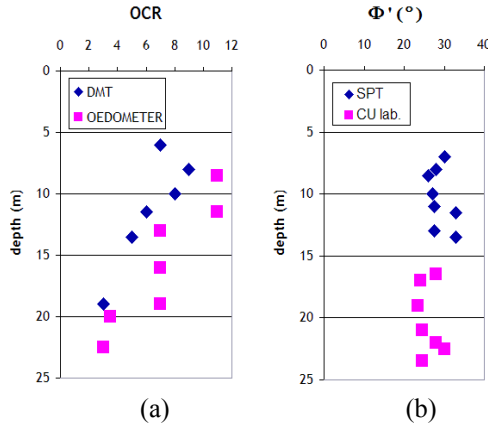


Figure 6: Campo di Pile: (a) Overconsolidation ratio (OCR) from oedometer tests and in situ DMT; (b) angle of shear strength (Φ') from SPT (sands) and CU lab. Tests (clays).

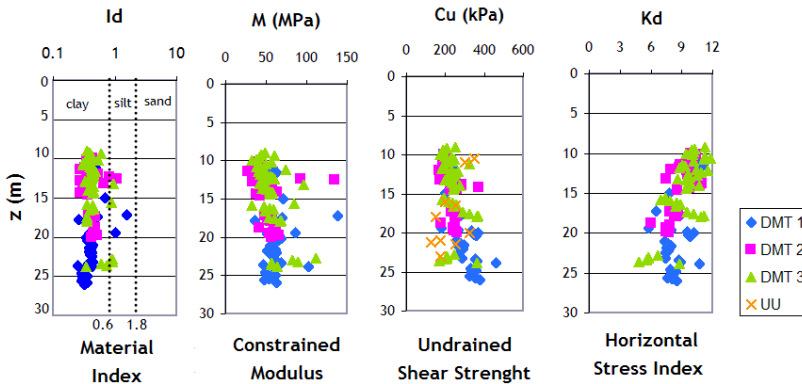


Figure 7: Campo di Pile: results of in situ DMT and laboratory UU tests.

The coefficient of consolidation c_v in the clayey substrate is equal approximately to $2.30 \cdot 10^{-3} \text{ cm}^2/\text{s}$. The calculation of settlements shows that foundation soil is suitable to build an embankment about 2.00 meters high, fig. 8. The first bottom, created by the embankment, could be used for maintenance works and for recreational activities.

Numerous particle-size distribution tests have been performed to judge if alluvium soils in the area of study are suitable to use as fill materials to build the



embankments. Figure 9 illustrates the range of natural material particle-size composition: it is appropriate to fill the embankment.

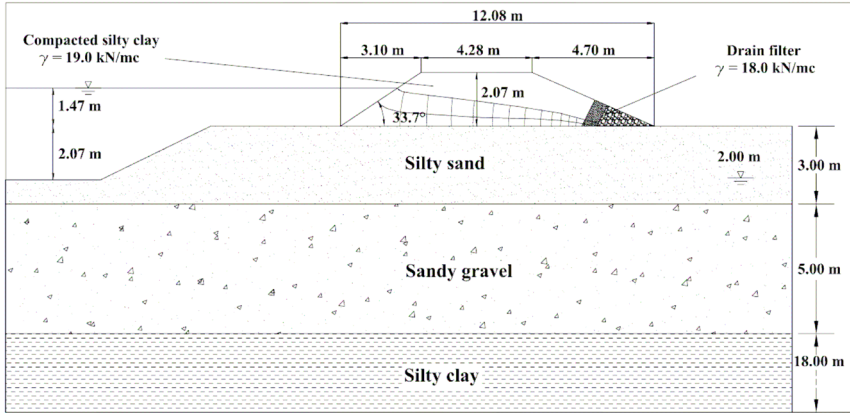


Figure 8: Embankment to realize (Section 5).

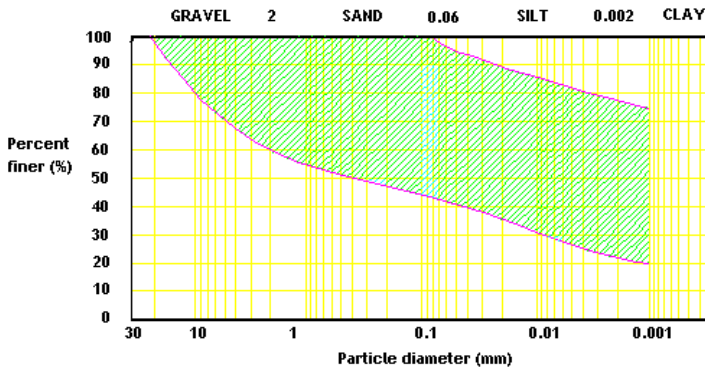


Figure 9: Range of particle-size composition of soil layers underlying the embankments in the area of study.

5 Mitigation works and measures with low environmental impact

In order to combine the reduction of the hydraulic hazard with low environmental impact measures, in the sections of study innovative solutions could be introduced using both natural materials and new methods of work.

Figure 10 shows one of the most appropriate design solution: Reno mattress. It consists of double twist wire mesh filled with rockfill and top soil. Above this layer there is the bio-mat to avoid the washout. Thus, it will be realized a mulch hydro-sowing to get a better vegetation regeneration.

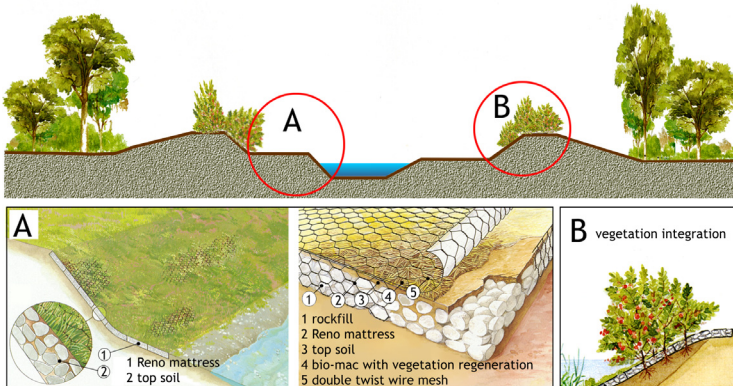


Figure 10: Reno mattress.

Another solution is the reinforced soil, fig. 11: double twist wire meshes are fitted into the soil layers to increase the tensile strength of the soil. Moreover, it is important to insert willow cuttings and a wire mesh gabion, as foundation, to avoid the work scouring.

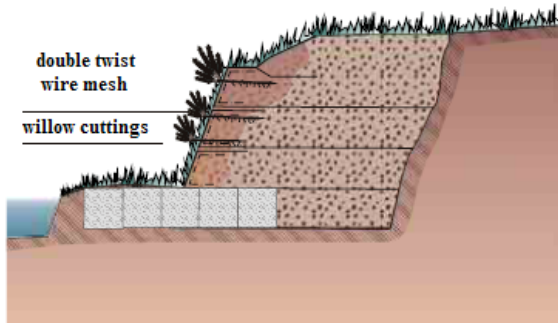


Figure 11: Reinforced soil.

6 Concluding remarks

The case history presented in this paper is an example of environmental engineering design, involving the contribution of different specific studies (geology, geotechnics, hydraulics and hydrology).

In this case, the selection of an in-situ soil to fill the embankment, in combination with proper design of the layout of the stabilization works, careful planning of the construction stages and optimization of the execution techniques, has enabled restoring the hydraulic capacity of the river and improving the stability of the banks, and at the same time to preserving the existing environment and help renaturalization of the site.

This case history may be considered as a prototype which could be possibly used/improved by further applications, where taking into account the design of the environmental features of the site as being as important as the pure engineering practice.

References

- [1] Tallini, M., Magaldi, D., Lorè, A., Reale, E. & Scozzafava, M., *Geologia del Quaternario e pianificazione territoriale della piana intramontana L'Aquila-Scoppito (Italia Centrale)*. Italian Journal of Associazione Georisorse e Ambiente (GEAM). 105 (1), pp. 55–67, 2002.
- [2] Bertini, T., Cugusi, F., Totani, G. & Farroni, A., Caratterizzazione geologica e geotecnica dei sedimenti quaternari del settore occidentale della conca aquilana. *Proceedings of Department of Structures, Waters and Soil Engineering*, University of L'Aquila, 1992.
- [3] Marchetti, S., *In Situ Tests by Flat Dilatometer*. Journal of the Geotechnical Engineering Division, ASCE, 106 (GT3), pp. 299–321, 1980.
- [4] Marchetti, S., Monaco, P., Totani, G. & Calabrese M., The Flat Dilatometer Test (DMT) in soil investigations A Report by the ISSMGE Committee TC16. *Proceedings from the Second International Conference on Flat Dilatometer*, Washington, D. C. April 2-5, 2006, pp. 8–48, 2006.
- [5] Totani, G., Calabrese, M. & Monaco, P., In situ determination of c_h by flat dilatometer (DMT). Geotechnical Site Characterization. *Proceedings of the First International Conference on Site Characterization*, pp. 883–888, 1998.
- [6] Alessandroni, M.G., Leopardi M. & Remedìa G., *Deflusso minimo vitale Considerazioni idrologiche sulla portata residuale del Fiume Aterno*. Pubblicazione DISAT n.4, 2001.
- [7] Leopardi, M. & Remedìa, G., *Eventi estremi: le magre e le piene del Fiume Aterno*. Associazione Idrotecnica Italiana – Sezione Italia Centrale, 2002.
- [8] Leopardi, M. & Di Nardo P., *Taratura di alcune procedure numeriche per la valutazione delle portate di piena su piccoli e medi bacini privi di dati idrometrici*. Regione Abruzzo - Direzione Regionale Gestione Bacini Idrografici, 2004.

