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Geo4P - Geothermal Pilot Project Pisan Plain: quantitative assessment of very low, low and medium temperature shallow geothermal resources

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ABSTRACT

This paper presents the first results of an integrated geothermal research project. Geo4P (Geothermal – Pilot Project Pisan Plain) is started in July 2014 for the development of a multidisciplinary methodology, aimed at carrying out a quantitative assessment of low temperature shallow geothermal resources in Pisa plain. The ultimate aim is to produce a tool useful to enhance the use of geothermal heat pumps in heating and cooling plants, for public utilities. Concerning geological and geothermal researches, 3D integrated subsoil models are produced within Geo4P, whereas 3D results are implemented in thermo-fluid dynamic simulations in order to increase the thermal knowledge of the subsurface.

1. INTRODUCTION

The aim of this project is to develop an innovative multidisciplinary approach, including geological, geochemical, geophysical and numerical modelling, for assessment of low temperature geothermal potential of the Pisan plain. Despite the existence of many information and many data have already been collected in the past, all the investigation elements took into account by this Project are not always treated in a systematic way and made easily accessible. In addition difficulties are encountered within local authorities, which does not always have appropriate tools for a proper use of local resources.

The Geo4P Project is therefore mainly aimed at supporting public and private players potentially interested in considering the opportunities offered by a more efficient development of shallow geothermal resources.

The studied area includes the municipalities of Vecchiano, San Giuliano Terme, Calci, Buti, Bientina, Vico Pisano, Calcinaia, Pisa, Cascina, Pontedera, Fauglia, Crespina Lorenzana, Casciana Terme Lari and Ponsacco and it covers more than 570 Km^2 (Fig. 1).

The project is developed on the following steps:

- research and collection of existing data from different sources,
- creation of a geographical information system for data storage, management and updating,
- data validation and analysis and interpretation to obtain a geothermal conceptual model,
- 3D geological modelling,
- surveys for collection of geothermal chemical and physical subsoil parameters,
- thermofluidodynamic 3D modelling
- recommendations to local decision makers and presentation of project results to local stakeholders.

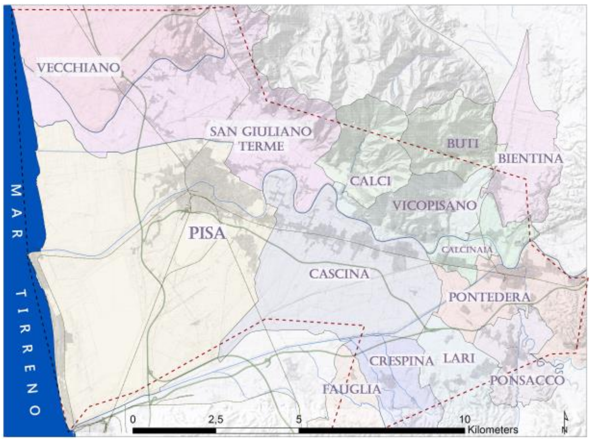

Figure 1: The studied area.

2. GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The Pisa plain is located in Nord West side of Tuscany region and is mainly made up of neoautochtonous deposits that fill a wide graben striking NW-SE (Bellani et al 1995). The coastal plain is bounded by the Pisa Mountains to the Northeast, the Leghorn and Pisa hills to the South, and the Tyrrhenian Sea to the West (Sarti et al 2012).

Because of tectonic and climatic events, sediments were deposited on the rock substratum from Miocene to Quaternary. After two major transgressive cycles (Upper Miocene, Lower Pliocene), which led to the deposition of conglomerates, sands, clay and evaporitic sediments, an important regressive phase ensued during the Middle Pliocene. This brought about land emergence and widespread erosional activity (Grassi and Cortecci 2005). During the Pleistocene there were several eustatic fluctuations and the sediments were deposited in the area according with the flooding stage of Arno-Serchio water system. Then (Upper Pleistocene – Holocene), mainly fluvial and marshy sediments were deposited, due to reduced fluvial activity linked to both the eustatic sea-level lowering and progressive drying of the climate (Grassi and Cortecci 2005).

The historical evolution of Pisa plain results in a complex stratigraphic pattern: the generally accepted hydrogeological scheme (Trevisan and Tongiorgi 1953; Dini 1976; Fancelli 1984, Baldacci et al 1994; Rossi and Spandre 1994) is that there is a multi-layered confined aquifer (MCA) system with two major confined aquifers, locally connected.

3. GEOGRAPHICAL INFORMATION SYSTEM FOR GEOTHERMAL PLANNING

The first step of the project was to research and collect all available information on Pisa basin evolution: geology, stratigraphy, hydrogeology, chemical and isotopic analysis of aquifers. All data were collected in a dedicated geo-database developed on Esri ArcGis 10.2.2. Gis structure reflects the following scheme (Fig 2) and is organized in 5 information layers (shapefiles) mutually connected to each other from the key field "identifies".

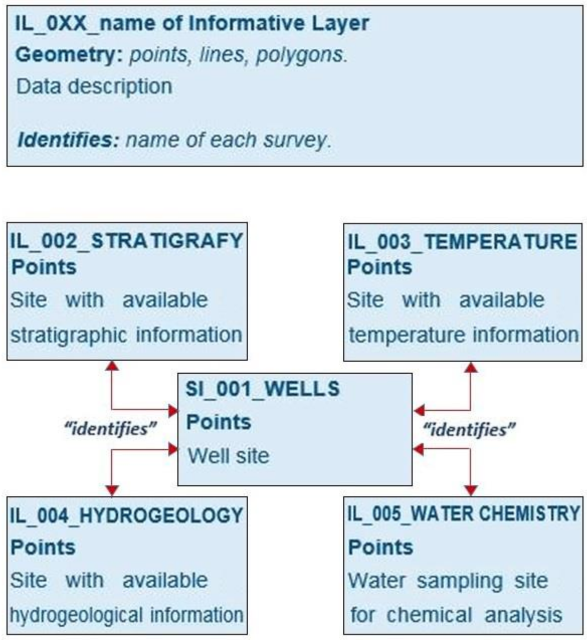

Figure 2: DB setting with Informative Layers

The Geographical Information System also contains raster elements:

- Geomorphologic map of Pisa (Cerratori et al 1994),
- Geological map of Tuscany, sheet 273, Pisa Section 273010, scale 1: 10.000 (ISPRA),
- Rocks permeability map, Aquifer System of Pisa plain (Baldacci et al 1998),
- Geological Map of the North-western part of Pisa Mountain, scale 1: 25.000 (Giannini and Nardi 1964),
- II interpretative geological map of the Pisan hills to the Southeast of the Guappero Valley, scale 1: 25.000 (Rau and Tongiorgi 1974),
- Topographic map in scale 1: 10.000
- Digital elevation model (DEM) of the area, cell size 20m.

All data were georeferenced in WGS_1984_UTM_Zone_32N (WKID 32632) coordinate system.

3.1 Informative layer "IL_001_Wells"

"IL_001_Wells" contains all the available information regarding 2740 water wells and geotechnical surveys (Fig 3) in the area of study: latitude, longitude, altitude, depth and data source.

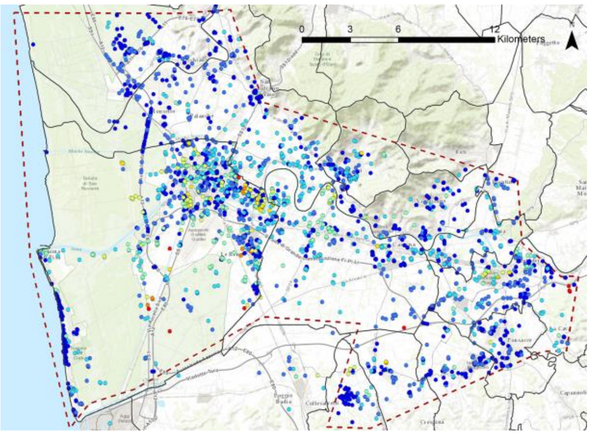

Figure 3: IL_001_Wells; features are coloured according to the depth of survey, hot colours for deeper wells.

3.2 Informative layer "IL_002_Stratigraphy"

"IL_002_Stratigraphy" contains the stratigraphic description for each survey. Each point represents a lithological layer (Fig 4).

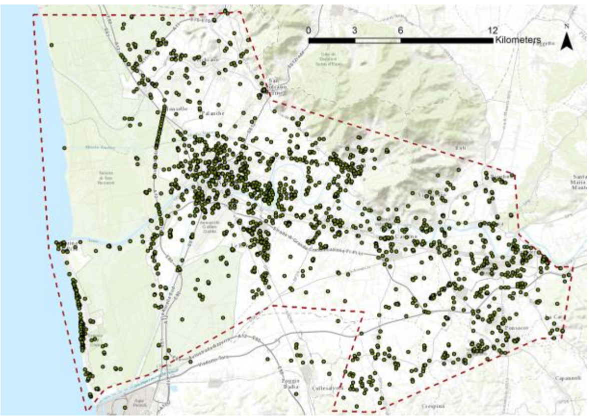

Figure 4: IL_002_Stratigraphy.

3.3 Informative layer "IL_003_Temperature"

"IL_003_Temperature" collect 193 temperature measures (Fig. 5): these data come from bibliographic sources and fieldwork survey that interested 97 wells between 2015 and 2016. Temperature values are associated, where is possible, with the filter depth.

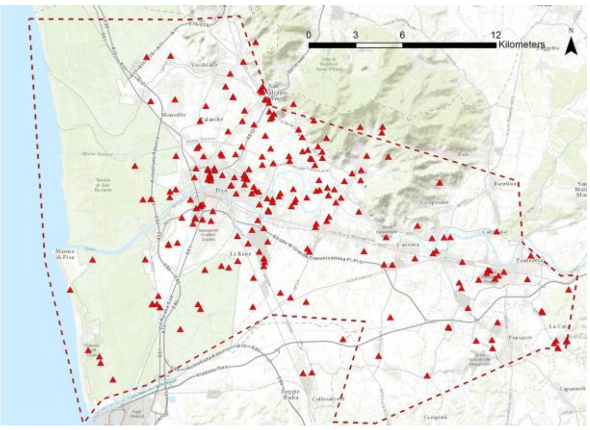

Figure 5: IL_003_Temperature.

3.4 Informative layer "IL_004_Hidrogeology"

"IL_004_Hydrogeology" holds 1449 elements (Fig. 6) and manages the hydrogeological information like permeability, transmissivity, flow rate, storage coefficient, number and depth of filters in wells.

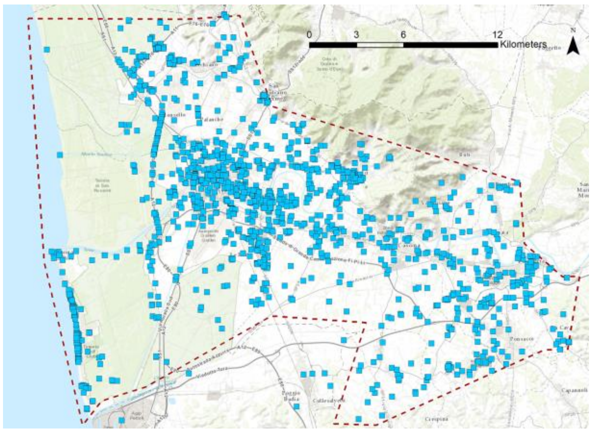

Figure 6: IL_005_Hydrogeology.

3.5 Informative layer "IL_005_Water_chemistry"

"IL_005_Water_chemistry" contains chemical results of water analysis from bibliography and from field sampling during the last year (Fig. 7). Light blue points represent sampling taken during this project and subjected to chemical and isotopic analysis.

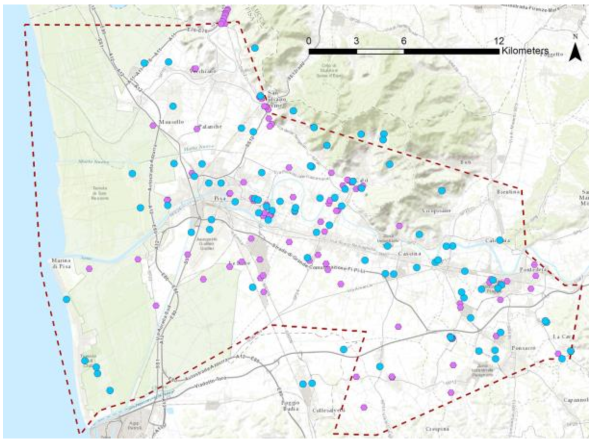

Figure 7: IL_005_Water_chemistry. The map shows the wells for which you have the results of chemical analysis.

Chemical analysis results (Fig. 8) and isotopic survey will be useful to improve the knowledge of underground circulation in aquifers.

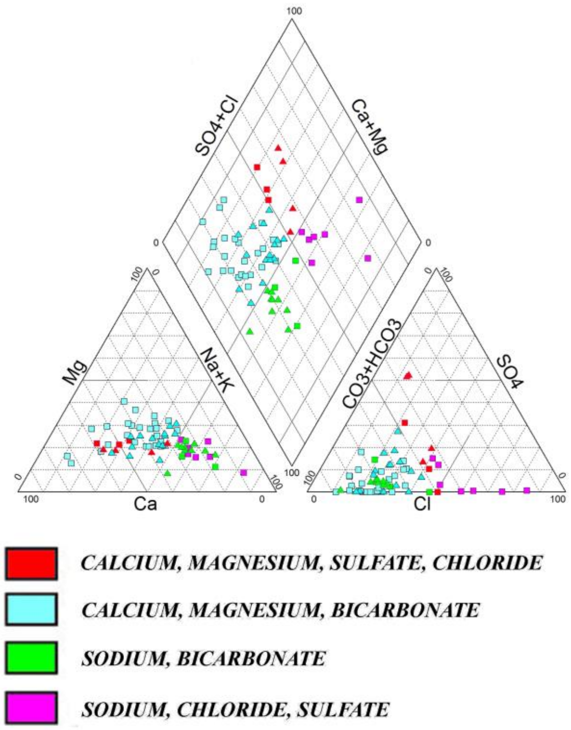

Figure 8: Piper diagram for chemistry classification of Pisan plain underground waters.

4. 3D HYDROGEOLOGICAL MODELLING

4.1 Hydrogeological conceptual model

According with existent bibliography (Baldacci et al 1994, Sarti et al 2012, Grassi and Cortecci 2005.) and using database information, a 3D hydrogeological model of Pisan plain was set. The model realization was carried out through a series of operations that allowed extending punctual information to the whole studied area. The hydrogeological interpretation of significant stratigraphy and the creation of 16 hydrogeological sections provided the characterization of following hydrogeological units:

- Recent Alluvial Cover: clays and discontinuous sand bodies, related to recent Arno and Serchio flooding deposits, host suspended aquifers with low flow rates;

- Multilayer Confined Aquifer (MCA): is composed by 2 permeable levels with sands and gravels, locally connected. It hosts aquifers with high flow rates;

- Clay 1: where it exists, separates the permeable horizons of MCA System.

- Clay 2: clayey sediments below MCA deposits.

- Coastal Dune Aquifer: eolian and marine sand deposits. It extends from the coast to the western side of Pisa. This aquifer is locally connected with MCA.

- Alluvial Fans Aquifer: dense succession of gravelly deposits that move from Pisan mountains to Arno valley. It hosts several spring and high water circulation.

4.2 Petrel workflow for model creation

Modelling process was performed with Petrel E & P Software Platform, Version 2013.6, using the following input data:

- 450 wells (Fig. 9 and Fig. 10), selected considering depth and quality of information. For each well, hydrostratigraphic units top (“well top”), was located (Fig. 11),

- 16 hydrological sections (Fig. 12). For each section were located points (“additional points”) matching with the top of hydrostratigraphic units,

- Petrel has processed well tops and additional points, building the surfaces of the different units to be modelled. The interpolation was led by “convergent interpolation algorithm” generating regular mesh grids, 50x50 m. The surfaces were further refined by the operator where software performed anomalous or irregular results (Fig. 13),

- Bedrock top surface was obtained by inversion of gravimetric measures (Fig. 14),

- Finally, starting from surfaces, a complete 3D hydrogeological underground model of Pisan plain was built (Fig. 15, Fig. 16, Fig, 17).

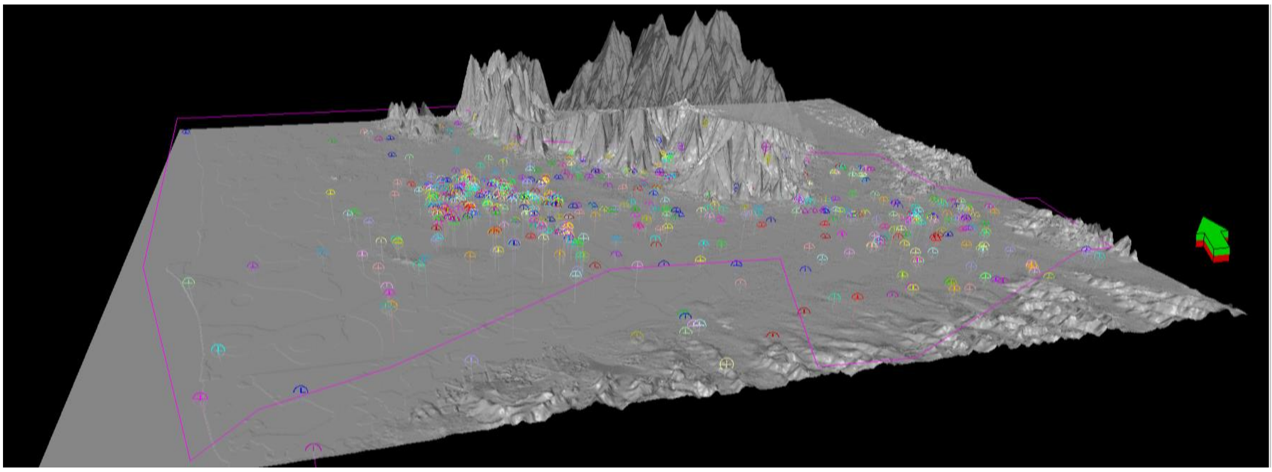

Figure 9: Wells imported in Petrel project, in studied area.

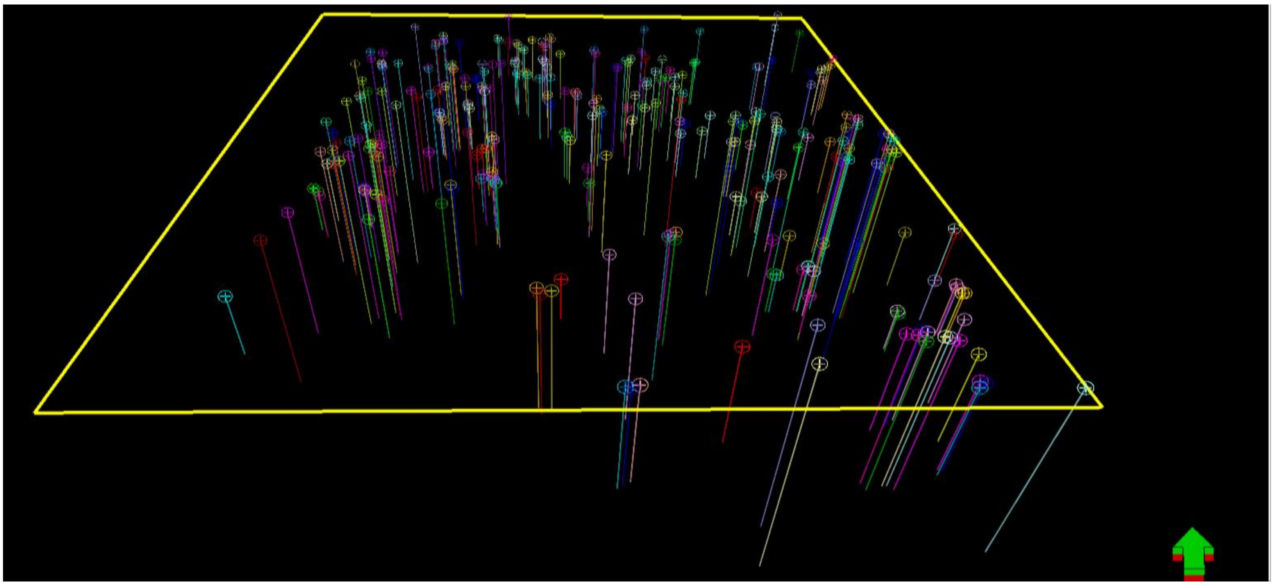

Figure 10: Wells in Pisa city.

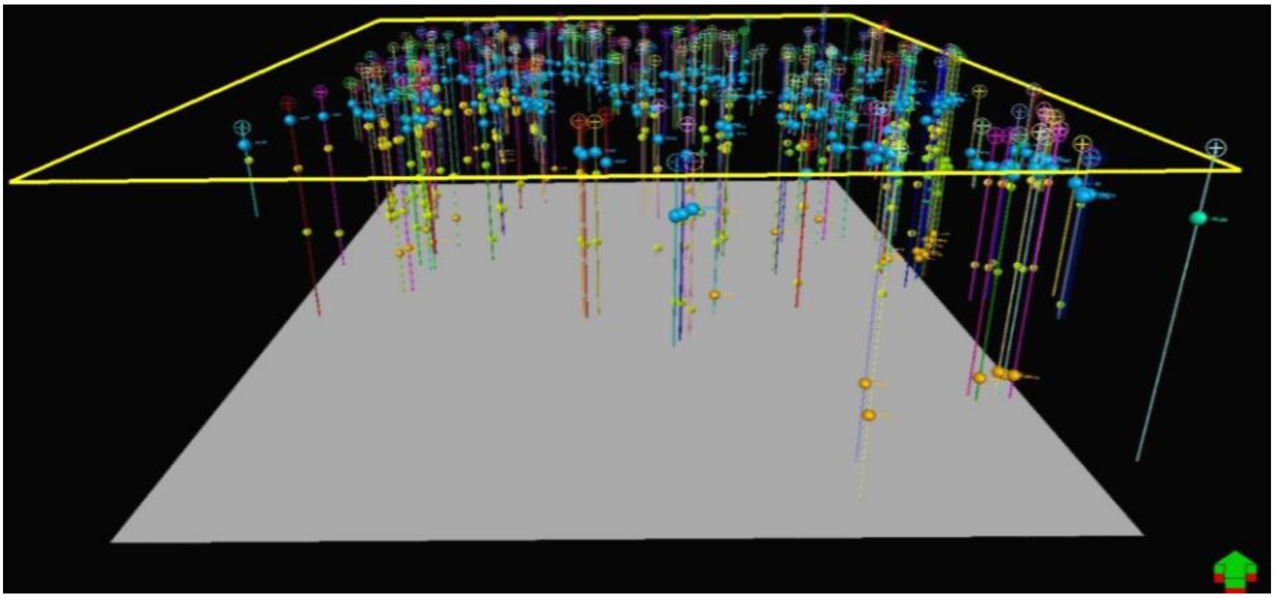

Figure 11: Well tops in Pisa city area.

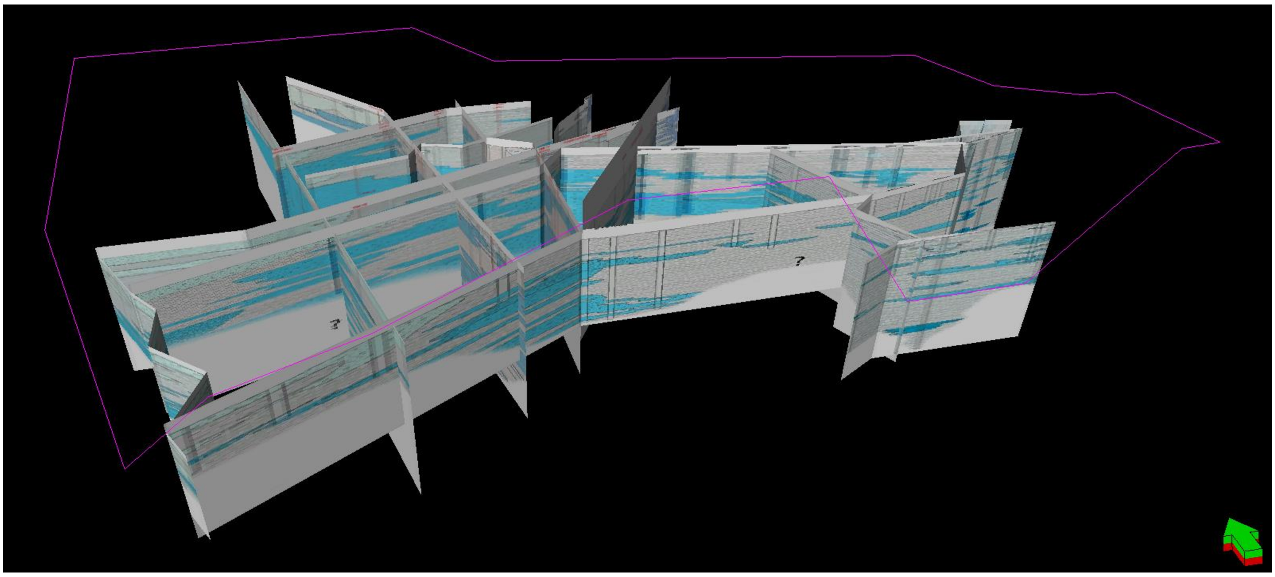

Figure 12: Hydrogeological sections imported in Petrel project, in studied area.

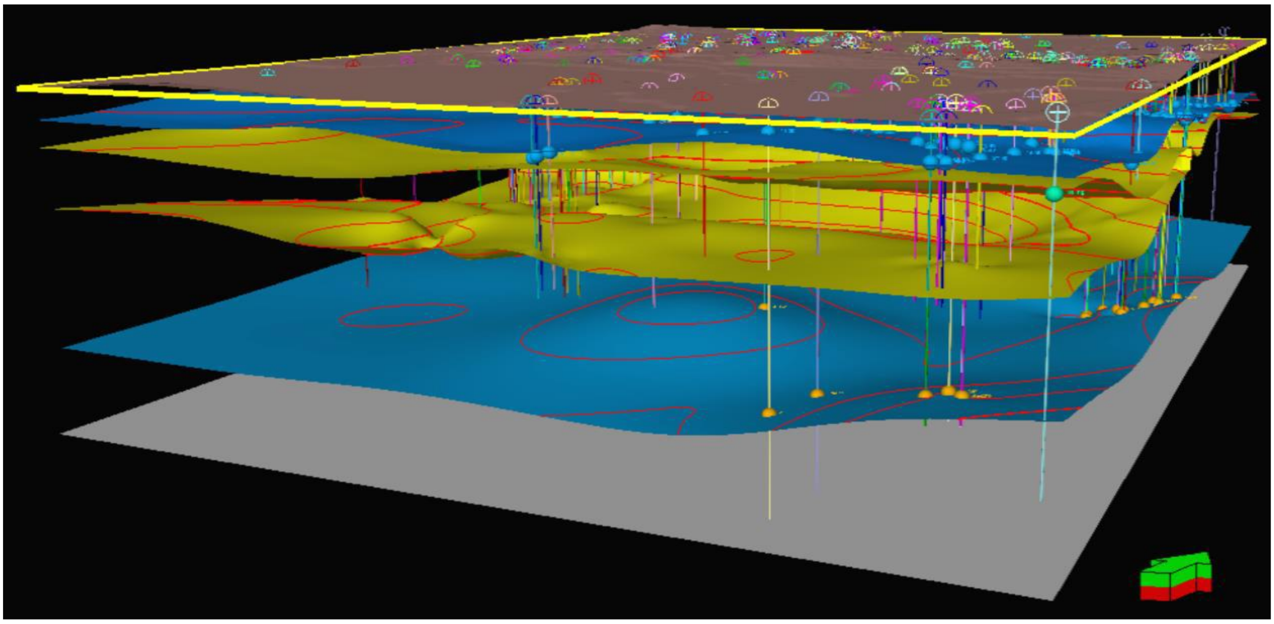

Figure 13: Obtained surfaces, in Pisa city area.

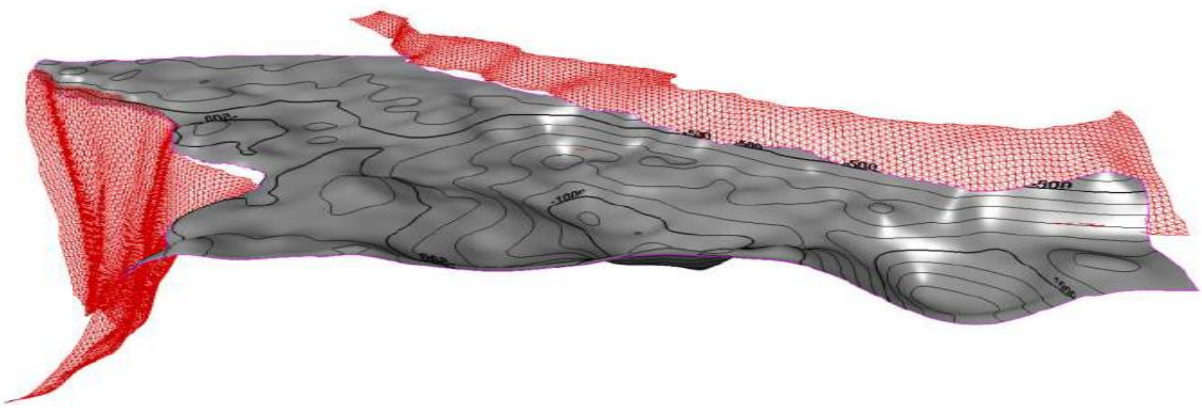

Figure 14: Bedrock, top surface.

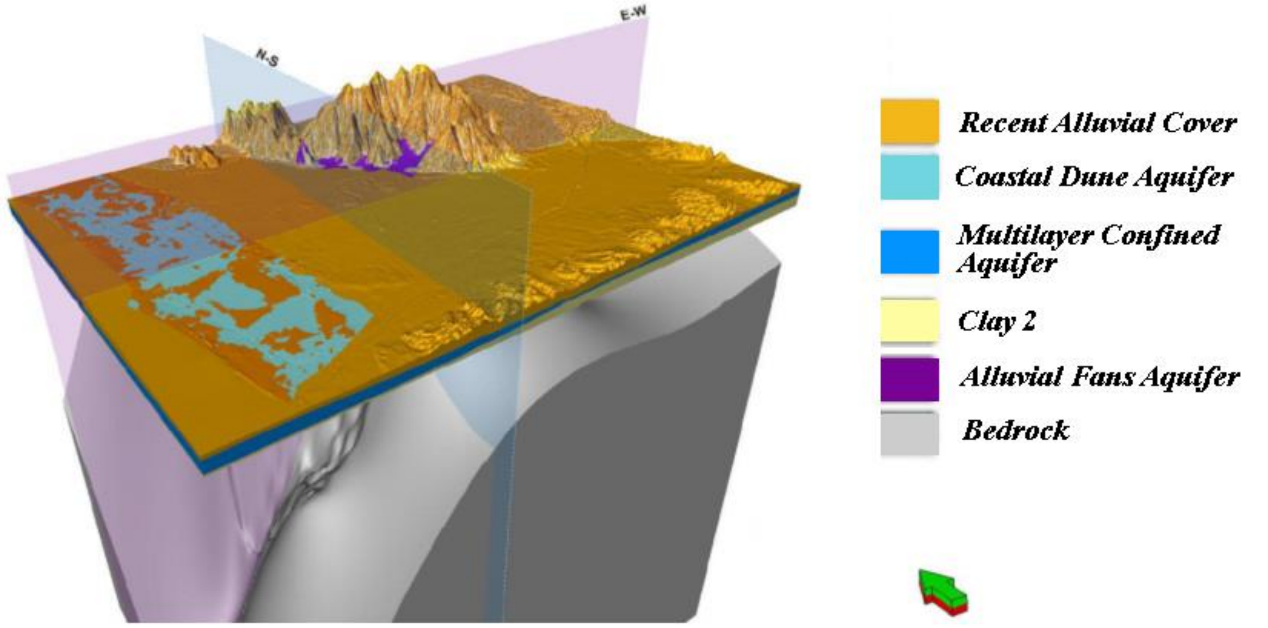

Figure 15: 3D hydrogeological underground model of Pisan plain.

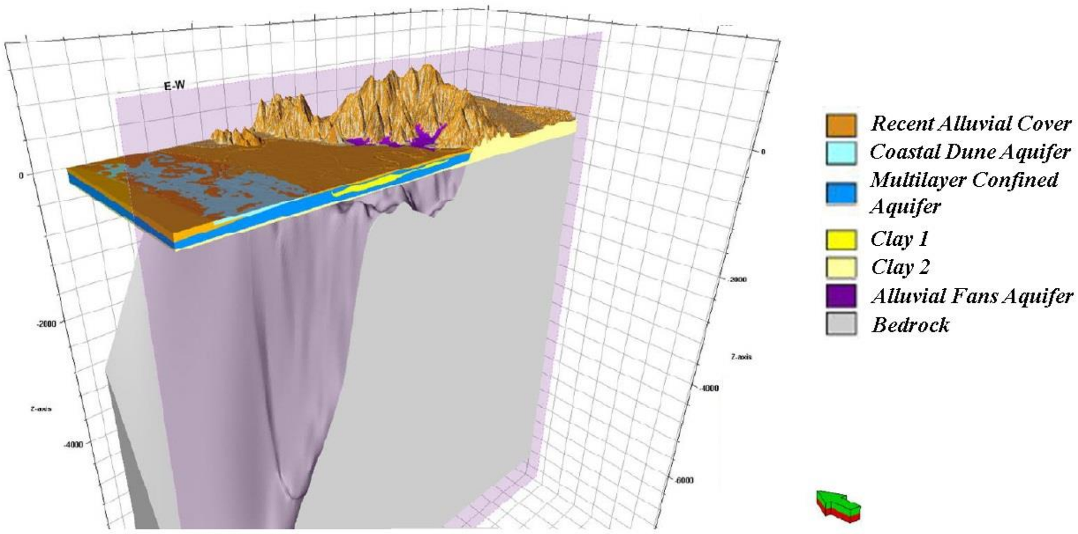

Figure 16: EW model section.

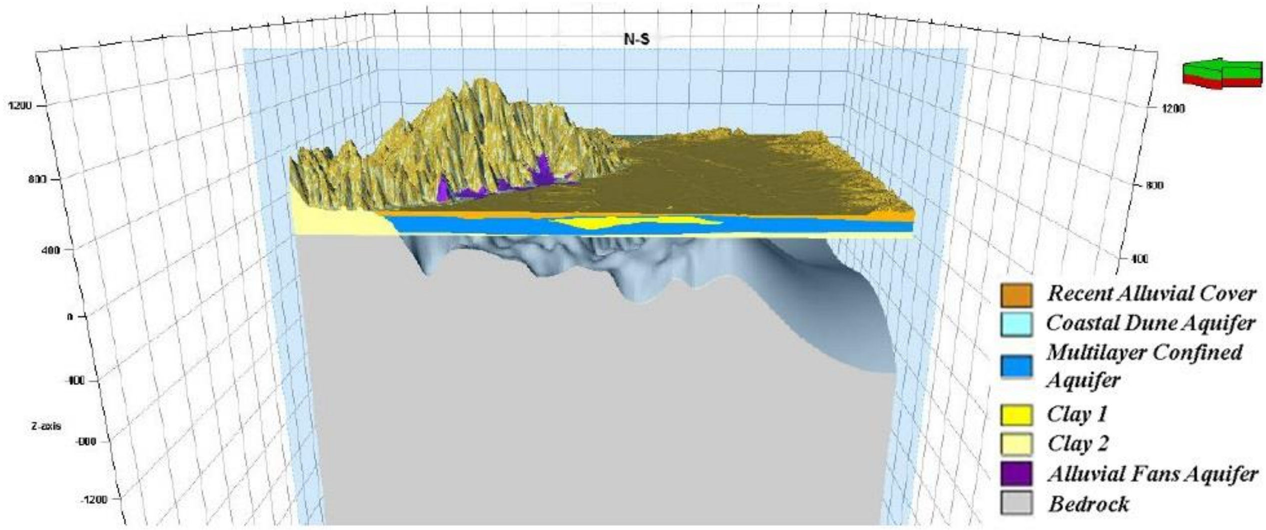

Figure 17: NS model section.

5. THERMOFLUIDODYNAMIC MODELLING

A portion of the hydrogeological model was imported in PetraSim 5, RockWare software with graphical interface for the TOUGH2 family of simulators. (Fig.18, Fig.19, Fig. 20). Values of density, permeability, porosity, conductivity and specific heat were associated to single hydrostratigraphic units.

The top of model, has been set with a temperature of 16°C (mean value of atmospheric temperature in Pisa). For the bottom of the model, represented by bedrock surface, were used temperature values variable, according with the depth and with the local geothermal gradient.

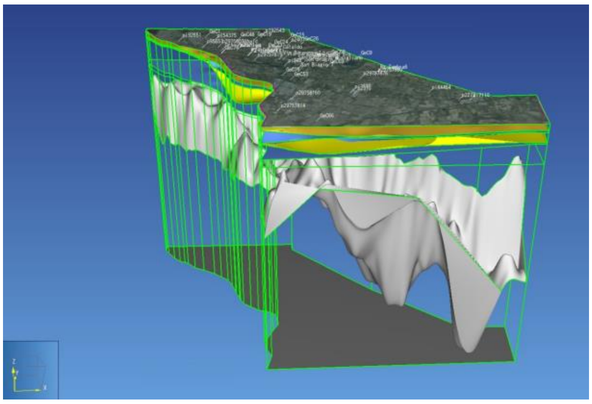

Figure 18: Surfaces imported in PetraSim 5.

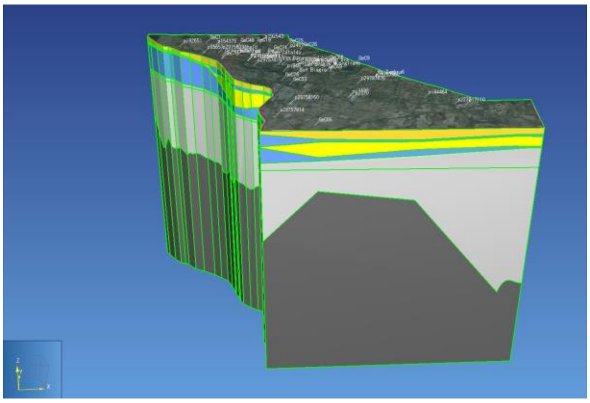

Figure 19: Hydrogeological model in PetraSim 5.

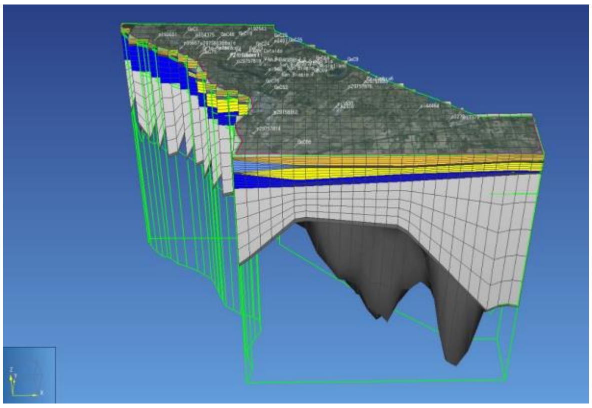

Figure 20: Layers volumes were divided in regular cells on XY plane (500x500 m).

5.1 Simulation results

The simulation distributes temperature values on all the cells of model (Fig.21, Fig.22), according with initial condition and with the lithological and geothermal properties of sediments.

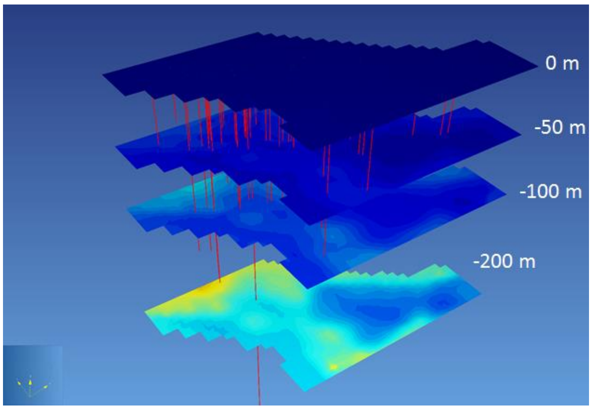

Figure 21: Temperature results, interpolated at specified horizontal slice. In blue cold temperature, in yellow hottest sectors.

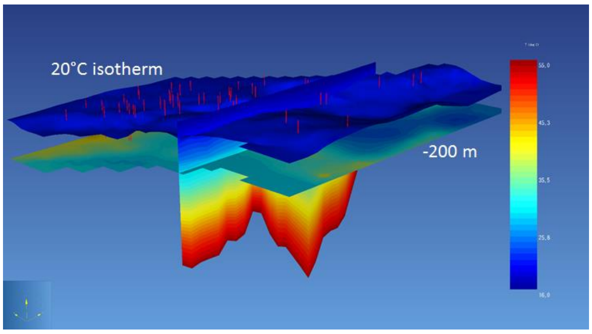

Figure 22: Temperature results. The upper blue surface describes the trend of 20°C isotherm. The horizontal slice below represents temperature values at -200m of depth. The vertical slices show the complete temperature range from the top to the bottom of the model.

Temperatures in the middle of upper Multilayer Confined Aquifer level were extracted from this model (Fig. 23 and Fig. 24). Obtained results are comparable with the temperature collected during field surveys.

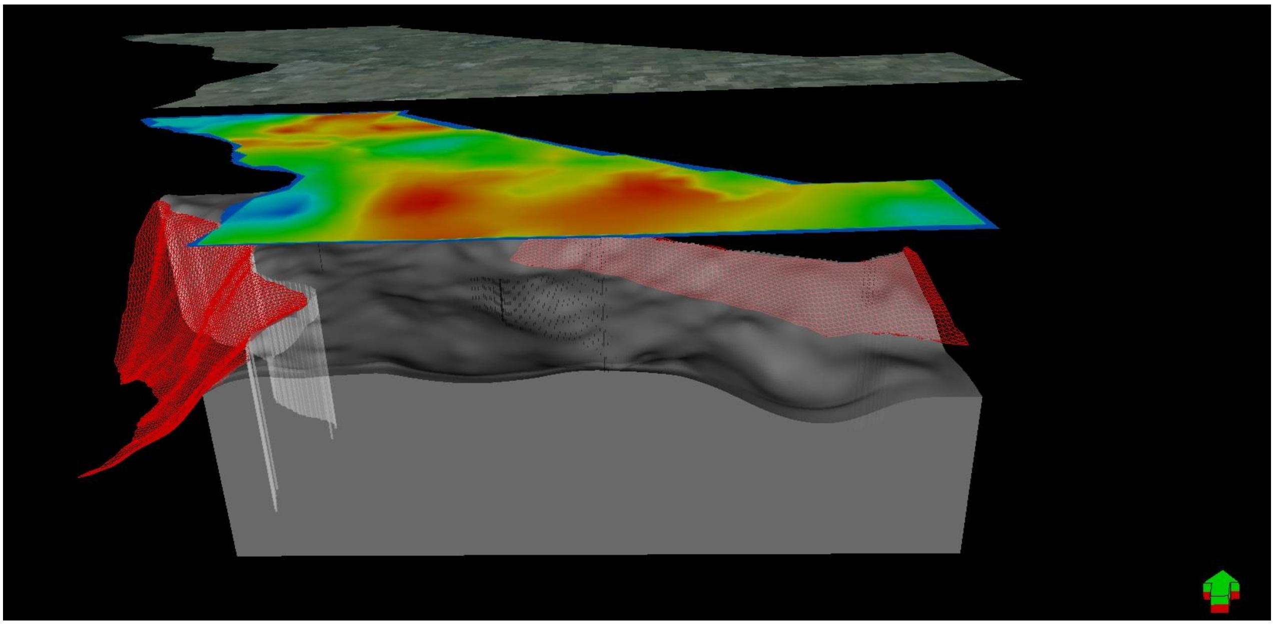

Figure 23: temperature interpolation simulated at the middle of upper MCA level. The hot colours represent areas with higher temperatures. South view.

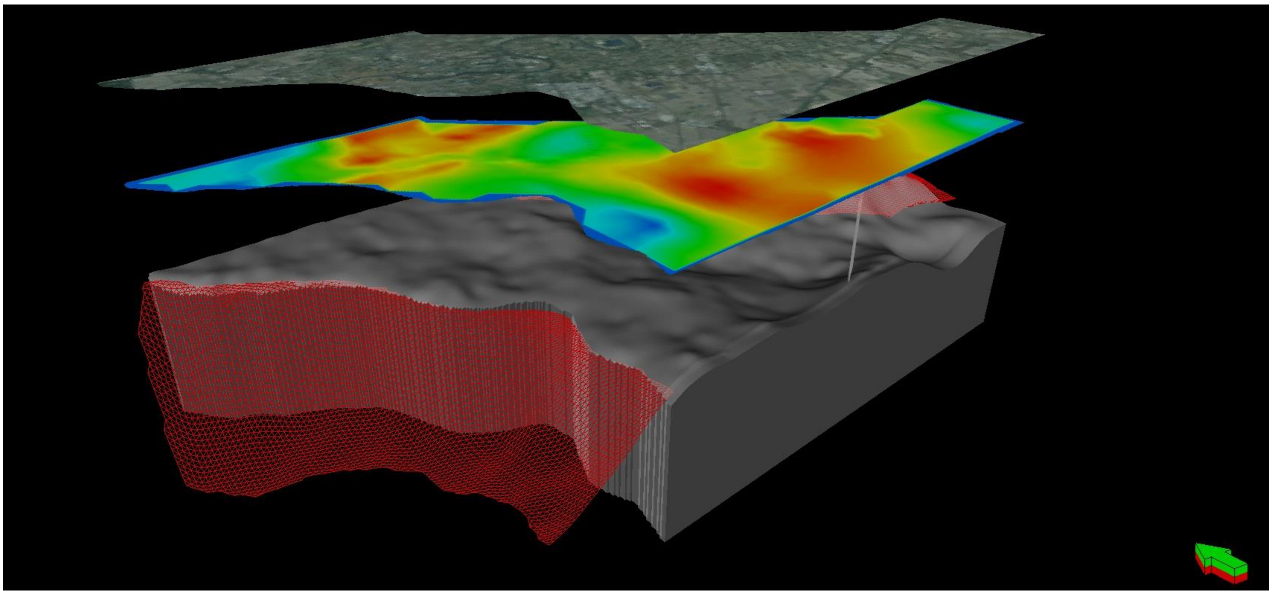

Figure 24: temperature interpolation simulated at the middle of upper MCA level. The hot colours represent areas with higher temperatures. Southwest view.

6. LOCAL IMPLEMENTATION OF PROJECT RESULTS

As well as giving information about the shallow geothermal potential of the whole study area, geological results so obtained will be used to suggest best suitable technologies to use locally available geothermal heat, also taking into account specific users features and requirements. These plant solutions will be indeed identified taking into account the sustainable use of geothermal resources, both under the economy related issues and the environmental point of view, avoiding negative impacts in shallow aquifers.

Project results will be particularly helpful in case of integration into urban plans and/or local energy plans. Municipalities will thus be able to better support their decision-making processes, the preparation of datasheets in SEAPs or other local energy planning tools, thanks to the use of results obtained by the Geo4P Project.

In a time when public acceptance towards geothermal projects the involvement of territories involved in the project has not been overlooked. Local decision makers and technicians of municipalities are indeed being involved, proposing them useful recommendations to allow the promotion of appropriate local energy planning tools and to foster appropriate activities for the use of geothermal resources. Project results will also be made available to citizens and companies who intend to take into account geothermal resources for thermal uses and to produce cool, with economic and environmental benefits.

7. CONCLUSIONS

Once the multidisciplinary methodology for the Geo4P project will be validated, as well as promoting sustainable energy consumption in territories of the Pisan plain, through the use of shallow geothermal resources, it will be made available to stakeholders. This will allow to export and implement these geology and energy related analysis techniques in similar contexts. The Pisan plain is indeed a typical example of alluvial plain, as many others in Italy and Europe.

Projects results will be published by the second half of 2016 at the following web address: http://www.distrettoenergierinnovabili.it/der/s/energea/progetto-geo4p/progetto-geo4p.

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