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APPENDIX

Culverted watercourses as an anthropogenic constraint of flood risk in the historical centre of Genoa (Italy)

Francesco Faccini[1,2,], Roberto Bixio[2], Andrea Mandarino[1], Pietro Piana[1], Stefano Saj[2,3], Martino Terrone[4], Mauro Traverso[2], Stefania Traverso[4]*

Abstract

In recent years, artificial cavities have raised interest among the scientific community, both due to their relevance in terms of cultural and landscape heritage and because they are linked to potential hazards to surface structures. Underground voids in cities have been often established over time with a specific purpose or have resulted from the layering of different urban evolution phases, which in Mediterranean cities are often thousand years old, the case of culverts being particularly frequent. Generally, culverts have been associated with the need to expand urban areas due to space constraints. Underground voids have been established and modified (or even under-dimensioned) over time and their state of efficiency and preservation is hardly verified, leading to very hazardous conditions. This research presents the waterways in the historical centre of Genoa, the coverage of which, now almost complete, began in the Middle Ages. While the historical channelization of the streams of the old city can be considered as a structure of cultural value, it should be pointed out that the subsequent modifications and state of preservation of such artifacts have led to localized hazardous conditions and thus risk to buildings and infrastructure, some of which have been recognized as UNESCO World Heritage Sites ("Strade Nuove and Palazzi dei Rolli"). Therefore, there is need to acquire detailed surveys of the entire channelized and culverted hydrographical network in order to assess its hydraulic efficiency, hydrogeomorphic features, and structural suitability, and to activate a monitoring network. Such measurements are crucial for effective management of hydrogeomorphic risk in urban areas, also in light of Global Climate Change.

Keywords: culvert, flood hazard, man-made landforms, artificial cavities, Genoa.

Introduction

The city of Genoa is internationally known for its recurrent floods, mainly related to the Bisagno River (Paliaga *et al.*, 2019). The high level of river-related risk is linked on the one hand to meteo-hydrological hazard, associated with an atmospheric circulation prevailing over the Ligurian Sea, and on the other hand to the high level of urbanization in hazardous areas and the relevant exposure of vulnerable elements to floods (Acquaotta *et al.*, 2019). Ongoing climate change, which is expressed by a growth in average air temperature and a change in the rainfall regime, increases the degree of hazard, while unregulated urban planning interventions and modifications to the hydraulic balances in the city increase the vulnerability component, worsening the overall risk for buildings and infrastructure. The present research concerns the hydrographical network that characterises the historical centre of Genoa, i.e. the natural amphitheatre located between the Polcevera valley to the W and the Bisagno valley to the E and which is bordered by the seventeenth-century historical walls (fig. 1). In this area of just 8.5 km^2 there are seven small catchments and this hydrographical network flows into the old port of Genoa.

The watercourses of the city have been subject to relevant anthropic modifications (diversions, rectifications, culverts, and in general channelization, Rovereto, 1938) since the Middle Ages; today the hydrographical network appears almost entirely artificial, flowing under the streets and buildings of the historical centre (Brandolini *et al.*, 2020; Faccini *et al.*, 2021). The name of some streets recalls the presence of underground streams and the original morphology of the city, which is otherwise not perceptible (Bixio *et al.*, 2015). Only a couple of catchments have their main fluvial system characterised by natural riverbed

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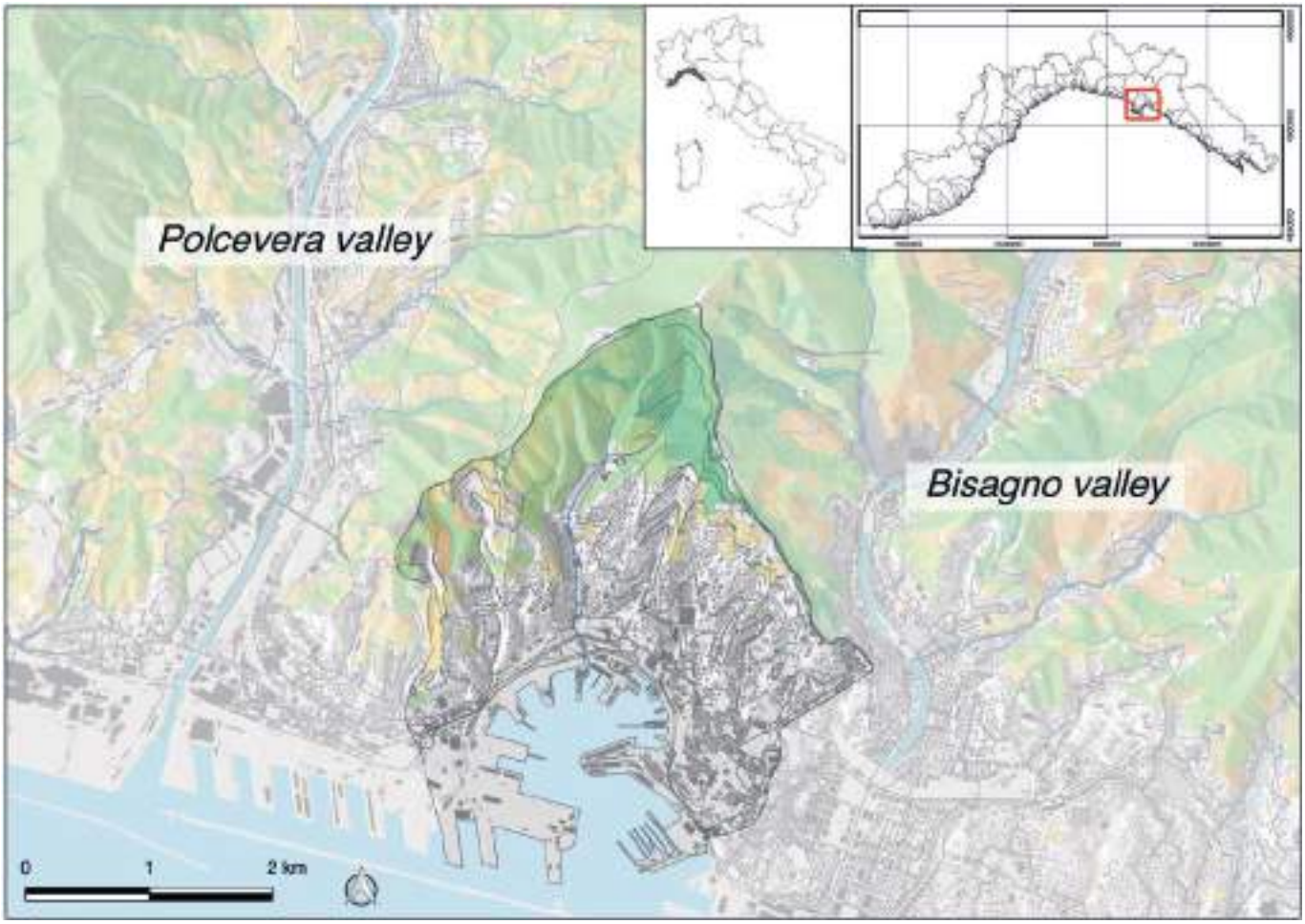

Fig. 1 – Geographical location of study area [modified from Brandolini *et al.*, 2018] (graphics M. Terrone).

in their upper stretch, but even in this case the landscape is significantly urbanised. These waterways represent artificial cavities referable to the type "A-hydraulic underground works", category "A8-water ways" (Parise *et al.*, 2013).

The construction of these culverts over time and the modifications they have undergone over the centuries up to very recent times due to progressive urbanisation led to a reduction in the riverbed cross-section, which can lead to possible overflows of water under pressure and consequent floods. This makes a better knowledge of culverted streams in Genoa historical city crucial for hazard and risk assessments and for the planning of related hydraulic risk reduction activities.

Since more than thirty years, the Centro Studi Sotterranei of Genoa has been carrying out underground inspections and surveys of the hydrographical network, using both traditional and innovative techniques, with highly detailed reconstructions of the geometry of the culverted riverbed. Among the watercourses in the historical centre of Genoa, recent surveys along the Carbonara and Sant'Anna streams have been carried out. The preliminary results have highlighted both localised flood-hazard conditions and great elements of cultural value.

Physical geography of Genoa historical centre

The natural morphological amphitheatre of the old historical town covers an area located between the two main catchments of Genoa, the Polcevera (W) and the Bisagno Streams (E) (fig. 1). It is a roughly triangular-shaped area surrounded by the seventeenth-century walls which started from the Promontory of the Lighthouse up to M. Peralto (489 m asl), where Sperone Fort is located; the eastern walls were along the western bank of the Bisagno Stream in order to protect the hill of Carignano, which is the eastern ridge of the natural amphitheatre of the historical centre (Brandolini *et al.,* 2018).

This sort of morphological amphitheatre includes seven small and steep catchments that today are barely identifiable due to high urbanisation (fig. 2). They are effectively represented by the "Genova Zero" map (Barbieri, 1938) (fig. 3): from W to E we can identify

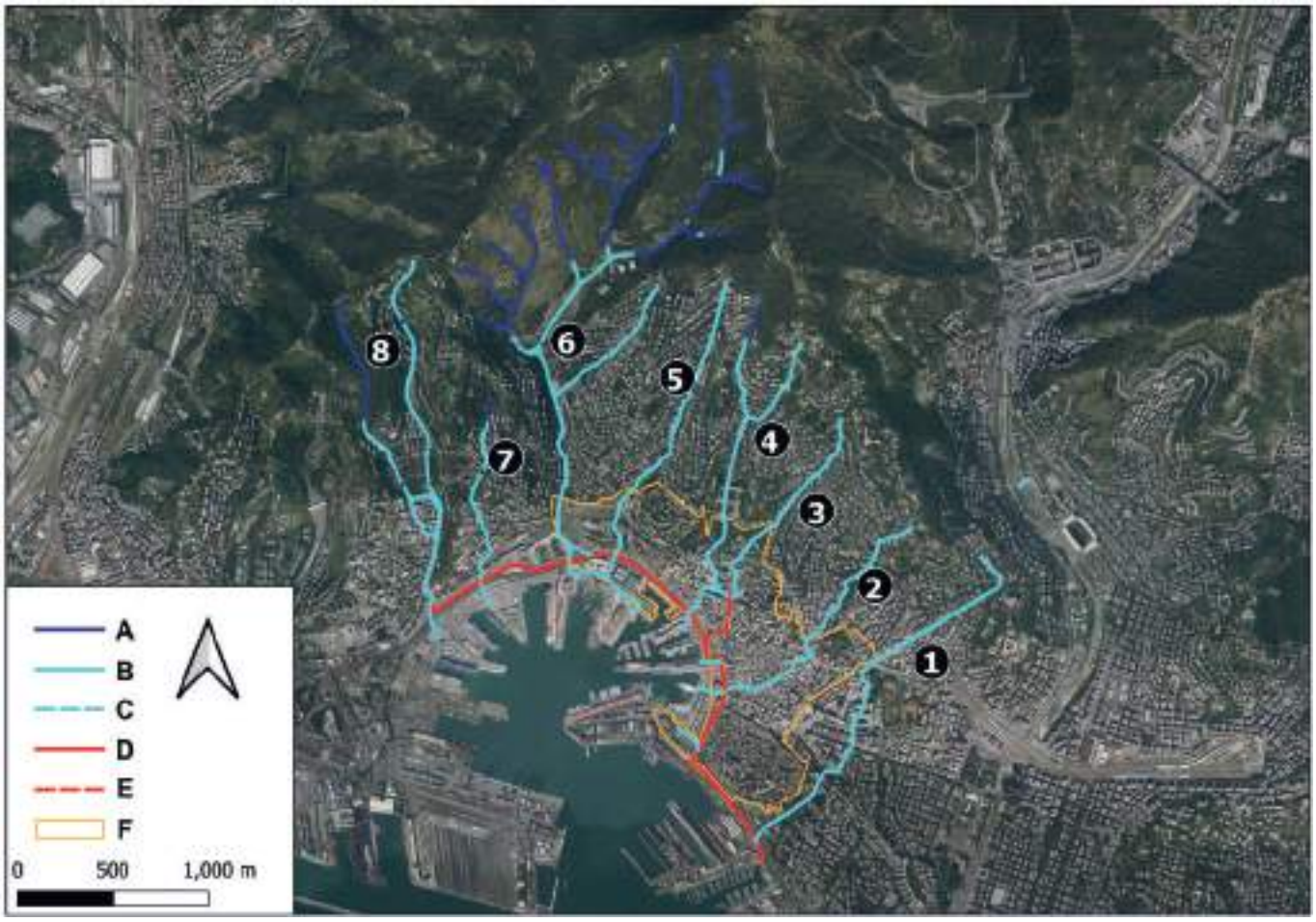

Fig. 2 – Stream network in old Genoa city morphological amphitheatre (base map: ortophoto 2018 by Genoa Municipality): A) poorly modified and/or natural riverbed; B) culverted stream; C) concrete channel; D) eaves channel; E) abandoned channel; F) "Strade Nuove and Sistema dei Palazzi dei Rolli" UNESCO World Heritage limits. Main Streams: 1) Torbido; 2) Sant'Anna; 3) San Gerolamo; 4) Carbonara; 5) Sant'Ugo; 6) Lagaccio; 7) San Teodoro; 8) Di Negro (graphics M. Terrone).

the catchments of Dinegro (or S. Lazzaro), San Teodoro, Lagaccio, Sant'Ugo, Carbonara, Sant'Anna and Torbido.

From a geological point of view the area is characterised by flysch formations belonging to the tectonic units of Antola and Ronco and by post-orogenic deposits (APAT, 2008; AA.VV., 2008). The Antola Unit is represented by the formation of Mt. Antola Flysch - mainly consisting of marly limestones, occasionally silty, with thin interlayers of shales, and by the formations of Montoggio shales, a basal complex represented by blackish or greenish shales, which crops out in some limited areas along the western ridge. The Ronco Unit and formation is featured by siltstone, marly limestone and shales and it crops out in the western sector along the watershed divide between the historical amphitheatre and the Polcevera valley. The post-orogenic deposits, represented by the formation of Ortovero Clays, crop outs in the area of the medieval historical centre and old harbour area, within a graben structure with WNW – ESE direction (Limoncelli e Marini, 1969).

The climate of Genoa is Mediterranean, with dry and hot summers, relatively mild winters and rainfall mainly concentrated in spring and autumn. The mean annual temperature is 15.8 °C, the annual rainfall is 1268 mm and the rainy days (>1 mm) are 101. The historical weather station of Genoa University, located in the study area and in use since 1833 allowed the reconstruction of statistically significant climate trends: the mean annual temperature shows a positive trend, while the number of rainy days has a negative trend. The amount of annual rainfall does not show any significant trend and therefore the rainfall rate increased. Based on this data, it is possible to state that the rainfall is concentrated in fewer days, particularly between the second decade of October and the first decade of November and it is more intense. This is confirmed by the numerous flash flood events which affected Genoa in the last 50 years.

The history of Genoa probably dates back to the pre-Roman period and the first fortified settlement was on the hill of Castello along the Eastern edge of the nat-

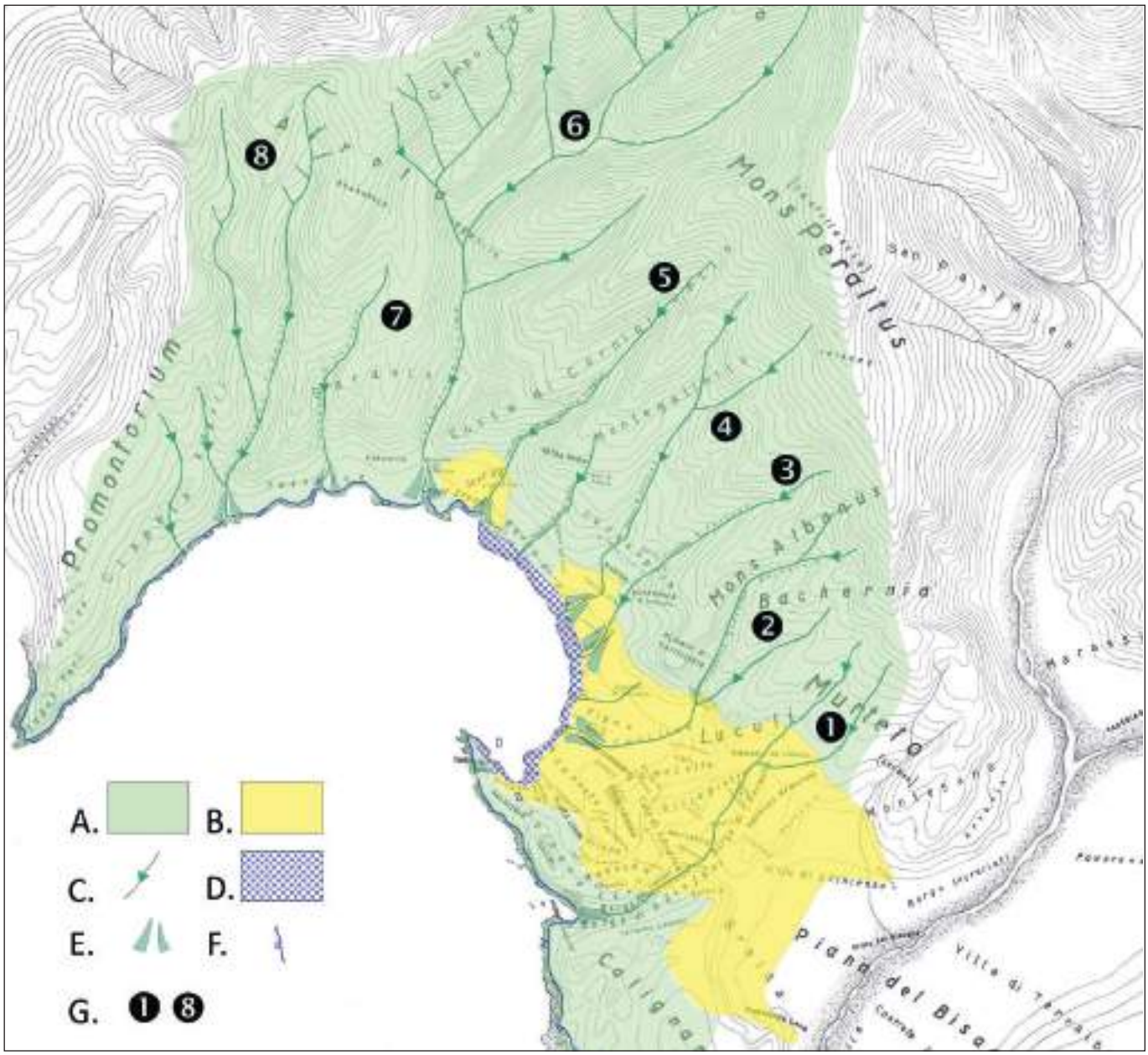

Fig. 3 – Geomorphological sketch map of the morphological amphitheatre of Genoa (base map: Genova Zero by Barbieri, 1938): A) marly limestone, marly siltstones with shales and calcarenites Interlayers; B) stiff fissured clays; C) v-shaped valley; D) sandy and gravelly beach; E) alluvial fan; F) edge of seacliff; G) catchment number: 1) Torbido; 2) Sant'Anna; 3) San Gerolamo; 4) Carbonara; 5) Sant'Ugo; 6) Lagaccio; 7) San Teodoro; 8) Di Negro (see Fig. 2 for comparison with man-made landforms) (graphics M. Terrone).

ural amphitheatre (Grossi Bianchi & Poleggi, 1980; Melli *et al.,* 2006). The *castrum* was located above the primitive harbour which was naturally protected by the peninsula of Il Mandraccio. In the Middle Ages the historical centre progressively expanded around the port and in the inland area where *Strada Nuova* (Via Garibaldi), built in 1550, and the late *Via Nuovissima* (Via Balbi, built in 1606) constituted for centuries the northern limit of the city (Bixio *et al.,* 2015).

The culverted watercourse network

The morphological amphitheatre within which the historic city of Genoa has developed over centuries represents as a whole a composite catchment area presenting a series of small basins, described below from east to west (fig. 4).

The catchment area of the Torbido Stream (so named for its erosive activity on the stiff fissured clays), which is entirely urbanized, covers about 1.17 km^2 and consists of two branches: the first, to the W, flows along the axis of Via Palestro; the second originates just upstream Via Solferino and bends to the E until it reaches Via Assarotti.

The two waterways join underneath piazza Corvetto in a decantation chamber; the watercourse continues following largo Eros Lanfranchi, cutting perpendicularly through via Vernazza and via XX Settembre reaching piazza Dante, then it descends via Madre di

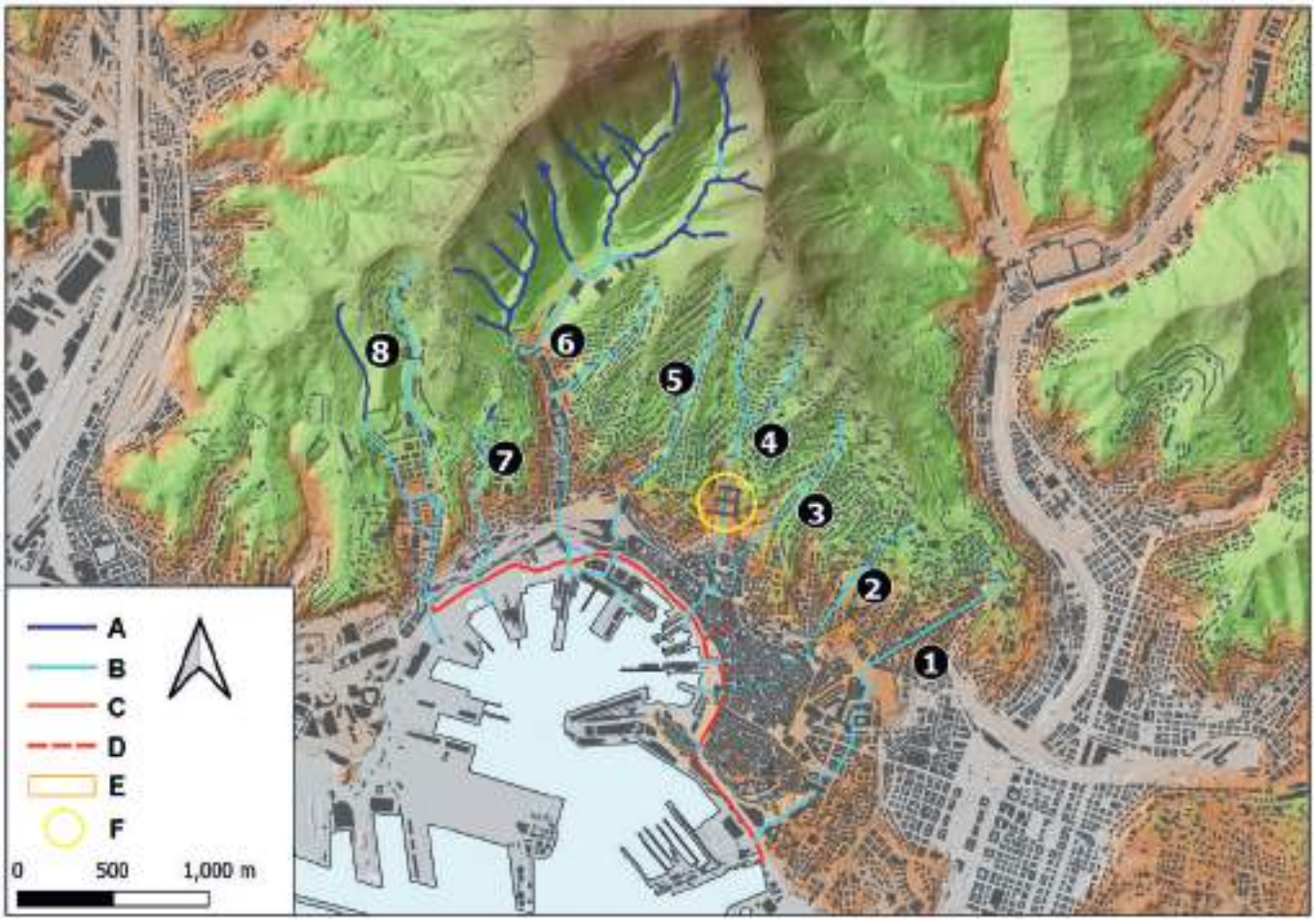

Fig. 4 – Stream networks in old Genoa city morphological amphitheatre (Base map: shaded relief on Lidar by Genoa Municipality): A) poorly modified and/or natural riverbed; B) culverted stream; C) eaves channel; D) abandoned channel; E) "Strade Nuove and Sistema dei Palazzi dei Rolli" UNESCO World Heritage limits; F) historical building of Albergo dei Poveri (Hotel of the Poor) - Catchment number: 1) Torbido; 2) Sant'Anna; 3) San Gerolamo; 4) Carbonara; 5) Sant'Ugo; 6) Lagaccio; 7) San Teodoro; 8) Di Negro (see Fig. 3 for a comparison without man-made landforms) (graphics M. Terrone).

Dio, always having on its orographic left the hill of Carignano, and it flows at the docks. In 1519 the watercourse was still uncovered while today the riverbed is entirely culverted, with a rectangular cross-section and an estimated flood discharge for T=200 years of 55 m^3/s (Autorità di Bacino, 2019).

The Sant'Anna stream catchment area, which is fully urbanized and covers 0.72 km^2, is also composite, as two main axes join approximately at Piazza Portello while the watershed has its edge along Salita Sant'Anna.

The right tributary flows under Via Caffaro, the left one under the route of the Portello-Magenta funicular. The watercourse then follows Via Luccoli, it continues through Piazza Campetto and Piazza Banchi, and it flows to Piazza Caricamento. The lower part of the catchment, partly due to inadequate hydraulic section, is characterized by flood hazard (Lanza, 2003): the estimated maximum flow rate for T=200 years is 44 m^3/s (Autorità di Bacino, 2019.

The Carbonara Stream basin is articulated, as it also includes the basin of the San Gerolamo Stream, once independent and later diverted into the Carbonara stream itself (Bixio *et al.* 2015). Overall, the basin is 1.10 km^2 and only ¼ of the surface area is not or scarcely urbanised.

The San Gerolamo Stream (also called Vallechiara) originates at the top of Via Pertinace, crosses Corso Carbonara, Via Lomellini and Piazza Fossatello to flow into Ponte Calvi. In the 13th century, the riverbed was diverted at Largo della Zecca toward via Bensa. This diversion made this creek a tributary of the Carbonara; their confluence is located in Via delle Fontane (Bixio *et al.* 2017). The Carbonara catchment (also known as Nunziata) presents two main valleys in its upper part. Their main channels join in a collector that, between Via Bellucci and Piazza F.lli Bandiera, crosses Piazza della Nunziata and continues along Via delle Fontane, flowing into the sea at Ponte Morosini. In the stretch between Albergo dei Poveri and Piazza della Nunziata, the riverbed shows several hydraulic works, such as weirs, waterfalls, settling chambers, spillways and anthropogenic secondary branches. In 1336 the Carbonara Stream was uncovered, while today the entire riverbed is culverted.

The downstream-most stretch has a reduced hydraulic section due to foundation structures that partially obstruct the conduit; the flood discharge for T=200 yr is estimated to reach 68 m^3/s (Autorità di Bacino, 2019.

The Sant'Ugo stream shows an almost entirely urbanized basin of only 0.80 km^2, and an estimated maximum flood discharge for T=200 years of 45 m^3/s. The watercourse flows at the S. Limbania inlet, originates in Oregina, crosses Acquaverde Square (the name suggesting the old presence of a pond made green by marsh grass), and at its mouth it flows under the Commenda di San Giovanni di Pre, which dates back to the twelfth century.

The Lagaccio stream is the largest basin of the historical Genoese amphitheatre with 2.3 km^2. More than 50% of the area (at higher elevation) presents agricultural areas, woodlands, shrubs, and herbaceous vegetation, with maximum flood discharge for T=200 years of 103 m^3/s (Autorità di Bacino, 2019. This catchment is made up of 5 sub-basins whose main fluvial stems merge into the Lagaccio ditch (formerly San Tomaso) and flows near Ponte dei Mille, at Via Adua, alongside Palazzo del Principe. Two tributaries drain the upper basin: one is close to Via Bartolomeo Bianco; the other one originates at Via Vesuvio and it flows into the main collector at Via Ponza. The hydraulic situation is critical in the downstream-most section because the slope of the culvert, built in the 19th century, is moderate and some foundation structures obstruct the water flow.

The San Teodoro stream has a catchment area of 0.54 km^2 and a discharge of 44 m^3/s for T=200 yr (Autorità di Bacino, 2019); about 50 percent of the basin is urbanised. This fluvial stem has no tributary, and it flows into the sea in the middle of via Buozzi (next to Ponte Doria). The downstream-most section presents critical conditions with potential flood hazard due to the limited hydraulic section and the slope of the culvert.

The San Lazzaro stream, formerly Di Negro ditch, has a catchment area of 1.33 km^2 and a discharge for T=200 years of 74 m^3/s (Autorità di Bacino, 2019). Approximately 60 percent of the basin is urbanised and is characterised by a series of small, parallel-axis tributaries leading to a collector that flows into the sea at Ponte Colombo. Piazza Di Negro is located on the ancient alluvial fan shaped at the outlet (or mouth) of this stream, which was modified in the terminal section as early as 1150 (Limoncelli, Marini, 1969). The hydrogeomorphic hazard is related to the first culverted section after the confluence of the stream into the San Lazzaro channel.

Natural hazard and final remarks

Mediterranean cities have undergone significant anthropogenic changes in recent centuries, especially in riverine, slope, and coastal areas: although still debated by the scientific community, the term Anthropocene has become commonly used, at least to highlight the anthropogenic impact on the natural processes of the earth's surface (Brown *et al.,* 2017).

A first analysis of the hydrographical network in the historical centre of Genoa revealed a very articulated situation, as anthropogenic modifications over the centuries have led to the almost complete transformation of the riverbeds into artificial cavities (*sensu* Parise *et al.,* 2013) (figs. 5, 6) and a progressive urbanization of the catchments, which now reaches values around 75 percent.

Hydraulic sections, sometimes under-dimensioned since their construction or designed in another geomorphological and climatic context, are now inadequate: sealed surface areas have changed over time, and experimental data useful for determining the relationship between surface water flowing to the urbanized catchment area and the actual flow rate flowing through the culvert are not updated.

As mentioned in the introduction, Genoa is a Mediterranean city in which climate change is evidenced by an increase in average air temperature and a change in rainfall patterns (Acquaotta *et al*., 2018). Recent years have experienced an increase in flooding episodes in the metropolitan city of Genoa, concentrated mainly in the autumn period and often characterised by exceptional rainfall values with records even at the international level (Cat Berro, 2021): 181 mm/1h were recorded in November 2011, while in October 2021 378 mm/3h, 496 mm/6h, 741 mm/12h, and 884 mm/24h were measured (not far from the Italian historical record of 948 mm registered in October 1970 in Genoa). Flood hazard in the historical city is also associated with pluvial flood hazard, due to the inefficiency of the urban drainage system because of the intensity of rainfall, which has been particularly frequent in the past 30 years.

In situations such as those of Genoa's historical centre, with such a high anthropogenic impact on the natural morphogenetic system, it is particularly difficult to design risk mitigation actions: it is not possible to operate with structural interventions aimed at increasing the hydraulic section due to urbanization, nor is it possible to significantly reduce the impervious area. One possible solution could be to use cisterns connected to buildings as temporary floodwater storage basins in order to laminate the peak discharges, which is usually very rapid given the physical-geographical layout of Genoa's historical centre.

Based on preliminary research, it has been verified that there are 2 hectares of cisterns with an average height of 4 m and, thus, about 80 million litres of reservoir capacity in the historic centre. These structures could be also useful for sanitary and hygienic purposes during possible drought periods.

To the light of the above considerations, it is crucial to carry out detailed surveys of all the culverted watercourses that characterise the historical centre of Genoa. The first relevant inventory began in 2000 within the frame of the Civis project supported by the Municipality of Genoa; this work allowed a first fundamental collection and overlap between urban fabric

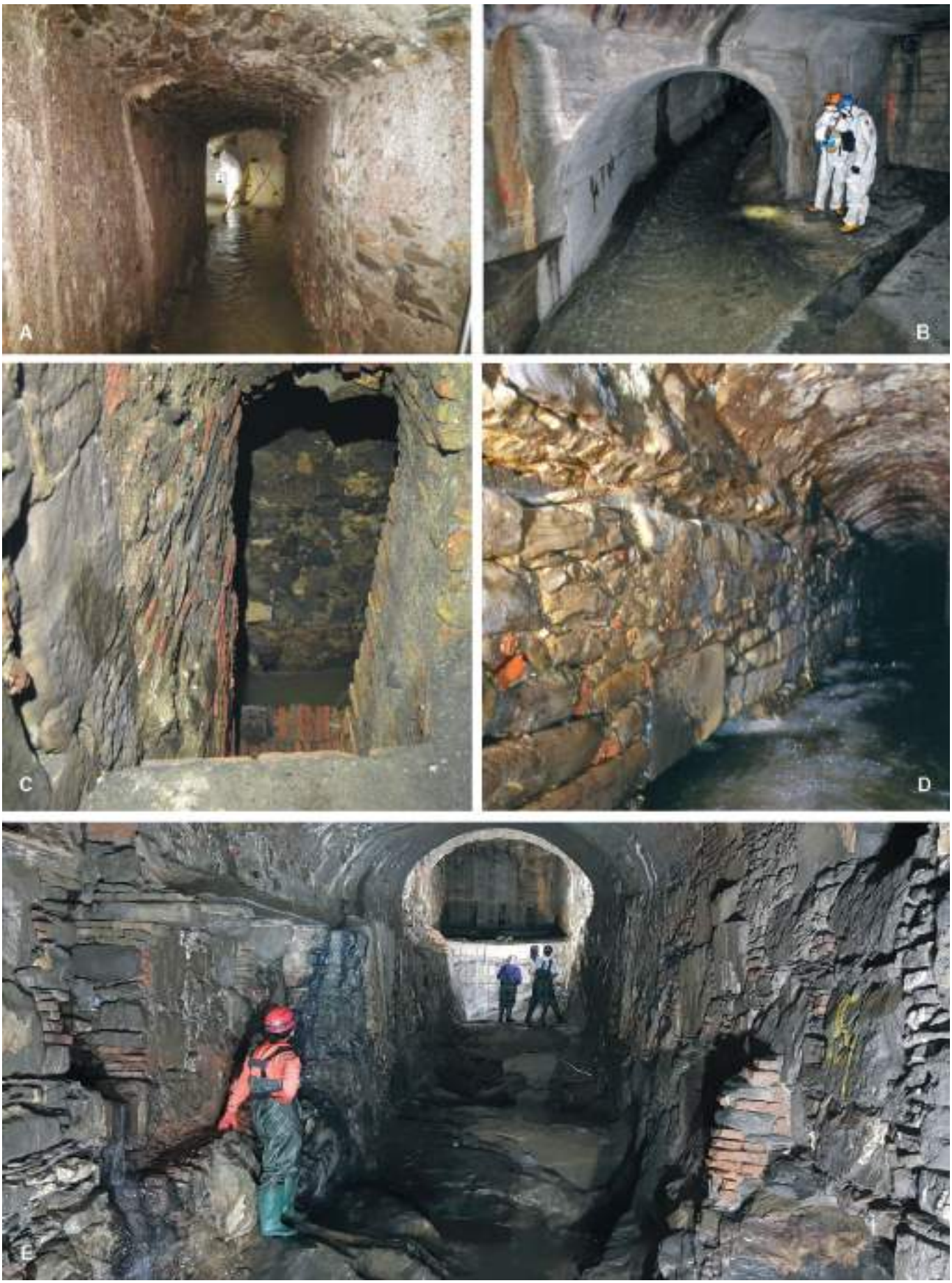

Fig. 5 – A) Rio Torbido [see n. 1 in Fig. 2] (photo L. Perasso); B) Rio Torbido [see n. 1 in Fig. 2] (photo L. Perasso); C) Rio Sant'Anna [see n. 2 in Fig. 2] (photo S. Saj); D) Rio Sant'Anna [see n. 2 in Fig. 2] (photo S. Saj); E) Rio Carbonara [see n. 4 in Fig. 2] (photo F. Faccini).

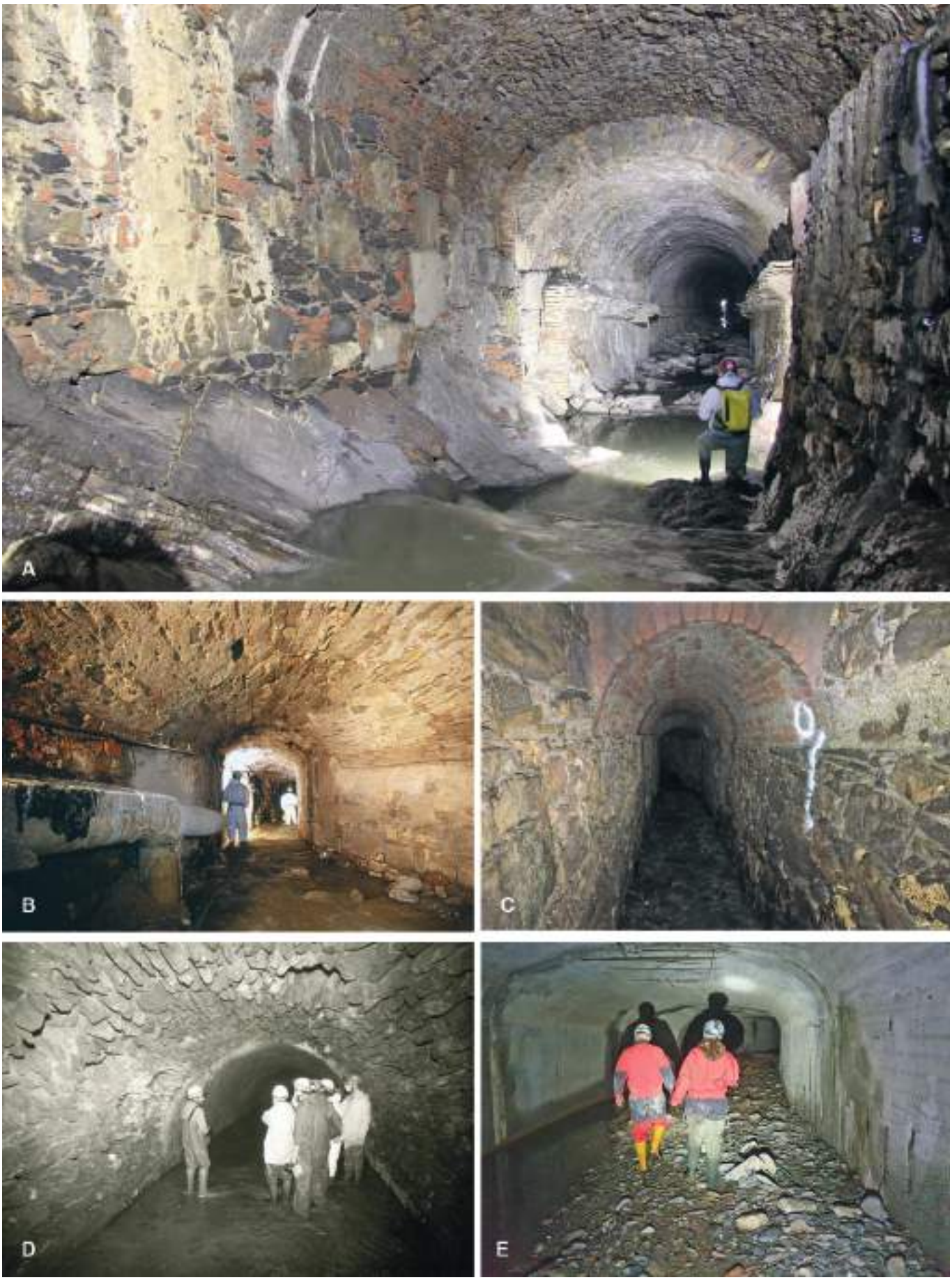

Fig. 6 – A) Rio Carbonara [see n. 4 in Fig. 2] (photo M. Traverso); B) Rio San Gerolamo [see n. 3 in Fig. 2] (photo M. Traverso); C) Rio San Barnaba, Carbonara catchment [see n. 4 in Fig. 2] (photo L. Perasso); D) Rio Sant'Ugo [see n. 5 in Fig. 2] (photo M. Traverso); E) Rio Lagaccio [see n. 6 in Fig. 2] (photo L. Rosselli).

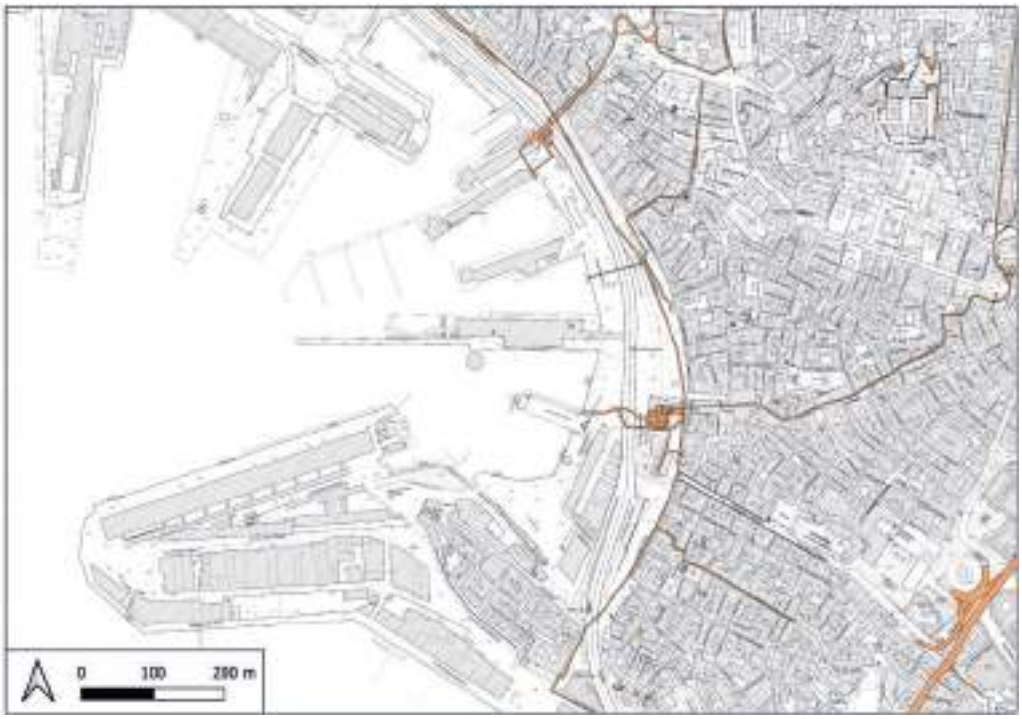

Fig. 7 – Overlap between urban fabric and culverted hydrographical network (Civis project, 2000).

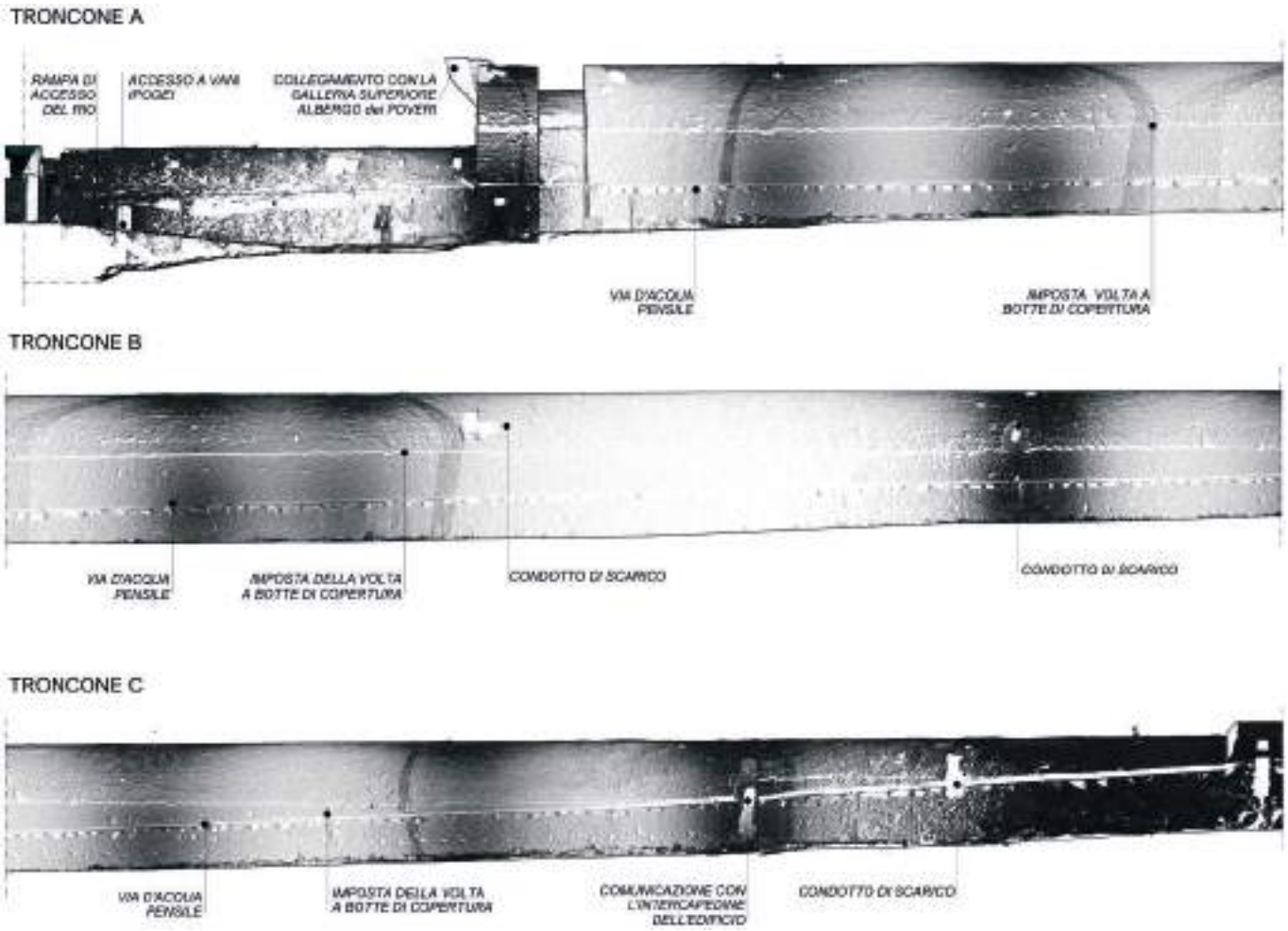

Fig. 8 – Longitudinal section of Carbonara Stream below the historical building of Albergo dei Poveri (see point F in Fig. 4). Instrumental relief was carried out with Faro Laser Scanner Focus 3D and Leica ScanStation 2. Digital restitution was carried out with BIM Design Software of Autodesk and was graphically divided with three consecutive parts (A, B, C). The drawing shows the information of the relief point cloud (graphics T. Bonassi).

and underground development of watercourses and other artificial cavities (fig. 7).

However, thanks to the intervention of the Municipality of Genoa, knowledge of the landscape and of geo-environmental dynamics has assumed a relevant importance as a fundamental element for hydrogeomorphic risk management only over the last years. The systematic survey of underground cavities by means of traditional and innovative techniques has recently begun and is ongoing. Some preliminary results have been obtained along reaches of the Carbonara Stream (fig. 8), the Sant'Anna Stream and at the cistern below Piazza Fontane Marose.

A second key activity is related to the implementation of a meteo-hydrological and structural monitoring system of culverted watercourses and related structures, both for cognitive and warning purposes. The involvement of experienced and scientifically qualified speleologists and professionals is crucial in order to collect data for both hazard assessment and consequent risk management, as well as for the analysis of artificial cavities under cultural and historical perspectives.

Bibliography

Acquaotta F., Faccini F., Fratianni S., Paliaga G., Sacchini A., 2018, *Rainfall intensity in the Genoa Metropolitan Area: secular variations and consequences*, Weather, 73(11), pp. 356-362.

Acquaotta F., Faccini F., Fratianni S., Paliaga G., Sacchini A., Vilìmek V., 2019, *Increased flash flooding in Genoa Metropolitan Area: a combination of climate changes and soil consumption?*. Meteorol. Atmos. Phys., 131(4), pp. 1099-1110.

APAT, Regione Liguria, 2008, *Foglio 213230 "Genova" della Carta Geologica d'Italia alla scala 1:50.000*, Selca Editore, Firenze.

AA.VV., 2008, *Note Illustrative del Foglio 213-230 "Genova" della Carta Geologica d'Italia alla scala 1:50.000*, APAT-Regione Liguria, Selca Editore, Firenze.

Autorità di Bacino Regionale, 2019, *Piano di Bacino Stralcio per l'assetto Idrogeologico, Ambito 14*, [Basin Master Plan for the Geo-hydrological risk reduction], Retrieved from http://www.pianidibacino.ambienteinliguria.it/GE/ambito14/ambito14.html

Barbieri P., 1938, *Forma Genuae*, Ed. Municipio di Genova.

Bixio R., Faccini F., Maifredi A., Perasso L., Saj S., Traverso M., 2017, *The culverted streams in the historical amphitheatre of Genoa city (Italy): flood risk or geoheritage protection?*, Hypogea2017, Proceedings of International Congress of Speleology in Artificial Cavities – Cappadocia, Turkey, March 06/10, pp. 165-176.

Bixio R., Saj S., Traverso M., 2015, *Urban hydrographic network of Genoa's historic centre: the underground course of the Fossatello stream,* in: Parise M., Galeazzi C., Bixio R. & Germani C. (Eds.) - Proceedings of the International Congress in Artificial Cavities "Hypogea 2015", pp. 129-140, Rome, March 11-17.

Brandolini P., Cappadonia C., Luberti G.M., Donadio C., Stamatopoulos L., Di Maggio C., Faccini F., Stanislao C., Vergari F., Paliaga G., Agnesi V., Alevizos G., Del Monte M., 2020, *Geomorphology of the Anthropocene in Mediterranean urban areas,* Progress in Physical Geography, 44(4), pp. 461-494.

Brandolini P., Faccini F., Paliaga G., Piana P., 2018, *Man-Made landforms survey and mapping of an urban historical centre in a coastal Mediterranean environment*, Geogr. Fis. Din. Quat., 41, pp. 97-102.

Brown A.G., Tooth S., Bullard J.E., Thomas D.S.G., Chiverrell R.C., Plater A.J., Murton J., Thorndycraft V.R.,Tarolli P., Rose J., Wainwright J., Downs P., Aalto R., 2017, *The geomorphology of the Anthropocene: emergence, status and implications*, Earth Surf. Process. Landforms 42, pp. 71–90.

Cat Berro D., 2021, *4 Ottobre 2021: Nubifragi alluvionali e precipitazioni record sull'Appennino Ligure*, SMI / Redazione Nimbus 5 ottobre 2021, http://www.nimbus.it/eventi/2021/211005PioggeRecord-AppenninoLigure.htm

Faccini F., Giardino M., Paliaga G., Perotti L., Brandolini P., 2021, *Urban geomorphology of Genoa Old City (Italy)*, Journal of Maps, 17(4), pp. 51-64.

Grossi Bianchi L., Poleggi E., 1980, *Una città portuale del medioevo*. *Genova nei secoli X-XVI*, Sagep Ed., Genova.

Lanza S.G., 2003, *Flood hazard threat on cultural heritage in the town of Genoa (Italy)*. Journal of Cultural Heritage, 4(3), pp. 159-167.

Limoncelli B., Marini M., 1969, *Condizioni geologico-strutturali, idrografiche e geomorfologiche del territorio urbano della città di Genova e loro riflessi applicative*, Tamburini ed., Milano.

Melli P., Bixio R., Saj S., Traverso M. & Ferrando L., 2006, *Genova sotterranea*, Erga Editore, Genova.

Paliaga G., Luino F., Turconi L., Faccini F., 2019, *Inventory of geo-hydrological phenomena in Genova municipality (NW Italy)*, Journal of Maps, 15, pp. 28-37.

Parise M., Galeazzi C., Bixio R., Dixon M., 2013, *Classification of Artificial Cavities: A First Contribution by the UIS Commission,* in Proceedings of the 16th International Congress of Speleology, edited by M. Filippi and P. Bosak, 2, pp. 230-235. Brno: Czech Speleological Society, July 21-28.

Rovereto G., 1938, *Genova e la geomorfologia urbanistica*, Consiglio Nazionale delle Ricerche, Comitato per la geologia, estratto da "La ricerca scientifica", vol. I, n. 11-12.

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