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RELATIONSHIP BETWEEN FLOOD HAZARDS AND GEOMORPHOLOGY APPLIED TO LAND PLANNING IN THE UPPER AVETO VALLEY (LIGURIA, ITALY)

ABSTRACT: BRANDOLINI P., FACCINI F., ROBBIANO A. & TERRANOVA R., *Relationship between flood hazards and geomorphology applied to land planning in the upper Aveto Valley (Liguria, Italy).* (IT ISSN 1724-4757, 2007).

In the framework of an analysis of geomorphological hazards for environmental protection and land planning, a multidisciplinary survey programme has been conducted, promoted by Genoa Province, in order to assess the flooding risk in the fluvial plain of the Aveto stream. The studied catchment basin extends over an area of 172 km2 in the eastern Ligurian sector of the Apennines, close to the border with the Emilia-Romagna region.

A detailed geomorphological analysis was carried out by means of field observations in the flood plain and aerial photograph interpretation of the entire basin, particularly focusing on those slope sectors affected by processes due to gravity and running water potentially involving the stream. This included comparison of aerial photographs taken during the last few decades, and comparison with historical maps dating as far back as the 18th century.

Comparison of the collected data has allowed for the zoning of the fluvial plain into three areas, characterized by different levels of geomorphological hazard due to floods: high - present day river bed and contiguous fluvial terraces, subject to ordinary floods; medium - alluvial plain occasionally subject to floods and slope areas affected by active geomorphological processes potentially involving the stream; low - terraces, alluvial deposits, and fluvial plains subject to catastrophic floods and slope areas contiguous to the river bed without active geomorphological processes involving the stream.

Finally, the comparison between maps of flood hazard, historical flooding areas, and hydraulic zones showed satisfactory results with the overlapping of zoning based on different criteria, confirming the reliability of flood risk assessment based on geomorphological data.

KEY WORDS: Geomorphological hazard, Environmental geology, Floods, Eastern Liguria.

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RIASSUNTO: BRANDOLINI P., FACCINI F., ROBBIANO A. & TERRANOVA R., *Rapporti tra pericolosità da esondazione e geomorfologia applicata alla pianificazione territoriale nell'alta Val d'Aveto (Liguria).* (IT ISSN 1724-4757, 2007).

Sono presentati i risultati delle indagini geomorfologico-ambientali a supporto degli studi di difesa del suolo e pianificazione territoriale a scala di bacino, svolti nell'ambito di un programma di ricerca interdisciplinare, attivato dalla Provincia di Genova, per la valutazione del rischio da esondazione lungo le fasce fluviali del T. Aveto.

Il sottobacino ligure di pertinenza padana del T. Aveto si estende su una superficie complessiva di 172 km^2, presente nell'entroterra appenninico della provincia di Genova, nel settore confinante con la regione Emilia-Romagna.

La metodologia di indagine si è basata su rilevamenti geomorfologici di dettaglio concentrati sui fondi vallivi, estesi a tutto il bacino, con il supporto dell'analisi fotointerpretativa di immagini aeree multitemporali, focalizzando l'attenzione anche sulle porzioni di versante interessate da fenomeni gravitativi in grado di interferire con la dinamica fluviale. Si è svolta inoltre una ricerca d'archivio, relativa in particolare al reperimento di documentazione cartografica, iconografica e di testimonianze dei più importanti eventi alluvionali storici.

La determinazione delle fasce fluviali, secondo i criteri di riferimento del Piano di bacino per l'Assetto Idrogeologico del F. Po, basata principalmente su studi idraulici (tempi di ritorno delle portate, tiranti idraulici, carta delle aree esondabili) e solo in subordine geomorfologici ed ecologici, ha consentito la distinzione di tre ambiti fasce con caratteristiche omogenee: una fascia di di deflusso della piena (Zona A), una fascia di esondazione per piene eccezionali (zona B) ed un'area d'inondazione per piena catastrofica (zona C).

Successivamente si è proceduto alla delimitazione delle fasce fluviali esclusivamente su base geomorfologicoapplicativa, giungendo sempre alla distinzione di tre ambiti: un'area a fascia esondabile per piene ordinarie definita a pericolosità elevata, coincidente con l'alveo attuale e le zone terrazzate adiacenti; una fascia zona esondabile per piene eccezionali, coincidente con la piana alluvionale ed estesa alle aree di versante con processi geomorfologici in atto che possono interferire con il corso d'acqua, definita a pericolosità media; una fascia fascia esondabile per piene catastrofiche, a bassa pericolosità, riferita alla piana alluvionale, alle alluvioni terrazzate e alle aree di versante adiacenti all'alveo senza processi geomorfologici in atto in grado di interferire con il corso d'acqua.

Il confronto tra le carte delle fasce fluviali determinate su base idraulica e quella della pericolosità geomorfologica ha evidenziato una soddisfacente sovrapposizione delle diverse zonizzazioni, confermando la validità dell'uso dei criteri geomorfologici legati alla dinamica di un corso d'acqua anche per la valutazione del rischio da esondazione.

TERMINI CHIAVE: Pericolosità geomorfologica, Geologia ambientale, Alluvioni, Liguria orientale.

INTRODUCTION

Land planning aimed at land protection requires an interdisciplinary approach so as to draw a summary of all aspects within a catchment basin. The contribution of applied geomorphology is particularly essential to the understanding of dynamic landscape processes and their possible consequences on natural and anthropogenic elements (Fattorelli & *alii*, 1999; Bell, 2007).

Among the tools for planning within the basin, the Plan of the Fluvial Zones of the Po River provides for the management of the stream consistent with hydraulic safety, the management of water resources, land exploitation, and environmental protection. The Plan of the Fluvial Zones has the following aims: a) defining the boundary of the flood areas for the reference flood, and protecting the settlements, infrastructure, and the productive activities at risk from such a flood; b) marking the boundary of the flood bed and the areas of its spreading together with the respective geomorphological and hydraulic features to allow the preservation of natural flood areas, where this is compatible with settlements and anthropogenic activities, and to establish a balance between the need for flood containment and lamination; c) promoting the natural geomorphological evolution of the riverbed to minimize the anthropogenic interferences on the fluvial dynamics; d) promoting the recovery and preservation of the natural conditions, protecting at-risk areas and the systems which are naturally and environmentally important and ensuring the ecological continuity of the fluvial system.

This paper presents a case-study of the Ligurian basin of the Aveto Stream, located in the Ligurian-Emilian Apennines, in an area of great landscape value with active geomorphological dynamics and frequent recent floods. The hazard of the flood-prone areas was defined on the basis of geomorphology, by dividing the zones surrounding the river into corresponding areas and by following an original operational method.

The classification of the fluvial zones was emphasized by an *ad hoc* chromatic matching on the graphic tables of the extracted plane. The classification was made mainly on the basis of hydraulic analysis; the geomorphological and ecological analyses were secondary. The classification shows three zones: a zone of flood outflow (Zones A), a zone of flood (Zones B) and a zone of catastrophic flood (Zones C).

GEOGRAPHIC AND CLIMATIC FRAMEWORK

The Aveto Stream is in the Ligurian-Emilian Apennines. It has a basin size of about 251 km^2 (172 km^2 in the Province of Genoa and 79 km^2 in the Province of Piacenza), and is a tributary of the Trebbia River (fig. 1).

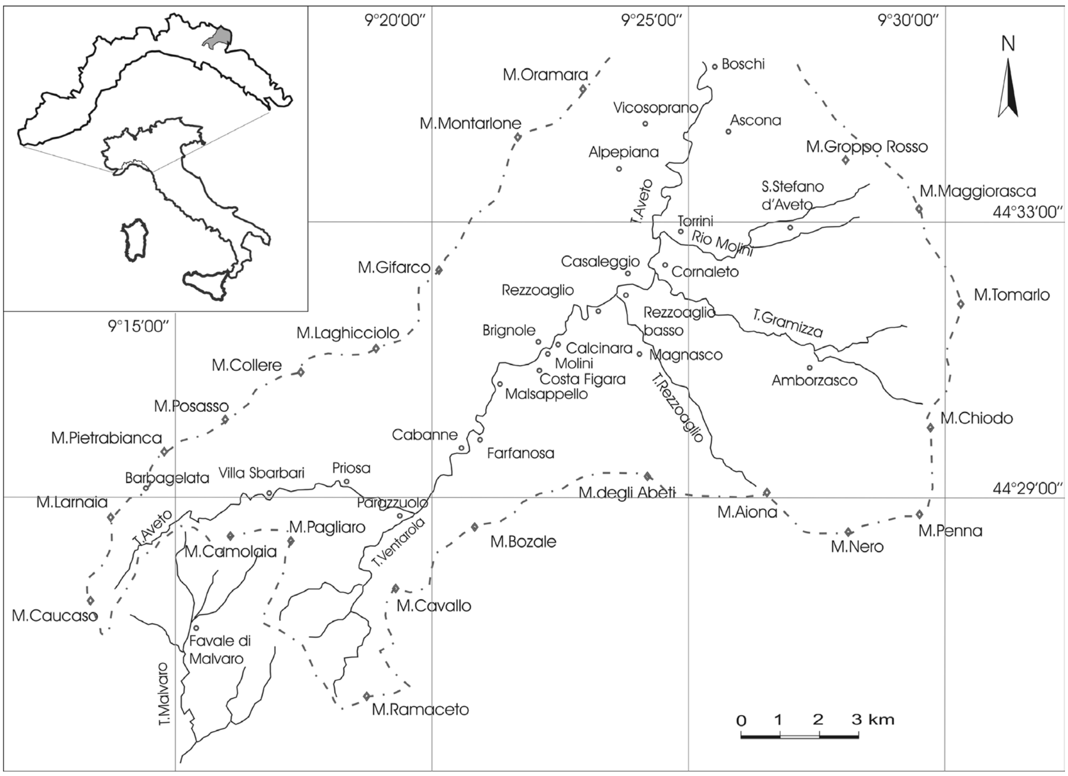


FIG. 1 - Geographical sketch map of the Aveto Stream basin.

The river originates on the eastern side of Mt. Caucaso (1245 m), on the Acquapendente Pass, a few meters from the watershed ridge between the Aveto Valley and the Malvaro Valley. It flows into the Trebbia River at Confiente, slightly upstream from the village of Marsaglia in the municipality of Cortebrugnatella.

At first, the Aveto Stream flows in a SW-NE direction in an open valley as far as Parazzuolo, where it turns towards NE and continues across the plain of Cabanne where it receives the Ventarola Stream. In the area between Brignole and Rezzoaglio, it shows a narrower thalweg because of the ophiolitic bedrock, and at Casaleggio its direction changes again toward the north.

The highest mountain of this basin is Mt. Maggiorasca (1804 m). The boundary of the studied area was placed at the dam of Boschi d'Aveto (615 m); the average altitude is 1210 m a.s.l., with a main stream length of 35 km.

The maximum flows of the stream, calculated on the basis of a 200 year recurrence time, are of about 400 m^3/s in Cabanne, 850 m^3/s in Lower Rezzoaglio, and slightly over 1400 m^3/s at the dam of Boschi.

The Aveto Valley has a great landscape and environmental value; this area includes a wide part of the Regional Natural Park of Aveto, which extends over nearly 5700 ha of general reserve, protection and development areas, natural monument and contiguous areas, in a mountain 3 environment along the Tyrrhenian-Po river watershed. Three *Sites of Community Importance* exist (Mt. Ramaceto, Park of Aveto, and Mt. Maggiorasca - Ciapa Liscia - Mt. Nero) which are included in the *Nature Network 2000* (Rete Natura 2000). This network was created in order to ensure the protection of *habitat* and species in environmentally valuable areas.

Many historical testimonies and scientific documents exist concerning the geomorphological instability and the frequent floods that have occurred in this valley, which have damaged settlements and infrastructure (Terranova, 1968; Brandolini & *alii*, 2006).

Among the catastrophic events were those that occurred in 1912, 1915, 1941, and 1963 (fig. 2), whereas other significant events were recorded in the years 1956, 1958, 1976, 1992, 1999, and 2000. Therefore, the recurrence time for such events is no more than 10 years.

Between 1986-2006 the public authorities invested about 5,5 million euro in land protection; of these, 2 million were used for work on the hydrographic network, whereas more than 4 million euros were spent for the water course defenses during the 2000 event.

The climatic features of the area were assessed by means of data recorded at the weather stations at Boschi d'Aveto (630 m), Cabanne (812 m), and S. Stefano d'Aveto (1014 m), between 1965 and 2005.

The mean annual rainfall fluctuates between 1400 mm at Boschi d'Aveto to as much as 2000 mm at Cabanne; it is mainly concentrated during the Autumn (absolute) and spring (relative), and is at the lowest level in Summer. The mean annual temperature is between 9°C and 10°C; temperatures are highest in summer (slightly below 20°C) and lowest in winter (about 4°C).

According to the Köppen classification, temperature and rainfall show a temperate climate typical of Mediterranean middle latitudes, with hot and dry summers. Ac-

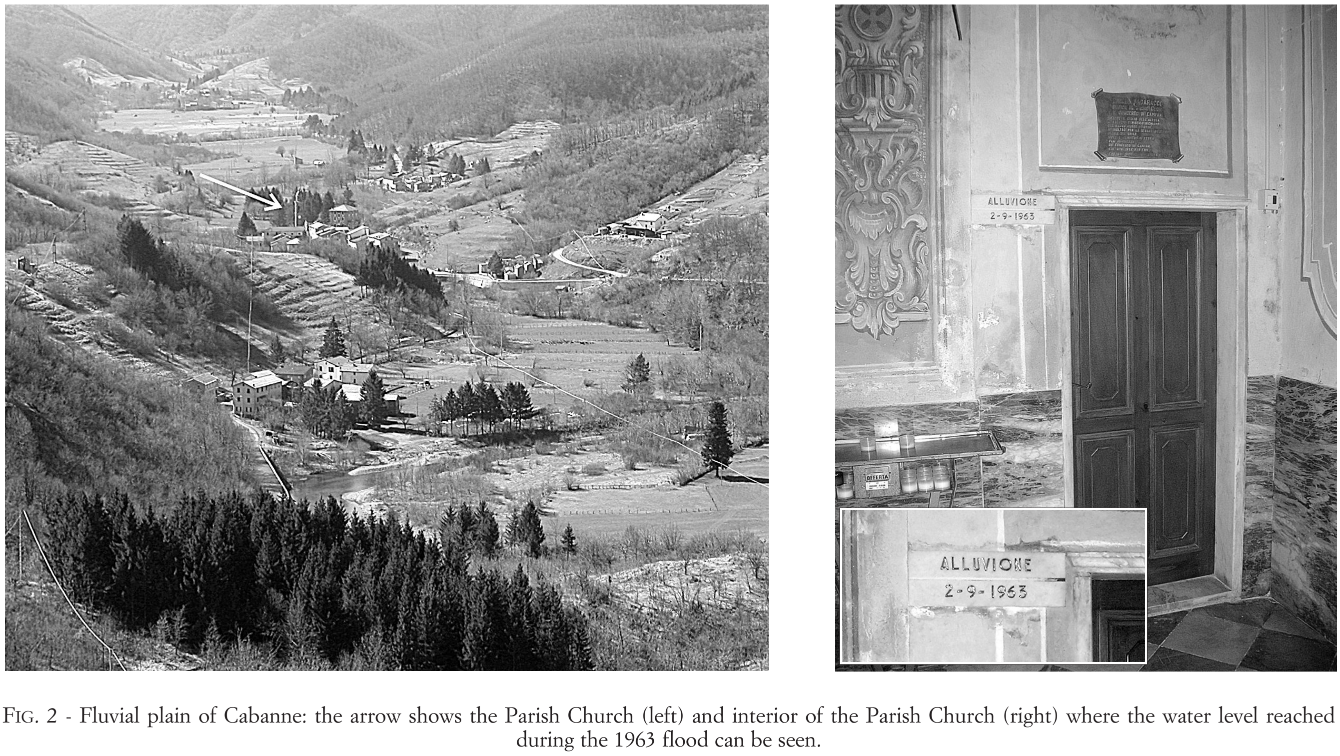


FIG. 2 - Fluvial plain of Cabanne: the arrow shows the Parish Church (left) and interior of the Parish Church (right) where the water level reached during the 1963 flood can be seen.

cording to the Italian meteorological-climatic region, its features ascribe the area to the subcontinental type (Smiraglia & Bernardi, 1999).

Snowfall varies from year to year, but usually occurs between November and March, with the absolute maximum in January (about 30 cm) and an annual mean quantity of about 75 cm. Rainfall is also increased by «hidden precipitations» such as condensation out of the air. Consequently, there is often a particularly significant annual surplus of water, so a great number of springs are exploited by municipal waterworks in the area.

The ombrothermic diagram processed by the stations of Boschi d'Aveto and S. Stefano d'Aveto shows the absence of dry months as the trend of precipitations is always higher than the temperatures (fig. 3). Hydrologic accounting following the method of Thorntwaite shows a coincidence between potential and real annual mean evapotranspiration; a dry season is observed only between June and August, but it does not imply a water deficit, whereas the annual water surplus spreads over the remaining months for an overall quantity between about 700 mm and 900 mm. The mean annual precipitation of over 1400 mm is thus balanced by at least 600 mm of actual evapotranspiration and an outflow of about 700 mm.

GEOLOGICAL OUTLINE

The Upper Aveto Valley is made up of the Internal Ligurides tectonic Units in the upper area, the Eastern Ligurides Units in the middle area, and the Subligurides Units in the lower area (Bellinzona & *alii*, 1968; Casnedi & *alii*, 1983; Terranova & Zanzucchi, 1983; Casnedi & *alii*, 1993; Regione Liguria & Regione Emilia-Romagna, 2005).

The Internal Ligurides are formed by the Mt. Gottero tectonic Unit, made up of siltstones and sandstones, clays and marls (*Scisti Zonati, Auct.*), and occasionally olistostromes composed of subangular clasts of calcilutites mainly in a shale matrix, such as in the area of Parazzuolo. Moreover, in the area of Cabanne there are outcrops of grey shales with siliceous micritic limestone interlayers (*Argille a palombini Auct.*).

The Eastern Subligurides Units start near Cabanne then extend downstream along the axis of the Aveto Stream until the bridge of Alpepiana. The Eastern Ligurides Units spread on both sides of the stream, and are composed of the following formations (Terranova & Zanzucchi, 1982; Elter & *alii*, 1991):

– Casanova Complex: composed of ophiolitic sandstones, monogenic and polygenic breccias with shaly matrix, and polygenic breccias of sandy matrix, containing olistoliths of different sizes made up of basalts, ultramafics, gabbros, granitic breccias, cherts, micritic limestones (*Calcari a Calpionelle Auct.*), and clays with limestones;
– Mount Veri Complex: composed of shales and limestone layers with monogenic breccias, ophiolitic sandstones, polygenic breccias, and basaltic olistoliths, ultramafics, and granitic breccias;

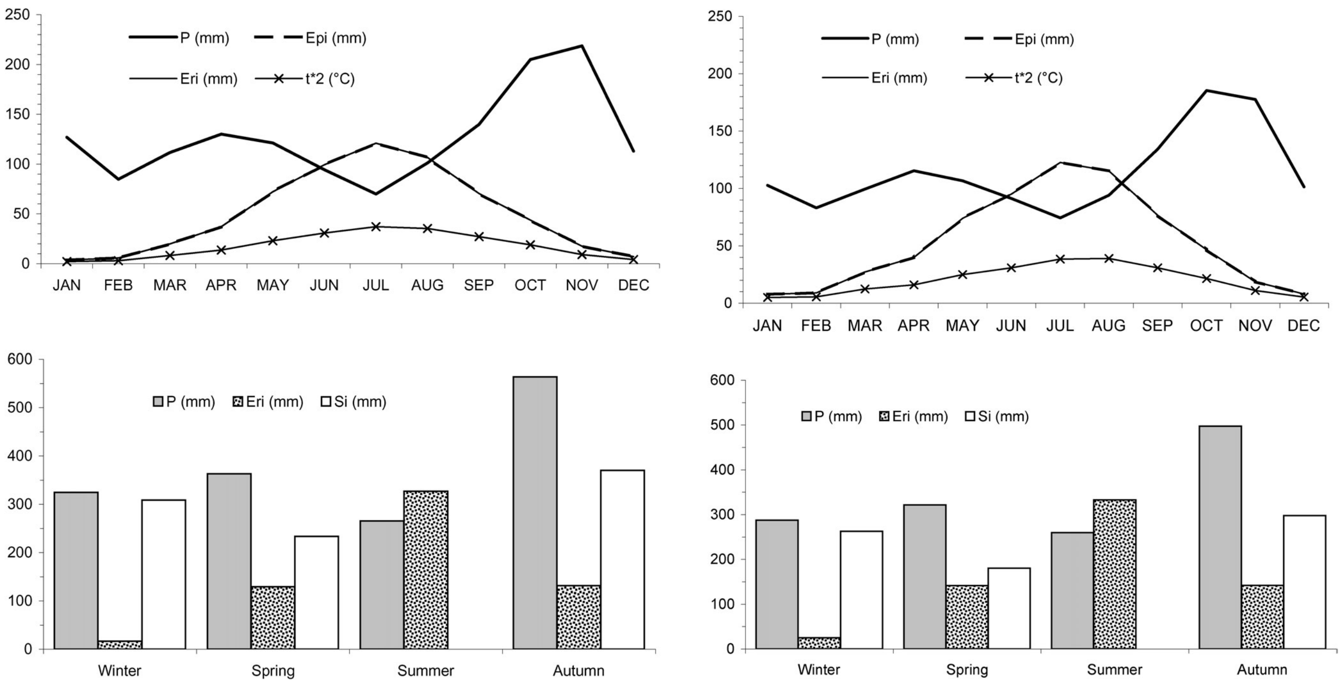


FIG. 3 - Meteoclimatic diagrams using data recorded in the stations of Boschi d'Aveto (left) and S. Stefano d'Aveto (right) in the 1965-2005 period: ombrotermic diagram and trend of the potential (Epi) and real (Eri) evapotranspiration; seasonal water balance indicating rainfalls (P), real evapotranspiration (Eri) and water excess (Si). Water supply was 200 mm.

– Ottone Flysch: composed of marls, calcareous marls, and marly limestones occasionally with, polygenic breccia lenses at the base, made up of clasts of ultramafics, basalts, ophicalcites, cherts, and limestones;
– Mount Orocco Flysch: composed of marly limestones, marly sandstones, and marls, with interlayers of dark shales and turbiditic sandstones (*Flysch ad Helmintoidi Auct.*).

The Subligurides tectonic Units begin from the bridge of Alpepiana downstream with the Canetolo tectonic Unit, formed by limestone, marly limestone, and marls (Vico Flysch) and by grey-black shales alternated with calcilutites, and marly limestones intercalated by sandstones and siltstones (*Argille e Calcari di Canetolo*).

Further downstream, the Aveto Unit is present. It is formed of green mid-coarse sandstones, very thick layers of conglomerates with clasts of metamorphic, magmatic, and sedimentary rocks, and silico-clastic sandstones, siltstones, and shales (Aveto Valley Formation).

A simplified tectonic scheme, from upstream to downstream in the valley, consists of an overlying of the Mt. Gottero Unit (Internal Ligurides Units) onto the Ottone Unit. This Unit in turn overlies the Orocco Unit; these both belong to the Eastern Ligurides Units. The latter, in turn, overlies the Subligurides Units, namely the Canetolo and Aveto Units (Marini & Terranova, 1979; 1980).

GEOMORPHOLOGICAL FEATURES

Among the processes shaping the landscape of the upper Aveto Valley, gravity or slope degradation and fluvial-stream phenomena are the most common. Among the first several landslides are found, with various kinematic mechanisms and actions, evidence of recent to historical settlement linked to the development of deep seated gravitational slope deformations, whose origin was due to the significant geomechanical contrast between the different lithologies. The main landslide bodies are concentrated in the valley on the hydrographic right, which features high relief and a complicated and articulated geological and structural setting.

The wide area ends up at the catchment of the Rezzoaglio Stream. This area includes the villages of Magnasco and Cerisola, and it features shallow landslides and deep seated gravitational slope deformations which are bounded downstream by the Rio Crosa Scura and Rio Dugaia Streams. These phenomena begin on the northern slopes of Mt. degli Abeti, where reverse slopes and wide landslide deposits of complex origin can be found. These can be partially ascribed to actions of the morphoclimatic periglacial environment. In the catchment of the Gramizza Stream, an ancient landslide body is found on the hydrographic left. It originates on the northern slope of the Mt. Aiona, and partially developed through debris flows. The village of Amborzasco is located on it. In the catchment of Rio Molini, the village of S. Stefano d'Aveto is located on a large landslide body. This originates on the western slopes of Mt. Maggiorasca, Mt. Bue, and Mt. Groppo Rosso (Terranova, 1968; De Stefanis & *alii*, 1975), where the morphological areas of wide deep seated gravitational slope movement (Cruden & Varnes, 1996; Dikau & *alii*, 1996), such as trenches, counterslopes and closed depressions – today filled by marsh deposits – are found. The huge landslide spreading over several kilometres can be ascribed to the main debris flow, which is still active, as shown by the monitoring of inclinometers and piezometers at Rocca d'Aveto, Roncolongo, and S. Stefano d'Aveto and which show centimetres of movement per year.

On the hydrographic right side of the Aveto Stream, close to the smaller catchment of Rio Casalino and Rio del Pozzo, the active landslides of Ascona and Costa Figara are located, respectively. They are also being monitored, and their motions interfere with the fluvial processes of the Aveto Stream (fig. 4).

On the hydrographic left side of the Upper Aveto Valley, some significant landslides exist and they threaten the villages of Alpepiana, Esola, and Villapiano. They are caused by deep seated gravitational slope deformations, later evolving with shallow flow and sliding movements (Faccini & *alii*, 2007). Among these, the Alpepiana landslide has been the subject of drilling and surveys for monitoring, and they have shown evidence for active deformation (fig. 5a, b, c). Some of these villages have been studied recently (Federici & *alii*, 2004): however the studies show significant differences in interpretation, especially concerning the origin and activity of the landslide bodies.

Due to the recent uplift of the Apennines (Cortemiglia & Terranova, 1987; Perotti & *alii*, 1988), the Aveto Stream shows a course that varies from winding to meandering due to running waters and outwashing. Besides the spreading of the colluvial deposits, several streams, which are being further investigated, can be found. They carry a great deal of sediment, therefore increasing the alluvial deposits downstream of the confluences. The floodplain in the area of Cabanne spreads almost continuously over the studied region (fig. 2). It was formed as a result of the natural dam caused by the mass movement at Malsappello, even though some structural evidence suggests a tectonic origin (Maifredi & Nosengo, 1973). Further downstream lays the Rezzoaglio alluvial fan. It was formed by the confluence of the water course into the Aveto Stream, whose reactivation, at the time of the 1976 flood, caused serious damage to the village of Rezzoaglio Basso (Brandolini & *alii*, 2006). The main bank erosion along the Aveto Stream, which mainly affects farmlands and more seldomly road infrastructure and human settlements, is located between Priosa and the gorge of Malsappello and between Rezzoaglio and the confluence with the Remorano Stream, upstream the Boschi d'Aveto dam (fig. 6).

FLOOD HAZARD ZONE EVALUATION

In the master plan, the fluvial zones of a stream are defined by means of a comparative analysis of the hy-

FIG. 4 -Aveto Stream downstream from the Malsappello Gorge. On the right bank the settlement of Costa Figara can be seen. It is located on a large landslide (dashed line), due to a deep seated gravitational slope deformation.

draulic, geomorphological, and ecological-environmental aspects (Autorità di Bacino del Fiume Po, 1999). These elements contribute to the definition of three different areas, each with its own homogeneous features: a flood outflow zone (A), a flooding zone (B), and a catastrophic flood zone (C).

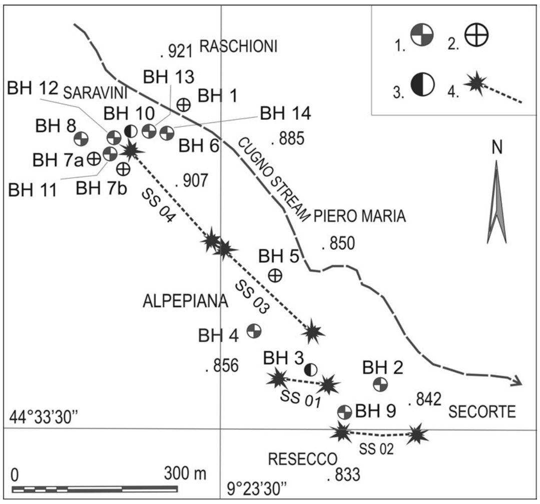
Geomorphologic aspects are significant only in zones B and C, where landforms and processes linked or not linked to the fluvial dynamics must be distinguished, whereas in zone A only hydraulics must be taken into account, and the flood recurrence time is defined on a statistical basis (fig. 7).

In the Ligurian catchment of the Aveto Stream, fluvial areas were also determined exclusively on the basis of applied geomorphology; an operating methodology, including a series of studies and surveys, both on large and detailed scales, was adopted. This resulted in a geomorphological map aimed at assessing the flood hazard, as it was done in similar studies concerning nearby basins (Canepa & *alii*, 1998).

Among the main aspects of this map, particular attention was given to the present-day river bed and to the development of deposits and erosion, to the landforms which could be reactivated due to running waters, and to the slope processes which can interact with the fluvial dynamics. In this way it was possible to determine three zones with different hazard levels (fig. 8):

– High hazard: This zone includes the present-day river bed and contiguous fluvial terraces subject to ordinary floods. This zone exists continuously along the entire fluvial axis and significantly spreads both at the main confluences (Ventarola, Farfanosa and Rezzoaglio Streams) and downstream of the bridge leading to Alpepiana, because of the effect caused by the fluvial dam of Boschi d'Aveto;
– Medium hazard: This zone includes the alluvial plain occasionally subject to floods and the slope areas affected by active geomorphologic processes potentially involving the water course dynamics. This zone, which lies out of high hazard zone, widely spreads upstream of the gorge of Malsappello and more discontinuously as far as Rezzoaglio and contains only alluvial deposits, whereas the downstream portion reaching the dam of Boschi mainly includes both alluvial deposits and slope erosion. This zone includes, entirely or partially, some important settlements such as Cabanne, Farfanosa, Molini, and S. Stefano d'Aveto;
– Low hazard: This zone includes the terraced alluvial deposits and alluvial plains subject to catastrophic floods; it was extended to include the slope areas contiguous to the river bed without active geomorphological processes involving the stream dynamics. This zone shows similar features to the medium hazard zone; however, it is usually more external, often including alluvial fans where some more important settlements such as Sbarbari, Priosa, Parazzuolo, Calcinara, and Rezzoaglio Basso were established.

The overall summary of the flood hazards of the Ligurian sector of the Aveto Stream shows that in only a few



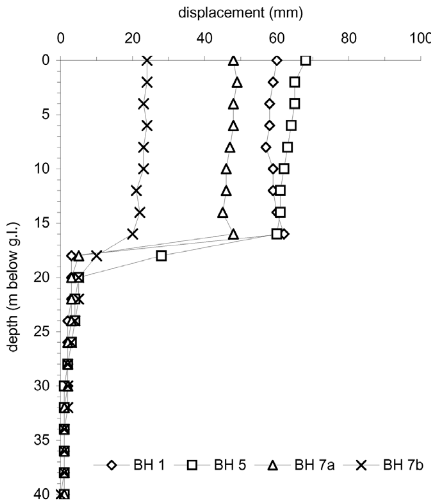


FIG. 5 - Panoramic view of Alpepiana landslide (A). Drill location map and monitoring instruments (B): 1) piezometer; 2) inclinometer; 3) piezometer-well; 4) seismic refraction survey. Inclinometric data (C) in the periods of June 1999-March 2000 (BH1), June 1999-January 2001 (BH5), June 1999-December 1999 (BH7A), April 2002-July 2002 (BH7B).

areas, among which the villages of Parazzuolo, Cabanne and Farfanosa are the most important, some anthropogenic settlements lying along the fluvial plain can be affected by exceptional floods, whereas only the zone closer to the present-day river bed, mainly covered by farmlands, is affected by geomorphological processes due to the fluvial dynamics.

Landslide movements can interfere with the Aveto Stream; those near Ascona and Costafigara are the most significant, whereas only the Alpepiana landslide markedly affects minor streams (fig. 5a).

The considerable erosion observed along the stream axis of the Aveto Stream has a significant effect. In many settlements the erosion required the building of bank protections to slow the erosion. The stream is starting a stage of lateral expansion, affecting the embankment area, as it is already approaching its longitudinal profile and is influenced by the local base level (gorge of Malsappello and Boschi d'Aveto dam).

CONCLUSION

The importance of geomorphology applied to land planning has been recognized for a long time. However, the study of watercourse dynamics should be included in the study of slopes to form the basis of understanding landform evolution.

Only using both can a complete understanding of a hydrographic basin be obtained and the interference of the waters course evolution on the natural and anthropogenic elements can be correctly assessed. Thus, the fluvial zones can be defined and their distinction allows a differentiated management and exploitation of the land corresponding to the different degree of flood hazard.

In this way, the interdisciplinary approach for defining the fluvial zones of the Ligurian section of the Aveto Stream basin represents a particularly significant example, since the comparison between the flood hazard maps defined on a geomorphological basis, the historically flooded areas, and the hydraulic depth shows that these regions generally overlap.

FIG. 6 - Example of flood at Cabanne (A) and of bank erosion of the Aveto Stream at Farfanosa (B).

ZONE	ASPECT	DESCRIPTION
A	Hydraulic	Ordinary floods area with return time up to 50 y
B	Hydraulic Geomorphological Ecologic	Floods area with return time up to 200 y Fluvial processes and landforms inactive High naturalistic and environmental values; hystorical, artistic and cultural heritage connected to fluvial area
C	Hydraulic Geomorphological	Catastrophic floods area with return time up to 500 y Fluvial processes and paleo-landforms

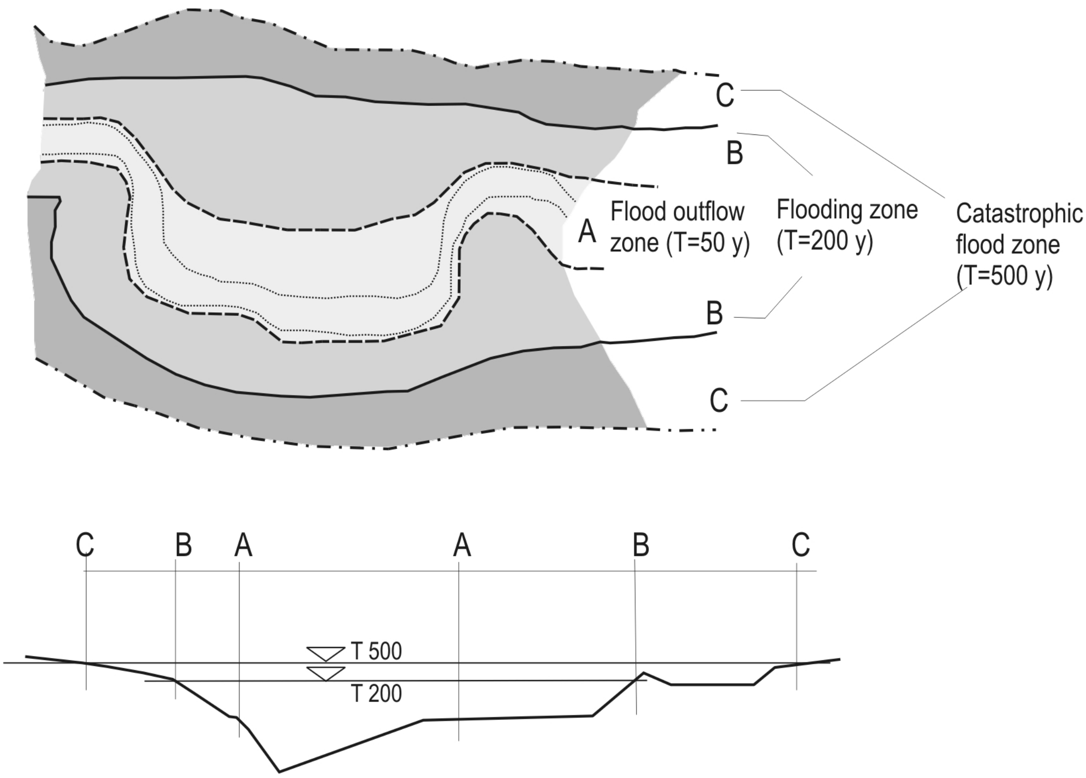
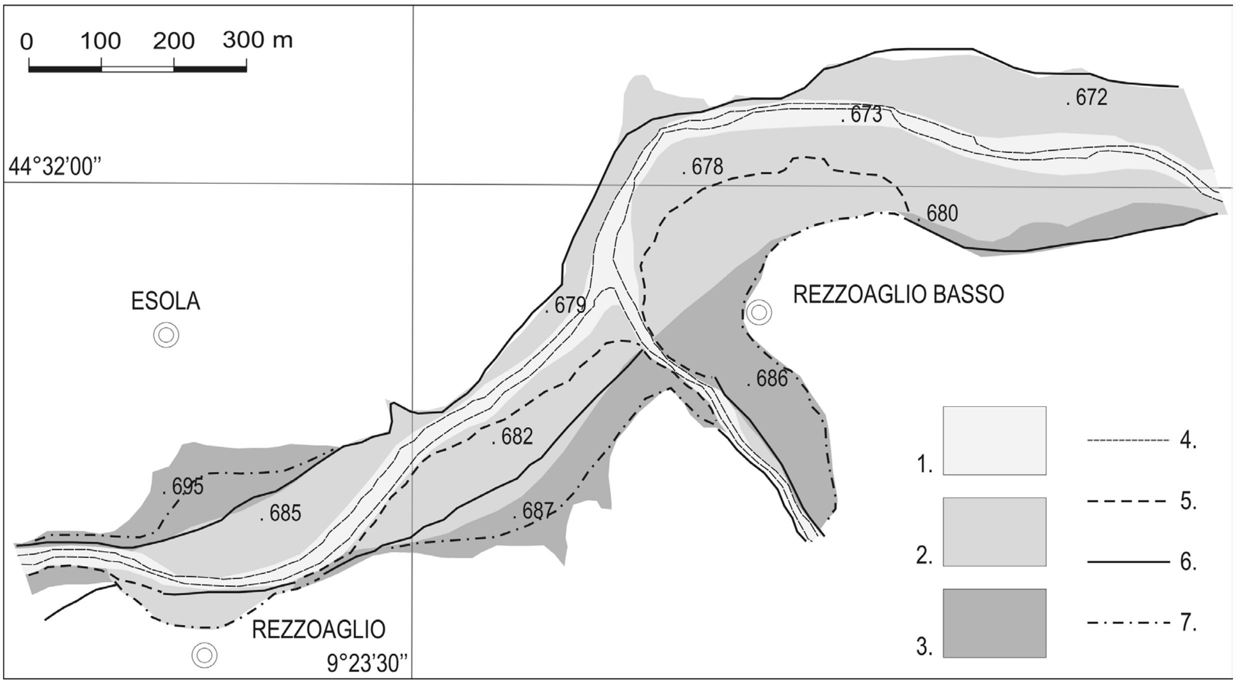


FIG. 7 - Criteria for defining the fluvial zones plan (redrawn from AUTORITÀ DI BACINO DEL FIUME PO, 1999).



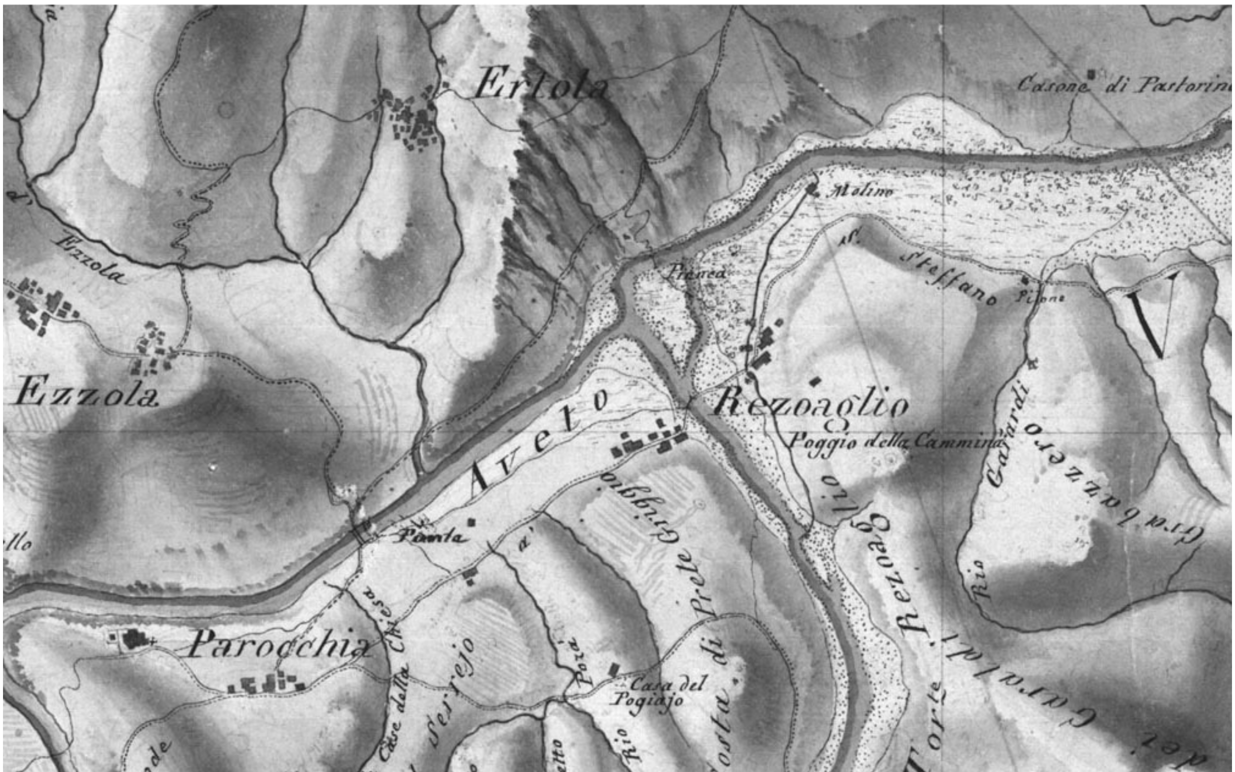


FIG. 8 - Overlapping of geomorphological flood hazard map and hydraulic fluvial zones map in the area of Rezzoaglio (A): 1) present-day river bed and terraces contiguous to the banks that can be flooded by ordinary floods (high hazard); 2) alluvial plains which can be flooded by exceptional floods and slope sections affected by geomorphological processes which can interfere with the stream dynamics (medium hazard); 3) ancient alluvial terraces of alluvial plain which can be flooded by catastrophic floods with slope areas contiguous to the river bed without active geomorphological processes which can affect the fluvial dynamics. Historical cartography dating back to the first half of the XIX century at Rezzoaglio (B) showing the alluvial fan of Rezzoaglio, formed by the confluence with the Aveto Stream.

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