Hypogea 2015

Proceedings of International Congress of Speleology in Artificial Cavities
Italy, Rome, March 11/17 - 2015

EDITORS

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SOCIETA' SPELEOLOGICA ITALIANA
ROMA SOTTERRANEA

INFILTRATION GALLERIES, ANCIENT CONSTRUCTIONS AND GEOLOGY INTEGRATED IN THE LANDSCAPE OF NEMI MAAR (ALBAN HILLS, CENTRAL ITALY)

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Abstract
In the basin of Nemi Maar some aspects of the engineering of the territory that represent a landscape value can be identified. These aspects are represented by hydraulic structures for collection and distribution of water which are part of the physical structure of the study area. It is also well known that other sources of water were very abundant until the second half of the twentieth century. Waters are collected in infiltration galleries, fountains and springs located in many parts of the territory. This investigation concerns the study of the system of underground drainage channels. This capillary system rediscovered, completed and maintained over the centuries (the oldest tunnels are dated back to the fifth century B.C.), has been preserved until today, demonstrating its ingenious functionality. The final aim of the study has been the realization of a Geographic Information System (GIS), where all the hydraulic, geological and archaeological data are in relation between them. The informative system is open and can be questioned on several levels of knowledge by providing cognitive data.
Keywords: Nemi Maar, Infiltration galleries, Landscape, Satellite data, Geographic Information System.

***Riassunto**:*
Nel bacino del lago di Nemi (Nemi Maar) possono essere identificati alcuni aspetti dell' ingegneria del territorio tali da rappresentare un valore per il paesaggio. Questo insieme di elementi è costituito dalle strutture idrauliche per la raccolta e la distribuzione dell' acqua: tali opere fanno parte, ormai, della struttura fisica del territorio. E' ben noto che tali risorse d' acqua erano abbondanti fino alla seconda metà del ventesimo secolo: le acque venivano raccolte in gallerie filtranti, fontane e sorgenti diffuse in diverse parti del territorio. Questo lavoro riguarda lo studio del sistema sotterraneo dei cunicoli di drenaggio. Tale sistema capillare riscoperto, completato e sottoposto a manutenzione nei secoli (le più antiche gallerie risalgono al quinto secolo avanti Cristo) si sono conservate fino ad oggi a dimostrazione della loro straordinaria funzionalità. Obiettivo finale dello studio è stato quello di realizzare un Sistema Geografico Informativo (GIS) in cui sono raccolti e messi in relazione tra loro, i dati relativi alle strutture idrauliche, geologiche ed archeologiche. Il sistema informativo è aperto, può essere interrogato a diversi livelli di conoscenza e può fornire informazioni specifiche e dettagliate.
***Parole chiave**: Nemi Maar, gallerie di infiltrazione, paesaggio, dati satellitari, Geographic Information System.*

Introduction

The area of the Nemi Maar due to its environmental characteristics favoured human settlement since ancient times. In fact, traces of human settlement are attributed to the Neolithic Age concerning the gardens of Saint Nicholas and to the Middle Bronze Age with regards to the area Tempesta-Monte Calvarione. In pre Romana age the lake of Nemi was the political and cultural center of the Latin League. Latin population, devoted mainly to agriculture, realized impressive hydraulic galleries. These galleries aimed at ensuring appropriate use of the land through the irrigation and water drainage from water logging risk areas.

Hydraulic galleries represent the artificial emissaries of Lake Albano (IV century B.C.) and Nemi (V century B.C.). Aqueducts of classic Roman age were added to the previous emissaries after the defeat of the Latin League by the Romans (497 B.C.) and the subjugation of Latium Vetus (338 B.C.). In 312 B.C. the construction of the Via Appia established a close connection between Rome and the Alban hills, witnessed by the discovery of fifty houses of the imperial age.

After the fall of the Roman Empire the Nemi area was depopulated and any documents have not been found any documents until the twelfth century. In fact, small monastic communities are reported near lake Nemi by several papal bulls. In the following centuries the Nemorensis area is characterized by the events of the Papal state. Finally, during the nineteenth century the study area represented a tourist resort with Lord Byron and J.W. Goethe as the most famous visitors. In addition, in the nineteenth century, this area became one of the stops of the Grand Tour.

The close link between history, archeology, construction technique and hydraulic engineering has characterized this place since the antiquity. This close and important link represents a peculiarity of the Italian territory and has not escaped the attention of specialists from several disciplines. In fact, there is a wide literature on this subject [Bersani & Castellani, 2005; Germani

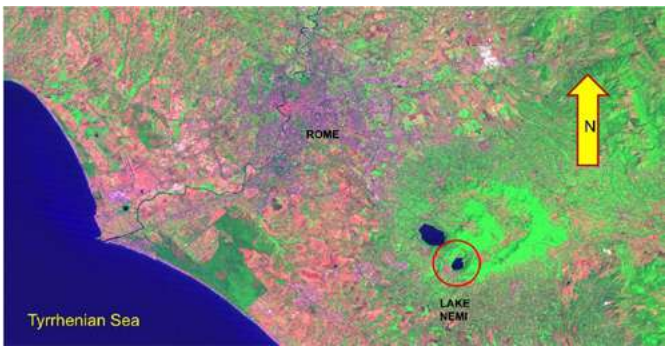

Fig. 1: the study area from a Landsat TM image of 1996 (741RGB).
Fig. 1: l'area di studio da un immagine Landsat TM del 1996 (741RGB).

& Bersani, 2011; Medici & Testana, 2009]. The most comprehensive collection of bibliographic data is organized into the information system named Demotec-A (2001-2004) [Storemyr et al, 2004]. This information system concerns the monitoring and evaluation of the risk assessment of the archaeological heritage. Later (2010-2012), a Geographic Information System (GIS), built utilizing environmental data, was realized [Loret et al., 2010; Loret et al., 2012].
The final aim of this work is to build a new information system using the resources provided by ESA-ESRIN (Frascati). The Geographical Information System will collect all the information (hydraulic, archaeological and geological data) to highlight the waterworks and the underground channels peculiar of Nemi Maar.

State of art
This work is inspired by the results of a series of European projects and extensive studies on Alban Hills volcanic area (Grande Vulcano Laziale). These studies focus on the environmental emergencies and, in particular, on a correct utilization of the water resources. These projects called Primavera and Demotec-A have developed an integrated methodology for the preservation and conservation of cultural and environmental heritage of Europe [Loret & Lichtenegger, 1996].
The information system, named "sub-urban park", was developed in the period 1998-2000. This information system is a part of the Primavera project (4th Framework Programme: Environmental and climate). Primavera is an acronym of "Park Resources

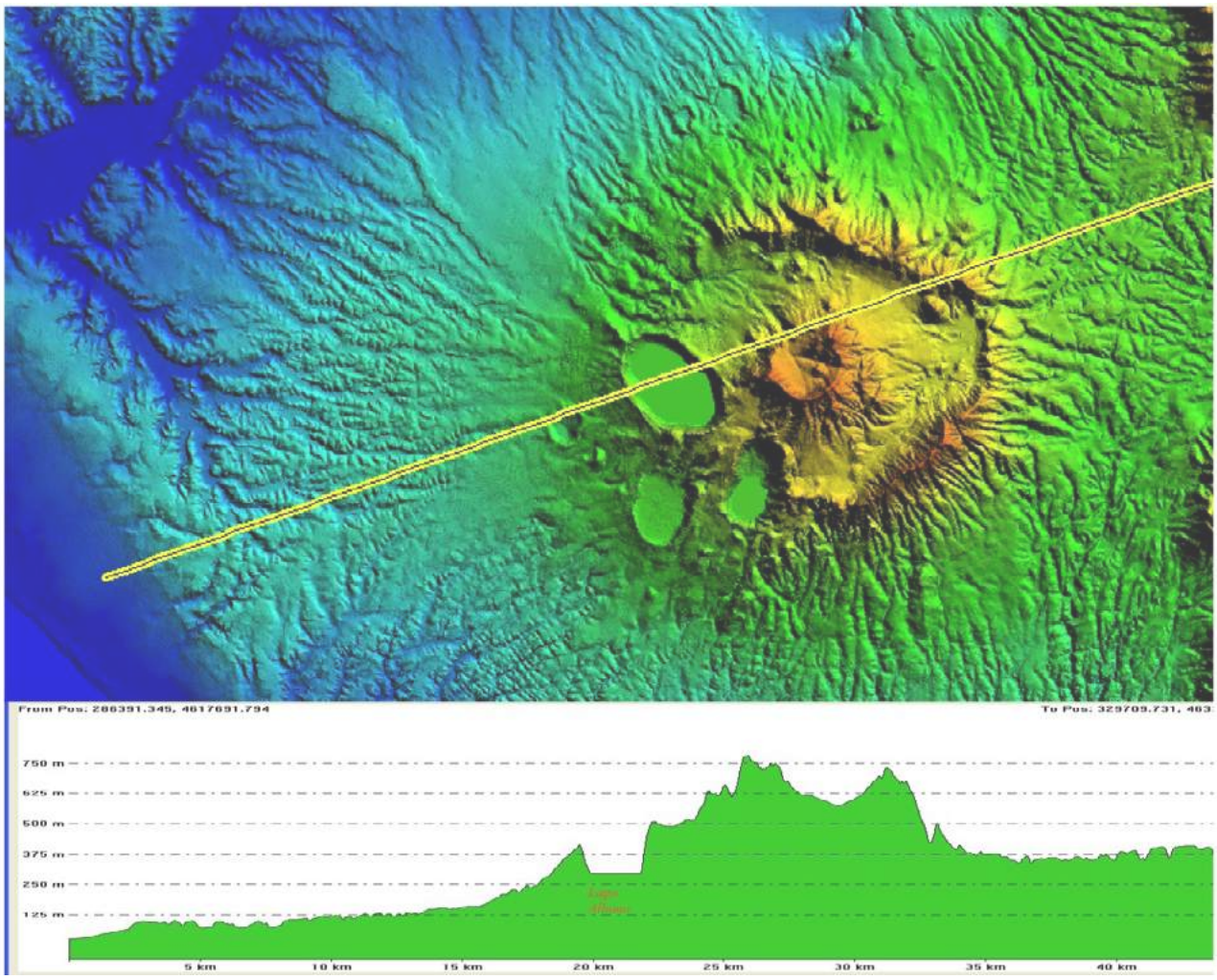

Fig. 2: morphology of "Grande Vulcano Laziale" and related section.
Fig. 2: morfologia del "Grande Vulcano Laziale" e sezione caratteristica.

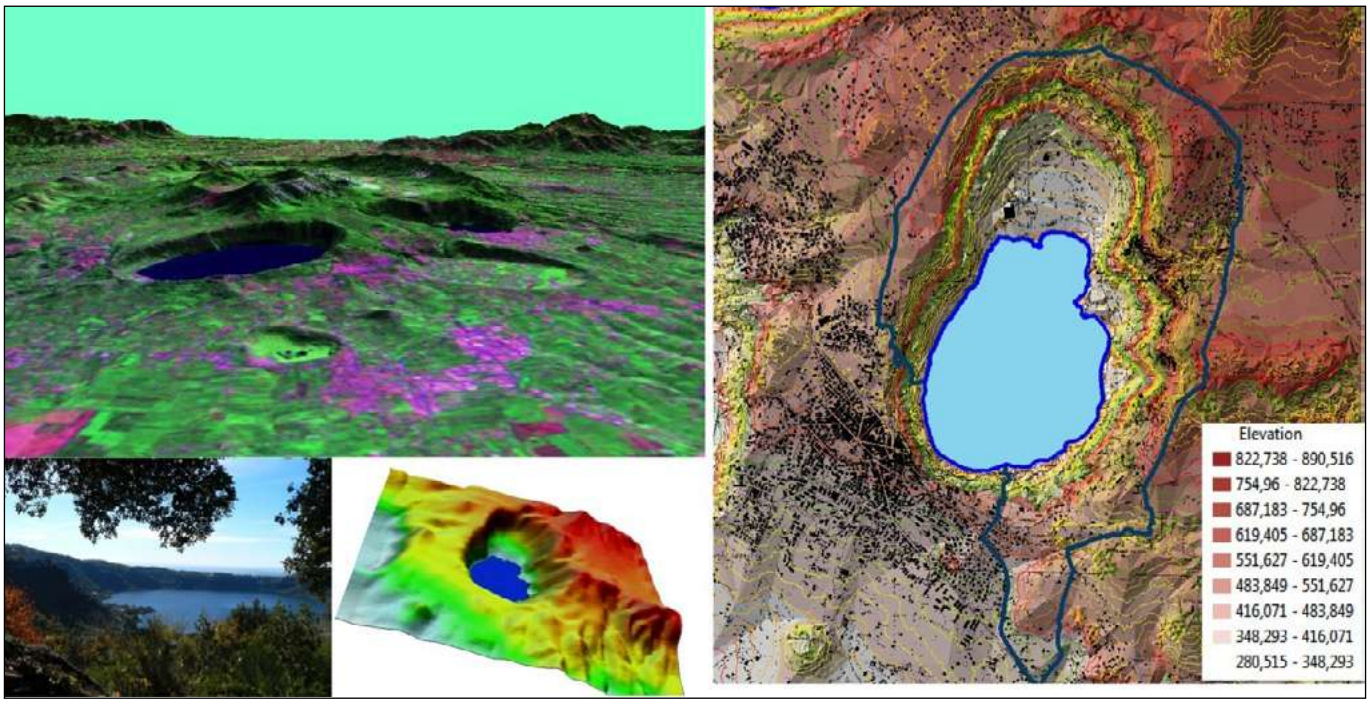

Fig. 3: processing of the digital terrain model (ESA-SARDEM): three-dimensional modelling of the crater.
F*ig. 3: sviluppo di un modello digitale del terreno (ESA-SARDEM): modello tridimensionale del cratere.*

Information Management Via Environmental Remotely sensed data Analysis".

The system dataset was drawn from the Regional Technical Map (CTR 1: 10.000) and was integrated utilizing satellite data (Landsat TM, SPOT PAN, ERS-SAR and IRS-1C PAN). The information system aims to provide local authorities (State, Region, Parks) of information for a better urban planning. Moreover the use of the sensor IRS-1C PAN has allowed the updating of maps, dated 1990, with a better allocation of classes of land use. The sensor IRS-1C PAN achieved a more precise localization of forest and a development of risk maps. Demotec-A is an acronym of "Development of a Monitoring System for Cultural Heritage through European Co-operation". The project, carried out between 2002 and 2004, was supported by the European Commission in the framework of the Key Action 4: City of Tomorrow and Cultural Heritage (EU - EVK4-CT-2002-80011).

The purpose of the project led to develop an intervention methodology which is very effective for the organization of a "universal" model to study protected areas. Moreover, this method is applicable to other sites in the European Community.

Area of interest, for this pilot application, regards the Castelli Romani Regional Park, with particular focus on the town of Nemi, (see Figures 1, 2 and 3). Both the projects have been carried out since 2005 with the implementation of information in order to realize a Geographic Information System (GIS) integrated with satellite images.

Later studies regarding the situation of geo morphological risk have been realized for the pilot area of the Nemi Maar [Loret et al., 2010; Loret et al., 2012]. This allowed to expand the architecture of the informative system, to add information and to build risk maps to predict landslides. All these information is very useful in an urban analysis and in the formulation of a municipal plan.

Data processing

Satellite images (Landsat TM, ALOS and AV2 Kompsat) have been processed with an "Erdas Imagine software". This software allowed the realization of thematic maps which have been variously transformed and incorporated into a Geographic Information System (GIS). Images and maps were geo-referenced using an UTM geographic system (UTM zone 33 North, 1924 international ellipsoid, 1950 European datum).

The base cartography is the 1:10.000 CTR (Carta Tecnica Regionale) of the Latium Region (1991), the 1:5.000 aero-photogrammetry of Nemi (1985) and the aero-photogrammetry of "Volo Italia 2000". Moreover special maps were used: these maps were produced by the Province of Rome and Latium Region. Furthermore geological maps were made available by "Sapienza" University of Rome, concerning the 1: 50.000 Alban Hills geological map and the 1: 5.000 Nemi geological map [De Rita et al., 1998]. This preliminary work allowed the digitization, the geo-referencing and integration into the Geographic Information System (GIS) of cadastral maps (sheet and particle) of the entire municipality.

The analysis, started from cartographic situation dated 1985, has gradually been upgraded with the inclusion of a series of tabs that produce information on location, land registry, cadastral data and conservation status. Such information provided basic thematic maps, sector by sector (scale ratio 1: 2.000). Development of the information system led to the integration and correlation of these data with the most recent satellite images (2008), by means of further analysis and field control. This methodology allowed the relief of the entire urban structure, landscape and environmental

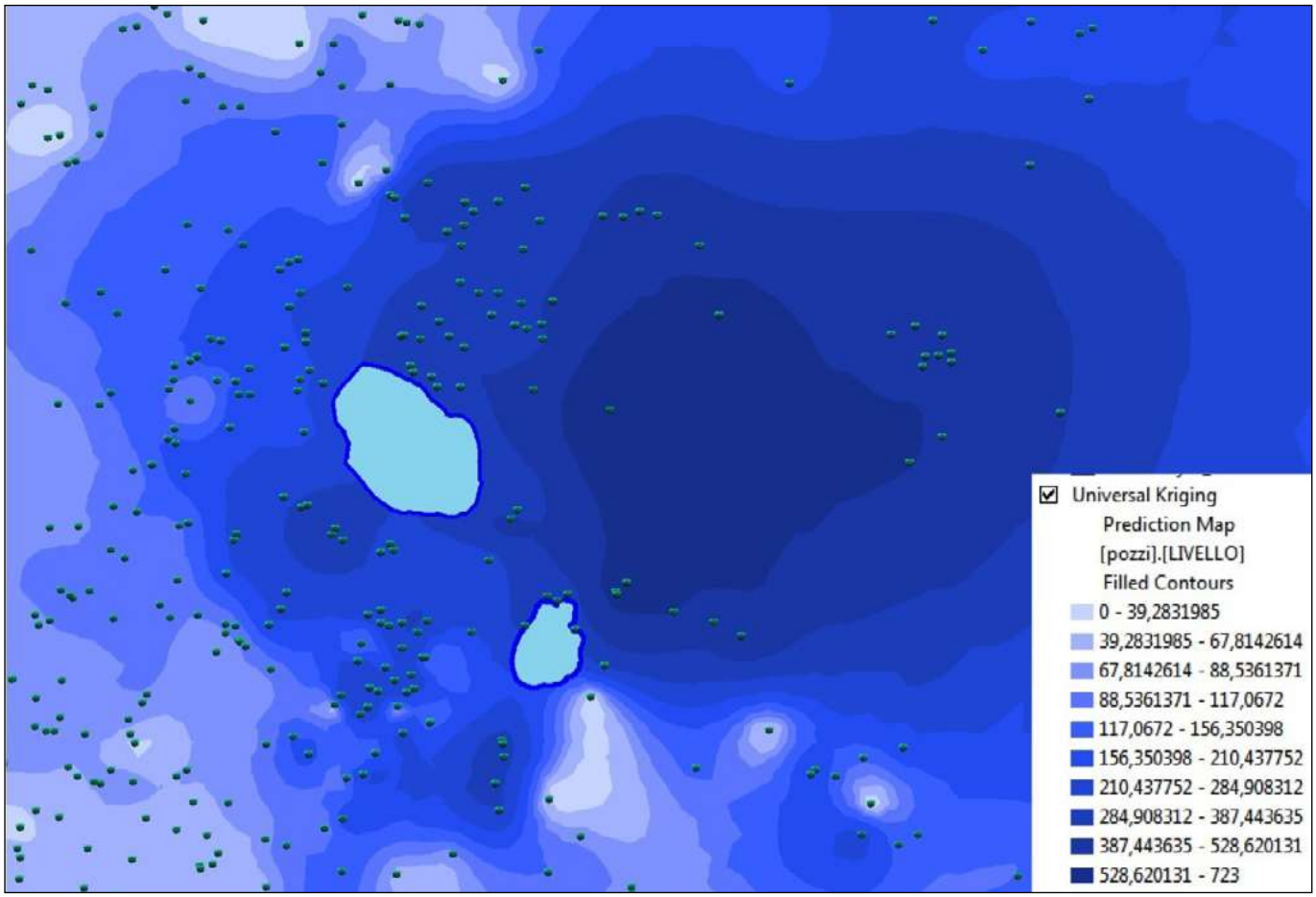

Fig. 4: development of the groundwater levels obtained by interpolation from wells' data (dynamic water level).
Fig. 4: sviluppo dei livelli di falda ottenuto attraverso l' interpolazione dei dati dei pozzi (livello dinamico dell' acqua).

system at different scale levels.
Several field trips, using a Global Positioning System (Trimble Navigation and Garmin GPS) and a digital camera, have been carried out. The field work allowed the connection of images of the area with spatial objects (vector objects) of the GIS. The information system is equipped with a broad raster basis where old maps, dating from the eighteenth century to 1898, were included and connected to the reference maps and aero aero-photogrammetry cards. Satellite images and various thematic maps, in three dimensions, derived from SARDEM, were also included in the Information System.
Regarding the hydraulic system, the work is started from an analysis of the possible extension of the aquifer. Geo-statistical methods, based on the concept of autocorrelation, and technique of Kriging allowed the spatial interpolation of static levels of wells in the Alban Hill volcanic area [Ventriglia U., 1990; Capelli et al., 2005]. All used data allowed to construct a isopieze map, for estimating the trend and the performance of underground waters (see Figure 4). Groundwater levels, obtained by interpolation from wells' data and integrated with permeability data of the geological units, are consistent with the layout of the infiltration galleries.
For each drainage gallery, inserted as a vector object, has been organized a detailed information sheet (see Figure 5). From the information system it is possible to access to the aqueducts data base and to open the imagines of each subject.
All detailed file includes a short description, history of the excavations, literature, drawings and photographs (see Figure 6).
Collecting all available information it is possible to obtain a reliable picture about the organization of the life of the communities living in the basin of lake Nemi, concerning their ability to draw water, the organization of the water distribution network and the reclamation of agricultural land.
All these elements were in balance for centuries ensuring the survival of the inhabitants and mitigating environmental risks. In this area all the works of man are perfectly integrated into the natural landscape without contrast and irreparable strains.
All these references are contained in the information system at different scales to identify good practices of conservation of a cultural heritage, unique and unrepeatable.

Conclusions

The proposed Geographic Information System (GIS) allowed to view different environmental scenarios overlaying satellite images, thematic maps and vector objects.
The case study of Nemi filtering system highlights the

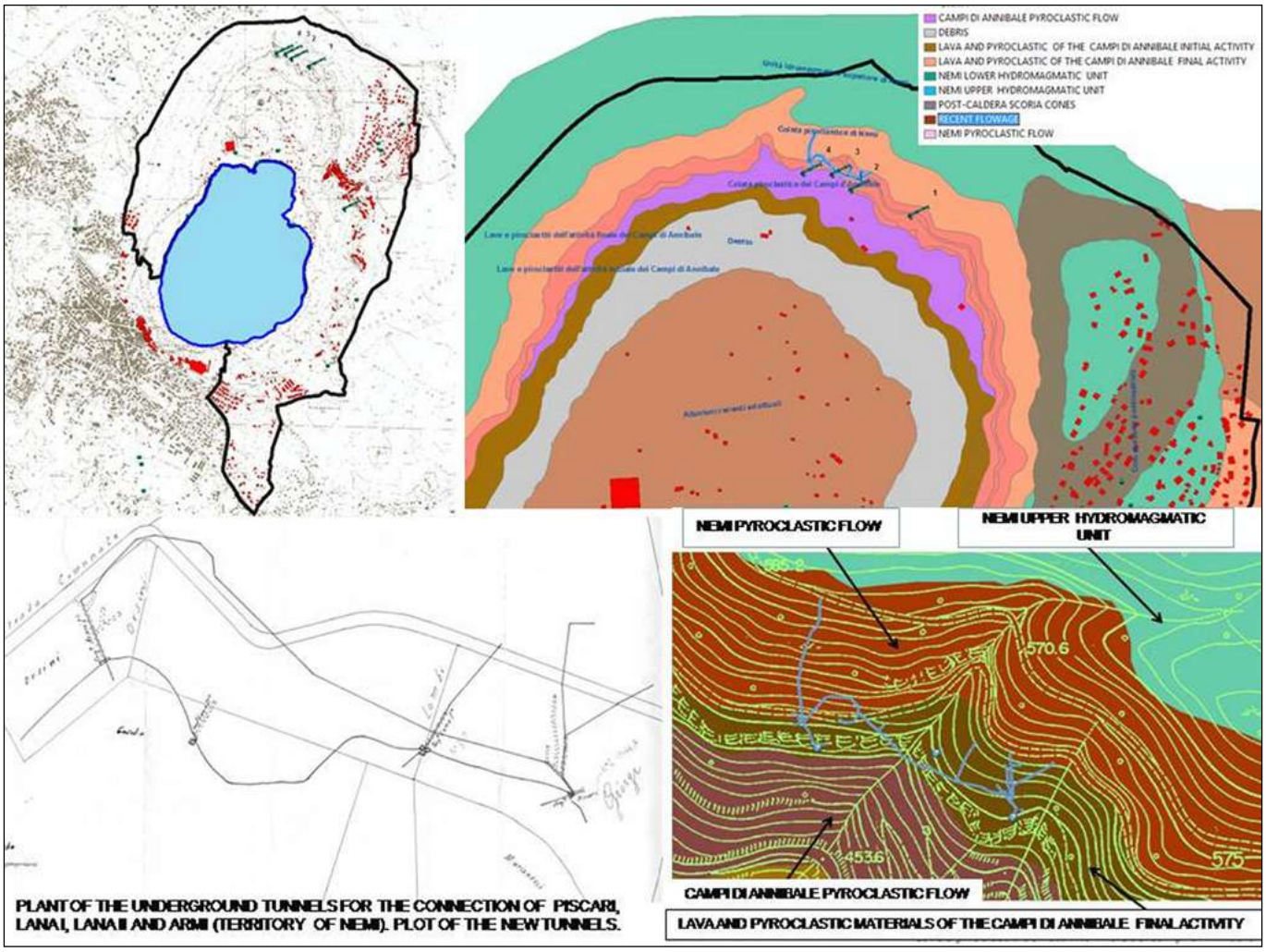

Fig. 5: classification of tunnels and infiltration galleries in the geological context of the lake Nemi crater. Comparison with a relief of 1889.
Fig. 5: individuazione dei cunicoli e delle gallerie filtranti nel contesto geologico del cratere del Lago di Nemi. Confronto con un rilievo del 1889.

close relationship between the development of galleries and geological system. These relationships have been intuitively identified by the ancient engineers who have developed an efficient system of recovery of the water still used in modern times.
In addition, the realized Geographic Information System (GIS) allowed to demonstrate that the infiltration galleries have been carried out by exploiting different permeability and land slope. Finally, authors hope to expand and deepen the study collecting in a broader information system all the information from different disciplines with the final aim to make data useful for a wider consultation.

Acknowledgements
Authors express their gratitude to ESA/ESRIN (Frascati, Italy) for availability and collaboration and in particular to Dr. Francesco Sarti for his helpful comments and constructive suggestions.

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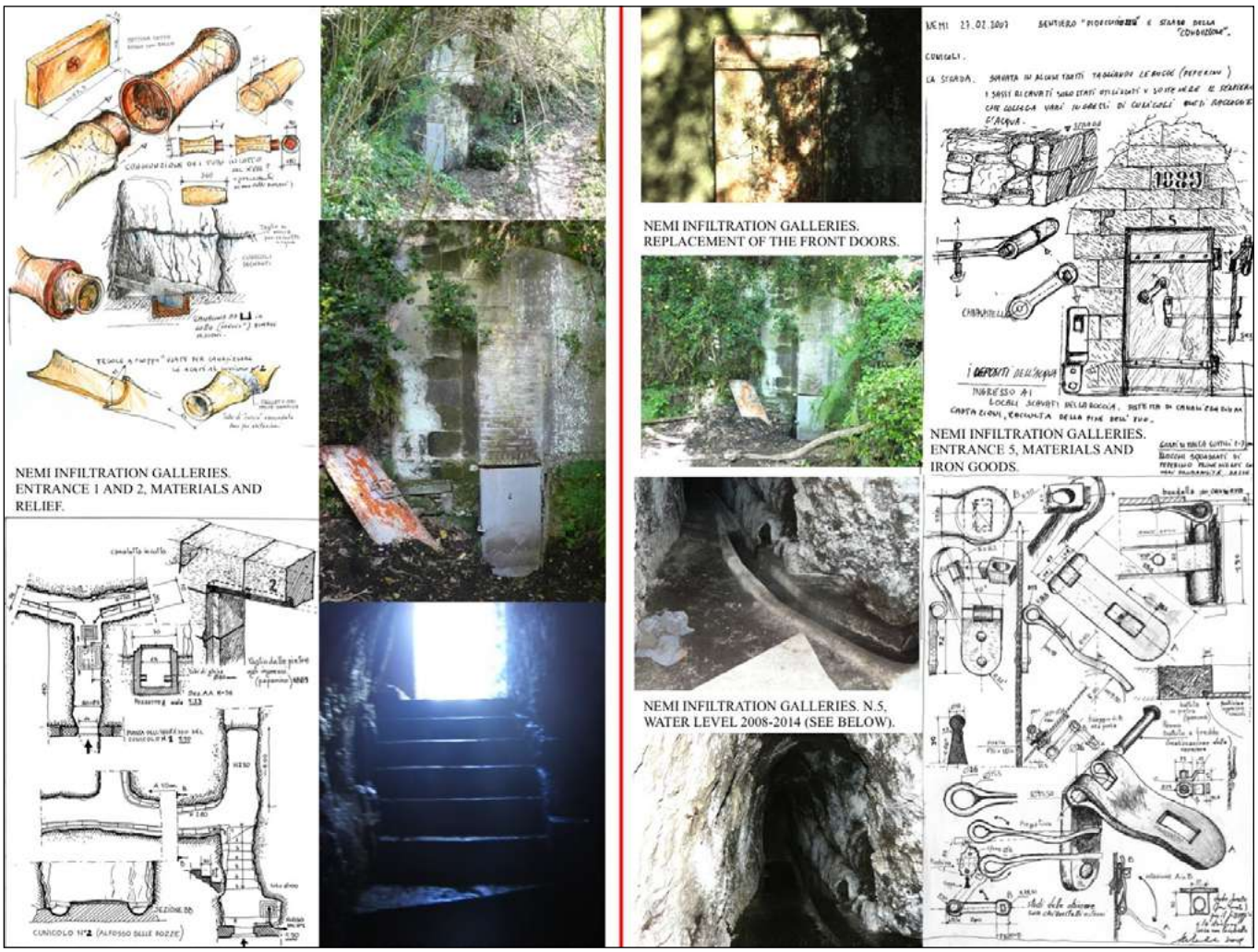

Fig. 6: imagines and cards of the infiltration galleries.
Fig. 6: immagini e schede delle gallerie filtranti.

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