



Università degli Studi di Cagliari

DOTTORATO DI RICERCA IN SCIENZE DELLA TERRA

Ciclo XXVIII

TITOLO TESI

Analysis of geological parameters for optimization of geothermal probes applied to heat pumps: individuation of a technical and procedural iter.

Settore scientifico disciplinare di afferenza

GEO/05 GEOLOGIA APPLICATA

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Esame finale anno accademico 2014 – 2015

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Abstract

The geothermal heat pump systems have been developed in Italy only during the last few years and today only some regions are investing in this field. In particular, the Tuscany Region and the Autonomus Bolzano Province have promoted the study of these systems with the objective of being able to promote and to disclose in the time this technology. A fundamental aspect for a oculata planning and a greater knowledge of the real predisposition of the territory to the installation is sure the acquaintance of the specification of the geological, geophysical, geotechnical and hidrogeological systems and the parameters that enter at stake. The fundamental parameter in a position to discriminating from a point of view not only economic but also of real thermal yield is the thermal conductivity that the determinated site is able to offer.

This research examines the essential elements that they characterize a system of geothermal heat pump system. It has been to such respect important to study at first the various type of systems from a technical-engineering point of view that of principle operation. In a second phase, the parameters were characterized to consider in phase of thermal characterization, therefore the study of the heat conductivity, the transmission of heat between probe and land, the thermal stability and the thermal behavior of the ground. In particular, regarding the study of the heat conductivity, in the Capitol 3 are given the tools used for the acquisition of such parameter through investigations in the laboratory and in situ.

Successively the normatives elements that regulate the phases of authorization were characterized and analyzed, afterwards planning and installation of the heat pumps systems in the various international and national contexts were considered. A panoramic pre-emptive of the normative picture of the Nations and Regions was drawn to the vanguard in the field of geothermal energy to low and the lowest entalpy. This was dictated by the requirement to define the problematic ones met from the agencies that have legislated in matter and to put of in evidence virtues and criticality. The checks carried out both in terms of legal and procedural provided an

inspiration for the creation of authorization processes and procedures for the installation of various types of geothermal heat pump systems in various geological contexts, in order to assess the possible impacts that these systems can cause on the environmental matrices.

Central part of the research project is the study of the heat conductivity, parameter key for the development of a useful cartography in this field.

It was decided to perform a literature search of that parameter, in order to process and then compare the data of thermal conductivity obtained from detailed investigation carried out in a pilot site and found through the stratigraphy. In fact, nowadays the available data measured on lithologies of the Italian territory are few and hard to find.

The literature research has allowed later to thermally classify the lithostratigraphic units of the geological legend of Sardinia Region, in scale 1:10000, one of the few regions to boast of an updated geological territorial Continuum.

The performed research is based on the possibility of drawing up maps of the thermal conductivity from the investigation and trying different methods, ultimately, to compare the two approaches.

The first method concerned a detailed investigation of the pilot site located in proximity of Lago Baratz (Municipality of Sassari) through a geological and hidrogeological framework, a pedologic survey and at last, investigations of geoelectrical type. The detailed study has afforded to frame the site potentially interesting to the installation of a system being afforded to characterize from a thermal point of view the area. Therefore, it has been possible to calculate the value of thermal yield for 1800 – 2400 hours of operation of the system in modality cooling and heating.

By means of the second method of calculation, it was considered appropriate to disclose a test personally conducted in the territory of the Arezzo Province. Thus, it is reported below an example of processing of the data of thermal conductivity from the stratigraphic information. Giving the high number of information (about 12566 stratigraphic data points), it was decided to perform a first test in order to verify and consolidate the processing procedure.

In the Chapter 7 all the passages executed for the elaboration of the thermal conductivity data from the stratigraphic information for the provincial territory are illustrated. Three maps for the depths of interest of 30, 60 and 100 meters Were elaborated. Successively the respective papers of the errors were calculated, allowing to divide the province territory in areas for which it can be identified different planes of address to be followed in the process of thermal characterization.

The last chapter contains a possible synthesis of a procedural iter initially for defining the parts that enter as stake in phase of realization of a system. They will follow some detailed lists reported to the criteria to follow, in sensitive areas, for the study and the control from a thermal point of view, of a potentially apt site to the installation of a system

The entire research aims to set an example as well as the application of geological information at a scale of detail, the stratigraphic information and spread knowledge of the parameters involved can be combined to create thematic maps useful for public authorities and citizens.

Riassunto

I sistemi di geoscambio si sono sviluppati in Italia solo negli ultimi anni e ad oggi solo alcune regioni stanno investendo in questo settore. In particolare, la Regione Toscana e la Provincia Autonoma di Bolzano hanno promosso lo studio di questi sistemi con l'obiettivo di poter promuovere e divulgare nel tempo questa tecnologia.

Un aspetto fondamentale per una progettazione oculata e per una maggiore consapevolezza della reale predisposizione del territorio all'installazione è sicuramente la conoscenza delle caratteristiche tecniche degli impianti e dei parametri geologici, geofisici, geotecnici ed idrogeologici che entrano in gioco. Il parametro fondamentale in grado di discriminare da un punto di vista non solo economico ma anche di reale resa termica è la conducibilità termica che un determinato sito è in grado di offrire.

Questa ricerca prende in esame gli elementi essenziali che caratterizzano un sistema di geoscambio. È stato a tal riguardo importante studiare dapprima le diverse tipologie di sistemi sia da un punto di vista tecnico-ingegneristico che di principio di funzionamento.

In una seconda fase sono stati individuati i parametri da considerare in fase di caratterizzazione termica, quindi lo studio della conducibilità termica, della trasmissione di calore tra sonda e terreno, della stabilità termica e del comportamento termico del terreno. In particolare, per quanto riguarda lo studio della conducibilità termica, nel Capitolo 4 si riportano gli strumenti utilizzati per l'acquisizione di tale parametro tramite indagini in laboratorio ed in situ. Successivamente sono stati individuati e analizzati gli elementi di normativa che regolano le fasi di autorizzazione, progettazione ed installazione degli impianti a pompe di calore nei diversi contesti internazionali e nazionali.

Una panoramica preventiva del quadro normativo dei Paesi e Regioni all'avanguardia nel settore della geotermia a bassa e bassissima entalpia, è dettata dall'esigenza di definire le problematiche incontrate dagli enti che hanno legiferato in

materia e metterne in evidenza pregi e criticità. I riscontri effettuati sia dal punto di vista giuridico che procedurale hanno fornito lo spunto per la creazione di iter autorizzativi e procedurali per l'installazione dei vari tipi di sistemi di geoscambio nei diversi contesti geologici, al fine di valutare i possibili impatti che questi sistemi possono provocare sulle matrici ambientali.

Parte centrale del progetto di ricerca è rappresentato dallo studio della conducibilità termica, parametro chiave per lo sviluppo di una cartografia utile in questo settore.

Al fine di elaborare e successivamente poter confrontare il dato di conducibilità termica ottenuto da indagini di dettaglio eseguite in un sito pilota e quello ricavato dall'elaborazione stratigrafica, si è ritenuto opportuno eseguire una ricerca bibliografica di tale parametro. Infatti, ad oggi i dati a disposizione misurati su litologie del territorio italiano sono pochissimi e di difficile reperimento.

La ricerca bibliografica ha permesso successivamente di classificare da un punto di vista termico le Unità Litostratigrafiche egeografica geologica in scala 1:10000 della Regione Sardegna, una delle poche regioni a vantare di un Continuum geologico territoriale aggiornato.

La ricerca svolta si basa sulla possibilità di elaborare carte delle conducibilità termiche a partire da indagini e metodi differenti cercando, in ultima analisi, di confrontare i due approcci.

Il primo metodo ha visto l'indagine di dettaglio del sito pilota ubicato in prossimità del Lago Baratz (Comune di Sassari) attraverso un inquadramento geologico, idrogeologico, un rilevamento pedologico ed infine, indagini di tipo geoelettrico. Lo studio ha permesso di inquadrare in modo preciso il sito potenzialmente interessato all'installazione di un impianto permettendo di caratterizzare da un punto di vista termico l'area. È stato quindi possibile calcolare il valore di resa termica per 1800 – 2400 ore di funzionamento dell'impianto in modalità raffrescamento e riscaldamento.

Con il secondo metodo di calcolo, si è ritenuto opportuno illustrare un test eseguito personalmente sul territorio della Provincia di Arezzo. Si riporta quindi un esempio di elaborazione del dato di conducibilità termica a partire dall'informazione stratigrafica. Avendo a disposizione un numero elevato di informazioni (circa 12566

punti stratigrafici), si è pensato di eseguire un primo test al fine di verificare e consolidare la procedura di elaborazione.

Nel Capitolo 8 si illustrano tutti i passaggi eseguiti per l'elaborazione del dato di conducibilità termica a partire dall'informazione stratigrafica per il territorio provinciale. Sono state elaborate a tal riguardo tre carte per le profondità di interesse di 30, 60 e 100 metri. Successivamente sono state realizzate le rispettive carte degli errori che hanno permesso di suddividere il territorio provinciale in zone per le quali si possono individuare differenti piani di indirizzo da seguire in fase di caratterizzazione termica.

Nell'ultimo capitolo si riporta la sintesi di un possibile iter procedurale definendo inizialmente le parti che entrano in gioco in fase di realizzazione di un impianto. Seguiranno alcune specifiche riferite ai criteri da seguire, in aree sensibili, per lo studio ed il controllo da un punto di vista termico, di un sito potenzialmente adatto all'installazione di un impianto.

L'intero lavoro di ricerca intende così costituire un esempio applicativo di come l'informazione geologica ad una scala di dettaglio, le informazioni stratigrafiche diffuse e la conoscenza dei parametri in gioco possono essere combinate per realizzare cartografie tematiche utili per impieghi pubblici e privati.

1 The geothermal heat pump systems

In an energetic scenario that still shows a strong dependency on fossil fuels, renewable sources represent a sustainable response, also in the long period, allowing to significantly reduce greenhouse gas emissions, develop local and decentralized energy resources, stimulate new high technological industries and reduce dependence on energy imports.

Amonog renewable energies available in Italy, geothermal energy has been the first to being taken advantage of, and this is tied to the endogenous heat of the Earth.

This heat, generated by the Earth's core and from the decay of radioactive isotopes present mainly in the mantle, is distributed unevenly in the crust. This distribution is due both to the heterogeneity of the earth's crust in the uprisings of movement of fluids at different temperatures (magmatic, hydrothermal and meteoric). The temperature increase in the Earth's crust at different depths is known as geothermal gradient and, in Italy, this value is estimated to be 3 °C/100 meters (Toro & Ruspandini, 2009).

The local variation of geothermal gradient implies that the geothermal resource is not the same for different areas of the earth's surface.

The most widely used classification of the resource is based on the concept of enthalpy of the fluids that transfer the heat from deep hot rocks to the surface. Such magnitude, usually indicated with the H letter, is a state function that expresses the amount of energy that a thermodynamic system can exchange with the environment, and it is defined by the sum of the internal energy and the product between the volume and pressure of a system.

Depending on the enthalpy, Muffler & Cataldi (1978) divide the geothermal resources in:

- high enthalpy, with fluid temperature exceeding 150 °C;
- medium enthalpy, with fluids at a temperature comprised between 90 °C and 150 °C;

- low and very low enthalpy, with fluids at a temperature below 90 °C.

In areas where the geothermal resource is characterized by high enthalpy, the high heat of fluids can be directly exploited for the production of electrical energy by means of electric power plants. Our country is, as noted, to the vanguard in this field: in the early twentieth century, the Larderello's plant has started the production of electricity from geothermal energy and still continues.

Thirty thermal power plants (Source ENEL) are currently working in Larderello-Travale-Monterotondo complex and Monte Amiata complex. In the rest of the country, the geothermal resource is mainly characterized by low and medium enthalpy.

Other countries like Sweden, Switzerland, Germany and the United States were among the pioneer countries in the use of plants that can be air-conditioned environments by exploiting the low enthalpy geothermal energy. These systems are called "geoexchange installations" or "geothermal probes coupled to the heat pumps"; then for their operation they do not need high temperatures in the subsoil, but take advantage of the ownership of the land to maintain a constant temperature throughout the year from 10 meters deep.

Also in Italy, during the last few years, an increase of the demand for installation of these systems is being recorded due to probably to the exit of the Legislative Decree n.22 of the 2/11/2010 that recognizes this system like "renewable". The deployment of geothermal heat pump is very important from the environmental point of view because lets the replacement of traditional heating systems that use natural gas boilers, whose combustion is a source of pollution. Another advantage of the geothermal heat pump systems is that they are also able to conditioned the environments in the summer, replacing the summer air conditioners that have a haigh consumption of electrical current. Although they are recognized as systems of renewable energies, it is important to specify that draft of a resource in a position to guaranteeing to "energetic saving": if the thermal capacity of the land is considered a renewable resource, the use of the heat pump and the movement of fluids inside the probes, impose the use even if limited, of electrical power.

1.1 Principle of operation

At the base of the functioning of the geothermal heat pump is the characteristic of the subsoil to maintain a constant temperature throughout the year.

In fact, despite the first few meters of the subsoil are affected by seasonal variations in temperature, to depths greater than 15 m about the soil temperature stood at around 10-12 °C (Figure 1.1).

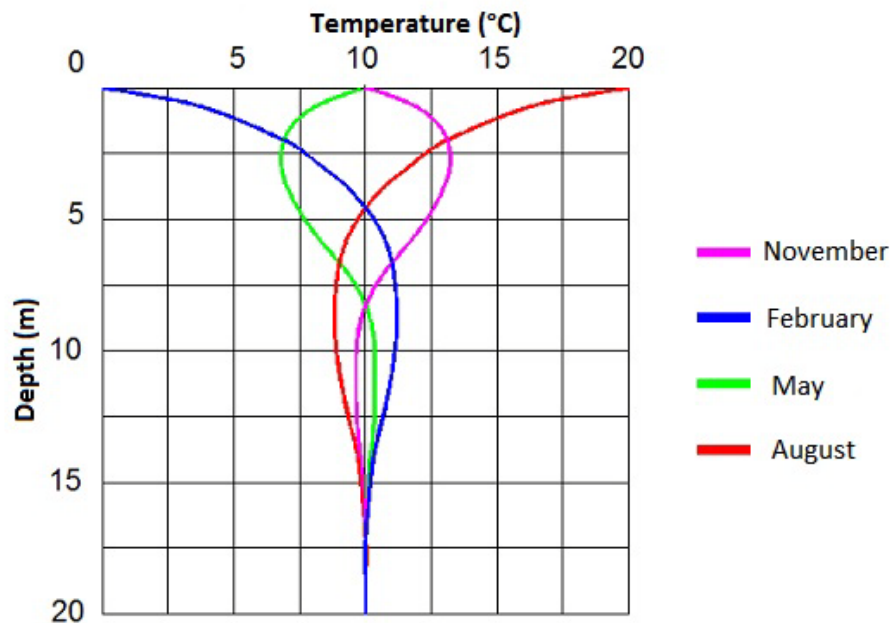


Figure 1.1 - Distribution of the temperatures to varying of the depth during four months of the year (from Tinti, 2008).

Fundamental part of a plant of geothermal heat pump is the system of probes in that, it allows the transfer of heat among the subsoil and the heat transfer fluid that it circulates inside them (Figure 1.2).

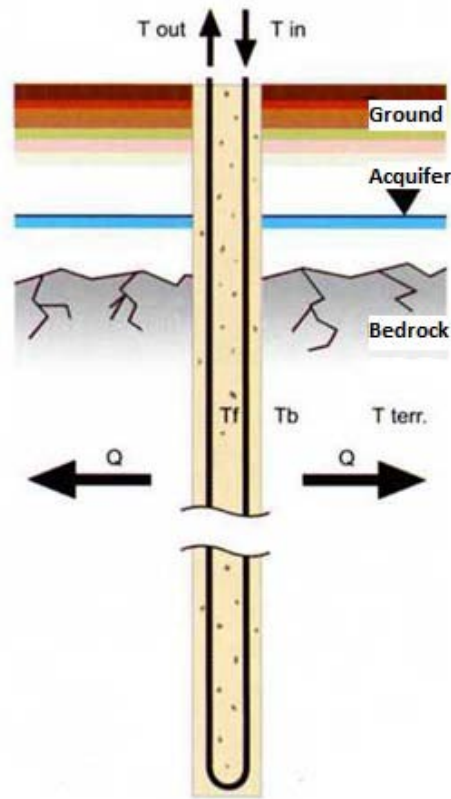


Figure 1.2 - Diagram of transmission of heat in a vertical probe where, T_f is the temperature of the fluid while, T_b is the average temperature of the soil in the wall of the probe (from Tinti, 2008).

It is necessary to distinguish between the heat exchange that occurs in the winter and that which occurs in summer (Figure 1.3). Whereas the heat transfer always occurs from the warmer body to the colder, as dictated by the First Law of Thermodynamics, and that the temperature of the subsoil over the 15 m depth is equal to about 10-12 °C, it happens that: in winter the land transfers heat to the fluid flowing within the probe, while in summer it is the fluid that flows through the probe to release heat to the soil.

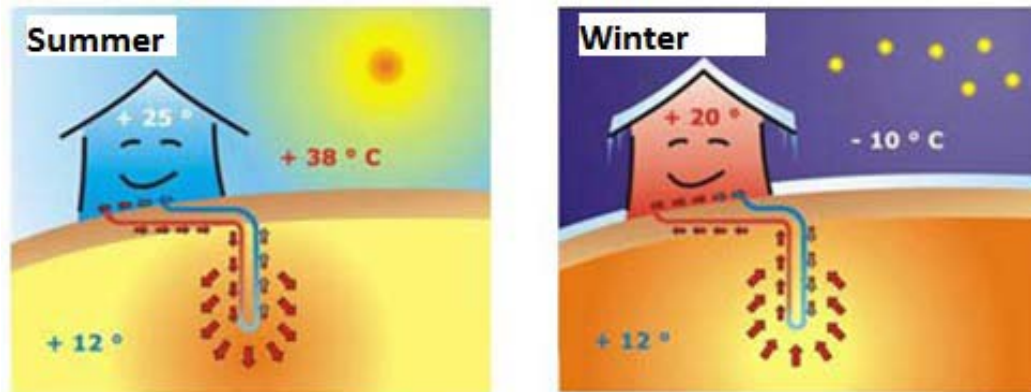


Figure 1.3 - Means for heat exchanging between the ground and the circulating fluid within a borehole heat in winter and in summer (the large red arrows indicate the direction of heat transfer).

In both cases the fluid that flows inside the probe, after having exchanged heat with the ground, it returns in surface and it comes to contact with the cooling fluid of the heat pump that will allow of condition the building. In winter, when the system is used in heating modality, the cooling fluid exchanges heat quantity coming from the heat-transfer fluid. At this point, the heat pump, making the "work" is able to condense and compress the fluid in according to the reverse Carnot cycle, and release it through the distribution system to the rooms to be heated. In summer instead, the heat pump, inverting own cycle is able to cool the rooms. In fact, the cooling mode heat is transferred from the environment to be cooled to the subsoil.

A fundamental aspect is surely the economic convenience that the geothermal heat pump systems are able to offer, when compared with traditional systems of air-conditioning. The efficiency of heat pumps depends on the temperature difference (ΔT) between the temperature of the source (the ground) and that of the environment to be conditioned. In detail, the air heat pumps does not succeed to reach yields comparable to those "geothermal" as, using as source the air does not succeed to guarantee constant yields during all the year. The source "air" in fact, endures strong oscillations employee from the seasonal variations (Figure 1.4). For that reason, the geothermal heat pumps are very more efficient of the air heat pumps.

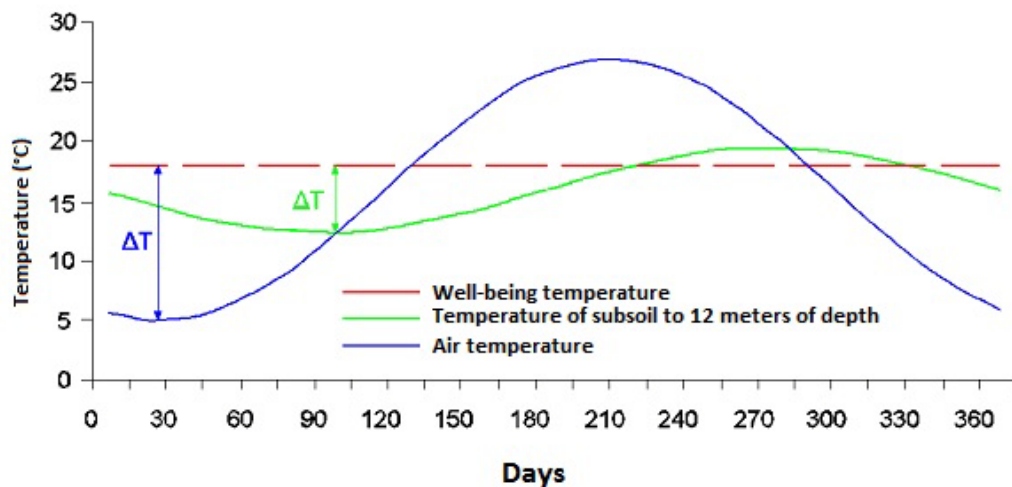


Figure 1.4 - Course of the temperature of the soil and air during the year and relative Δt function of the temperature of well-being (from Pasquini, 2008).

At this point, it is clear why the characteristic of the subsoil to maintain a constant temperature, as mentioned at the beginning of this paragraph, is of fundamental importance to ensure the proper functioning of this type of plant. A geothermal probe system consists, in general, of three parts (Figure 1.5):

- **heat exchanger:** is a geothermal probe which is installed inside the ground, constituted by tubes (mainly in High Density Polyethylene, HDPE probes) inside which is made to slide a thermal carrier fluid;
- **heat pump:** is a thermal machine which, using a certain quantity of energy, allows the transfer of heat from a colder body to a warm environment;
- **heat distribution system:** is formed by elements that allow the exchange of heat with the environments to be conditioned. Generally, for geothermal heat pump systems are use radiant panels.

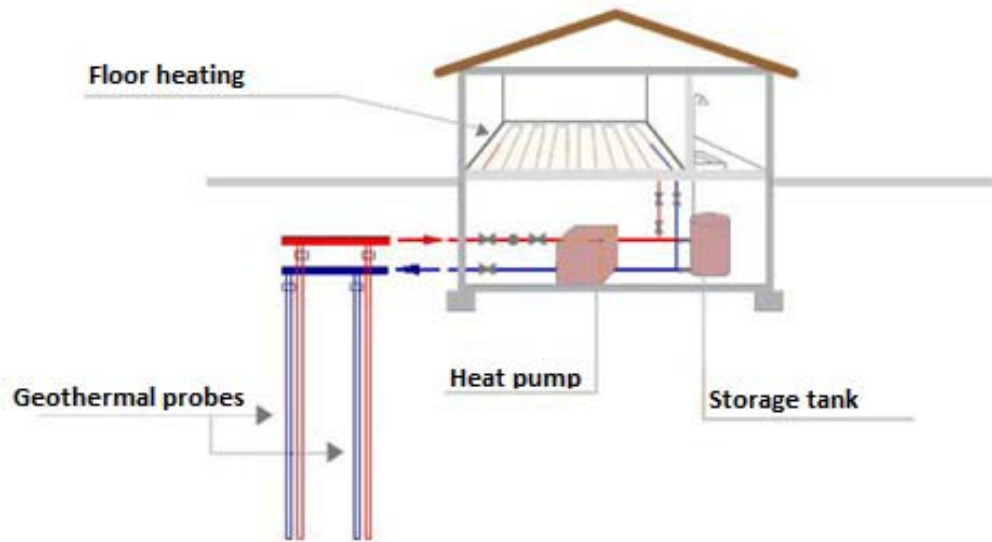


Figure 1.5 - Constructive scheme of an installation of geothermal heat pump (from www.tekneco.it).

1.2 Types of geothermal heat pump systems

The system types (Figure 1.6) are divided into:

- closed loop system;
- open loop system.

The closed loop systems are part of the vertical and horizontal geothermal probes. These systems are so called because for their operation is not provided for the use of ground water, while in contrast to the open loop systems it involves the use of water that can be drawn directly from the aquifer or even from water surfaces free as rivers and lakes.

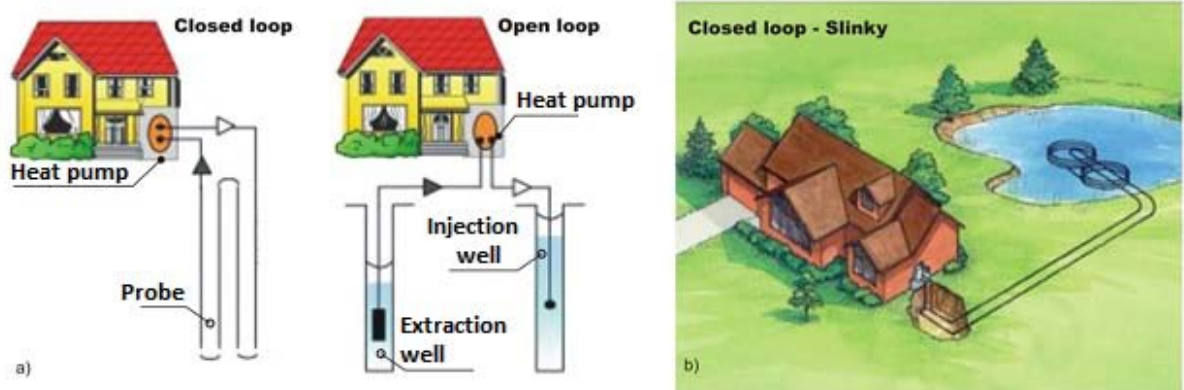


Figure 1.6 - a) Schematic of closed and open loop systems; b) Closed loop systems which heat exchange with the water surface (from www.geoexcel.com).

Among the closed loop systems, even if not properly geothermal, they may be inserted the systems which make heat exchange with the water surface. For this purpose basins or lakes of a certain depth (minimum 5-10 m) are necessary for ensuring the isolation from solar radiation of closed collectors (a circular geometry, slinky) immersed inside of the water mass (Figure 1.6). These systems if well designed can ensure yields comparable to those of the horizontal closed loop systems. The vertical geothermal probes (Figure 1.7) are among the most popular in Europe given the reduced spaces that go to interest. The average maximum depth varies from region to region and depends, obviously, on the type of concerned land.

In Germany, for example, you can not go beyond 100 meters depth (limit established by law VDI4640); in Switzerland instead, where the density of vertical heat exchangers is the highest in the world, it is from 50 to 350 meters with the tendency to increase the depth to exploit the higher temperature of the subsoil.



Figure 1.7 - Schematization of the vertical geothermal probes (from www.tekneco.it).

The mainly mode adopted for the installation of vertical geothermal probes consists of the insertion of the same in wells drilled specifically for the purpose.

The installation yard requires a space for maneuver not less than 60 m² in order to allow the drill to operate smoothly (Figure 1.8).

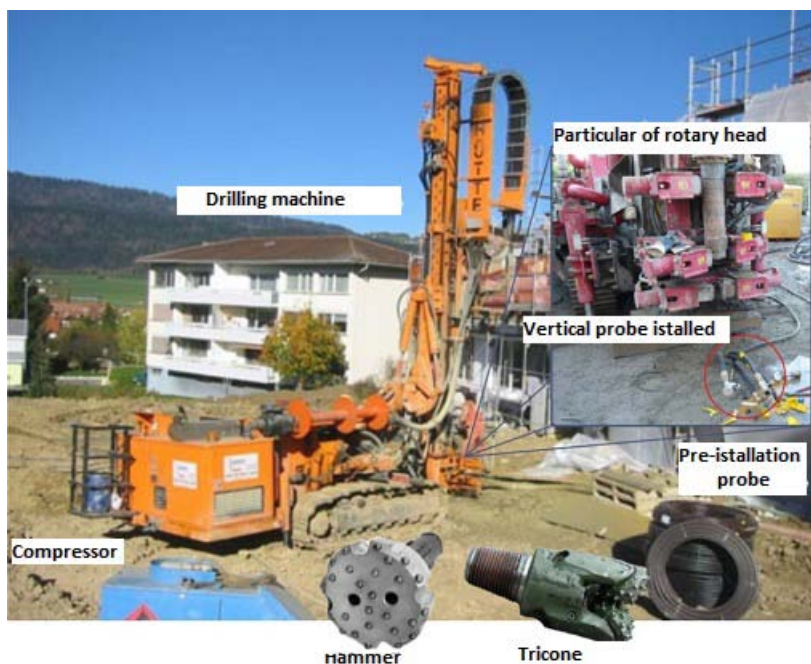


Figure 1.8 - Site of installation for vertical probes.

The perforation, usually realized in core destruction, involves the use of a series of rods screwed in succession to the ends of which are brought the cutting tool.

The rock types in the subsurface determine the choice of the latter and the adoption or not of a coating in support of the walls of the hole.

The diameter of the perforation is about 140-150 mm. In the presence of compact lithologies is used a downhole hammer actuated by compressed air. The debris products are brought to the surface from the air, in the space between the walls of the hole and the drilling rods. It is used, instead, to perforation by means of tricone with the circulation of water or bentonite, in the presence of little compact lithologies (gravel, sand, silt, clay and soft rocks). The removal of debris from the bottom of the hole is performed by the drilling fluid, which brings them back to the surface where they are discharged in a suitable collection tank and left to decant to allow the reuse of the drilling fluid. In the case where it is necessary to resort to the coating of the hole, the shirt will accompany the drilling and will parade without any rotation only after the insertion of the probe. Alternatively you can use bentonite as drilling fluid, which ensures the support of the walls of the hole, avoid the use of the coating.

The corrected realization of the hole (rectilinear and with regular walls) is a fundamental aspect of guarantee a good operation and for this reason, there is a need for remarkable attention in all its phases. Eventual shunting lines from vertical in phase of perforation or the scabrous and excessive irregular walls can hinder if not to prevent it puts down it of the same probe (Figure 1.9). In particular, it is frequent that during the extraction of the covering the shirt is rotated in order to facilitate of the escape being provoked but the screwing of the tubes of the probe. This screwing of the tubes unavoidably carries to compromise the operativity.

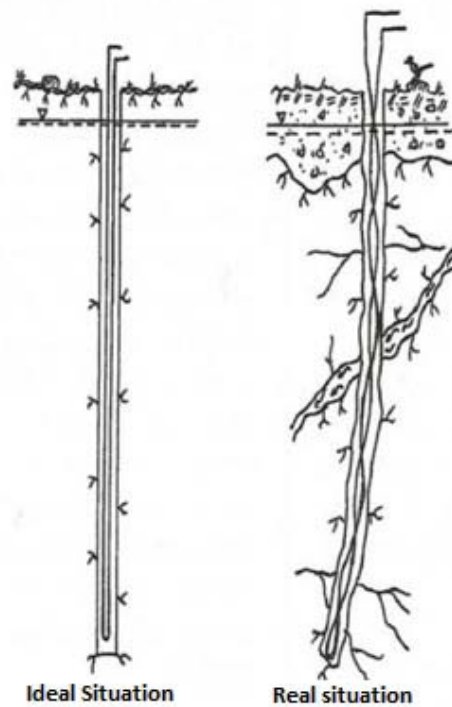


Figure 1.9 - Realization of borehole (from Tinti, 2010).

Once reached the wished depth is proceeded with the installation of the probe. This is constituted by two essential elements: the heat exchanger and the filling material.

The types existing of vertical heat exchangers are two (Figure 1.10):

- U heat exchangers (simplex or duplex)
- coaxial heat exchangers.

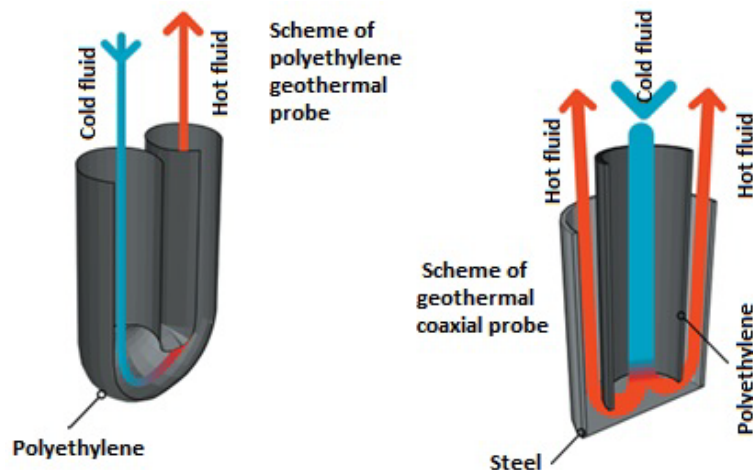


Figure 1.10 - Types of heat exchangers.

The mainly used heat exchangers are those to U (Figure 1.11a), which in turn are divided into:

- single U (simplex): of simple installation and greater reliability;
- double U (duplex): continuity of exercise in case of occlusion of a branch; the thermal equivalent resistance of the well is smaller of the probes to single U. the diameters of the tubes is smaller regarding those to single U with consequent increase of heat exchange. With the choice of opportune diameters minors can themselves be had losses of cargo to capacity parity.

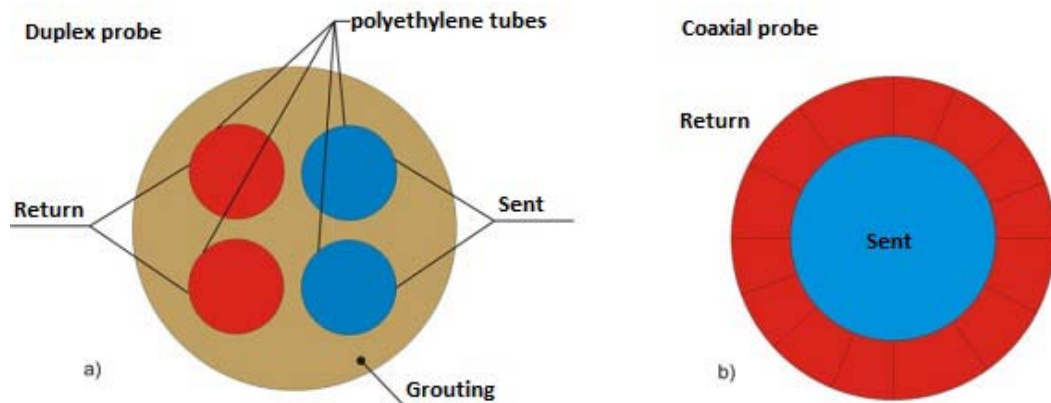


Figure 1.11 - a) double-U vertical probe (duplex); b) complex coaxial probe.

The coaxial exchangers instead are subdivided in:

- simple coaxial tubes;
- complexes coaxial tubes (Figure 1.11b).

They consist in two concentric tubes in which the sent pipe is inserted in return, or vice versa. It is clear that the heat exchange with the ground will be mainly in the outer pipe, causing an increase of the thermal resistance in the hole with respect to the U type exchangers. Of this type of probes are studying the new materials and new geometries to assert its use. From the point of view of the technical specifications the material are made the probes must combine high capacity of heat exchange with a good operational resistance.

Today almost the totality of the heat exchangers is in high density polyethylene (PEAD or HDPE), PE100 PN 10/16, that are normally used for the water network or networks antifire,, detectable from this last exclusively for the absence of marks (this

problem is found above all in the horizontal systems). Notation "PN 16" indicates that the tube is guaranteed in order to maintain the own mechanical characteristics until 16 bars (is considered that on the foot of the probe to 100 m of depth, the pressure is that of 100 m of water column corresponding to 10 bars).

Of the valid alternatives to the HDPE available on the market are the Peax (reticulatedpolyethylene) and the Pe-RC (resistant to crack). The first has a greater resistance to point loads and a lower heat conductivity of the HDPE, however guaranteeing the operation down to a temperature near to 90 °C. The Pe-RC, instead, associates to the same conductivity as HDPE a better mechanical behavior in terms of both concentrated loads that of traction. The temperature range in which it operates, however, is lower than that of Peax.

The choice of the diameter and the thickness of the tubes is anything but simple because the designer finds himself to having to conciliate various requirements. The thickness of these tubes in fact, would have to be smallest possible in order to favor the heat exchange while, to the extremity of the pipe, the diameter would have to be greater in order to guarantee an adequate mechanical resistance. The diameter moreover, must be large in order to limit the pumping power, but sufficiently small to assure a turbulent regime. A major diameter of the tube determines greater costs: it would serve greater antifreezing solution and it would create put up installation difficulty.

The most used pipes for polyethylene vertical probes are of the type: PE 100 SDR 11 PN 16 with an outside diameter of between 32.0 and 40.0 mm, and thickness of between 2.9 and 3.7 mm.

A very important element of the "U" heat exchangers is represented by the foot or base of the exchanger itself, point in which happens the reversal of the motion regarding the vertical one of the heat-transfer fluid. Draft in short of a "U" junction that connects the tubes of sent and of return. Like emphasized previously, the severe operating conditions of the probe impose a sure shrewdness in the realization of this element. They must be avoided reductions of the sections of passage of the fluid and right angles that produce load losses. Moreover, the form must favor the insertion of the probe in the borehole avoiding lateral projections or sharp edges.

The first installations saw the assembly of the heat exchanger directly in yard where with appropriate welding machines the pipes joined of sent and return with a "U" or more frequently with "Y" connection (Figure 1.12). In the latter extension downwards of the junction was closed with a flat element provided with rings which can be fixed to the ballast. After closing was to assume the role of "tank" for the filing of any impurities present in the circuit.

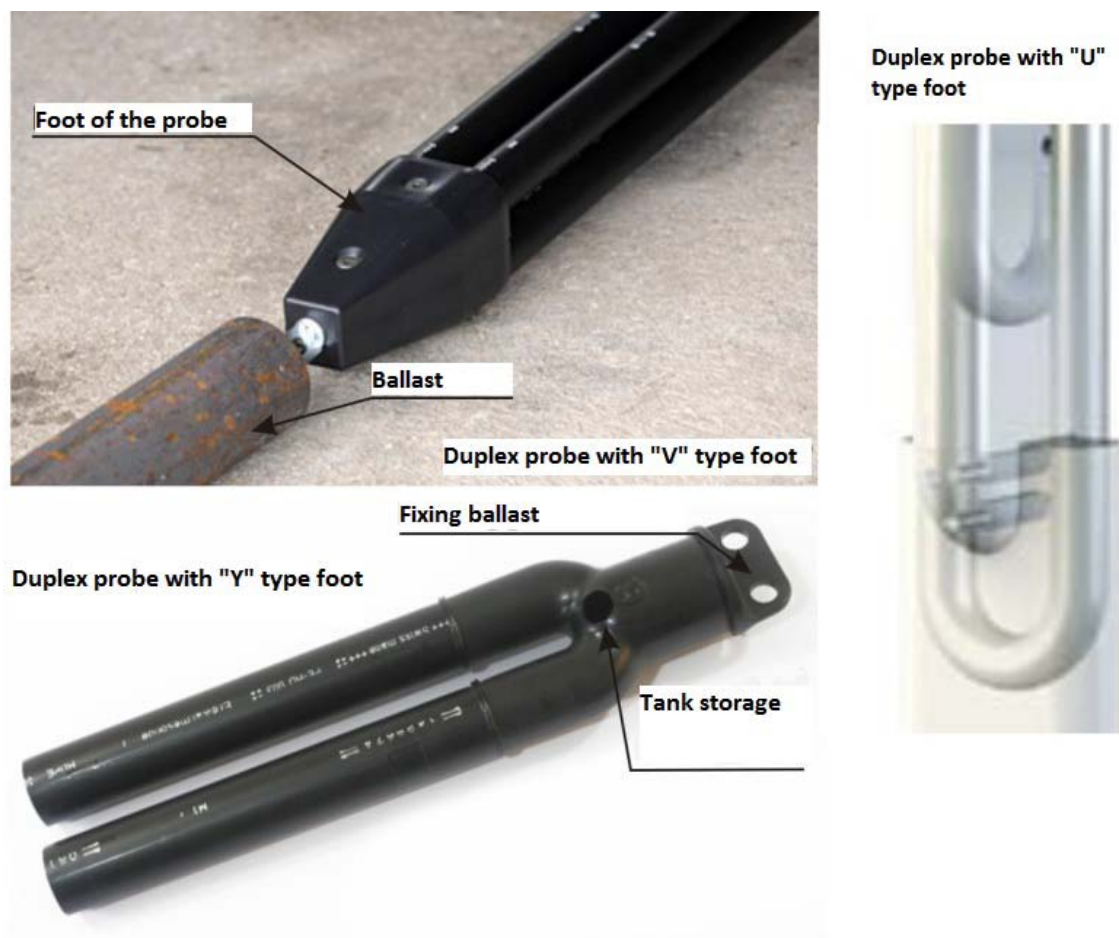


Figure 1.12 - Foot of vertical probes.

With the refinement of techniques have been proposed several solutions to speed up the assembly operations with contain the costs (for example, the electro-welded sleeve or electrofusion foot, unique collector systems only in duplex). However, against the investment made for this type of system, the risks legacies to a bad

assemblage have pushed the manufacturers societies to supply probes already assembled, provided with appropriate guarantee certificate (for example Rehau).

To obviate thermal interference that might develop between the flow pipe and the return pipe of some manufacturers recommend the use of appropriate spacers. Draft of plastic elements that provided with appropriate lodgings to joint for the pipes of the probes and eventually for the tubes of injection of the filling material of the hole. They are equally spaced, the whose value is object of strong discussions (in any case is advised never exceed 10 m), are installed at the time of installation of the heat exchanger in the hole. If the well is realized with the aid drilling fluid (bentonite or water) the installation of the probe demands the application of a ballast to the foot in order to contrast the floatation thrust that the fluid exercises in the pipes. Moreover, the same probe is filled up of water in order to increase of its weight. The ballast is a cylinder of the 8-10 cm diameter in iron or concrete and of variable length in according to the necessary weight. Some operators have previewed systems for its recovery, but being minimal the gain and elevated the risks of damaging of the probe, is preferred to consider it material to lose. Therefore it is necessary not to underrate the eventual environmental impact that the materials could have, above all if the aquifers used like hydropotable resource are intercepted. Once inserted the probe in foro must be proceeded with the cementation of the same one.

If it is opted for a filling with loose material, the installation of the probe can be dry for fall or by pumping a mixture with water. In this case it is useful to use of an injection tube and to proceed with the filling of the hole from the low towards the high.

The injection of the mortar will be carried out through a tube of injection in HDPE in a position to putting up with pressures of 20 bars. The tube, usually to lose, is fixed to the probe and allows the filling from the hole bottom to the soil level taking care to flow on the surface the material as verification of clogging of all cavities present (Figure 1.13). In case of very deep perforations it can be necessary to install more tubes than injection to different depth, one to deep hole, the other between 50-100 meters of deep. Eventual top up will have to consider the times of machinability of the mortar. These if too much tightened would produce a viscosity

increase such to prevent an optimal cementation of the hole with consequent decrease of performance of the probe.



Figure 1.13 - Operations before the installation (left); probe after the injection of the cement (right).

Moreover, a corrected cementation affords a reduction of the difference between the static pressure of the heat-transfer fluid that outside circulates in the tubes and the pressure of the same tubes. An incorrect cementation of the borehole is not immediately visible but it manifest itself in the course of the years with a yield of the not optimal heat pump.

At completed probe, before to proceed to the connection with the remainder of the system, it is necessary to execute an estate test. This test consists in the injection of air or water to a determined pressure (10 bars for the air increased of 0.1 bar/m beyond 80 m of depth; 6 bars for the water) and observe the variation in a predetermined time (minimal 1 hour for the air and 4 hours for the water). If the losses of pressure are greater than the tolerances (0,2 bar for the air; the 0.5 for the water) the probe will have to be abandoned. Per ovviare agli inconvenienti e ai costi legati alla realizzazione del perforo sono state sviluppate differenti tipologie di sonde.

In commerce are available steel coaxial probes, fixtures in the land with a equipment of thrust similar to that used for the static penetrometers (Figure 1.14). With this technique is guaranteed a better connection of the probe-land system in this way avoiding the cementation and consequently reducing the times of

realization. Against this type of probe incurs in a greater cost and a reduction of the length.

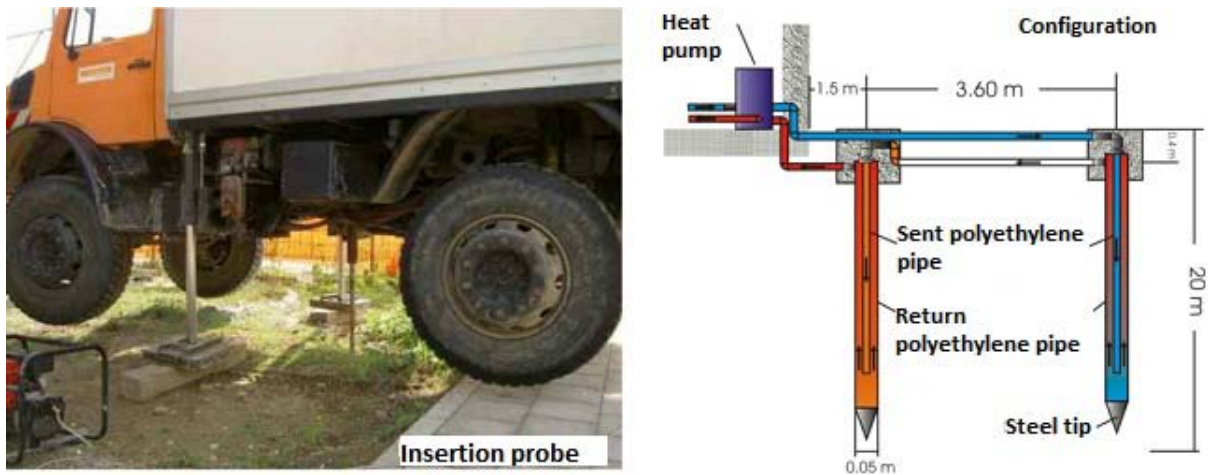


Figure 1.14 - Coaxial probe RED 8.

In the case of a request for thermal power elevated by the heat pump, and then the building to be air conditioned, in place of a drilling too deep it is preferred to provide a system to more geothermal probes.

These probes cannot be inserted in the land in accidental way as, because the exchanger generates in the land a kind of thermal basin in which the temperatures assume a funnel shape. It is therefore opportune, at the moment of the installation of the probe, to consider the effect of thermal interference between the various exchangers. The indicative distance in order to reduce the interference is not less and than 4 m for one cold climate and is not less than 6 m for one warm climate.

The most common geometries for the arrangement of the probes are consist of parallel rows possibly phase shifted like an honeycomb (Figure 1.15).

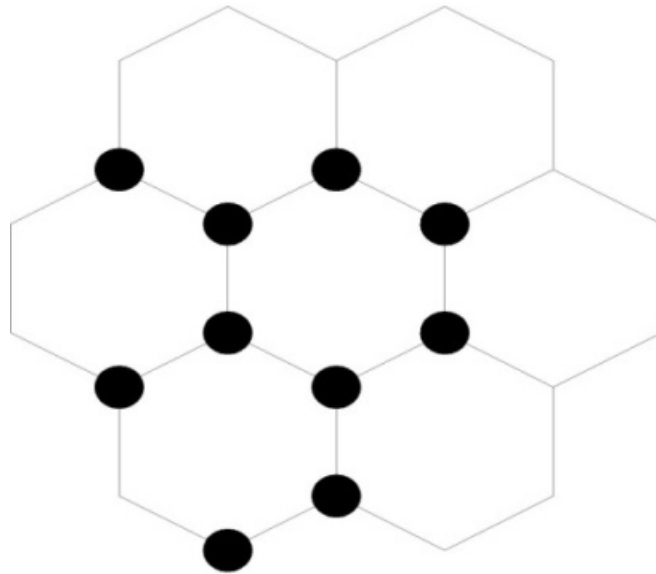


Figure 1.15 - Representation of the disposition like a honeycomb of vertical geothermal probes.

There are countless possibilities for the disposal of the probes (Figure 1.16): configurations on line, like an L (single or multiple) or rectangular closed or open, like an U.

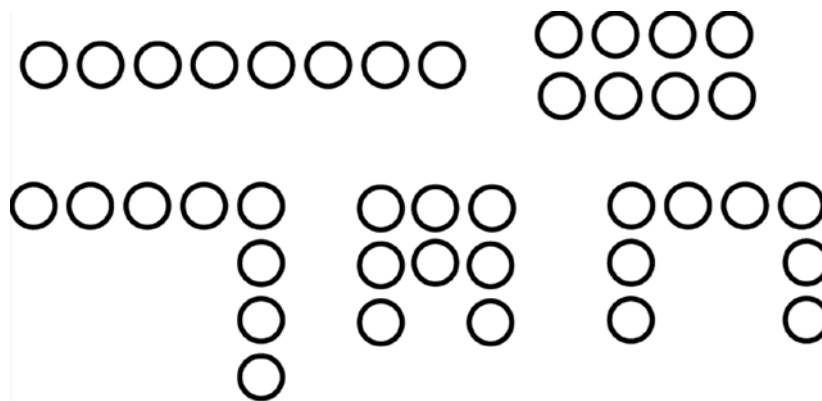


Figure 1.16 - Possible configurations for vertical heat exchangers; from top left: Line, Rectangle, L-shaped, rectangular open and U-shaped.

The geothermal probes can be installed in any position regarding the building as, because, do not require any maintenance. Once installed is necessary to connect all sent pipe and the all return pipes in parallel. If it is installed a single vertical probe is

sufficient to connect the two pipes (sent and return) to the heat pump. If more probes are installed, when it is proceeded to the horizontal connections, is necessary to guarantee that there is a homogenous and balanced flow in every probe of the circuit.

This can be obtained connecting the probes in different ways. The hydraulic schemes mainly used are:

- system to distributing collectors with regulation valves;
- system of the so-called “inverse return”.

The first it consists in the installation of two collectors (one of sent and one of return) to which connecting all sent pipes and the all returns pipes of the probes (Figure 1.17).

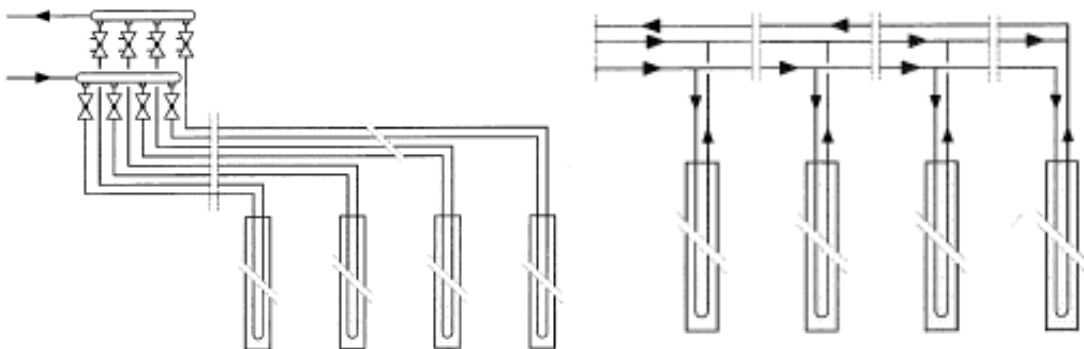


Figure 1.17 - Collectors distributors with control valve (left) and schematic reverse return (right) (from Basta & Minchio, 2007).

The collectors can be lodged in opportune niches or wells. On every pipe of the probes they are installed of the regolatrici valves of flow that have the function to introduce a loss of cargo localized on the probes hydraulically more favorites so as to balance the flows. The system “inverse return” mainly is used in the cases in which the probes they are found distributed in scattered order or forms perimeter distributions around the building.

The “inverse return” is a hydraulic trick that is adopted in order to obtain the same losses of cargo in each probe, that always each probes has the same linear development. In phase of planning it will be necessary to consider the influence they

have on the yield of the heat exchanges that take place in the connecting pipes between the probes and collectors.

The vertical geothermal probes can be used in the cases in which the spaces turn out reduced, like of buildings situated in city. A matter itself of closed loop systems it is not gone to carve the acquifer and then should not have pollution cases. On the other hand it can be said that the efficiency of the system strongly depends from geology. Moreover, it is difficult to achieve for large buildings would serve as many probes, further perforations and consequently higher costs.

Another type of geothermal plants which are part of the closed loop systems are horizontal exchangers (or collectors) (Figure 1.18). The probes realized in polyethylene, polybutylene or copper, are arranged horizontally in the subsoil approximately 2 - 3 meters of depth, lodged on a sand bed.



Figure 1.18 - Schematic representation of horizontal probes.

This type of system uses the coming thermal flux from the surface determined in direct or indirect way from the solar energy (solar radiation, rain, etc.). The medium ability to heat exchange is approximately 1 KW every 20 – 40 m of pipeline.

The planning of the horizontal collectors will have to bear in mind of the exposure of the surface in which it is installed the system avoiding, if of systems finalized to

the heating, the shadow zones. On the contrary this positioning will be privileged if of systems finalized to the cooling of the buildings. The deepening of the plan of rests in order to reduce lessened the influence of the fluctuations of surface temperature on the system involves such a increase of the costs that cancels the economic benefits of this technical solution. The installation (Figure 1.19) can happen through earth work of a land part, digging tight and deep trenches or inserting the exchanger directly while a vibrating plow moves the superficial layer of the land.



Figure 1.19 - Installation of the geothermal horizontal.

Inside of the polyethylene probe is circulated water possibly added with glycol, ethylene or propylene. Similarly to what we saw for the vertical probes we find different types of horizontal collectors (Figure 1.20).

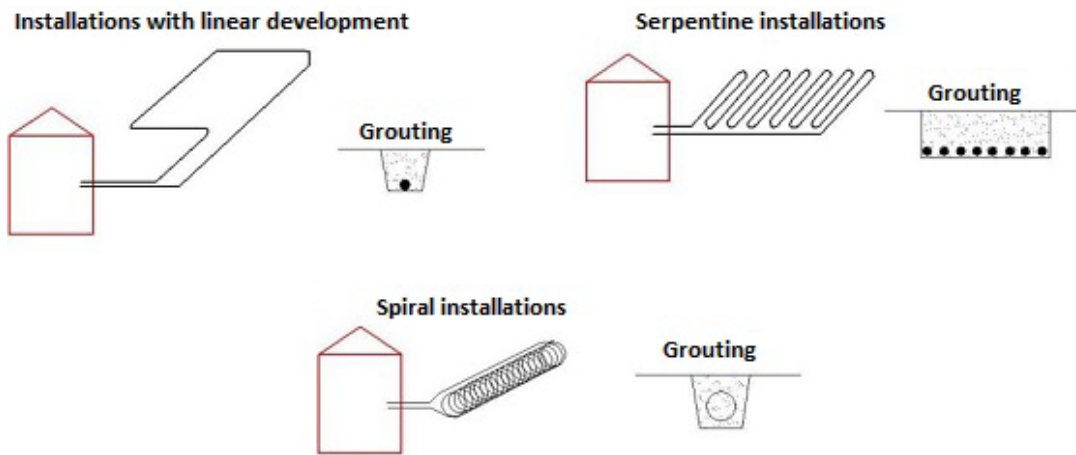


Figure 1.20 - Different types of horizontal probes.

The variability is related mostly to the distribution of pipes in the subsoil, infact are observed:

- **installations with linear development**: the collectors are placed on the bottom of a digging, that he can accommodate one or more exchangers, arranged on one or two plans. In this case the interdistanza between the probes can cause interferences for this reason the heat flux it can be inferior to that with an only tube. It is important for this to maintain a sure distance between the pipelines. The minimal distance must be of approximately 50 – 80 cm;
- **serpentine installations**: classic configuration for this system type. The collectors are disposed on the bottom of earth work with realizing of coils in series or parallel. A varying detail of this last outline sees the adoption of tubes finned in alternative to the common tubes in polyethylene or copper;
- **spiral istallation**: between the horizontal collectors this solution is the more interesting,because it diminishes the surface of I block. The folding of the tube can be realized in yard but it is necessary lend much attention to the operation in order to avoid the damaging of the tube, thus requiring a minimal beam of the curving of 20 times the external diameter. This type of exchanger turns out to be less expensive because no one needs to build a

hole to insert the probe. It can be realized in geological contexts in which there are waters of shallow groundwater that would not be affected in any way since, even these systems as the vertical ones, are part of the so-called closed loop systems.

The potential difficulties that can be met in the installation of the horizontal probes are essentially of areale type, in fact these need of wide spaces for their positioning. Medium esteem that the employed surface must be greater until 2 times the surface to air-condition. Such zones moreover cannot be cemented and cultivated because the roots of the plants and the activities of working of the land could damage the probes. An other aspect not to underrate is the phenomenon of the thermal saturation, if the system is placed in a little rainy area and therefore tend to dry land the heat exchange between the probe and the soil would be affected. Would be ideal for this reason the humid sandy-gravelly lands.

The heat exchange with the subsoil is not realized only by means of closed loop in which circulates the heat transfer fluid but can also take place via the circulation inside the probes of groundwater and surface water (Figure 1.21). The water captured from a point of taken (well, lake, channel or river) will be conveyed by pumping in the circuit where it will go to interact directly or indirectly (in this case through an intermediate exchanger) with the heat pump. Carried out the heat exchange this last one comes reimmessa in circle through a drainage (injection well, drainage on superficial water bodies or in drain). Systems of this type are defined to open loop.

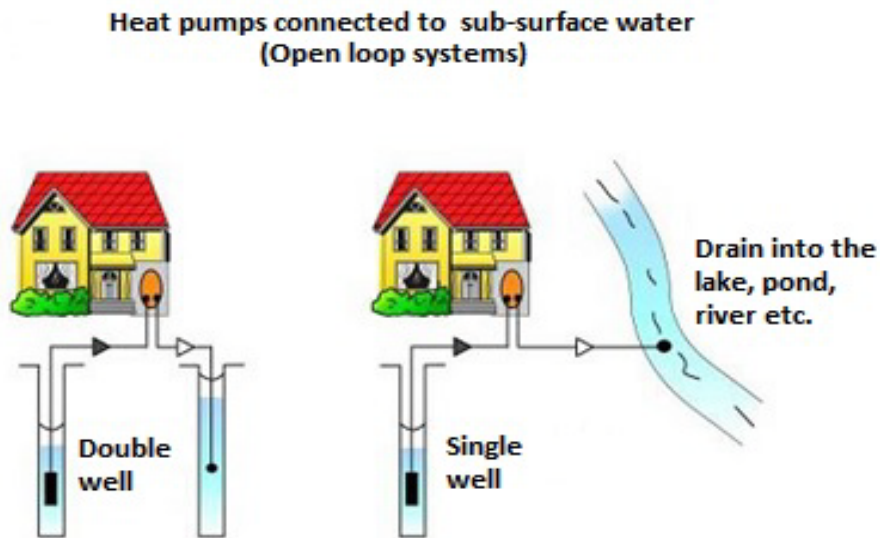


Figure 1.21 - open loop systems (from Toro & Ruspandini, 2009).

This system type in its turn is subdivides in superficial waters systems and systems.

The majority of groundwaters open loop systems uses one or more wells.

The water is sucked by a well (extraction well or production well) and then reintroduced in nature with various modalities:

- through a so-called injection well (system of two wells);
- in the same extraction well, "standing column" modality, that minimizes the amount of water discharged into the environment and eliminates the need to have the injection well;
- through a surface drain (groundwater or drain into the sewage system).

The systems which provide the presence of an injection well can be distinguished (Figure 1.22):

- **systems with two wells in direct exchange:** this type of configuration generally is utilized in systems of small size and it is not equipped of an intermediate exchanger between the circuit of the heat pump and the circuit of the well. In this case it must carry much attention to the type of water that is used since the water in this case, enters directly in contact with the superficial ones of exchange of the heat pump for which, if it has

particularly high pH, it can directly cause incrustations and corruptions to the thermal engine provoking serious damages;

- **systems with two wells and indirect exchange:** these systems undoubtedly the most reliable since they have an intermediate heat exchanger between the circuit of the wells and the circuit of the heat pump avoiding in this way any problem related to the chemical-physical characteristics of the waters. With this solution you can operate with different flow rates on two circuits by optimizing the adjustment. The water withdrawn from the production well arrives through the heat exchanger tubes in high density polyethylene or PVC and then to return in the aquifer. Compared to the closed-loop systems these offer an efficiency comparable with a significant reduction in costs.

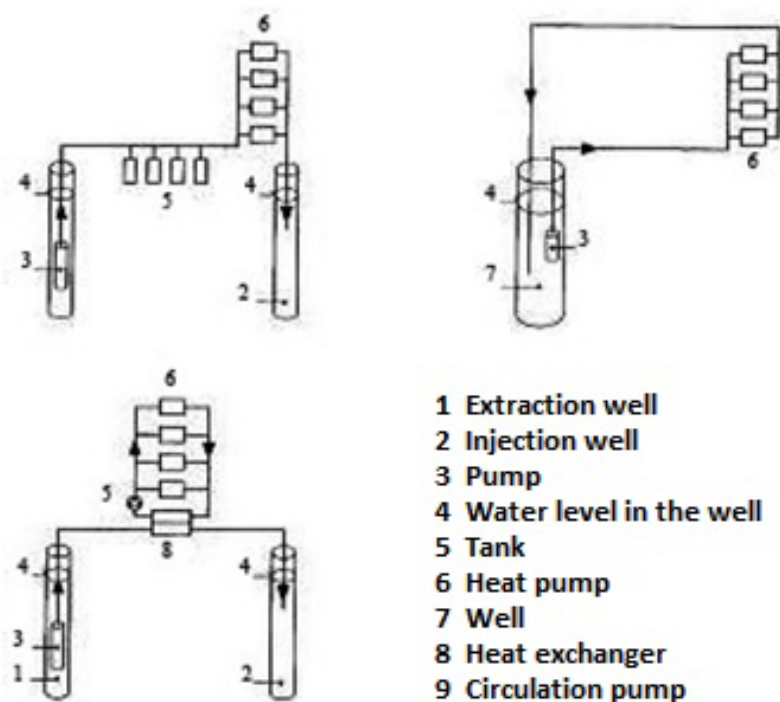


Figure 1.22 - Open loop systems with drain in injection well (from Basta & Minchio, 2007).

The systems of a single well, sayings “standing column”, are constituted by an only very decidedly deeper perforation regarding the average of the traditional systems (used solution a lot in the USA). In this case, the warm fluid is captured in

the final part of the well (the depth allows to obtain temperatures very higher regarding the part in which the fluid comes reinjected). This solution is adopted in rocky terrains in which the well does not produce sufficient flow rate to achieve a traditional system and where the water has characteristics excellent, in fact, also in this case, is not provided for an intermediate exchanger. The medium depth of the wells is elevated approximately 300-400 m with obtainable temperatures comprised between those of the traditional systems to open circuit and those closed circuit.

Another very important aspect concerns the level of the aquifer, this should be as static as possible, at a depth slightly higher than the ground level to avoid increases or drops in average temperature in summer and winter operation, respectively. To prevent this practice is not to download the full extent but to reinstate about 10 to 15% of the same one.

The choice of the type of reimmissione of waters needs of a deepening. It has been said that in open loop systems maybe used to discharge in superficial water bodies or groundwater (aquifer). The first they represent the ideal solution in many cases, as they prevent further drilling (if not operating in mode standing column) reducing the risk of putting into communication of groundwater in aquifers multilayer. The choice of a discharge surface involves careful consideration of the draft drainage, administrative and physical constraints that affect its implementation. It is therefore clear that the construction of a pipeline too long, possibly bound in the path, it will make the solution of the discharge surface inconvenient. They must also be certain chemical and physical characteristics of the water together with the flow of media and the tip, in order to establish their compatibility with the receiving body of water.

In alternative it is possible to estimate to directly realize the drainage in white waters of the sewage system as a result of an agreement with the agency manager for the acceptability of the hydraulic load (the compatibility of the downloaded fluid must be estimated).

The solution of discharge into groundwater through an injection well needs special attention that will define not only the impact of the same in terms of chemical and physical characteristics, of flow rates water released into groundwater and

consequent changes in groundwater levels, but also the location in relation to the well pick that, it is essential to ensure the efficiency of the system.

The efficiency of the well is defined also by the relationship between the capacity and the lowering induced from the withdrawal of money of the water, expressed in l/s/m:

- a high value, around 2.1 l/s /m (Rafferty, 2001) identifies a good pit;
- a low value, around 0.1 l/s/m (Rafferty, 2001) identifies an inadequate well.

This value in the artesian aquifers is quite stable for a large range of flow rate, indicating a linear function of the flow induced sag; for groundwater aquifers, however, it tends to be decreasing with increasing flow rate.

In some circumstances it can be had the fortune to find in proximity of the area in which it must be installed the system, of the wells being able to use these In the majority of the situations the wells must be constructed because not present or used for other scopes. The assessment should then proceed initially with drilling and after you must enter the casing. If the soil has drilled present instability phenomena is opportune to cover the well in all its depth otherwise is sufficient to stop itself to little meters from the surface.

The casing can be realized with various materials according to the characteristics of the water (steel, stainless steel, iron covered with copper sheet, plastic) according to the corrosive properties that must be insured (Basta & Minchio, 2007).

The interface between well and ground water must be realized in order to decrease the load losses. The possible types are essentially 3 according to the hydrogeological characteristics of the aquifer:

- **open wells:** are deprive of interface in the terminal part. Are realized with rocky terrain for which there is no need for filtering water;
- **wells for natural development:** perforated cylindrical column to the height of the aquifer with a size which allow water to pass but not the material surrounding gravel. Adapt for lands to large or medium grain;
- **coated gravel wells:** the diameter of the well in this case is advanced to that of the column of aspiration and a gravelly covering is previewed that it avoids the ingression of the specks of sand and several detritus, typical of

the sandy aquifer. The column also in this case is windowed in way such not to make to pass the gravel that it is around. Is realized in this case a filtration system that makes these wells the most expensive.

Once that is achieved the well requires two operations: the bleeding and the flow test. In some cases, should they be required by law, must be carried out other operations:

- filling of the interspace between the walls of the excavation and those of the outer column coating of low-permeability material (cement, bentonite);
- creation of systems for connection between circuit parts (eg exhaust insulating) to facilitate the maintenance;
- coverage of the well;
- disinfection of the well following the installation of the heat pump.

Like already said, the mutual location of the wells cannot be accidental but it depends on the characteristics of the acquifer and its natural flow. Various configurations exist that can be adopted if of meaningful flow of the stratum water:

- **configuration with four wells** (Figure 1.23): in summer the two central wells C1 and W2 are used so that the warmer water comes to find again itself in the W1 well transported from the natural flow. Own the W1 well is the well of winter aspiration while that of reinjection is upstream, C2, where the colder water is downloaded and transported by the natural flow towards the central well, C1, of summery aspiration (Basta & Minchio, 2007);

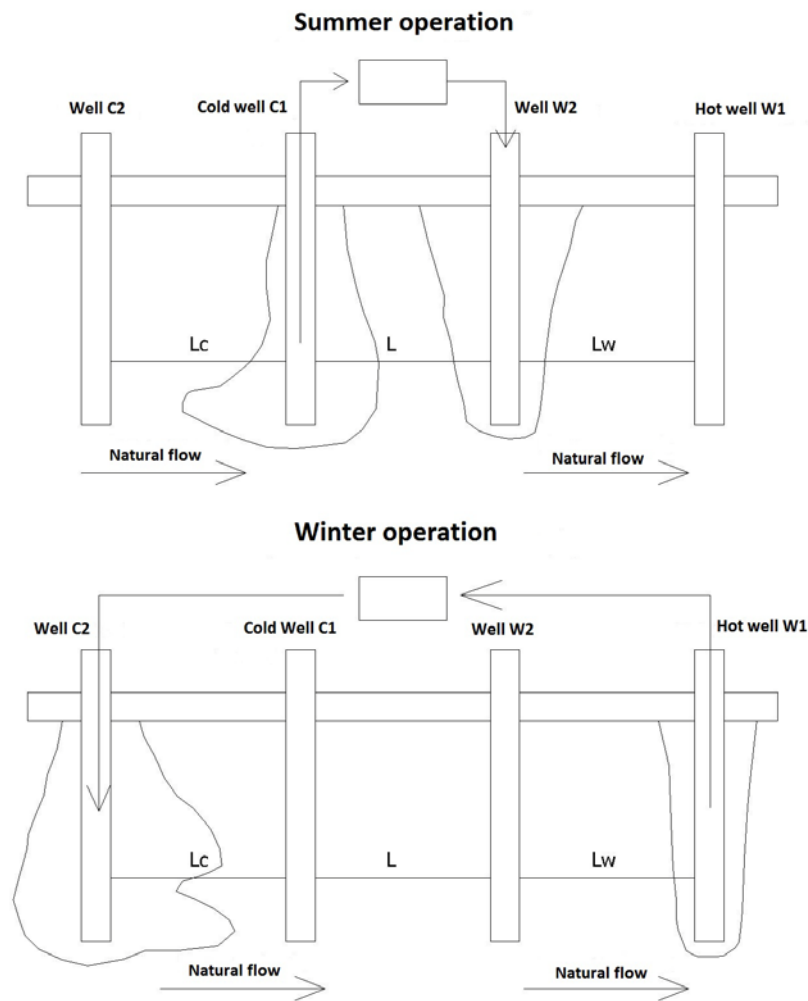


Figure 1.23 - Disposition and operation of the wells in the event of significant groundwater flow (configuration with four wells) (from Basta & Minchio, 2007).

- **configuration with two wells** (Figura 1.24): in this case, said also configuration to anisotropic wells, rather than to realize four wells if they install two, one of which on two different levels of depth. In the lower level occurs aspiration in summer and winter discharge (cold storage) while, at depths less than occurs in the well W1 and the withdrawal in the well C1 discharge. The natural flow transports warm water in summer towards the well W1 (Basta & Minchio, 2007). Water is pumped from the deep well and discharged into the surface to reduce recycling and for health reasons.

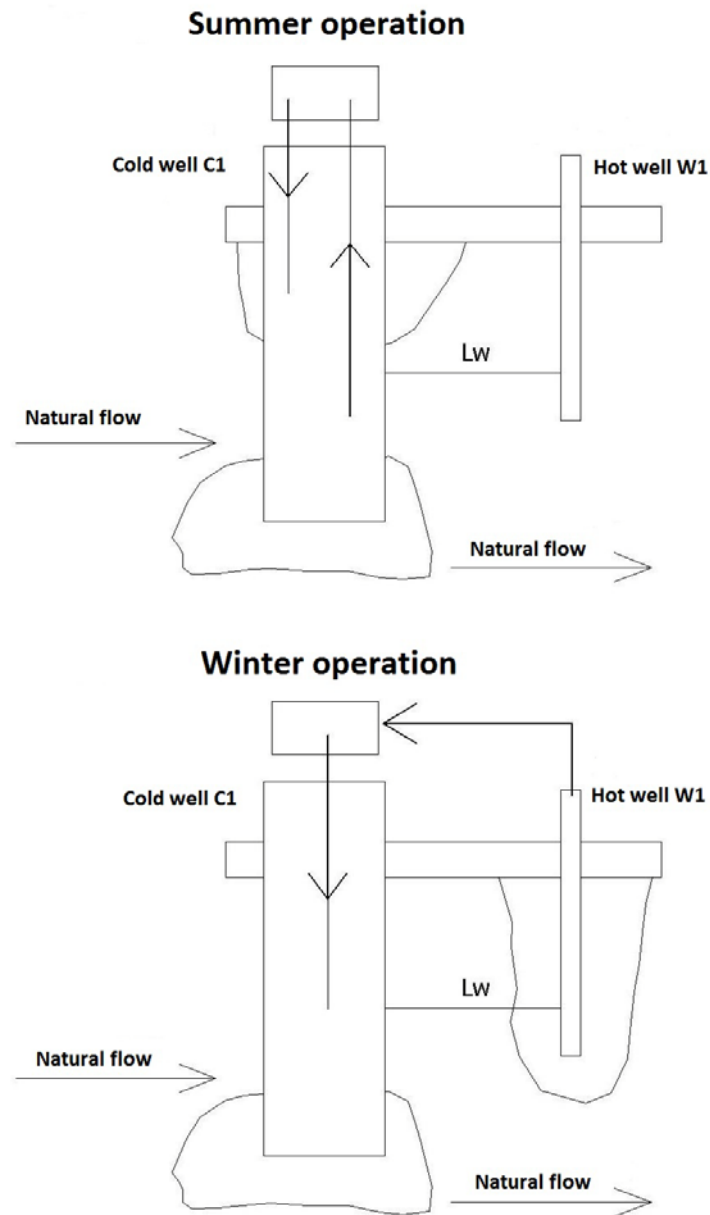


Figure 1.24 - Disposition and operation of the wells in the event of significant groundwater flow (configuration with two wells) (from Basta & Minchio, 2007).

It is also possible to make the configurations with alternating operation of the wells in order to take advantage of it of static water table the temperature difference that is created in the two wells in the summer and in winter. In winter, the production well is located at the highest temperature of injection well in which is entered the cold water downstream of the exchange. This temperature can be used

in the summer by reversing the role of the wells (extraction in the previously reinjection). Taking water cooler improve the performance of the heat pump and at the same time, thanks to the placing of warmer water downstream of the exchange, in winter pit mining accumulates thermal energy for the next season.

With the exception of the closed loop systems they exist of the limitations and the prohibition of normative character that does not afford of being able to realize these systems everywhere. The directed use of groundwater in the exchange process discourages many potential users, above all because of these problematic ones. This although, the opens loop systems are revealed very efficient, ideal solutions for the energy requirements of great users.

A problematic one tied to this type of systems is sure from referring to economic factors, in fact, in phase of planning must be considered also the operating costs, above all those relative ones to the surge of the groundwater. In fact if the withdrawal take place to a very high depth, the costs of the pumping can be so high, as to affect the benefits and make more convenient the closed circuit systems.

The ideal localization of the open loop systems, being tied to the presence of the aquifer, should be in areas of outflow and in the presence of multi-layered aquifers, limitedly to the superficial aquifer. To avoid or however to limit the presence of this type of systems in the zones of recharges and in presence of monolayer aquifer.

As mentioned at the beginning of this chapter, they exist also of the systems that take advantage of the superficial water like rivers, lakes, seas etc. Some operators of the field provocatively insert this type of systems in a different category, the hydrogeothermal systems.

The use of surface water presents different problems that make it difficult to use a solution:

- changes of flow rate in the river or in the basin used procuring important and substantial lowering of the water level, especially in summer;
- adequacy of the volume of the water body, the depth and the maximum thickness of ice that can potentially develop during the winter season;

- need for adequate filtering of the water which has suspended solids, impurities with favorable conditions for the growth of aquatic plants and mosses;
bureaucratic administrative obstacles, due to environmental constraints and regulations on the use of water. Very important is the maximum thermal jump allowed for the pumped water and the environmental impact assessment that entails for the flora and fish fauna.

1.3 The heat pump and its operation

An installation of geothermal heat pump can be divided into two parts (Figure 1.25):

- superficial part, that comprises the installation of all house i (radiating panel, heat pump, etc.);
- underground part, that comprises the geothermal probe and all the horizontal connections.



Figure 1.25 - Superficial and underground part of a geothermal heat pump system.

Fundamental element of the system is the heat pump. This is a thermal car that affords to move the heat (Figure 1.26) from one environment to the lower level of heat to an environment having a higher thermal level by means of the input of energy from the external environment (usually mechanical work).

The physical principle that regulated the heat transfer is according to principle of the thermodynamics that asserts, independently from the transfer mechanism, the thermal energy is transferred from the body at a higher temperature than body at lower temperature. For being able to transfer heat in opposite sense it is necessary therefore fulfill work, and then use a certain amount of energy forms other than thermal.

The operation principle that is to the base of the heat pump is a thermodynamic cycle called "refrigerator cycle" and is analogous to what ago working a common refrigerator.

Inside of the heat pump the fluid follows a thermodynamic principle that consists in an evaporation, a compression, a condensation and an expansion (Figure 1.26).

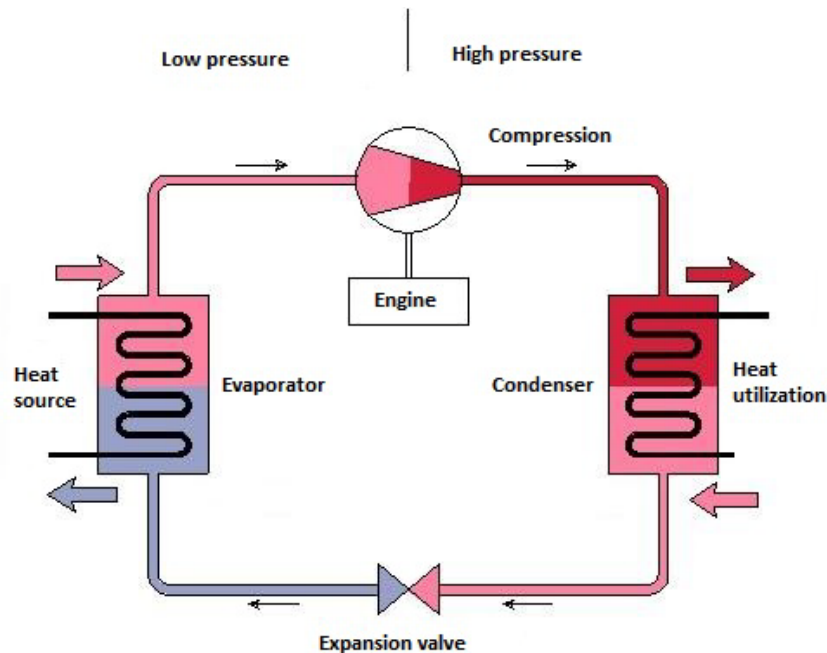


Figure 1.26 - Schematic representation of the heat pump operation.

Inside of a heat exchanger, said evaporator, the cooling fluid evaporates absorbing the heat supplied from an external source.

The steam produced from the evaporation enters in the compressor and is carried to the condensation pressure. During this transformation occurs an increase in temperature. In escape from the compressor the steam is overheated.

The superheated steam inside of heat exchanger, said condenser, where it exchange thermal energy with the water of the heating system, it yields heat and gets cold. In the first part of the heat exchange, the steam reaches the temperature of condensation. It follows a phase to constant temperature in which the change of phase comes true until to obtain in escape the fluid to liquid state.

In order to complete the cycle, the liquid must return to the evaporation pressure; this passage happens through an expansion process.

The heat pumps must work in heating modality and in cooling modality: for this reason are said "reversible" (Figure 1.27) because in summer the pump reverses its operation to the direction used in winter. With the exception of the heat pumps to air, those geothermal ones can work in cooling also in passive modality: they extract heat from the building pumping in the system the cold water or the antifreezing liquid, without the action of the real heat pump

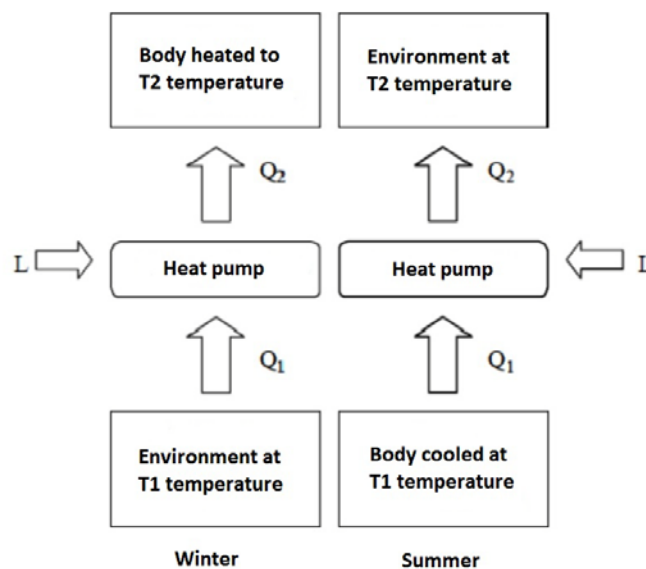


Figure 1.27 - Schematization of the principle operating of the heat pump in winter and in summer (from Basta & Minchio, 2007 modified).

The thermodynamic cycle of reference of the heat pumps is the inverse cycle of Carnot.

The fundamental feature of the machine of Carnot is that its yield does not depend from the fluid used in the cycle, but only by the temperatures of the sources with which exchanges heat, more precisely, by the ratio of the two temperatures (Carnot's theorem).

The yield or COP (coefficient of performance) of a thermal car that follows the inverse cycle of Carnot is, the relationship between the heat obtained and absorbed from the system Q_1 (KJ) and the supplied job L (KJ). This parameter, that it indicates the energetic yield of the heat pump, depends on the constructive technology of

every model, as well as from the climatic conditions and of operation of the system. This yield is as greater how much more lowland is the difference of temperature between the environment to be heated and the heat source that is used. In phase of cooling the index of the yield of a heat pump is indicated also with acronym EER (Energy Efficiency Ratio).

Below the formulas for the calculation of the COP in heating and cooling phases (EER are brought back):

$$COP = \frac{\Delta Q_{hot}}{\Delta A} \leq \frac{T_{hot}}{T_{hot} - T_{cold}} = \frac{1}{\eta_{Carnot's cycle}} \quad (\text{Heating})$$

$$EER = \frac{\Delta Q_{cold}}{\Delta A} \leq \frac{T_{cold}}{T_{hot} - T_{cold}} \quad (\text{Cooling})$$

where:

- Q_{cold} : is the amount of heat extracted from a cold source at T_{cold} temperature;
- Q_{hot} : is the amount of heat distributed to a hot source at T_{hot} temperature;
- ΔA : is the work dissipated by compressor.

The classic heat pumps that take advantage of as thermal source the air usually succeeds to reach a COP of approximately 3, while the geothermal heat pumps succeed to reach $COP > 3$, and thus able to achieve higher yields.

In phase of dimensioning, the heat pump is calibrated in order to satisfy the 60-70% of the maximum cargo (sum of the thermal energy in order to heat the entire building and the demanded warm water from the users), leaving an additional system the occasional demands. So making, the heat pump comes to supply 95% of the total of used thermal energy.

2 The parameters considered in the thermal characterization process

2.1 Thermal conductivity

The acquaintance of the thermal properties of the land is fundamental for the planning of a geothermal heat pump system. In order to characterize thermally the land it is necessary, in first of all, know the attitude of the land to transfer heat. The "conductivity" or the "thermal conductivity" (indicated with the Greek letter " λ ") indicates just such attitude and is defined like the heat quantity transferred in an orthogonal direction to a surface of unit area, caused from a temperature gradient, in the unit of time and stable conditions.

To explain the process of thermal conductivity is supposed that a bar, considered homogeneous and isotropic, has its two ends in contact with two heat sources at different temperatures (Figure 2.1). The thermal conductivity is given by:

$$\lambda = \frac{\frac{\Delta Q}{\Delta t} \cdot L}{S \cdot \Delta T} \quad \text{that is} \quad \frac{\Delta Q}{\Delta T \cdot S} = \frac{\lambda}{L} \Delta T$$

where:

- $\frac{\Delta Q}{\Delta t}$: is the heat flow in the time $\left[\frac{J}{\text{sec}} = W \right]$
- λ : is the thermal conductivity $\left[\frac{W}{m} \cdot K \right]$
- S : is the surface of the bar $[m^2]$;
- L : is the length of the section of the bar $[m]$;
- $\Delta T = T_2 - T_1$ is the difference of temperature $[K]$.

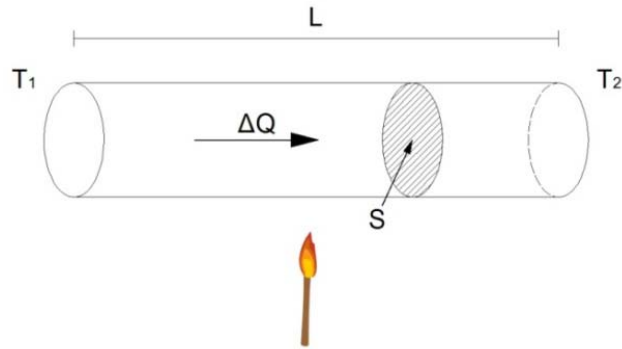


Figure 2.1 - Heat conduction through a homogeneous and isotropic body.

From the previous equation the heat flow can be defined in time and space:

$$\phi_T = \frac{\lambda}{L} \Delta T$$

Calling "resistance to a phenomenon" (R_T) the relationship between cause (ΔT) and effect (ΦT) we obtain:

$$\frac{\Delta T}{\phi_T} = \frac{L}{\lambda} = R_T$$

where:

- R_T : heat resistance $\left[\frac{K}{W \cdot m^2} \right]$;
- $\Delta T = T_2 - T_1$ is the difference of temperature [K];
- Φ_T : heat flow;
- λ : is the thermal conductivity $\left[\frac{W}{m} \cdot K \right]$;
- L : is the length of the section of the bar [m].

The thermal resistance is inversely proportional to thermal conductivity, and this parameter, known as conductance, is the inverse of the thermal resistance whereby:

$$C = \frac{1}{R_T} = \frac{\lambda}{L}$$

where:

- C: Conductance $\left[\frac{W}{m^2 K} \right]$;
- R_T : heat resistance $\left[\frac{K}{W \cdot m^2} \right]$;
- λ : is the thermal conductivity $\left[\frac{W}{m} \cdot K \right]$;
- L: is the length of the section of the bar [m].

Assuming that the thermal conductivity takes place along a z-direction, for

$\left(\frac{\delta T}{\delta x} \approx \frac{\delta T}{\delta y} \approx 0 \right)$ a homogeneous and isotropic, is given by:

$$\phi \left[\frac{W}{m^2} \right] = -\lambda_{app} \cdot \frac{\delta T}{\delta z}$$

For the study of the thermal conductivity of lands is opportune to introduce the concept of apparent heat conductivity (λ_{app}) because the lands are not homogeneous and isotropic bodies; it can be seen as the sum of the effective thermal conductivity of the ground (λ_h) and a contribution that holds account of eventual latent members or not pure conductive (λ_{pseudo}).

The apparent thermal conductivity depends on:

- density $\left[\frac{kg}{m^3} \right]$;
- porosity [%];
- moisture content [%].

During the last few years they are introduced, from several students, various analytical models in order to determine the effective thermal conductivity, like for example:

- **De Vries**: model based on ellipsoidal shaped particles in continuous means of water or air;
- **Kersten**: it makes reference to an empirical formula based on the measures carried out on five various types of ground. his method is not applicable on dry soil and rock and is based on generic equation that depends on three adimensional constants a_1 , a_2 , a_3 defined in Table 2.1:

$$\lambda_h = 0,1442(a_1 \log \phi_w - a_2)10^{a_3 \rho_d}$$

where:

- λ_h : is the effective thermal conductivity $\left[\frac{W}{m \cdot K} \right]$;
- ρ_d is the dry density $\left[\frac{g}{cm^3} \right]$;
- Φ_w is the moisture content [%].

Type of soil	a_1	a_2	a_3
Clayey	0,9	0,2	0,6243
Sandy	0,7	0,4	0,6243

Table 2.1 - Kersten's equations for the thermal conductivity of the clay and sandy soils (from Begal, 1994).

Analyzing the formulations of Kersten it turns out that the value of heat conductivity of the land is strongly influenced by the moisture content. In fact the air and water presence in the porosity of the soil remarkably influences the value of the heat conductivity, since the air has a heat conductivity 20 times higher than the air.

Using the parameters written in Table 2.1 is calculated the heat conductivity of a sand and a clay according to the moisture content (Figure 2.2).

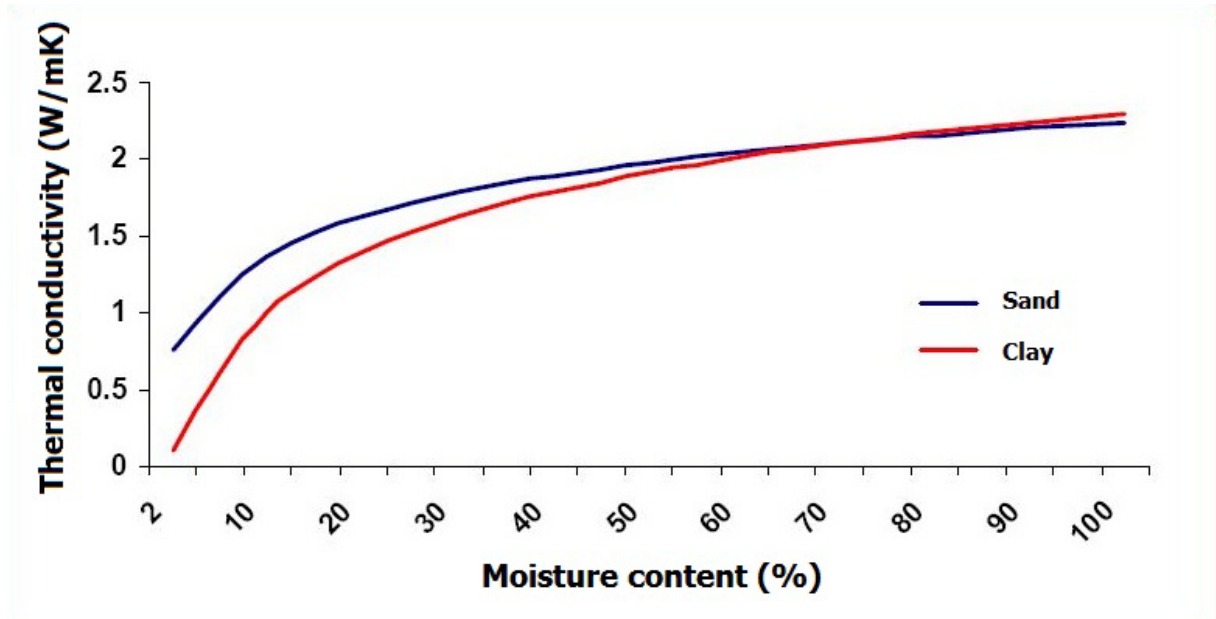


Figure 2.2 - Graph of thermal conductivity of the sands and clays (from Bose et al., 1985).

For the sand is used dry density value of $1,5 \text{ g/cm}^3$ while for clay $1,6 \text{ g/cm}^3$.

As can be observed in the first part of the graph the sands has greater a thermal conductivity of the clay until of the moisture content is approximately 70%, while in the second part the two curves are intersect and assume values similar conductivities until of 80% of moisture content. Once exceeded this moisture content value of is assisted to a reversal as, the sand is less conductive of the clay even though of least.

Making the inverse of the conductivity is obtained the graph of the thermal resistivity as a function of the water content (Figure 2.3).

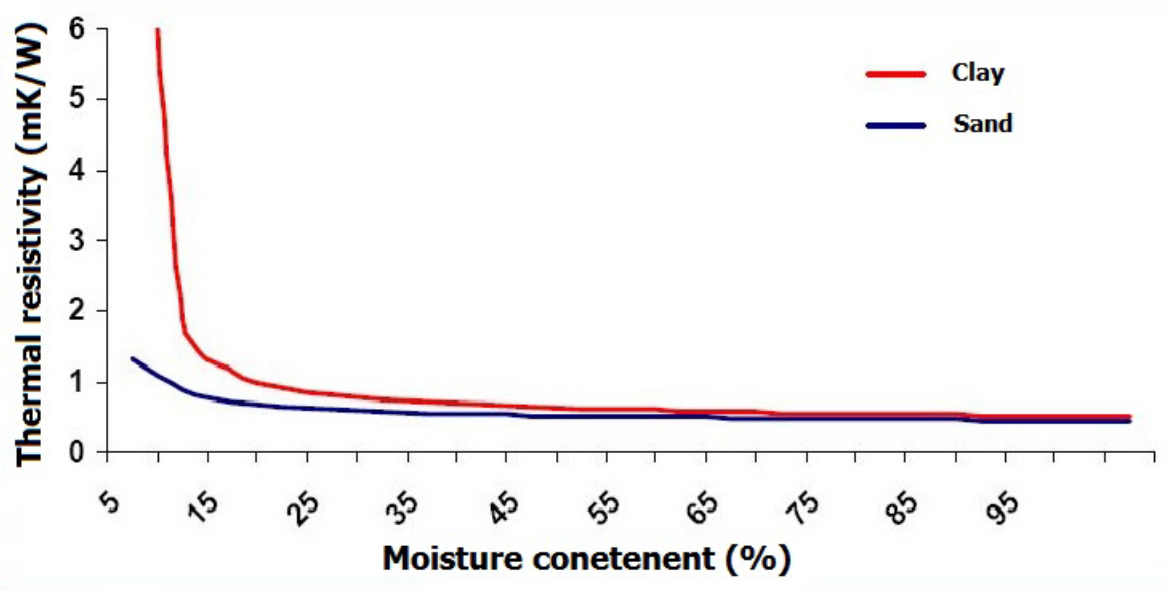


Figure 2.3 - Graph of the thermal resistivity of the sand and clay (from Bose et al., 1985).

For low moisture content, beneath of 15%, the sand and the clay they are both resistive. The clay assumes values of resistivity extremely elevated for low moisture contents to difference of the sand, that maintains however resistivity values contained. For both lithologies exist the so-called “critical point” that it beneath represents the limit of water content of which the two lands do not have to never go in order to avoid that the two means more do not succeed to transfer heat. The graphical one shows the particularity that the curves, with increasing water content, stretch to a constant value becoming parallels between they.

Therefore, is clear that the heat conductivity of a ground depends very from own water content: if a ground is come down under the critical point that could be considered a good heat exchanger, instead, it risks to become a very bad conductor. In this case the geothermal probe is thermally isolated and stops to work. The water presence in the land depends in its turn from the porosity of this.

Besides the heat conductivity it is opportune to describe to others two important properties of the land that contribute to its thermal characterization.

The thermal capacity mass (said also specific heat) indicates the value of the caloric amount in Joule, that 1 kg of matter it absorbs or it emanates, when its temperature is raised or lowered of 1 Kelvin:

$$C_s = \frac{Q}{(T_2 - T_1) \cdot m}$$

where:

- C_s : is the thermal capacity mass $\left[\frac{J}{kg \cdot K} \right]$;
- Q : is the heat released or absorbed [J] ;
- T_1 and T_2 : are the initial and final temperatures, respectively, [$^{\circ}C$] ;
- m : is the mass of the material [kg].

Larger is the thermal capacity mass to a material, greater is its ability to accumulate energy.

The thermal diffusivity, instead, expresses how quickly a material able to diffuse heat inside it and is given by the ratio between the effective thermal conductivity and specific heat:

$$D_f = \frac{\lambda_h}{C_s}$$

where:

- D_f : thermal diffusivity $\left[\frac{m^2}{s} \right]$;
- λ_h : is the effective thermal conductivity $\left[\frac{W}{m \cdot K} \right]$;
- C_s : is the thermal capacity mass $\left[\frac{J}{kg \cdot K} \right]$

For the corrected dimensioning of a field probes is therefore indispensable to carefully define the values of the thermal properties as soon as exposed, even if these are not easy determinable, neither in laboratory neither in site, because of the necessity to use instrumentations and methodologies of difficult to find. The

techniques used for the thermal characterization of lands can be divided in two classes:

- **steady state methods:** it necessary the attainment of a steady state and therefore much time in order to execute the measurements of the several parameters;
- **variable regime methods:** it necessary the attainment of a steady state and therefore much time in order to execute the measurements of the several parameters;

In particular, the most used technique belonging to the methods in variable regime is the Ground Response Test (GRT). With this instrument the yield and the thermal resistance of the geothermal exchanger are defined besides the thermal parameters of the land.

2.2 Modality of heat transmission between probe and land

The heat transfer between the probe and the land can happen two processes second distinguished physicists: the conduction and the convection. We will see in this paragraph as the prevalence of one of the two processes depends on the type of soil in which the probe is installed. In the thermal conduction the heat transfer from the zones to higher temperature to those to temperature more lowland happens for directed molecular contact, even if the physical phenomenon that is to the base of the conduction is different for the three states of the matter:

- **gaseous state:** the heat transfer has had to the atomic and molecular diffusion;
- **solid and liquid state;** the heat transfer is caused from elastic waves.

The thermal conduction is the dominant modality of the heat transfer in the geothermal probes, so much so that some software consider it the only mode of heat transfer possible.

The convection is instead a process in which the heat transfer it happens by the movement of particles of a fluid. Two types of thermal convection are distinguished:

- **natural**: when the motion is generated by the differences of density caused by the differences of temperature due to the presence of a heat source;
- **forced**: when the motion depends on external causes (natural or artificial).

Both can be had the types of convection in proximity of the probes. If the convection is natural will create upward motions and discensionali in the vicinity of the probes, while if it is forced the movement of the fluid will depend on the water flow of the groundwater, than entering in contact to lowland speed with the probes will put into effect the heat exchange. Especially if the flow rate of the stratum is high the convection could prevail on the conduction. It is possible to determine which it is the modality of dominant heat transfer through the Peclet number (Pe), defined from Domenico and Schwarz from the following equation:

$$Pe = \frac{\rho_1 c_1 q L}{K_{eff}}$$

where:

- $\rho_1 c_1$: volumetric heat capacity of water $\left[\frac{J}{m^3 \cdot K} \right]$
- L : characteristic length or geometry of the system [m] ;
- q : water flow in a porous body [m/s] ;
- K_{eff} : average thermal conductivity of the soil $\left[\frac{W}{m \cdot K} \right]$

In the cases in which the Peclet number he is greater of 1 dominates the convection, while when it is smaller of 1 it dominates the conduction. In Table 2.2 it is evident that the prevalence of a mode of transmission of heat over the other depends on the type of terrain. In fact, in the gravelly soil it dominates the convection and conduction in clay soils.

Porous body	Peclet number	Heat transfer
Lands		
Gravel	$5.72 \cdot 10^2$	Convection
Coarse sand	$1.34 \cdot 10$	Convection
Fine sand	$1.15 \cdot 10^2$	Convection
Silt	$1.28 \cdot 10^{-2}$	Conduction
Clay	$3.24 \cdot 10^{-5}$	Conduction
Rocks		
Limestone, Dolostone	$5.92 \cdot 10^{-3}$	Conduction
Karstified limestone	$5.28 \cdot 10$	Convection
Sandstone	$1.77 \cdot 10^{-3}$	Conduction
Schist	$1.05 \cdot 10^{-6}$	Conduction
Fractured igneous and metamorphic rocks	$6.32 \cdot 10^{-2}$	Conduction
Not fractured igneous and metamorphic rocks	$1.00 \cdot 10^{-7}$	Conduction

Table 2.2 - Peclet number for different types of soil and rocks.

This happens because the lands to large grain are characterized by high values of permeabilities that favor the phenomenon of the convection, while lithologies characterized from low values of permeability favor the thermal conduction.

2.3 Thermal stability of the soil

The thermal behavior of the land is strongly conditioned by the percentage of moisture, infact, like already said, the presence water or air in the porosity of the land remarkably influences the heat exchange.

Considering that the water present in the soil tends to move away from the areas by evaporation at a higher temperature and to accumulate by condensation in those at a lower temperature, the accumulation zones will be different between winter and summer.

In the heating modality capturing heat from the land, the temperature of the land near the probe will be smaller regarding the more distant zones from it. For this the water will concentrate around the probe having favored the heat exchange between

this and the land, even if when the temperature reaches the 0°C it risks the freezing to the land with the consequent damaging of the probe. In the summer mode instead occurs the opposite, releasing the heat to the soil in the vicinity of the probe will have the higher temperatures. Therefore the present water in the land will stretch to move away from the probe and if a water inflow is present towards the zones left free from the water in removal from the probe, a cycle kind will be established that guarantees always the presence of a certain amount of water in the vicinity of the probe. Instead, when this influx water is not sufficient the soil in the vicinity of the probe will face drying, causing an increase of the thermal resistivity of the soil itself which will lead to the thermal insulation of the probe.

It is observed through the relation between moisture and resistivities, than when the water content is high, small variations of it cause to minimal variations of thermal resistivity (stable behavior). Instead, when the water content it is low also small variations can provoke great variations of thermal resistivity. The thermal stability for the various types of land is determined therefore from the respective critical moisture value (Table 2.3).

Type of land	Standard unit of weight maximum dry (mg/m ³)	Critical moisture (%)
Gravel	1.92 ÷ 2.16	<12
Silt	1.76 ÷ 1.92	12 ÷ 16
Clay	1.60 ÷ 1.76	16 ÷ 22

Table 2.3 - Critical moisture content for gravel, silt and clay (from Bose et al., 1985).

The lands mainly exposed to the risk to go beneath of the critical moisture value are the clay soils (cohesive). For these types of lands the thermal characterization is carried out through an equation that defines the degree of criticality of the system, the so-called Thermal Stability Index (TSI) (Begal, 1994), according to the minimal humidity value in plan conditions:

$$TSI = \frac{W_d - W_p}{W_L - W_s}$$

where:

- W_d : minimum moisture content in the planning conditions (%);
- W_p : plastic limit;
- W_L : liquid limit;
- W_s : withdrawal limit.

The withdrawal, liquidity and plasticity limit represents the Atterberg limits, everyone of which is characterized by a humidity value (Figure 2.4). These limits define the behavior of a cohesive land according to the moisture content.

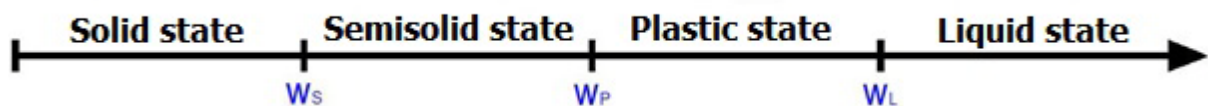


Figure 2.4 - Diagram of Atterberg limits.

According to the obtained value of TSI we will have three possible situations:

- **$TSI < 0$** : unstable situation. The migration of the humidity for the gradient is very easy;
- **$0 < TSI < 1$** : stable situation. The migration of the humidity for thermal gradient is improbable, the thermal resistance of the ground is practically constant;
- **$TSI > 1$** : stable situation. The thermal resistance increases with the moisture content.

Therefore if the water content is inferior at the plasticity limit (is semi-solid) are not filled up all empty and this cause thermal instability, while if the water content is advanced at the liquidity limit (liquid state) the land behaves like a viscous fluid getting worse the own thermal properties. The thermal stability of the clay is only reached for contained of water advanced at the best of plasticity and inferiors at the best of liquidity (is plastic). For lands to large grain instead the thermal instability he is very simple to calculate as it depends essentially from the degree of saturation.

2.4 Thermal behavior of the soil

As said in the previous paragraphs, the fundamental characteristic of the land, at the base of the operation of the systems of geoechange, it is that to maintain a constant temperature during all the year beyond i 15 m of depth. Beyond that depth, in the "neutral zone", the soil temperature is equal, as a first approximation, at the average annual temperature of the outside air. In fact the depth at which the temperature of the soil is no longer affected by seasonal variations, and depends on the thermal characteristics of the ground itself.

Wanting to more deepen in the detail the thermal behavior of the ground it is opportune to make reference the equation that allows to determine the temperature of a undisturbed, homogenous and isotropic land, according to the time and of the depth (Kirkham & Powers, 1972):

$$T_{(z,t)} = \bar{T} + \frac{A}{2} \frac{1}{e^{\frac{z}{\sqrt{\frac{\pi}{365D_t}}}}} \sin\left(\omega * t - \frac{z}{d} + \varphi\right)$$

where:

- $\bar{T}$: average temperature of the soil [°C] to the depth at which it is no longer influenced by the surface temperature;
- A : amplitude of the annual variation of the surface temperature;
- t : time [giorni];
- $Z \geq 0$: depth [cm];
- $\omega = \frac{2\pi}{365\text{giorni}}$: angular frequency;
- $\varphi = \frac{3\pi}{2} - \frac{2\pi}{365}t_0$ = constant of phase. It is calculated by knowing t_0 =the day of the year when the surface temperature reaches a minimum;
- D_t : thermal diffusivity expressed in $\left[\frac{m^2}{s}\right]$

The Figure 2.5 shows the typical trend of soil temperature at different depths during the course of the year, obtained with the formula previously illustrated.

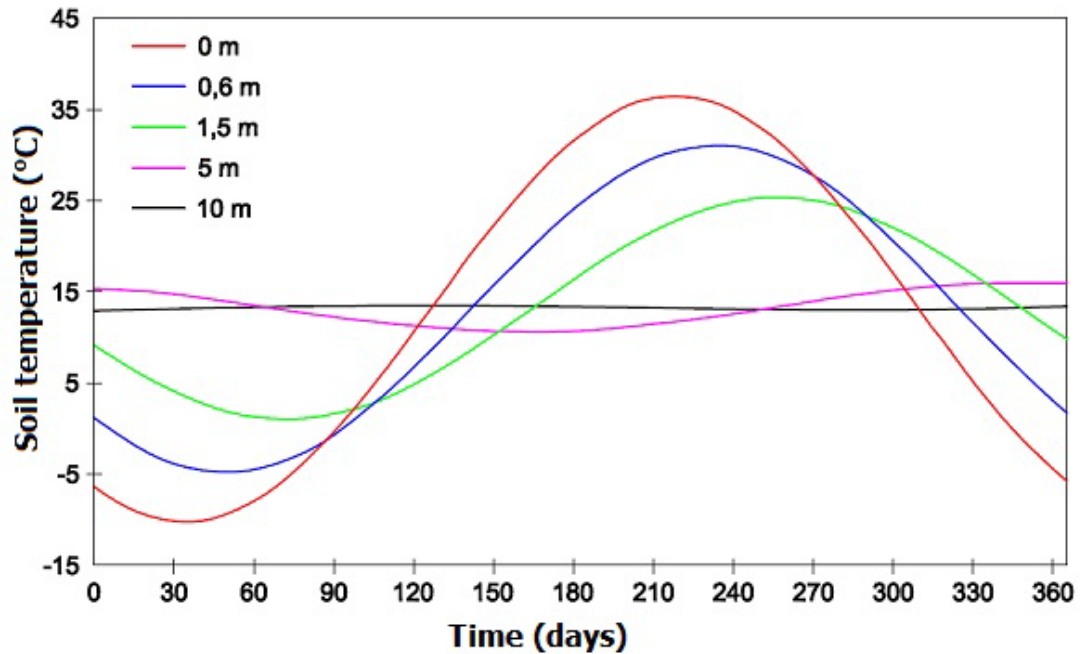


Figure 2.5 - Trends in soil temperature at different depths throughout the year (from Begal, 1994 modified)

The course of the temperature which showed in the above figure is online with how much it is exposed up to now: the temperature of the land with the increase of the depth stretches to a constant value during the year. It is to be highlighted, that in according to present lithologies the thermal stability is reached to various depths, as every lithology it has a various value of thermal diffusivity.

When a vertical probe is installed in the land, its thermal behavior is not riferibile to that than an undisturbed ground. The impact that can have the installation of a vertical geothermal probe in the ground is still object of studies.

In Figure 2.6 the curves of the land temperature are represented according to the distance from the vertical geothermal probe, after 3, 11 and 30 years from the putting according to the system and the curves of the system in pause (outlined curves).

Analyzing the course of the curves it is clearly that until a distance from the probe approximately 5 meters there is an important change in temperature of the soil, as the effect on the heat loss in the short term.

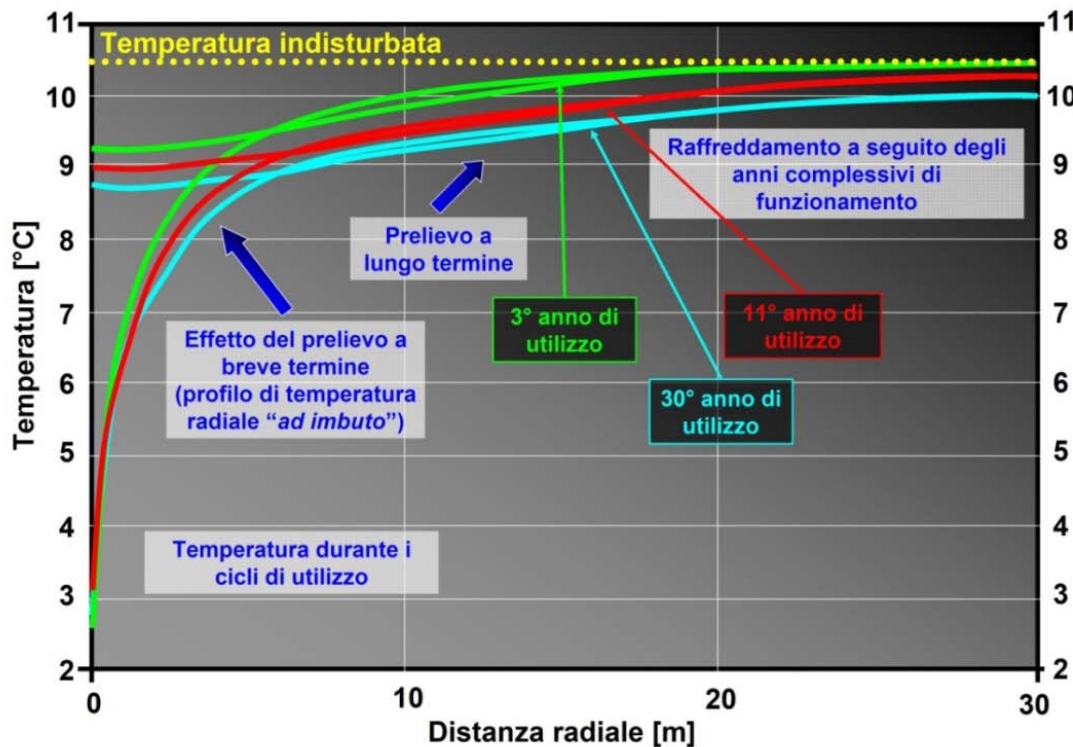


Figure 2.6 - Performance of soil temperature around a vertical probe after 3, 11 and 30 years of use of the system (from Eugster & Rybach, 2002, modified).

With the increase of the radial distance the cooling effect induced by the probe is less intense and determines the "funnel" course of the temperature in the soil. The fact that the curves of the temperatures of the above ground tend asymptotically to the value of the temperature undisturbed indicates that the soil even after 30 years of use of the plant does not lose its thermal characteristics but tends to reach a thermal equilibrium.

According to the hardly illustrated diagram can be supported that a system of geoexchange to vertical probes, planned and realized correctly, should have to always guarantee a good yield, also after many years of use.

3 Instruments for measuring the thermal conductivity

As previously described, the heat conductivity of the land is a fundamental largeness for the corrected dimensioning of the system. For this reason during the last few years various methodologies for its determination have been developed. These are different from each other for the cost and for the reliability and the precision of the supplied data. Moreover, is from emphasizing that there are of the tests to execute in laboratory and others in situ. Here below will be described two types of tests, one for the laboratory and one for the site, used for the determination of the heat conductivity of the land. The laboratory test is realized with uses of thermal probe A5000T, while the Ground Response Test (GRT) is used like test in situ.

3.1 Sensor temperature A5000T

The measurements of thermal conductivity in the laboratory can be performed with the thermal probe "A5000T" (Figure 3.1), produced by "Molisana Electronic Equipment" according to the standard ASTM 5534-00.



Figure 3.1 - Temperature sensor "A5000T" (frpm, Manual temperature sensor A5000T).

The instrument is based on the thermal needle proposed from De Vries and Peck (1958) and is characterized by a central processing unit and a probe of measure. The central processing unit is equipped of a display device that allows the visualization of the experimental curve and a tastierino. Moreover, a SD digital support for the memorization of the data is present .

The probe of measure, realized entirely in stainless steel, is formed by:

- support: of variable length according to the type of probe (from yard or laboratory);
- tip of dimensions standard (6,5 millimeter of diameter and 170 millimeter of length): inside it there are the heat source (electrical resistance) and the system for measuring the temperature (thermocouple), which allows you to record the temperature difference induced by the heating element on the probe itself.

The thermal probe “A5000T” affords to determine the heat conductivity of a land champion in not stationary regime, based on the principle of the radial spread linear a thermal source in an infinite medium and isotropo. If one takes in consideration two measures carried out in two times T_1 and t_2 we can write that (Manual of thermal probe A5000T):

$$T_2 - T_1 = \frac{-q}{4\pi k} \cdot \ln \frac{t_2}{t_1}$$

In according to this relation, the change of temperature as a function of time is linear at a r distance from the thermal source. If the temperature variation is represented in a plan $t/\Delta T$ we will have a straight line with slope equal to $\frac{-q}{4\pi k}$.

From the value of the slope of the straight line can be gone back to the heat conductivity of the champion. For the determination of such largeness he is fundamental to know with precision the heat (q) emanated from the thermal source, which must be maintained constant in the time. For having values of possible taken

care of heat conductivity is more opportune: to use sufficiently long times of measure, to verify that there is a good thermal contact between the probe and the champion, to guarantee the thermal stability of the atmosphere in which the measure is carried out and to allow with the champion to always reach the thermal equilibrium between two consecutive measures.

Before to carry out a measure of thermal conductivity the instrument verify the thermal stability, that is considered reached when $\Delta T < 0.5$. To such purpose it is found that with the instrument connected to the electrical network are had always greater values of ΔT of 0.5 and therefore not reliable. For this reason is fundamental carry out the measurements always with the fed battery instrument. If the measures of heat conductivity are carried out following the sagacities as soon as exposed, the obtained values will have an accuracy of 10% for values of advanced heat conductivities to 0.1 [W/mK].

The obtained experimental curve with thermal probe "A5000T" is characterized by a S course (Figure 3.2). According to the time passed from the beginning of the test two parts of the curve can be distinguished:

- short period: in this phase the thermal response is conditioned by the heat-transfer coefficient between the surface of the thermal source and the material;
- long period: in this phase the propagation of the heat in the sample suffers of the dimensional limits of the sample and the loss of heat of the source in the axial direction.

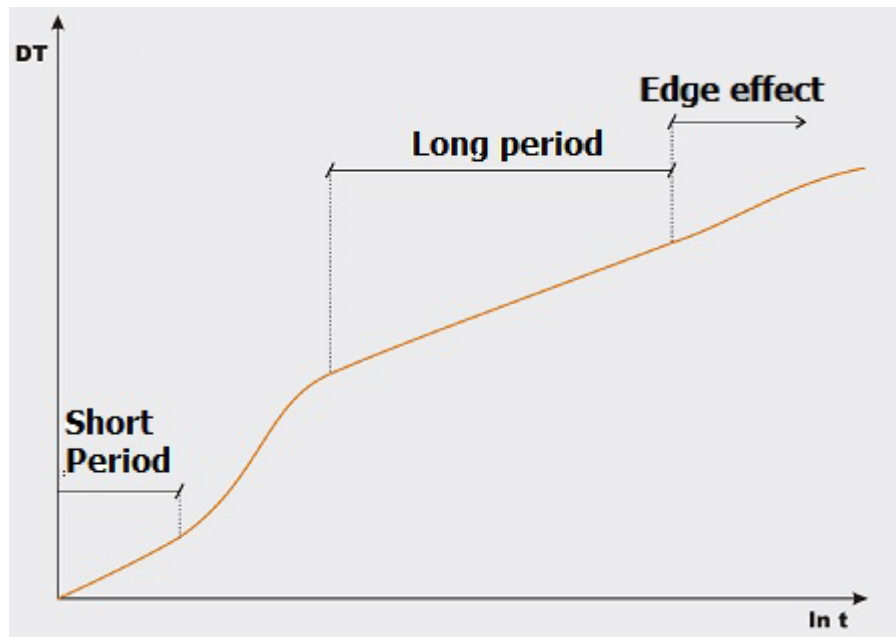


Figure 3.2 - Characteristic pattern of the experimental curve and its schematic (Manual temperature sensor A5000T).

Before to execute a measure it is possible to change some parameters of measurement, in particular, the duration of the test, the characteristic resistance of heating and the voltage to the heads of the resistance. While the value of the characteristic resistance of the heating one being in association with the constructive characteristics of the probe is only changed in case of a its substitution, the others two parameters can be modified based on the type of lithology that gets ready to measure. Regarding the duration of the test, the selectable values of factory vary from 300 s to 600 s with step of 30 s. The choice of the voltage to the heads of the heating one instead is made between three predefined values: 3V, 4V, 4.5V.

To increase this parameter is opportune when the champion has an elevated heat conductivity and therefore in presence of a curve of restitution of the particularly crushed instrument. When instead the champion the curve is equipped of a lowland heat conductivity will have a slope much elevated (Figure 3,3).

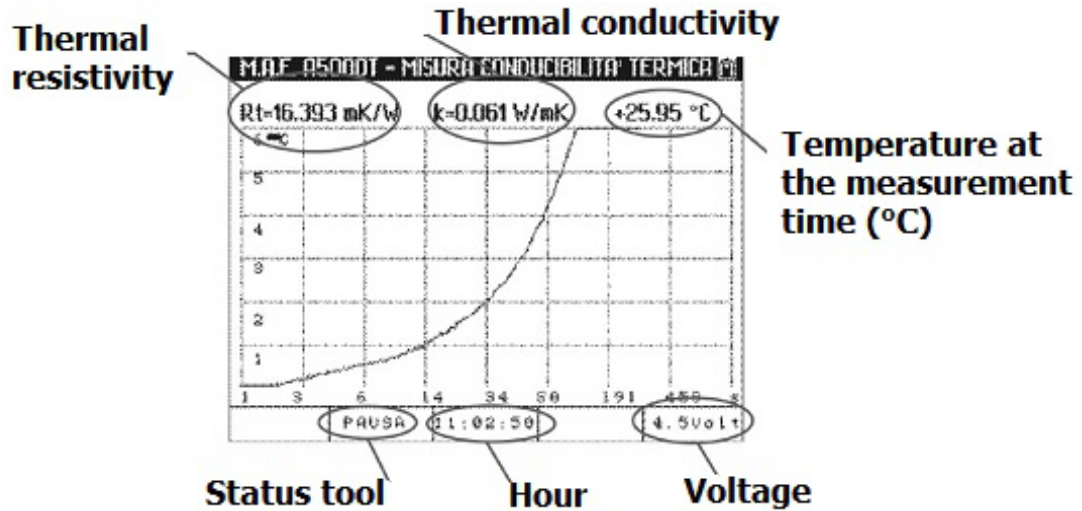


Figure 3.3 - Characteristic experimental curve for a sample of low thermal conductivity (from Manual of thermal probe A5000T).

The heat conductivity of the champion is calculated on the linear part of the experimental curve because in this drawn of the curve the exposed equation at the beginning of the paragraph is only valid. Based on the equation, knowing the values of the temperatures T_1 and T_2 recorded in moments t_1 and t_2 and being famous the heat supplied from the probe (q), the heat conductivity of the champion will be given by (Manual of thermal probe A5000T):

$$\lambda = \frac{Q}{4\pi(T_2 - T_1)} \cdot \ln\left(\frac{t_2}{t_1}\right)$$

bearing in mind that:

$$Q = \frac{I^2 \cdot R}{L} = \frac{E \cdot I}{L}$$

where:

- E: measured voltage [V];
- I: current flowing through the heating wire [A];
- L: length of the heating wire [m];

- Q: is the heat supplied [J];
- R: total resistance of the heating wire [Ω].

Regarding the restitution of the data, the instrument give the possibility to extract the data in bitmap format (bmp) and in textual format (txt). The .txt files are characterized by various lines, each of which from the top down indicates: durata della misurazione (s);

- characteristic heater resistance (Ω/m);
- the voltage applied to the heater: 0=3V, 1=4V, 2=4.5V;
- specific power of the heater (W/m);
- thermal conductivity of the sample (W/mK);
- number of measurements.

Follow as many integers (samples) representing the temperature rise (DT) measured above the initial temperature. The values are expressed in hundredths of a degree Celsius. The sample N-th of the list was recorded after a time t, in seconds, given by formula (Manual of thermal probe A5000T):

$$t = \exp\left(\frac{7N}{304}\right)$$

3.2 Ground Response Test (GRT)

The Ground Response Test (GRT) is a test in situ that it allows to determine the apparent thermal conductivity of the land and the thermal resistance of the completed probe. For the dimensioning of the geothermal probes the acquaintance of the thermal characteristics of the subsoil is of primary importance. For small systems (thermal power of inferior peak to the 30/50 kW) these parameters are generally estimated from “presumed” stratigraphy. For the systems of greater thermal potentiality instead, these properties are measured in situ. The data obtained from this test are very important because, inserted in the software used for the dimensioning of the fields probes, it gives indications on the planning choices.

Just for this reason the test itself carries out in course of work if not quite under executive planning, so proceeding to eventual modifications of the field probes before the system is finished, with time and cost optimizations, for example reducing the number of probes or the cantierizzazioni of the perforations. The system generally comprises a pump, a water heater resistance, a wattmeter, two thermocouples, a system for acquiring and storing data, pipes and a meter of capacity. The electric resistance can be replaced from an invertible heat pump, and in such case the test the test can be carried out both in the heating and cooling.

Generally the system is inside in a transportable cart and is arranged in order to avoid of must it mount and take apart to the occurrence (Figure 3.4). It is right to emphasize that not being defined from norms ONES a procedure of realization and analysis defined from the test, are admitted many varying in the construction (cars to gas, cars electrical workers, test in warmth, test in cold) and in the given analysis (linear method, method to the ended elements).



Figure 3.4 - Example of Ground response test (from Eklöf et al., 1996).

In order to carry out a GRT in the first place go connected the pipes of sent and return of the car to the probe, bearing in mind that the connections hydraulic engineers between the car and the probe must be as short as possible and well insulated. Once carried out the connection is put in pressure the circuit and after to have verified the absence of losses the circolatore is put in function. To this point it is

necessary to set up the capacity, (when it is possible is chosen that of plan for the single probe). Once regulated the capacity can begin the first part of the test that consists in the measurement of the indisturbata temperature of the land. The most effective way to get you through hydraulic pump activation and immediately checking the temperature measurements the probe output: this will reach a minimum that will be considered the value sought. It is important that the measure is made before fluid the steps through the circulating pump so as to avoid of a temperature increase and therefore an alteration of the largeness that is wanted to be measured. The water in the probe is considered in thermal equilibrium with the ground. This method turns out to be very accurate and relatively of easy performance (Zarrella, 2009). For the test of search of the equivalent heat conductivity of the land, the system must supply to the probe a constant thermal power. The flow rate must be measured by a flow-switch, the thermal power consumed by the resistance will be measured by the meter and the water temperatures at the inlet and output by the probes detected by thermocouples. All these information will be memorized periodically and diagrammate. It is important to emphasize that the GRT for being executed has the necessity that the pilot probe is left retired for 2 or 3 weeks, so that the maturation of the mortar happens. This praxis is necessary as the test is carried out injecting heat, for which the results of heat exchange they could turn out not representative of the inquired area: the total result could be an underestimate of the summery performances and a dangerous one overestimate of those winter ones.

Assimilating the system probe to a wire of infinite length, the heat transfer around of it occurs in a radial manner and is governed by the equation of Eskilson. This equation expresses the value of the average temperature of the fluid inside the probe over time (Delmastro and Noce, 2009):

$$T_f(t) - T_m = \frac{Q}{4\pi\lambda} \ln(t) + Q \left[R_b^* + \frac{1}{4\pi\lambda} \ln\left(\frac{4a}{r_b^2}\right) - \gamma \right]$$

where:

- $T_f(t)$: is the arithmetic average of the inlet temperature and outlet of the fluid in the probe [$^{\circ}\text{C}$] at time t [s];
- T_m : is the temperature of the undisturbed ground (average depth) [$^{\circ}\text{C}$];
- t : is the time [s];
- Q : is the linear thermal power injected into the probe, that is the ratio between the total power transmitted and the length of the probe [W/m]; is supposed perfectly constant throughout the course of the perforation;
- R_b : is the radius of the perforation [m] supposed constant and equal to the diameter of the drill bit or to the outer diameter of the shirt;
- γ : is Euler's constant, equal to 0.5772 (dimensionless);
- λ : is the thermal conductivity of the soil [W/mK];
- R_b^* : is the thermal resistance of the drilling [K/Wm];
- a : is the thermal diffusivity [m^2/s] calculated as:

$$a = \frac{\lambda}{\rho C}$$

where:

- ρ : is the average density of the traversed ground [kg/m^3];
- C : is the average thermal capacity mass of the ground crossed [$\text{J}/(\text{kg K})$].

It is evident from the last equation (see the first term after the equal sign) as the temperature of the fluid depends linearly on the logarithm of the time according to an angular coefficient defined by the parameter ϕ , defined as (Eklöf & Gehlin, 1996):

$$\phi = \frac{Q}{4\pi R}$$

where:

- Q : is the linear thermal power in the probe [W/m];

- R: is the radius of the perforation [m].

This equation can be represented in the form:

$$T_f(t) = \phi \ln(t) + p$$

where:

- $T_f(t)$: is the arithmetic average of the inlet temperature and the fluid outlet of the probe [°C] at time t [s];
- ϕ : is the angular coefficient described by the equation $\phi = \frac{Q}{4\pi R}$;
- t: is the time [s];
- p: is the initial fluid temperature in the probe [°C].

So is put in evidence that ϕ represents the angular coefficient of the function $T_f(\ln(t))$. This affords a resolution very simpler of the overhanging equation, very comprehensible for via diagram. The $T_f(t)$ function can be represented on a logarithmic diagram where in abscissa the time is represented while, in former, the experimental medium temperature (Figure 3.5).

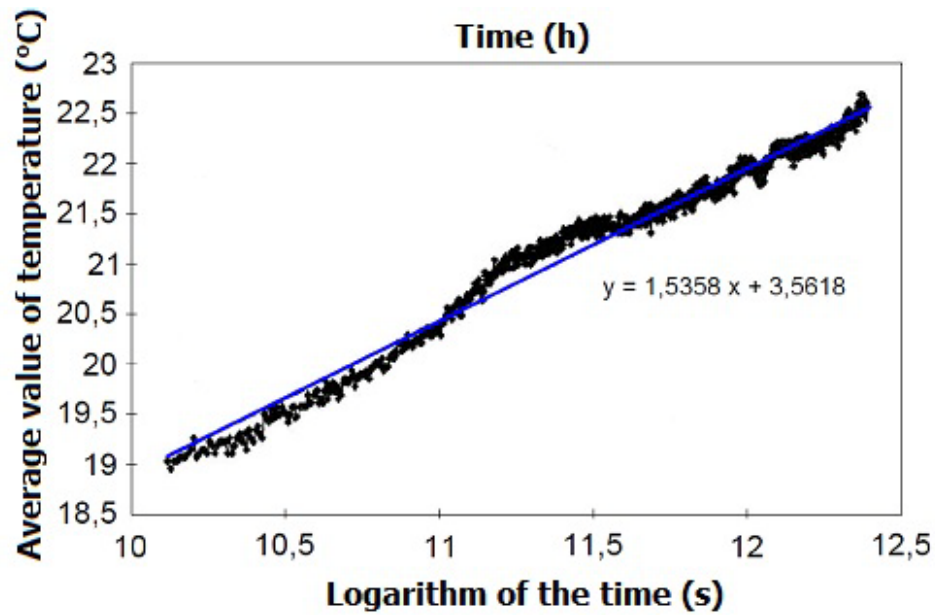


Figure 3.5 - Straight interpolation values of temperature between flow and return the logarithm of time (from Delmastro & Noce, 2009).

If the model is correct the fact, you should find a line. The slope is deduced by choosing any two points of the line calls $\ln(t_1), T_1$ and $\ln(t_2), T_2$, from the relation (Zarrella, 2009):

$$\phi = \frac{T_1 - T_2}{\ln(t_1) - \ln(t_2)}$$

where:

- T_1 [°C] is the temperature of the fluid measured in time t_1 [s];
- T_2 [°C] is the temperature of the fluid measured in time t_2 [s].

At this point the coefficient ϕ is used to find the value of thermal conductivity λ by the following equation (Zarrella, 2009):

$$\lambda = \frac{Q}{4\pi\phi}$$

where:

- Q : is the linear thermal power injected into the probe [W/m];
- φ is the angular coefficient of the function $T_f(\ln(t))$.

The value of thermal conductivity allows now to estimate the actual thermal resistivity of the probe laid and cemented R_b^* , using the following equation:

$$R_b^* = \frac{1}{Q}(T_f - T_m) - \frac{1}{4\pi\lambda}(\ln(t) + \ln\left(\frac{4\lambda}{r_b^2}\right) - \gamma)$$

where:

- Q : is the linear thermal power injected into the probe [W/m];
- $T_f(t)$: is the arithmetic average of the inlet temperature and the outlet fluid of the probe at time t [°C];
- T_m : is the temperature of the undisturbed soil in depth [°C];
- λ : is the thermal conductivity of the soil [W/mK];
- t : is the time[s];
- r_b : is the radius of the perforation [m];
- γ : is Euler's constant, equal to 0.5772 (dimensionless).

Because the thermal wave moves in the soil at very low speed, it is important to exclude from the analysis the initial results obtained, because they are relative to the filling material and not to the ground. Not being well known the position of the pipes of the hole, it takes significant time as that required for the heat wave passes through a path at least equal to the radius of the hole drilling. This time is expressed by the equation:

$$t > \frac{5r_b^2}{a}$$

where:

- r_b : is the radius of the perforation [m];
- a : is the thermal diffusivity [m^2/s];

This aspect is very visible in the experimental data: in the logarithmic representation of the measures of the test, the linear behavior of the temperature is had for elevated times, while for short times the behavior is anything but straight (Figure 3.6).

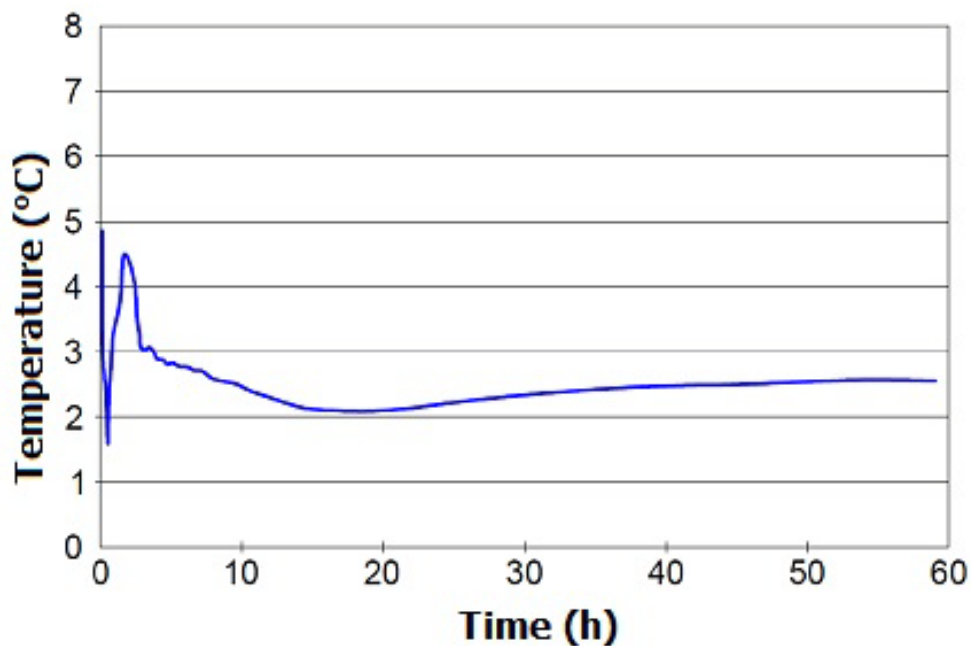


Figure 3.6 - Conductivity values obtained considering acquisition times shorter and shorter (from Delmastro & Noce, 2009).

The appraisal of the minimal time of validity of the test depends on the thermal diffusivity, than in its turn depends the thermal conductivity of the land . Remembering that this last parameter can be only estimated after the first part of the test, to estimate the time of validity (and therefore to exclude the data for the

interpretation) is necessary to assign a value to attempt to the thermal diffusivity. This introduces an uncomfortable interactivity in the interpretation procedure: based on the value of thermal diffusivity of first attempt the thermal conductivity is determined that it is used for the calculation of the thermal diffusivity of second attempt and so on. In practice it comes to interactivity only apparent because the variation of the time limit in a minimal influence generally the end result if you choose with a little 'of the thermal diffusivity guessed correctly. Where it is mistaken in the estimate it will still occur that the second attempt the stability of the function is such as not to require subsequent iterations.

Considering that the time limit for the significance of the test generally attests around the eight hours can affect the tests gradually portions of land less disturbed by drilling, you prefer to prolong the test for at least 50 hours, as recommended by Skouby (1998) and Spitler (1999). However other authors propose test of 24 hours and in the USA he is stretched to execute investigations of 12 hours hardly. If the test is sufficiently long is possible to step by step obtain a reliability index of the results through the interpretation of the test, that is only executing the interpretation on a part of the data. If the test is executed correctly, not there are meaningful fluctuations and the behavior of the land around the probe has turned out heavy influenced from the perforation, the apparent heat conductivity would have to remain substantially constant is only considering the first data after the minimal time of significance of the test, is considering all the data on the whole (Basta & Minchio, 2007).

4 Normative criteria

The following chapter is structured in order to characterize the normative elements that regulate the phases of authorization, planning and installation of the heat pumps systems in various international and national contexts. A pre-emptive panoramic of the normative picture of the countries and regions to the vanguard in the field of the low entalpy geothermal energy, it is dictated by the requirement to define the problematic ones met from the agencies that have legiferato in matter and to put of in evidence virtues and criticality.

4.1 United Sates of America

The heat pumps have been employees for many years but, only in the '70 years, in consequence to some studies that asserted the ability to the land to maintain a almost constant temperature for all the year to a determined depth, have moved greater interest towards this type of systems. This approach partially was promoted by the "National Water Well Association" of Dublino (Ohio). Currently in the American territory, above all in the center-western field and oriental, are installed approximately 50.000 open loop systems and beyond 30.000 closed loop systems (2/3 of these systems are vertical and 1/3 horizontals).

The systems of geoscambio are by now more and more of common use in the USA and given theirs increasing employment are becoming more and more important the acquaintances of the environmental norms that discipline to the planning and the installation of the system from the planners and the fitters.

To such fine an investigation on the regulations is lead by the American federal State that discipline to the planning and the installation of both systems to geothermal heat pumps (open and closed loop systems).

The regulations that interest the geothermal probes are not uniforms in all the nation: regarding the open loop systems some States have moved in order to define

of the norms standard while, for the "status" of the regulations of the closed loop systems turns out disorganized (some States has adopted of the standards defining regulations, many others does not have a specific regulation). It is written and approve by the government a synthesis of data to the <http://www.geoexchange.org/> site.

In the regulations that discipline the geothermal probes to open loop systems makes mainly reference:

- authorizations for the execution of the perforations;
- authorizations for the installation of the systems to geothermal probes;
- normative in reference to the type of construction for the water wells;
- procedures for the reinjection (open loop systems).

There is no centralization at national level between regulatory authorities in the field of regulations concerning drilling for open loop systems: each state tends to apply its requirements for the realization of this type of plant. The "National Ground Water Association" issued to its members, the guidelines for the proper discharge of drilling for open loop systems.

Forty-six of the fifty state members they officially demand an authorization for the perforation and the half demands moreover different authorizations for the installation of geothermal probes. There are federal regulations that disciplines the superficial drainage that in the acquifer. On a national level the "Environmental Protection Agency's" (EPA's) disciplines the expulsion of polluting substances from the system of drainage (NPDES), unless a State has not demanded and received "primacy" from the EPA or right to operate at state level the discharges. Nobody federal member prevents to a State or another organ to adopt severeer regulations. Some Member States prefer the superficial systems of drainage, while others prohibit it. Many inside turn the attention towards the variation of temperature of the water during the passage of the probes. Many States through a system of control (UIC) arrange of procedures standards that for example discipline to the distance between the wells and the permissible depth.

While for the open loop systems exist normative in reference to the construction of water wells, for the closed loop systems there is no specific regulation. The

increase of the number of systems is carrying moreover, to a greater interest towards the environmental problematic. The responsibility for the protection of the quality of groundwaters is of competence of the federal, state and local commission or of the governmental regional agencies. The federal regulations on the UIC and the NPDES are defined in order to avoid the contamination of waters superficial basements and. However, the UIC that is described in a part of the norm on waters to idropotabile use (Art. 40 CFR, parts 144-147) does not take in consideration the case of closed loop systems. In the same way the NPDES, defined in a portion of the same norm (Art 40 CFR, parts 122-124), ago reference to the fluid drainage in surface but it does not include the geothermal probes directly. Nothing prohibits that any State, County, Municipality adopt more rigorous regulations of the UIC and the NPDES. The majority of the relative regulations to the geothermal probes systems is controlled to state level.

In the regulations that discipline the geothermal probes systems are dealt the following general categories:

- construction of the horizontal systems;
- construction of the vertical probes;
- methodology of covering and materials; detailed lists of the antifreezing fluid;
- detailed lists on the dimensioning of the system.

In particular, the fluids recommended from the "International Association Heat pumps" (IGSHPA) are three:

- drinkable water;
- water with potassium acetate;
- water with propylene.

To the current state, twenty-six of the fifty States do not have a detailed normative list in reference to the fluid that can be deemed acceptable. In the majority of these vige moreover a specific regulation that norm the perforations. Of remaining the 24 States:

- 6 States do not have of specific regulations but they define of the "recommendations" (eg. specific fluid) that in some cases they are optional and they take part of the perforation licence;
- 6 States place detail attention to use of the fluid;
- 2 States do not have jurisdiction and the regulation is defined to regional or local level;
- the remaining the 10 States the directives with respect to the authorized fluid are written.

The list of the fluid granted varied in wide measure from State to State: the only fluid is always allowed drinking water, and locally it's possible to use propylene glycol and potassium acetate. In addition to the state norms, some Local governments have adopted the normative with respect to this type system. Once again not there is agreement, and the situation is "variable", "chaotic" also to state level. For example:

- in the Washington State, thirty counties have the possibility of develop standard on the construction for water wells in their normative premises;
- various counties in Montana have the faculty to release the licences for the costruction of water wells and the execution of perforations;
- all the counties of Minnesota have the authorization for being able to develop standard on the reinjection in well;
- various municipalities in Pennsylvania forbid the construction of the open loop systems.

Besides the regulations as above, a sure number of States has modified the proper regulamentation bringing more specific operating standards, in particular these is: Wyoming, Illinois, Iowa, Kansas, Washington, Ohio and Maryland.

In conclusion the norms that currently discipline the planning and the geothermal construction heat pump systems, with closed and open loop system, of all the United States are a mosaic of problematic adequate and inadequate answers to the environmental ones. For how much these systems become more and more common, the fear of being able to provoke an environmental damage has carried to the drawing up of a legislation.

The majority of the Americans States is concentrated on the open loop systems, however, but only a few possess a detailed normative like California and the New Jersey; others do not possess a regulation and have developed of the "guidelines" in order to encourage the correct construction of these systems like Pennsylvania. In order to contribute to the development an adequate constructive practices, the National Association Groundwaters, in 1997, has engaged itself reuniting the professional legislators, investigators, fitters and the other figures, in the development of "Lines Guide for the construction of vertical closed loop heat pumps systems". The main aspect taken in consideration in the document, regards the protection of the subsoil and the atmosphere.

4.2 European Union

In energetic sector one of the main European objectives is that to reduce the dependency the fossil fuel and to increase the renewable energy production, as proposed in the White Paper on the renewable energy sources, within 2010 had to reach at least 21% of the gross total consumption for every single Member States. In the following table (Table 4.1) the European Directives now in force for this area. With European Directive 2001/77/EC the geothermal energy is recognized like renewable energetic source while, with the Directive 2002/91/EC is indicated as an the heat pump represents an alternative system for energy-saving.

European Directive 2001/77/EC	Promotion of electricity from renewable energy sources in the internal electricity market. Geothermal energy is recognized as a "renewable energy source".
European Directive 2002/91/EC	Promotes the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions. The provisions as regards: • the general framework for a methodology for calculating the integrated energy performance of buildings; • the application of minimum requirements on the energy performance of new buildings; • the application of minimum requirements on the energy performance of existing buildings of great size subject to major renovation; • energy certification of buildings; • regular inspection of boilers and air conditioning systems in buildings, as well as an assessment of the heating installation in which the boilers are more than fifteen years.

	Also art. 5 is required for new buildings over a certain size to be considered and taken into account prior to the start of construction work on the technical, environmental and economic feasibility of alternative systems such as: • decentralized energy supply systems based on renewable energy; • cogeneration; • heating systems or cooling (complex of buildings/condos); • heat pumps.
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Table 4.1 - Summary table of the European directives of 2001 and 2002..

Besides the European Directives, with which the geothermal energy is recognized as renewable source and promotes the improvement of the energetic yield of the buildings, the European Union has adopted of the guide lines and the standards for the thermal use of the ground and the groundwaters by means of heat pumps.

Currently these detailed lists are anticipate alone in the nations that have developed by now from various years the market of the geothermal probes like Germany, Switzerland and Sweden. The dealt arguments regard in particular:

- planning and dimensioning;
- installation of horizontal, vertical probes and to open loop systems;
- environmental problematic for the protection of the territory and groundwaters.

The first norm EN that includes the technology explicitly “heat pumps to geothermal probes” is EN 1545. This norm illustrates the problematic ones that arise in the realization of a “geothermal standard” to European level:

- the climatic conditions vary remarkably in all Europe, with great differences between the heating/cooling questions and consequently, of the relative systems of planning;
- frequently are very different the geological conditions, demand an adaptation of the geothermal systems to the several local contexts;
- the various characteristics of heating and cooling do so as that EN 15450 only is able of giving to a general picture minimal in matter of planning and installation. Ulterior detailed lists are sent back to regional level.

In particular this norm includes:

- technical standards for the appraisal of the efficiency, safety of the system and its longevity;
- technical standards to follow above all for the environmental safeguard and for the procedures of installation, in particular for the phases of perforation;
- norms and the lines guide for the authorization to the installation of systems to geothermal probes with detail reference to the protection of the water resource. Moreover, the norms for the exploitation of the geothermal resource are included;
- certifications of quality of the system: they must be released from the fitters and drills.

All the States Member of the European Union have adopted “basic” standards for the putting in place, the appraisal and safety of the system. Switzerland, Norway and Iceland have realized already for a long time a uniform norm on a national level. Today the national standards are considered valid single in those areas not still bound from norm EN. It exists moreover, the possibility that these last ones coexist with norms EN but, in these cases is considered opportune to follow the European norm because more recent.

In Austria, Germany, Denmark, France, Holland, Italy, Poland, Rumania and Sweden are present national standards not more recent but still valid. Some standard ISO are employed in Denmark, Great Britain and Holland.

For systems GSHP (Ground Source Heat Pump) technical standards in the nations in which the market exist already it is developed by years, these are: Germany (VDI 4640 represents more specific and relevant standard), Sweden, Austria and Switzerland. These standards regulate the authorizations and the certifications for the operators of the field (fitters and drillers). In some nations the guide lines are realized for the installation with the exception of some states (Germany, some Swiss districts and a state of Austria) in which a dedicated norm is present.

As shown in Table 4.2 they are only listed the standards and the lines on a national level guide (Austria, Switzerland, Germany and Sweden). The majority of documents is not of the norms published from legislative organisms but they are of

the technical lines supplied by professionals or scientific organizations. For drilling there are few regulatory standards such as "BHE".

Number	Title	Purpose	Year
Heat pumps			
EN 255-3	Air conditioners, refrigerators and heat pumps with electrically driven compressors - Heating mode	Testing plant	1997-07
EN 378	Refrigeration systems and heat pumps - Safety and environmental requirements - Part 1-4	Requirements for safety and environmental protection	2003
EN 14511	Air conditioners, refrigerators and heat pumps with electrically driven compressors for heating and cooling of the premises - Part 1-4	Requirements and testing	2002-08
EN 15450	Heating systems in buildings - Planning of heat pump systems	Planning	2007-12
ISO 5149	Plant for cooling and heating - Safety requirements	Safety requirements for heat pumps	1993-09
ISO 5151	Testing and evaluation of the performance of air conditioners and air to air in Britain	Planning and test of performance of the heat pumps to air	1994-12
ISO 13256	Heat pumps water-water type - testing in Denmark and the Netherlands	Acceptance test of heat pumps	2001
VDI 2067 Blatt 6	Economic evaluation of the energy consumption of heat pump systems	Economic evaluation	1989-09 (DE)
VDI 4650 Blatt 1	Calculating the annual efficiency for electric heat pumps used for domestic heating	Efficiency calculation	2003-01 (DE)
ÖNORM M 7755-1	The electric heat pumps - Part 1: General requirements for the planning and construction of heating systems to heat pump	Systems of design and installation of heat pumps	2000-09(AT)
Geothermal probes apply to heat pumps			
DIN 8901	Refrigeration systems and heat pumps - Safeguarding of the subsoil, and water resources	The preservation of the subsoil, and water resources	2002-12 (DE)
VDI 4640 Blatt 1-4	Use of geothermal resources - Part 1-4	Planning and installation of geothermal probes	2000-2004 (DE)
ÖNORM M 7753	Testing of the probe and directions of efficiency	Test and verification of the resource	1995-10 (AT)
ÖNORM M 7755-2+3	Heat pumps	Planning and installation of systems to geothermal heat pumps	2000-09 (AT)
ÖWAV RB 207	Systems for the exploitation of geothermal energy	Control and protection of groundwater resources	1993 (AT)
Normbrunn-97	Energy standard (Energibrunnsnorm)	Proper installation of a geothermal system	1997 (SE)

SVEPstandard	Standard procedure for the installation of geothermal probes (Tillverkningsnorm för Bergvärmekollektorer)	Proper installation of a geothermal system	2005-11 (SE)
SIA D 0179	Geotermie - Erdreichspeicher für moderne Gebäudetechnik	Low enthalpy	2003 (CH)
AWP T1-5	Technische Merkblätter	Heating systems to geothermal closed loop and open loop	2007 (CH)
EN 791	The safety during the drilling phases	Safety during drilling	1996-01
DVGW W 110	Investigations into the hole	Investigations into the hole to get to know the specific geological and hydrogeological	2005-06
DVGW W 115	Exploration wells, pumping and groundwater analysis	Drilling wells	2001-03
DVGW W 116	Indications regarding the possible additives to be used in the drilling mud	Identification of drilling fluids in order to protect the groundwater	1998-04
PN-G-01201	Drilling	Specifications regarding the drilling	1992-12
PN-G-01215	Instrumentation to be used during the drilling phases	Drilling tools	1998-01
PN-G-02305	Drilling for water wells - requirements for good perforation	Tipology and methods of drilling	1994-11
PN-G-08611	Safety requirements during the drilling phases	Requirements for safety	1999-07

Table 4.2 - List of standards and regulations regarding heat pumps and Geothermal probes.

Arguments that can be object of new European norms for the installation of geothermal heat pumps are relative in particular to (cfr VDI 4640, parts 1-4):

- calibration of the geothermal system based on the various climatic and geologic conditions;
- materials to use in the wells, type of probes, systems of pipeline and collectors;
- open loop geothermal probes (perforation, construction and putting in function);
- heat exchangers (perforation, installation and putting in function);
- putting in place of horizontal probes systems.

In conclusion of the study the current norms and codes it is observed:

- norms EN are adapted and allow a free market of the heat pumps of its members. They exist alone in some countries of the detailed norms

(Austria, Germany, Sweden and Switzerland). In France, Ireland and Netherlands have not yet established specific norms;

- regarding the release of the licences and the certifications in single countries some functional procedures are in vigor. The latter to be effective, they must ensure that current and future national legislation in the field in question, does not foresee major changes.

Some new national norms regarding geothermal energy to low entalpy are functional for all the types of geothermal probes systems:

- Geothermal ÖWAV "to low entalpy" (in course the homogenization with the Germans guide lines VDI 4640);
- NF X 10/999, "realization, monitoring and dismissione of systems that take advantage of the water resource basement";
- HVCA TR330 in vigor in the United Kingdom for geothermal heat pumps systems;
- SN 565 384/6, "geothermal probes systems for the heating and the cooling of the buildings" in Switzerland.

4.3 The main national contexts

In this paragraph will be showed the main features of the regulatory frameworks of the countries that use geothermal probes as alternative and as a source of energy savings. Besides the European context has analyzed the situation of Switzerland, vanguard considered from a technical point of view that gives a legislative point of view. Besides this last one, the analyzed states are: Austria, Germany, Netherland, Sweden and Morocco. For everyone of they, after to have illustrated the current situation in relation to the amount and type of present systems on the territory, the currently enforced legislative order will be illustrated and, whereby possible, the positive aspects and those critics will be put in evidence.

4.3.1 Austria

The geothermal probes applied to heat pumps are in use in the Austrian territory from the 1976 (beginning of the first oil crisis). These systems being to low energetic consumption are framed currently like a "technology" in a position to reaching the objectives of sustainable energetic supplying based on renewable energy sources. Therefore, the heat pumps are inserted by the Austrian federal government in the within of the program "klima aktiv".

Currently Austria is composed from nine federal States that have various forms of subsidies, and also the techniques guide lines (for example, the norms of reference for the management of the water resource) and the technical demands for documentation and performance of the systems are not coherent in all the Austrian territory. Moreover a disparity of treatment in the system of financing of the alternative heating systems exists that neglects the contribution for the energetic efficiency and the reduction of the CO₂ emissions.

In Austria various subsidies for everyone of the nine federal States exist. There are two main forms:

- directed subsidies, granted as subsidies (Burgenland, Kärnten, Lower Austria, Oberösterreich, Tirol, Vorarlberg, Vienna);
- indirect subsidies of financing for the residential construction industry (Salisburgo, Stiria).

4.3.2 Germany

In Germany for how much it concerns the geothermal energy exists laws which are to federal level (Bund) and to state level (Länder). The field however is generally disciplined by the federal law "Mining" (Bundesberggesetz, or Bbergg), and lately they are adopted of the guide lines on the norms and the codes that regard the geothermal heat pumps. In Table 4.3 are brought back the norms and the guide lines for the heat pumps.

Name	Description	Year
DIN EN 14511	Air conditioners, cooling liquid, systems and heat pumps with electrically driven compressors for heating and cooling of environments (Part 1.4)	2004-07
DIN EN 15450	Heating systems for buildings - Planning of heating systems to heat pumps	2007-10
VDI 2067 Blatt 6	Economic evaluation of energy consumption with heat pumps	1989-09
VDI 4640 Blatt 1-4	Exploitation of geothermal resources	Part 1: 2000-12 Part 2: 2001-09 Part 3: 2002-06 Part 4: 2004-09
VDI 4650 Blatt 1	"Short cut" Method to calculate the annual energy consumption with heat pumps	2003-01
DVGW W 116	Type of drilling mud granted	1998-04
DVGW W 120 G	Quality requirements for a good drilling	2005-12

Table 4.3 - Standards and guidelines for heat pumps.

In Germany, currently, a common national norm for the installation of heat pumps does not exist. The procedure of installation to follow is disciplined by the Länder (Regions) and depends on the dimension of the plan. The authorization demand refer to the relative norm to water resources (WHG - Wasserhaushaltsgesetz exclusively). The demand to introduce to the competent Agency (Untere Wasserbehörde of the rural districts/provinces - Landkreise) is a permission of concession for the putting in opera of the geothermal probes system. Such permission, in relation to the dimensions of the plan, can be of two types: "limited" and "formal".

To the question the following documents must be attached:

- the plant of the real estate bottom;
- a description of the geological and hydrogeological structure;
- letter of assignment of the outsourcer;

- technical description of the system;
- description detailed on the thermal requirements;
- directory of the substances that will be introduced in the land and in the aquifer during the drilling.

Name Law	Field of Application	Synthesis
Guidelines VDI4640	Planning and installation procedures of the geothermal probes systems.	Provide standards for the planning and installation of geothermal probes. They make particular reference to the geological, hydrogeological and environmental problems.

The objectives of the German normatives (Lines guide VDI4640) are those to bring back of the indications that can be continuations during the phases of planning, installation and putting in opera the system. These lines guide bring back in particular some references, regarding:

- basic physical principles which make reference in particular to the heat exchange between the probe and the ground;
- geological and hydrogeological considerations;
- procedures to be followed in the design phase;
- certain physical properties to be considered for the different lithologies as density, thermal and volumetric conductivity;
- evaluation of the heat capacity of the plant is able to provide;
- environmental aspects are considered, the primary energy savings and the associated reduction in CO₂ emissions, as well as the possible environmental impacts that may cause the refrigerant.

4.3.3 Netherlands

In Netherlands exists a legislation on the energetic yield from 1996. A maximum rating of EPC (Energy Certification Performance) implies the realization and the planning of buildings to high energetic efficiency with a consequent reduction of energetic demand, efficient systems of conversion and use of sustainable energy.

With the heat pumps the EPC values are gone around around the 0,5 regarding the maximum rating of 1,4.

Regarding the legislation, besides EPC calculation for the construction permission, for the open loop systems is necessary an authorization for groundwaters uses. The Provinces beyond to being responsible for the authorizations are the supervisory bodies. For the open loop systems of small capacities (inferior to 10 m³/h) are not previewed concessions. For the open loop systems with great capacities to the 10 m³/h it is necessary to obtain a permission that it is released by one of the 13 Provinces. In order to obtain the permission the owner/contractor must supply to the Province a geologic relation containing the relative analysis of environmental impact and appraisal

of the previewed performances. In order to obtain the authorization a year is necessary almost.

The enforced norms in the Netherlands:

- norm on waters;
- relations on the environmental effects (MER). For the systems of advanced dimensions to 1.5 million m³/year the procedure it demands from 1 to 2 years;
- norms on the safeguard of the groundwaters;
- norms on the protection of superficial waters;
- laws on the environmental protection;
- in the case of water use by open loop systems is the province itself to indicate all practices to be followed for the application and issuing of the authorization.

4.3.4 Sweden

One of the reasons that has made possible the development of heat pumps in Sweden was undoubtedly legislation "free". There are however a series of laws and regulations in environmental field that must be considered in phase of installation of

a geothermal system. These laws regard the protection of groundwaters let alone the management of cooling fluid (HFC). In general terms is always required the authorization for the installation of this type of systems. Were published in the official guide lines for the planning of vertical geothermal probes systems by the Geological Survey of Sweden in cooperation with the Swedish Association of heat pumps (SVEP) and GEOTEC (Association of drillers).

These guide lines include the instructions on as to avoid eventual damages to the buildings and to prevent contaminations of the ground waters during the perforation. These are required at the moment of the perforation the installation of a steel liner until 3 meters of depth in order to avoid possible logons between the superficial aquifer and that deep one with consequent contaminations.

The remarkable increment of installations of geothermal heat pumps has raised the problem on the possibility of thermal interferences: to such care a distance of approximately 10 m between the same ones is advised. The thermal liquid that usually comes used inside of the circuit of the system is a solution with water and bioethanol to low environmental impact.

4.3.5 Switzerland

The Swiss experience in matter of geothermal probes applied to heat pumps probably represents the more functional and efficient scheme. Although the contexts pertaining to the several districts are uneven sometimes is observed a directed correspondence between the normative picture and the territorial reality from governed it. Like reference here, it has been considered opportune to more bring back the characteristics of the iter normative adopted from the District of the VAUD, considered to the vanguard in this field.

Name Law	Field of Application	Synthesis
Mining Code	Drilling	It requests a certificate for each perforation that exceeds the depth of 10 m; a license to include the environmental impact report for every drilling in excess of 100 m

Environmental Code	Pumping of water	It does not apply in the case of geothermal open loop systems.
Regulation on the use of heat pumps	Withdrawal and reintroduction of water for open loop systems	This Regulation is an overview of the necessary permits for the exploitation of geothermal resources.

The Regulations concerning the realization of a well turns out articulated enough: one makes use of various codes, in particular of the Mining Code and the Environmental Code (law on the water resource). In the Mining Code is required for each statement drilling more than 10 m deep and a license with its issues paper on the possible environmental impact, for drilling which exceeds of 100 m of deep. The Environmental Code refers in particular to the direct use of water resources without making any mention of the open loop geothermal plants. In this code must be declared if the levy is greater than 1000 m³/year. Authorization is required for all samples located within the perimeter of protection and/or the withdrawal of water is above 80 m³/h.

In Switzerland the legislation is vast and above all represents a problematic example to the European level regarding the environmental ones. All the national territory is classified according to "security zones": this classification defines the possibility to realize a sure type of system.

The articles that order I use it of the heat pumps are:

Art. 1 General condition

- the installation of heat pumps is allowed single if the protection of the groundwater resource and subsoil is assured and in case are not found adverse effects in the environment;
- the systems can be installed in privates property except some special restrictions;
- the installations are assimilated to heat pumps all that take advantage of the thermal exchange with the subsoil or that take advantage of the water resource like means of thermal exchange.

Art. 2 Exploitation of the water resource

- the use of the groundwater resource to the aim of the heat exchange is authorized only in case of derivation or pumping;

- a condition necessary in order to obtain the authorization to use of the groundwater resource for geothermal scopes (open loopsy stems) is that it must not be damaged by the physical-chemical properties of the same one in particular, must not be re-emitted the water at different temperature from that of levy.

Art. 3 Utilization of the groundwater resource

- it is only allowed the use of not drinkable groundwater. The captazione and pumping of the groundwater resource, situated in the zone "S" of protection of the water, is prohibited;
- the authorization is granted only if the characteristics of the acquifer assure the "thermal renewal" of it;
- the captured water must be re-introduced to "an appropriate" distance from the withdrawal point;
- the temperature of the re-introduced water does not have to be inferior to 5°C while, the temperature of the groundwater cannot be inferior to the 8°C;
- the static level of the stratum does not have to be modified from the system of exchange.

Art. 4 Utilization of the superficial water resource

- the re-introduction must be executed in the immediate vicinities of the withdrawal point; the lowering of the temperature of the water does not have to exceed, after the re-introduction 1°C while, the temperature of the water re-introduced does not have essere inferiore to the 2°C.

Art. 5 Utilization of superficial free water (which lakes or rivers) for the operation of the systems

The water catchment systems must be planned so as to:

- to allow the periodic maintenance;
- to resist at any risk of mechanical damaging that can cause the malfunctioning of the same system;
- not to hinder the navigation, the access, the swim and the fishing;
- make it possible if necessary monitoring;

- the water collected must be re-entered;
- the temperature of re-introduction does not have to be inferior to 2°C.

Art. 7 Use of the ground and subsoil

- the geothermal probes can be installed at least 2 meters from the nearest building;
- the systems to horizontal geothermal probes must be installed at least 0,8 meters of depth making attention to not damage eventual groundwater resources;
- in the zones “S” of protection of the water resource, the systems to horizontal geothermal probes must be installed at least 2 meters away from possible water resources present in the area where the system is installed;
- for the installation of this type of plant should be followed the guidelines of the Federal Office for the Environment, Forests and Landscape.

Art. 8 Safeguards measures

- the circuits of these systems must be sealed of way such that not is spillage of gas or liquids in the surrounding environments. Inside of the probes can be used like fluid for the heat exchange, only approved products indicated from the federal government;
- the probes must be planned of way such to preview and to facilitate the maintenance and the monitoring of the same ones;
- is allowed to discharge into the sewer;
- inspections are required by the Security Department of the Environment, not only during the installation steps, but also during operation of the same.

Art. 9 Control

- the owner of the system must adopt all the surveillance measures and maintenance so as to prevent any environmental damage;
- any defect, with consequent loss of liquids from the probe of heat pump must be immediately marked to the Department of Environmental Safety with the indication of the substance amount spillage.

Art. 10 Notice of beginning works and permission of constructions

- for the construction of a geothermal probes system it is necessary to inform the Department of Environmental Safety of the beginning of the intense activities;
- the demand for installation of the system must be addressed to the Departemnt of the Waters, of the Ground and the Hygienic-Sanitary Services, in twofold copy, with the following documents:
 - cadastral map with location of the probes;
 - description and outline of the plan.
- it must be realized a card that you bring back all the several phases of perforation which will have to be transmitted to the department;
- the permission of construction from the Municipality is limited in conformity with the disposition of law on the territorial planning.

Art. 11 Special Authorizations

- the installation of geothermal probes systems that use groundwaters or superficial waters is subject to special authorization. The demand of authorization must being sent to the Department of Safety, Environmental Services, of the Water and the Ground, with following documents in triplicate:
 - cadastral plan, specifying the location and the influence of the structures;
 - detailed plan for the taking and re-entry. In case of utilization of groundwater it must be made a feasibility hydrogeological study inclusive of all details relating to monitoring, including the amount of water which it intends to withdraw, the temperature for withdrawal and re-placing of the waters.

4.3.6 Morocco

Morocco has been equipped in 2009 of a normative detailed list for the energetic yield of the buildings, developed in the picture of a wider national program than energetic efficiency.

The objective announced from the Moroccan government, like analyzed by Comparetto (2014) and Castrucci (2014), is to realize a saving of primary energy through the performance of a plan of energetic efficiency in the different economic fields.

The Law 47/09 has the scope to increase the energetic efficiency, rationalizing the use of the energy from any source to avoid wastes to it, to reduce the burden of the energetic costs on the national economy and to contribute to the sustainable development.

Its performance is based mainly on the introduction of:

- Requirement minimums of energetic efficiency;
- Studies of energetic impact;
- Audit energetic required;
- Technical control.

It also tends to extend the techniques of energetic efficiency at the level of all the programs of sector development, to encourage the enterprises and the industries to rationalize their energetic consumption, to generalize the energetic diagnoses, to in existence put of the specific codes of energetic efficiency for the different fields, to promote the development of solar and geothermal heats of the water, to generalize the use of lamps and equipment to energetic saving. At fine to promote the energetic efficiency and the energetic saving, the law previews the spread of activity of formation and improvement of professional training and scientific search.

The law previews in particular five objectives:

- To reduce the energetic consumption for heating and cooling of the buildings;
- To improve visual thermal comfort for the inhabitants;
- To optimize the planning of the energetic systems;
- To create incentives so that engineers and architects for example plan efficient buildings from the energetic point of view (estimating shadowing and guideline regarding the sun in order to maximize the ventilation and the natural lighting system);
- Assistance in the realization of audit energetic in the existing buildings.

All programs of city development and all the plans of buildings (any are their use) are subordinates under consideration of energetic impact, in according to the threshold of thermal power consumption and/or specific electrical worker for each category of plan. The study of energetic impact must in particular:

- Estimate systematically and preliminarily the previewed energetic consumption from the plan;
- Estimate the potential of energetic efficiency of the plan;
- Identify the local energetic resources mobilized for the their plan and potential;
- Reduce the level of expected energy consumption, developing energy efficiency project.

The study of energetic impact must contain:

- A description of the main members of the plan and their characteristics, the used phases of the realization of the plan and energetic resources;
- An appraisal of must energetic during the phases of realization, operation or development of the plan;
- The considered measures in order to reduce the power consumption;
- A program of surveillance and monitoring of the plan;
- The measures previewed in the field of the formation, communication and management, to the aim to guarantee the performance of the plan and its operation;
- A synthesis note that reassumes the content and the conclusions of the study;
- Simplified reassuming of the information and the main data contained in the study, destined the public.

If the project is also subject to an environmental impact study, its approval covers both environmental and energetic issues.

The law establishing a technical inspection which aims to verify and certify compliance with energy performance and the provisions of the energy audit compulsory. The technical supervision will be conducted by agents of the administration the employees. These must, during the inspection, proceed to the

verification of all the documents mentioned above, and make sure the content of the information communicated to the administration.

4.3.7 Italy

The evolution of the normative panorama anticipates a complicated dynamics and indeed difficult to follow since, in absence of a national norm, every Region can emanate own regulations in matter of geothermal probes and in absence of regional regulations every Province can deliberate personalized authorize iter and prescription of installation. In absence also of provincial opinions remains to the Municipality the task to define which documents to demand for the authorization: it turns out some therefore a panorama extremely which variegated.

On a national level the realization of any type of perforation must adhere to the techniques described in the D.M. 236 of March 1988 and in particular for wells and piezometer it must adhere to Law 464 of 1984, that it imposes to make to reach the of the General Directorate of Mines of the Ministry of Industry the intention to the realization of wells that reach advanced to the 30 meters of depths. It anticipates that the decree it establishes the requirement of quality of destined waters to the human consumption, for the protection of the public health and for the improvement of the living conditions and introduces finalized measures to guarantee the defense of the water resources.

At national level there is not any norm that establishes of the lines guides to follow in matter of low and very low entalpy geothermal energy and that safeguards the water resource, and it makes always reference to the Law 236 of 1988. Here the areas of respect for the protection of the water resource are indicated. In particular:

- **zones of absolute protection:** it is constituted by the immediately surrounding the catchment area or derivations; it must have an extension, in case of groundwaters, and where possible, for superficial waters at least ten meters of beam from the catchment point, must be adequately protected and used exclusively to catchment works or taken point and infrastructures of service;

- **respect zones:** the zone of absolute protection is constituted by the portion of surrounding territory to subject to ties and destinations of use such to protect qualitatively and quantitatively the picked up water resource and can be subdivided in zone of narrow respect and zone of respect increased in relation to the type of the catchment work or taken point and to the local situation of vulnerability and risk of the resource. In particular in the respect zone they are prohibited the takeover of the following centers of danger and the development of the following activities:
 - dispersion of sludge and wastewater, even if separated;
 - Accumulation of chemical fertilizers, pesticides or fertilizers;
 - Spreading of chemical fertilizers, pesticides or fertilizers unless the use of these substances is carried out based on the guidelines of a specific-use plan that takes into account the nature of the soils, crops compatible agronomic techniques employed and the vulnerability of water resources;
 - Leakage of underground storm water from yards and roads;
 - Cemeteries;
 - Opening of quarries that may be in connection with the water table;
 - Opening of wells except those that extract water intended for human consumption and those related to the change in the extraction and the protection of the quantitative characteristics of water resources;
 - Management of waste;
 - Storage of products or dangerous chemicals and radioactive substances;
 - Collection centers, demolition and scrapping of vehicles;
 - Losers wells;
 - Grazing and stabling of cattle which exceeds the 170 kilograms per hectare of nitrogen present in the effluents, net of losses of

storage and distribution. However, it is prohibited housing livestock in the area of respect restricted.

The regions and autonomous provinces govern, within the buffer zones, the following facilities or activities:

- Sewers;
- Housing and related infrastructure works;
- Various works, railway and general service infrastructure;
- Distribution of chemical fertilizers and fertilizers in agriculture where there is a regional or provincial level of fertilization;
- Agronomic practices and content of the plans of fertilization.

In the absence of the identification by the region in the area of compliance under Article 4, paragraph 1, the same has an area of 200 meters radius compared to point of collection or derivation.

- **protection areas:** must be defined as shown in the Regions to ensure the protection of water resources. In them you can adopt measures relating to the destination of the territory concerned, limitations and requirements for civilian settlements, manufacturing, tourism, agro-forestry and livestock to be included in municipal planning instruments, provincial, regional, both general and sector. The Regions, in order to protect the groundwater, even those not yet used for human use, characterize and discipline, within the zones of protection, the following areas:

- Areas of groundwater recharge;
- Emergencies of natural and artificial groundwater;
- Reserve areas.

Are also important, some articles of the Civil Code, in particular:

Art. 840 - Underground and the space above the ground, which states: "The ownership of land extends to the underground, with all that it contains, and the owner can do any excavation or work without detriment to the nearby [...]. The owner of the land may not oppose the activities of third parties that are held in such deep underground or in the space above this height, that he has no interest in excluding". It is therefore permissible for the owner of the facility to install a

geothermal probes because it is nothing but a work of "excavation" and subsequent installation of a probe, obviously respecting any rule of environmental and procedural requirements.

Art. 889 - Distances for wells, reservoirs, ditches and pipes, which states: "Who wants to open wells, tanks [...] must observe a distance of at least two meters from the edge to the nearest point on the inside perimeter of the aforementioned works. For pipes of water, gas and similar ones and their branches must observe the minimum distance of one meter from the border. Are safe in any case the provisions of local regulations".

The Council of Ministers approved today the Leg. February 11, 2010, n. 22 "Reorganization of the legislation on exploration and production of geothermal resources, under Article 27, paragraph 28 of the Law of 23 July 2009, n. 99".

In that provision precisely art.1 "Scope of the law and skills" are called geothermal resources:

- high enthalpy geothermal resource characterized by a temperature of the fluid retrieved exceeding 150 °C;
- medium enthalpy geothermal resource characterized by a fluid temperature abruptly between 90 °C and 150 °C;
- low enthalpy geothermal resource characterized by a temperature of the fluid retrieved less than 90 °C.

Also in Article 1 it is established that depending on the fluid temperature and of the power of the plant:

- are of national interest, the high enthalpy geothermal resources that can provide a power output of at least 2 MW and all those found in marine areas;
- are of local interest geothermal resources in the medium and low enthalpy power less than 2 MW.

Art. 10 of Legislative Decree defining "small uses local" systems operating both with open loop systems (water withdrawal) and closed loop (only heat exchange) of competence of the Regions (or the Agencies from delegated they). These have both administrative and supervisory functions. Small local uses are divided into:

- uses with withdrawal of fluids or geothermal hot water within certain limits of thermal power and depth of the wells. Allow the construction of facilities of less than 2 MW, obtainable from the geothermal fluid to the conventional temperature of the wastewater of 15 °C. Obtained through the execution of deep wells up to 400 m for search, extraction and utilization of geothermal fluids or hot waters, including those gushing from springs for total heat capacity of not more than 2 MW, also for eventual production of electrical energy with installations binary cycle zero emission. Approval shall be granted by the Region of territorial jurisdiction in the manner provided by the consolidated text of the law on water and electrical systems, as described in Royal Decree of 11 December 1933 n.1775. The facilities of less than 1 MW obtainable from geothermal fluid temperature conventional wastewater of 15 ° C and uses a geothermal probe are disqualified from regional environmental verification of subjection;
- uses that by installing geothermal heat exchange with the ground without making the withdrawal and reintroduction of water or hot geothermal fluids into the aquifer. This type of plant is subject to specific regulations issued by the competent region in anticipation of the adoption of simplified procedures. Even this type of application is excluded from the verification procedures of subjection environment.

Although this legislative decree represents a first step towards the establishment of an appropriate regulatory framework for geothermal plants nationally, it is still very generic and still unclear in some parts.

4.3.8 The main regional and provincial contexts

This paragraph shows the characteristics of the regulatory frameworks of the Italian regions and provinces which use the geothermal probes as alternative and as a source of energy savings, and that first have a "provisions of geothermal energy". In addition to the context of the Lombardy Region and the Region of Tuscany has analyzed the status of the Autonomous Province of Bolzano, is actually considered

one of the most vanguard from a technical point of view than from a legislative point of view. Apart from the latter province was analyzed the Province of Milan, in the legislative framework of the Lombardy Region and the Province of Bologna.

4.3.8.1 Tuscany Region

The Tuscany Region has provided for the installation of geothermal plants of any type and nature is subject to authorization only.

Name Law	Field of Application	Synthesis
Tuscany Regional Law 24 February 2005 n. 39 Provisions on energy	This Act regulates the activities in the field of energy and in particular, the production, transportation, transmission, storage, distribution, supply and use of energy	This law defines the administrative functions relating to geothermal plants (Art.3 paragraph 2, letter a) as a competence of the Region

The Regional law n.39 of 2005 establishes the necessary authorizations for the installation of geothermal probes. In the particular case in which it exploits indirect heat exchange (that is without withdrawal of water), the bureaucratic process provides only for the compilation of the Single described in Article 11 of the law itself.

Relative the administrative functions to the authorizations of which to article 11, 13, 15 and to the concessions of which to article 14 they are of competence:

- Region, when involving geothermal plants, wind power plants with a power exceeding 50 kW, as well as lines and transmission, transformation, distribution of electricity voltage rating greater than 100000 volts if subjected to the procedure of environmental impact assessment (EIA) regional arrangement under the Regional Law of November 3, 1998, n.79 (Provisions for the application of environmental impact assessment) or if involving a territorial interregional;
- the provinces in other cases.

Administrative functions related to the start activity are competent:

- for work on existing works or in progress under paragraph 4 of Article 16, the administration responsible for the relevant type of work;

- for new works referred to in paragraph 3 of Article 16 of the Municipalities.

Below the articles of this law in particular those listed in Section II "Regional organization in the field of energy".

Art. 9 - Technical organizations operating in the energy sector.

1. For the activities required to perform the duties and implementation of initiatives in the field of energy, the region and local authorities may secure the cooperation of the R.E.A. SpA (Regional Energy Agency) as part of the functions assigned to it by Article 10 of Regional Law 26 June 1997 n. 45 (Norms on energy resources), as amended by Article 1 of the Regional Law 25 February 2000 n. 14, which also operates in partnership with provincial and municipal agencies for energy.
2. For the purposes of the funding provided by this Act or by the actions envisaged by the planning documents in the field of energy, the region may require the compliance of the projects with the requirements of the works is attested by the R.E.A., SpA or by qualified technicians that serve no other functions that could be considered incompatible.

Section III: "Regulation of energy activities"

Art. 10 - Construction and operation of plants.

1. Are subject to single authorization or commencement notice (DIA), as regards the competencies of the Region and local authorities, the construction and operation of facilities for production, transportation, transmission and distribution of energy, processing equipment and hydrogen storage, mineral oil and natural gas and liquefied, in any form, as well as outdoor lighting systems, to ensure that such activities are conducted in accordance with the purposes set forth in Article 2, without prejudice to the interests protected laws, plans and programs relating to the safety, health, environment, landscape and territorial government.
2. If several requests for permission prove mutually incompatible, in relation to public interests protected by the law and by the acts referred to in paragraph 1 and in the acts that flow into the unified procedure referred to in Article 12, an assessment is made on the basis of comparative general

criteria, also agreed in accordance with Article 4, paragraph 2, in accordance with specific guidelines resulting from programming tools of Chapter II and land covered by the Regional Law 1/2005.

3. For the tasks facing the regional council, through a resolution, decides how to identify cases in which you apply the comparative assessment referred to in paragraph 2 and the arrangements for those purposes. The procedures referred to in this paragraph shall also apply to areas of competence of local authorities until these provide otherwise.
4. The works and the intense activities object of this law are made in accordance with state regulations and regional regulations regarding seismic safety, and in particular with the provisions of the law on Nov. 5, 1971, n. 1086 (Regulations for the regulation of works of reinforced concrete and prestressed and metal structure), as well as those dictated by Part II, Chapter IV of the President decree of 6 June 2001 n. 380 (Consolidated laws and regulations on construction), and the Law of 28 June 1986. 339 (New standards for the regulation of the construction and operation of airlines external) and the respective implementing rules.
5. To the aims of the release of the only authorization or the presentation of DIA, inherent overhead lines and related facilities, stakeholders deposited, at regional jurisdiction under Regional Law 6 December 1982, n. 88 (Discipline of controls on construction in areas prone to earthquakes) and in accordance with regulations issued in implementation of Article 117 of Regional Law 1/2005, the elaborate project referred to in Article 12, paragraph 3, letter b) of this Act, which may be accompanied in the attestation issued following the controls referred to in paragraph 6, in the forms and in the manner provided for in this Law, by Ir 88/1982 and the regulations issued in implementation of Article 117 of Regional Law 1/2005. Its controls are carried out in accordance with the provisions of Article 6 of Regional Law 88/1982 and the regulations issued in implementation of Article 117 of Regional Law 1/2005.

6. The conceptual planning of the structural elements of a standardized type or repetitive, relative to the supports and the corresponding updates, are previously filed with the competent regional structure in the field of seismic safety, the purpose of the checks referred to in Article 6, paragraphs 5 and 6 , Regional Law 88/1982 and the regulations adopted in implementation of Article 117 of Regional Law 1/2005. Results of the checks shall be communicated by the same regional structure to the parties concerned.

Art. 11 - Single license.

1. Are subject to authorization only the construction and operation of the following systems:
- a) plants producing electricity from conventional sources with the exception of emergency generators or generators constituents activities to air pollution insignificant according to the President decree of 25 July 1991 (Amendments to the guidance and coordination in emissions insignificant and activities to reduced air pollution, issued through Decree 21 July 1989);
 - b) power lines and related facilities except for works subject to DIA under Article 16;
 - c) oil and gas pipelines, except for infrastructure constituents urbanization and changes to existing pipeline is not identified by the regulations in Article 39, as new work;
 - d) storage facilities for hydrocarbons with a capacity exceeding 25 m³, except as provided in subparagraphs e) and f);
 - e) storage facilities of mineral oil with a capacity exceeding 25 m³, in the cases referred to in Article 1, paragraph 56 of the l. 239/2004;
 - f) storage facilities for liquefied petroleum gas (LPG) with the exception of deposits of LPG cylinders, having storage capacity of not more than 500 kilograms of product;
 - g) processing plants and processing hydrocarbons except as provided in subparagraph h);

- h) processing plants and processing mineral oil in the case referred to the. 239/2004, article 1, paragraph 56;
 - i) plants for the production, transport and use of hydrogen as specified in the regulations referred to in Article 39.
2. With a single license shall be issued at the conclusion of the proceedings under Article 12, paragraph 2, all necessary approvals for the construction of the plant, including those of a landscape and environment. Limited to works subject to it not apply the method of "single window" in Title II, Chapter IV of the legislative decree 31 March 1998 n. 112 (Assignment of functions and tasks of the State to the regions and local authorities, in the implementation of Chapter I of the Law of 15 March 1997, no. 59). The exercise facility remains subject to the obligations subsequent to the execution of the works, imposed by law.
 3. With the single authorization are authorized also associated works and infrastructure necessary for construction and operation of the plant.
 4. At the request of the authorization measure referred to in paragraph 1 may be declared of public utility works, whereby not existing, the bond preordained expropriation, with the procedures laid down in Article 8, paragraphs 4 and 5, without prejudice to the provisions of Articles 52b and 52c of the President of the Republic decree of June 8, 2001, n. 327 (Consolidated laws and regulations on expropriation for public use) as amended by Legislative Decree 27 December 2004 n. 330.

Art. 12 - Unified process.

1. The single license is issued at the conclusion of a unified process, subject to the possibility for that person to directly acquire opinions, authorization, acts of assent required for issuing the license.
2. The competent administration referred to in Article 3 shall convene the conference of services under Article 14 and following of the Law of 7 August 1990, n. 241 (New rules of administrative procedure and the right of access to administrative documents), as last amended by the Law of 13 February 2001, n. 45. At the conference attended by all relevant

government departments for construction and operation of the plant under the rules in force, as well as managers of public works or public interest with interference with the same plants designed.

3. For the purposes of granting of stakeholders have appropriate application containing:
 - a) a description of the system applied for the authorization and any related works and infrastructure essential for the construction and operation of the same;
 - b) the design documents specified by the regulations in Article 39, which also contain the description of the actual state of the affected area, including the documentation referred to in Article 10, paragraphs 5 and 6;
 - c) any request for the declaration of public utility, indifferibilità and urgency, and to affix the constraint preordained expropriation;
 - d) the procedures and time limits for compliance with the requirements for the construction and operation of the plant.
4. Within thirty days after submission of the application, the authority shall give notice in the form and manner required by applicable law so that anyone interested can access them and submit comments within the time specified.
5. In order to ensure inter-regional and subregional coordination, the region can intervene in the proceedings and in conference services referred to in paragraph 2.
6. When the project is subject to environmental impact assessment (EIA) according to the regional law on Nov. 3, 1998, n. 79 (Norms for the application of environmental impact assessment), it may be acquired in the proceedings unified. The acts of assent expressed in the EIA process are still effective in the final authorization and must not be further acquired.
7. When the project is submitted, pursuant to Directive 96/61/EC of 24 September 1996 (Directive on integrated pollution prevention and control) to integrated environmental authorization, the same is acquired as part of

the unified process . If the administration authority shall only coincides with the administrative department for authorization integrated, it remains firm the right to proceed with the authorization act also unique integrated environmental authorization.

8. The conclusions of the conference facilities, the competent authority shall decide on the authorization of the instance found to meet the aims set out in Article 2 and to the programming instruments provided for in Chapter II of this Act , and spatial planning set out in Regional Law 1/2005, taking into account the interests of safety, health, environment, government land and landscape protection.

Art. 13 - Authorization for plants producing electricity from renewable sources.

1. under Article 12 of Legislative Decree 29 December 2003 n. 387 (Implementation of Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market) are only subject to the authorization referred to in Article 11 plants producing electricity from renewable renewable and hybrid plants as defined in Article 8, paragraph 2, of Legislative Decree no. 387/2003, without prejudice to the provisions of paragraph 2.
2. Pursuant to Article 12, paragraph 5 of Legislative Decree no. 387/2003, for the facilities referred to in this Article shall not be the authorization only in the case of interventions constituents free activity under Article 17 or subjects DIA solely under Article 16, if not necessary, for the construction and operation of these interventions, the acquisition of permissions environmental, landscape, protection of historical and artistic heritage, health and public safety.

Art. 14 - Mining concessions and to divert water for the purpose of energy production.

1. The concessions and permits or similar acts, relating to water diversions for energy and geothermal resources, are addressed by current rules.

2. The acts referred to in paragraph 1 are also qualifying title for the construction and operation of the works and infrastructure necessary for the activities covered by them.
3. With the acts referred to in paragraph 1 shall also be granted the authorization referred to in Article 13 of this Law.
4. The concessionaire of geothermal resources that it intends to suspend the work of cultivation and further research asks the prior authorization of the Region.
5. The dealer referred to in paragraph 4 may be suspended on its own initiative the work of cultivation and further research only for reasons of force majeure or for justifiable technical and economic reasons, and immediately informs the Region for approval.
6. The dealer referred to in paragraph 4 that aims to give a well considered sterile or not capable of ensuring commercial production calls for prior authorization from the region, presenting the same plan of arrangement of the well.
7. The Region gives any instructions about the arrangement of the well by identifying a deadline for their execution. Failure to comply with the instructions within identified action is taken at the expense of the licensee.
8. For the functions referred to in paragraphs 4, 5, 6 and 7 the region work as supervisors in accordance with Article 34 of the Decree. 112/1998.

Art. 15 - Direct use of geothermal heat.

1. the direct use of geothermal heat via heat pumps, also without withdrawal of fluid, is subject only to the authorization provided for in Article 11. In according to this process in geothermal plants may be authorized only after the completion of form of single authorization issued by the Region. Along with this should also include:
 - a) the technical /geological report;
 - b) the cadastral plan with the location of the probe;
 - c) scheme of the probe;
 - d) scheme of the geothermal probe - heat pump system;

e) declaration written by the designer certifying non-interference with groundwater.

With the new Regional Law of 23 November 2009, n. 71 were changed some articles of the Regional Law of 24 February 2005 39 - Provisions relating to energy. In particular, the Declaration Unica planned in the old Regional Law of 2005, article 11 which referred the authorization to the Region, it has been replaced with new processes. Art.15 "Extractions local warm-water geothermal purposes" of Regional Law of 71/2009 it states "the execution of the wells of depths up to 400 meters for search, extraction and utilization of hot water, including those gushing from springs for total thermal power not higher than 2000 kWt, and the realization of installations connected to the production of heat or electricity systems with binary cycle zero emission, is authorized by the province having territorial jurisdiction in the manner provided by the consolidated text of the law on water and electrical systems, referred to in rd 1775/1933".

For closed-loop systems is required DIA "Statement Home Activity" as stated art.16, paragraph 3, letter h. In this case the procedure is sent to the municipalities.

4.3.8.2 Lombardy Region

The Regional Regulation of 24 March 2006, n. 2, published in the Official Bulletin of the Region of 28 March 2006, regulates the use of surface water and groundwater, including even their exploitation at the hands of heat pumps or geothermal probes.

The article 5 paragraph 2 "Drilling aimed at the control of aquifers" of the Regulations refers to the authorization procedure required for plants for which drilling is designed for installation of geothermal probes that use water falda.

The article 32 "permits attingimento" is the explicit reference to the open-circuit systems for their operation need to exploit the surface and underground water resources.

The 5 March, 2010 was published the Regional regulation of 15 February 2010, n. 7 "Regional regulation for the installation of geothermal probes that do not involve the removal of water, in the Art. 10 of the Regional Law of December 11, 2006, n. 24 (Regulations for the prevention and reduction of air emissions to protect the health and environment)". The purpose of this regulation is to promote and enhance the use of low enthalpy geothermal resources and the adoption of simplified procedures for the construction and operation of geothermal probes, a closed loop, and systems of energy exchange with the subsoil.

With this Regulation shall govern in particular:

- the technical-operational for the installation and management of facilities and the minimum requirements of the related projects;
- the technical criteria, geological and territorial basis of which is authorized for the installation of geothermal probes;
- the depth of drilling and installation of geothermal probes, and the limits under which authorization is sought provincial;
- the stricter criteria to ensure respect for the environment;
- the requirements and procedures for the certification of quality of the enterprises operating in the field of drilling and installation of geothermal probes as well as controls on undertakings installers for the maintenance of quality certification;
- the characteristics of the database of the plant and the method of management, and the monitoring, by the Region;
- procedures for supervision by the provinces of the installations;
- criteria and procedures for the adoption of simplified procedures.

The article 3 of Chapter I of these Regulations defining the areas of application, in particular:

- apply to underground installation of geothermal probes that do not involve the removal of underground water (closed loop systems);

- not apply to geothermal systems involving the pumping of the groundwater, which remain governed by state and regional level concerning the derivation and use of public waters.

The article 4 are defined authorization procedures. In particular the installation of geothermal probes that reach a maximum depth of 150 meters below ground level, are free except as provided in Articles 5, 6 and 7 of Chapter I and Articles contained in Chapter II of this Regulation. The limit of this depth is to be referred to each single probe. The installation of geothermal probes that exceed the depth of 150 meters below ground level is subject to authorization by the province responsible for the area, according to the procedure governed by articles of Chapter III. The geothermal horizontal system may be installed freely.

The article 5 shows the key prohibitions and constraints. In particular the installation of geothermal probes:

- it is prohibited in the areas of absolute protection;
- the perforations must comply with the legal distances from the edge of the property determined by the Civil Code and a minimum distance of at least four meters from the edge of the property of the applicant with the neighboring property.

The article 6 lays down the detailed installation and operation of plants with its minimum requirements of the projects.

The article 7 is a summary of the regional registry of geothermal probes "RSG" (available online at <http://geotermia.cestec.eu/home>). RSG through the Region ensure constant monitoring of the spread of geothermal probes in the region.

In Chapter II of this Regulation are shown the proceedings aimed installation of geothermal probes that do not reach depths greater than 150 meters below ground level. Although for this type of probes is not provided any authorization, it is necessary to record the implant in the RSG database. The registration must be done electronically at least 30 days before the opening date of the drilling site. The owner must report the following information:

- personal data;
- cadastral data of the site;

- project data of the plant;
- the number of geothermal probes expected and their depth in the case of vertical probes or length in the case of horizontal probes;
- materials that will be used for cementing the borehole;
- constituent materials geothermal probes;
- geometry of geothermal probe;
- type of heat transfer fluid that circulates inside of the probes;
- stratigraphy alleged;
- opening date of the drilling site.

The owner is also required to produce a declaration by which he assumes responsibility for the constraints and prohibitions. The same statement will contain accountability on the implementation of the work. At the time of registration, the owner is also required to provide a statement of consent from the owner of the land in the case of a person other than the person who installs the system. Once the registration is processed an identification code valid for one year. This period is the deadline for the implementation of the intervention, once passed, it is necessary to proceed with a new recording.

Also through the regional registry of geothermal probes, the owner must notify the end of the work. A successful conclusion of the work must take place within one year from registration. The certification in this case must contain:

- statement of completion of work or certificate of regular execution or testing, if any;
- number of probes effectively installed and their depth, in the case of vertical probes, or length in the case of horizontal probes;
- the data and information relating to the perforations made and stratigraphy derived from them;
- the elements necessary to show that the creation of the probes, in each phase of construction, has constituted a risk factor of soil and subsoil, nor factor deterioration of groundwater quality, in relation to the legitimate uses of this.

In the case of large installations (power over 50 kW) more than the communication of the work, the owner must communicate through RSG data derived from Ground Response Test, in particular:

- average thermal conductivity of the subsoil;
- average temperature of the undisturbed ground;
- thermal resistance of the geothermal probe.

Once the latter documents also included the RSG produces a certificate of termination of the communication.

The authorization procedure to be followed for the installation of geothermal probes that exceed 150 meters in depth is illustrated in the articles listed in Chapter III of this Regulation. The owner who intends to proceed with the installation of a system of this type has the obligation to forward the authorization request to the province territorial jurisdiction. The documentation submitted in support of the application for authorization must contain all the elements necessary to show that the installation of the probes, in each phase of construction, there is no a risk factor for the soil and subsoil, nor factor deterioration of groundwater quality in relation to the legitimate uses of these. The authorized construction of borehole heat is released by the province concerned within 60 days from the date of notice of initiation. In case of a positive outcome of the licensing procedure, the owner must go through the registration to the RSG and send all documents as in the previous case.

Chapter IV of this Regulation reports the indication that the provinces must follow in order to check and verify the systems installed. The Provinces responsible for the control by accessing the RSG and the information obtained in it. The activity is carried out through the verification in situ. The checks are sent to the Region every six months.

The article 14 is mentioned also the "Regional Geoenergetical Map" as a basic tool for correct sizing. In that paper also shows the constraints and limitations to the exploitation of this resource.

The requirements and procedures for the certification of quality of the enterprises operating in the field of drilling and installation of geothermal probes should refer to ISO and UNI sector. In the attached 1 of this Regulation shall be given in addition,

the provisions for the installation and operation of geothermal probes. Are described in particular:

- technical requirements for the design and construction of facilities;
- the types of materials that can be used;
- the manner of drilling;
- procedures with the installation of the probes;
- the technical specifications for the functional verification of the probes;
- environmental monitoring;
- security tools;
- monitoring tools;
- thresholds of energy performance for heat pumps.

Before the release of this Regulation some provinces have scheduled a settlement. In particular, the Province of Milan has developed a verification method which was applied from case to case in relation to the specificity of each individual project. In particular, the province of Milan in its Rules of Procedure provides:

- Analysis of the design criteria:
 - audit matters related to energy efficiency in order to assess the correct sizing of the degree of use of the resource;
 - monitoring the implementation of the criteria of "best practice", for the construction and commissioning of the plant and related works;
 - existence of the geological and technical conditions in order to make the eventual re-entry into the aquifer of water derived geothermal purposes;
 - control protocol and testing, to be conducted during the preparation of the works (wells, probes, etc.) but also start-up, in order to verify the proper functioning of the system.
- Application of criteria "impact assessment":
 - verification of the possible involvement of the water intended for drinking water and picked up by public wells in the vicinity of the plant;

- definition of the effect of the works and possible alteration of local water circulation through modeling of flow;
- evaluation of the alteration induced thermal time and any effects of wet chemical alteration of water (eg. Leaching substances naturally present in sediments or in the aquifer: Fe, Mn. As etc.) with risk of contamination or induction of pathogenic bacterial activity.
- Definition of criteria for monitoring plant operational, both geothermal closed and open loop. In according to these guidelines technically the use of groundwater resources for geothermal energy can be done in two ways:
 - direct derivation of groundwater open loop with circulation in heat pump and heat exchanger;
 - positioning in the subsoil of geothermal probes with water circulation in a closed cycle to allow the heat exchange between the subsoil and the heat transfer fluid.

From the procedural point of view, depending on the different types of systems to be undertaken, it is necessary to follow two different technical and administrative procedures.

In the case of installation of a heat exchanger without the use of groundwater and with probes placed in the unsaturated soil, it is no requires authorization or concession; if it instead of geothermal probes with involvement of the aquifer must be activated a procedure under Regional Regulation n. 2 of 24 March 2006, Art. 3 paragraph 4 point I, Art. 5 paragraph 2, and Article 22 paragraph 5.

The administrative procedure is divided into two distinct phases:

- submission of the execution of the works, using the form downloaded from the website of the Milan Province together with the report of technical researches for the positioning of the probes and the definition of depth;
- submission of the license, together with the following basic documents:
 - certificate of regular execution, signed by the Director of Works and a geologist, attesting to the proper execution of drilling, perfect cementation the hole and no communication between the strata penetrated;

- certificate of testing the plant;
- mapping with final location of the probes, accompanied by Gauss-Boaga coordinates, and technical characteristics of the same.

Within thirty days from the date of the protocol of the first instance, the Milan Province gave the nod to the excavation for the installation of geothermal probes.

Following the presentation of the second instance the provincial offices they issued the license of unlimited duration, which provided for the payment of a fee annual.

The Milan Province has also established the following guidelines techniques:

- header of the geothermal probes than the traditional base of the aquifer. Only in exceptional cases to be examined individually and in the presence of restrictions for the protection of groundwater resources, it is allowed a greater depth;
- preferable to use water as a heat exchange fluid, or the presence of additives certified as non-toxic by specific technical details;
- definition of the groundwater quality affected by the perforation in order to avoid any leaching of contaminants from the most superficial to the deepest;
- any thermal alteration induced that occurs in the aquifer, through the appropriate modeling.

The procedure in case of derivation of groundwater provides a real concession granted by the province and if so requested by the user or owner of the plant area.

The references to the regulatory procedure for the concession are the Regional Law 26/2003 amended and Regional Law 2/2006, and the concession of water diversion involves the payment of an annual fee which is calculated on the average flow and the type of use required; the fee relates to the use of sanitation the amounts of which are set every two years by a regional regulation. It also recalls that in protected natural areas and parks, according to DPR 12 Aprile 1996, qualify for the Environmental Impact Assessment (EIA) for the derivation above 50 l/s, and that already with capacities from 25 l/s must be a procedure developed in EIA in any case for derivations that exceed 100 l/s the EIA is compulsory, while the verification

of EIA for those which exceed the 50 l/s. In presence of the SIC (Sites of Community Interest), the responsible agency may request a study of environmental compatibility, aimed at checking the effects of the leads.

In case of necessity, there is the possibility to perform the unloading of the water which derived to the geothermal use, it being understood that it is strongly recommended the reuse and recycling of the same (discharge water, irrigation green areas, fountains, ponds, cleaning roads and yards etc.). To authorize the quality discharge should be followed different procedures including:

- discharge into surface water - is made pursuant to Legislative Decree 152/06 Art. 145 (balance and water balance) and Art. 146 (water saving). The holder of the discharge must apply for permission in duplicate, as indicated on the following website (http://www.provincia.milano.it/ambiente/acqua/superficiali_cosafare_scarchi.shtml). The application must be accompanied by:
 - plan, in duplicate, of the sewerage network which is highlighted separately the path of the wastewater coming from the geothermal plant. In the plan must be highlighted the final delivery of all the waste water from setting up, the various wells for sampling;
 - a copy of the payment of the sum of EUR 18,08 for each discharge of civil point, and paid as a deposit for the costs of analysis and appraisal of the Milan Province;
 - technical report in duplicate.

With regard to the authorization to discharge the quantitative expertise it is managing the Managing Bodies of surface delivery networks (Consortium of Reclamation East Ticino- Villorese, municipalities, etc.). Reintroduction into the same aquifer of water withdrawn, as already mentioned, it is possible notwithstanding art. 104 c. 1 of Legislative Decree n. 152/2006 according to the following c. 2. In particular are asked to observe the following guidelines, carrying out the necessary checks in the project:

- maximum temperature allowed for the reintroduction of water of 20 °C;

- chemical change-bacteriological between the measured values of water taken and discharged in that;
- absence of thermal shorting circuit, to short or medium term;
- verification of the amplitude of the bubble of heat in operating conditions;
- verification of deformations induced locally on groundwater and the possible failure or damage to the works above and/or the surrounding;
- carrying out at least one analysis per year on water sampling and re entry using, by analogy, the table limits of the exhaust stream, appropriately integrated with the following additional parameters:
 - Escherichia coli, Enterococcus, Legionella sp., Bacterial load at 22 °C and 37 °C;
 - Fungal charges;
 - Organ-halogenated solvents and BTEX;
 - Hexavalent chromium;
 - Ph;
 - Temperature;
 - Conductivity;
 - TOC;
 - Oxidisability.

In special cases it may request the establishment of a genuine system of quality monitoring upstream/downstream, through the provision of ad hoc piezometers.

4.3.8.3 Bologna Province

The Bologna Province divides the manner of performance according to the type of plant, in particular:

- open loop geothermal systems with withdrawal and re-entry of ground water in the same aquifer - the competence is at the regional level for the withdrawal of the water, while provincial jurisdiction is when the re-entry of water occurs in the same aquifer of withdrawal;

- closed loop geothermal systems with no withdrawal of ground water or without fluid exchange with the subsoil - it's not provided any type of authorizations. In this case the energy sector of the province has provide that the applicant submit a simple communication in order to control the construction of these plants. The municipality in which the facility is built provides a simple DIA (Home Activity Statement).

For the installation of a closed loop geothermal system is requires completion of an information form indicating:

- Design characteristics;
- The diameter of the borehole;
- Depth presumed to be achieved;
- Any groundwater intercepted.

In addition to the question must be enclosed:

- Location of the site where the plant will be installed by locating it on cards to protect the PTCP (Provincial Territorial Coordination Plan);
- Copy of the building permit;
- Technical report and related statements of the project;
- Stratigraphy;
- Certificate of existence of supra-municipal bonds.

Currently the Authority is limited to collect questions and give advice on the communications received.

4.3.8.4 Autonomous Bolzano Province

The Autonomous Bolzano Province was the first institution in Italy to enact a legislative measure with specific reference to geothermal energy.

This province has defined in detail the requirements to be followed before and during the construction of the geothermal plant:

- 21 days before beginning work: notification form of the pose, Chorography and cadastral plan with location of the site (to be delivered to the Office of Water Resources Management);
- 30 days before the end of the work: drilling protocol, declaration of conformity in the case of plants with installed capacity of 35 kW.

The protocol of drilling must be completed as described in the Act

464 of 1984. In this province the installation of geothermal probes is prohibited in the following areas:

- areas for the protection of drinking water I and II established;
- areas for the protection of drinking water, established in the municipal development plan and within a radius of 200 meters around the public drinking water supply facilities for which there are established areas for the protection of drinking water. The Water Resources Management Office may authorize the installation, if the applicant, through a hydrogeological expertise, test that project of geothermal probes are outside the protection zones I and II;
- in reserve areas for drinking water established by the water resources management;
- in the vicinity of existing water users, if they can not be excluded negative consequences for the latter.

It also needs to be clarified by the client through appropriate inquiries the hydrogeological arrangement. In any case, you must observe the following safety distances:

- within a radius of 30 m from any well and 100 m from the drinking water wells private;
- within 30 m downstream and 200 m upstream of sources captured.

The buyer has an obligation, even before the plant design to clarify whether the location for the installation of geothermal probes is appropriate, since the existing water users could be put at risk and it must be considered that in the areas of protection of drinking water is covered by the special provisions. In these cases, the

more water resources management provides an extract containing data indicative utilities for licensed and declared as areas than drinking water.

The appropriate form for requesting information should be sent in writing, by fax or by e-mail, the Office Managing Water Resources showing the location of the plant project. It is the responsibility of the customer to verify if they are in the vicinity of the planned sales of water.

The Provincial Resolution n. 3564 of 26/09/2005 defines technical requirements and general legal and technical conditions for the installation of geothermal probes. The investigation for the release of the grant provides:

- applying for the concession of water and of the project. In case of impracticability of contradictions with the good hydraulic system or with other general interests it may be rejected without investigation motivated decree;
- the admission of the application is done by order of the director of the office, in which among other things contains the date and venue of the site inspection as well as the deadline for submission of objections;
- the publication of the order is carried out for 15 days in these communities and water resources management in the Office. During this period anyone can inspect the project. Any objections must be made in writing within the stipulated deadline (1 day before the survey) to the municipality or the Office Managing Water Resources;
- the inspection order unless the applicant or a representative appointed by him and the competent offices. Any interested can also participate and express its views and stance on the matter;
- competing applications are eligible within 30 days from the inspection. Are treated with the same process and forward the investigation evaluated together and given preference to. Decisive criteria for selection are the rational use of water resources in the aspect of essential criteria covering demand, avoiding waste and characteristic of water resources;
- at the end of the investigation are evaluated possible objections and is released the outcome of the investigation;

- concession received the opinion of the EIA and any other requisite, the decree granting containing all the necessary conditions and obligations is enacted the Councillor responsible.

5 Development of a thermal conductivity map

In phase of planning of a system of geoechange it is opportune, for a corrected dimensioning of the field probes, to characterize the site geologically. In the majority of the cases the planner finds himself to operate with little information. The more complicated parameters and less known are certainly those related to the thermal properties, in particular to the esteem of the heat conductivity. The appraisal of this parameter, in fact like described in the Chapter 2, is underlies a corrected planning. For this reason important has been considered to realize a cartography of the thermal conductivities to the aim to supply to the planners an instrument of preliminary appraisal of the thermal potentialities of the site and at the same time to characterize the more suitable areas to the realization of such systems.

5.1 Input data

The research work has been initially focused on the thermal characterization of the lithostratigraphic units of the legend of Geological Territorial Continuum of the Sardinia Region (the scale 1:10000). The legend of such database it is composed of 778 lithostratigraphic units each of which, wherever possible, it has been assigned a value of thermal conductivity determined according to the individual lithologies that make up the unit. The main problem encountered in attributing the values of thermal conductivity is in the type of information contained in the legend of the geological map. Those having a general character, in order to respond to different needs, often give information that hardly lend themselves for purposes of this study. In fact, the classification that frequently characterizes the geological maps is based on criteria lithostratigraphic, that is the pooling and division into units with different hierarchical order, on the base of the lithological and stratigraphic characteristics of the rocks bodies. It achieves some that in the same unit may be include rocks or lands with a different thermal behavior. For this reason it was necessary to determine the

individual lithologic components of each unit, estimating the proportions with which these are present, identifying a litotype thermal equivalent. Not always this approach allowed us to identify a litotype thermal whereby, in these cases, it was not possible to assign a value of thermal conductivity. In Table 5.1 is brought back the structure of the “Attached 1”.

Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
a	Slope deposits	Ghiaia	0,49	1,96	1,14
a1	Landslides	N.D.	N.D.	N.D.	N.D.
a1a	Landslides	N.D.	N.D.	N.D.	N.D.
AAZ	Atzori Andesite	Andesite	N.D.	N.D.	2,87
AAZa	Lithofacies Atzori Andesite	Andesite	N.D.	N.D.	2,87
ab	Anfibolite	Anfibolite	2,46	2,78	3,03
ABS1a	La Vedetta Facies (Capo Pecora intrusive Subunit)	Gabbro	2,13	2,54	2,22
ABS1b	Corru Longu Facies (Capo Pecora intrusive Subunit)	Granodiorite	2,29	2,73	2,83
ABS2a	Riu Mudaregu Facies (Gonnosfanadiga intrusive Subunit)	Gabbro	2,13	2,54	2,22
ABS2b	Facies Monte Omu (Gonnosfanadiga intrusive Subunit - Arbus intrusive Unit)	Granodiorite	2,29	2,73	2,83
ABS3	Rio Terra Maistus intrusive Subunit (Arbus intrusive Unit)	Granite	2,79	3,22	3,30
...	...	...	...	...	...

Table 5.1 - Structure of the “Attached 1”.

In the first column “Map label (CARG)” are presents the initials of the lithostratigraphic units of the in legend of the Geological Territorial Continuum of the Sardinia Region (in scale 1:10000), while in the second column are brought back the names of the geologic formations.

The second part of the table instead encloses the information reported to the thermal characterization of the various lithostratigrafiche units. In particular this block is composed of four columns:

- column “Equivalent thermal lithotype”, in which it was reported the thermal lithotype correspondent to the lithostratigraphic unit;
- column “ Thermal conductivity [Unsaturated]”, in which it was reported the the value of thermal conductivity unit in unsaturated conditions;
- column “Thermal conductivity [Saturated]”, in which it was reported the the value of thermal conductivity unit in saturated conditions;
- column “Thermal conductivity [Without definition of the water content]”, in which it was reported the the value of thermal conductivity unit with no definition of the water content;

5.2 Cartographic representation of thermal conductivity data

The reclassification of the different lithostratigraphic units allowed to represent three map of thermal conductivity in condition of saturated, unsaturated and without water content (Figure 5.1; Figure 5.2; Figure 5.3).

Thermal conductivity map for saturated lithologies of Sardinia Region

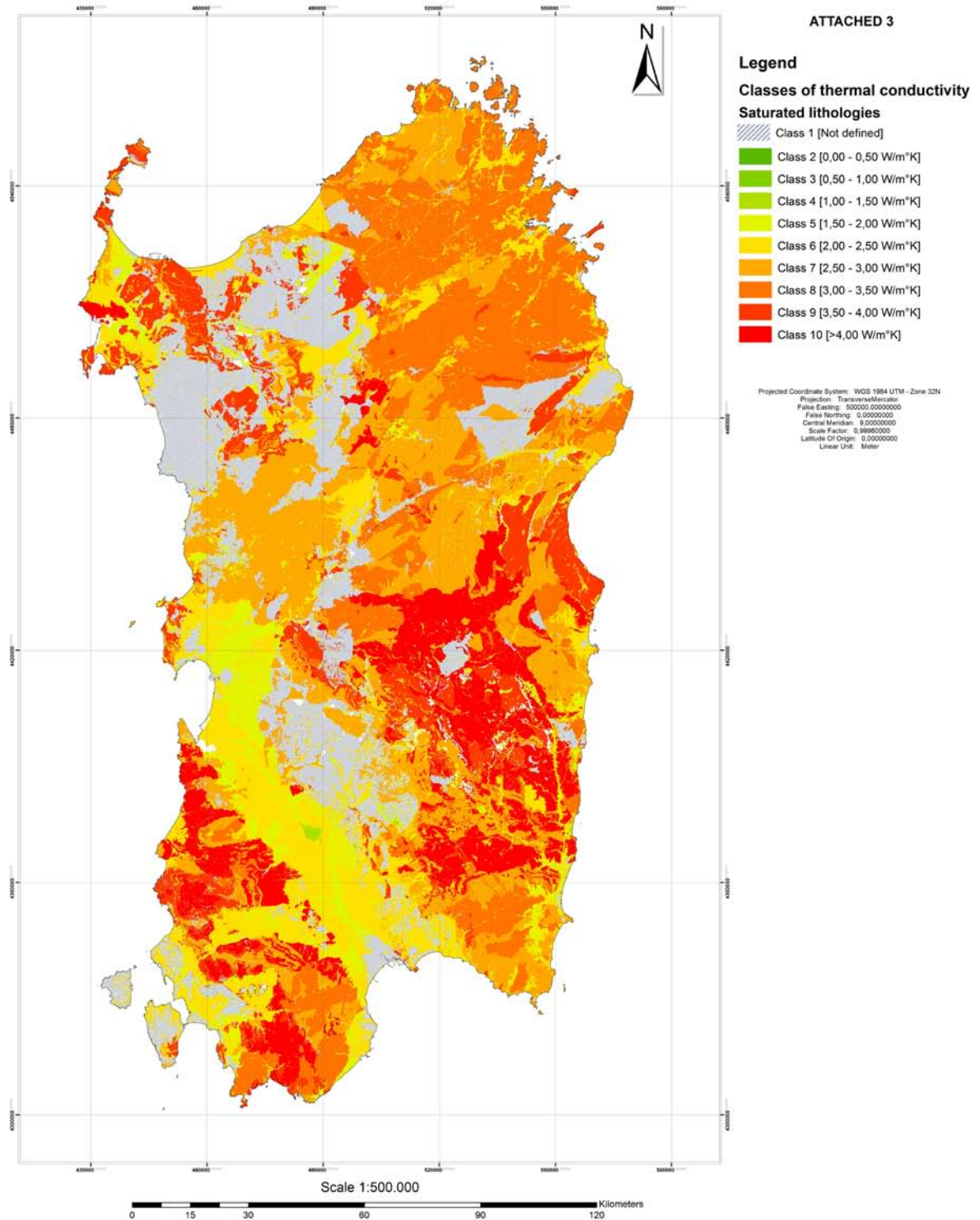


Figure 5.1 - Thermal conductivity map for saturated lithologies of Sardinia Region (scale 1: 500000).

Thermal conductivity map for unsaturated lithologies of Sardinia Region

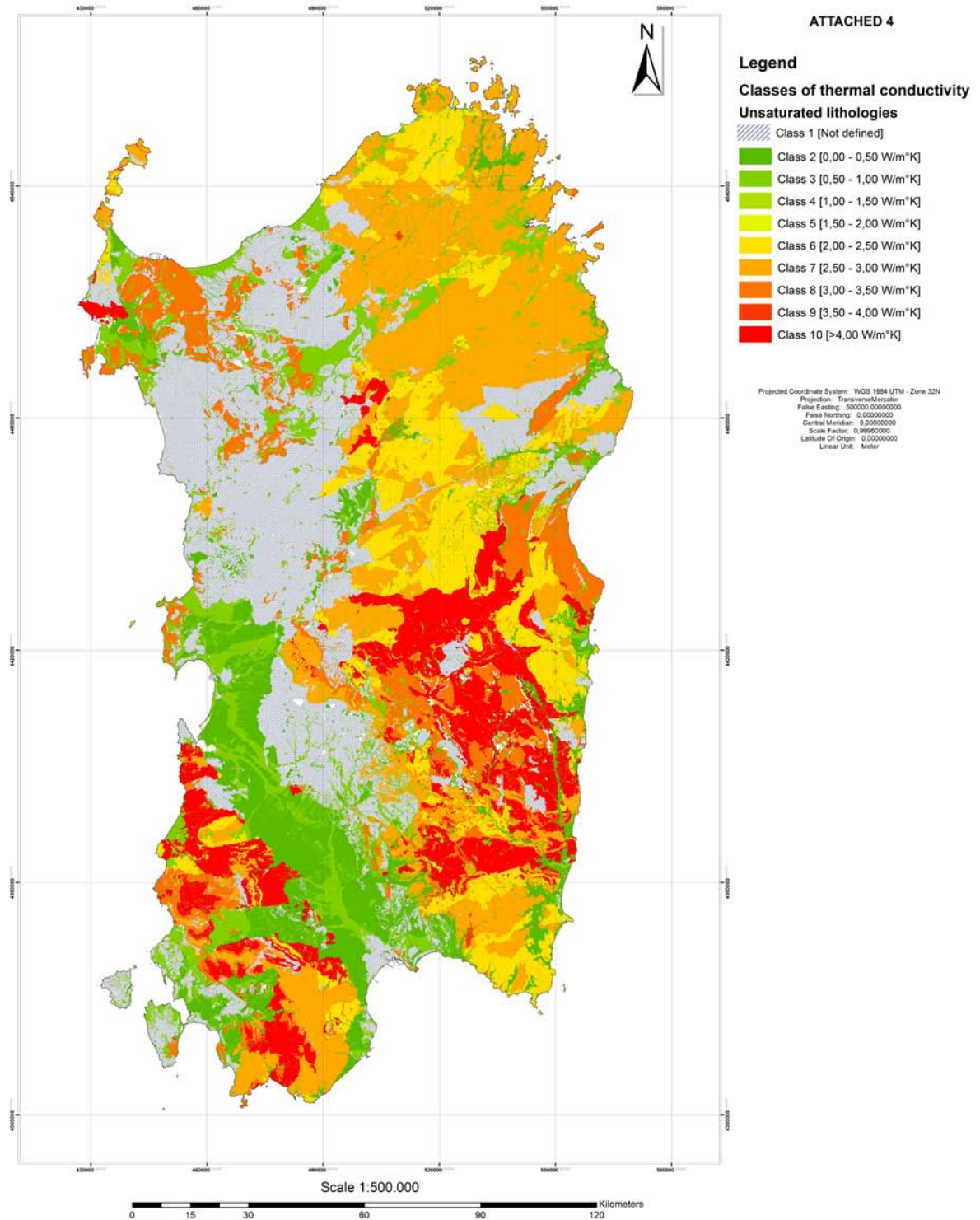


Figure 5.2 - Thermal conductivity map for unsaturated lithologies of Sardinia Region (scale 1: 500000).

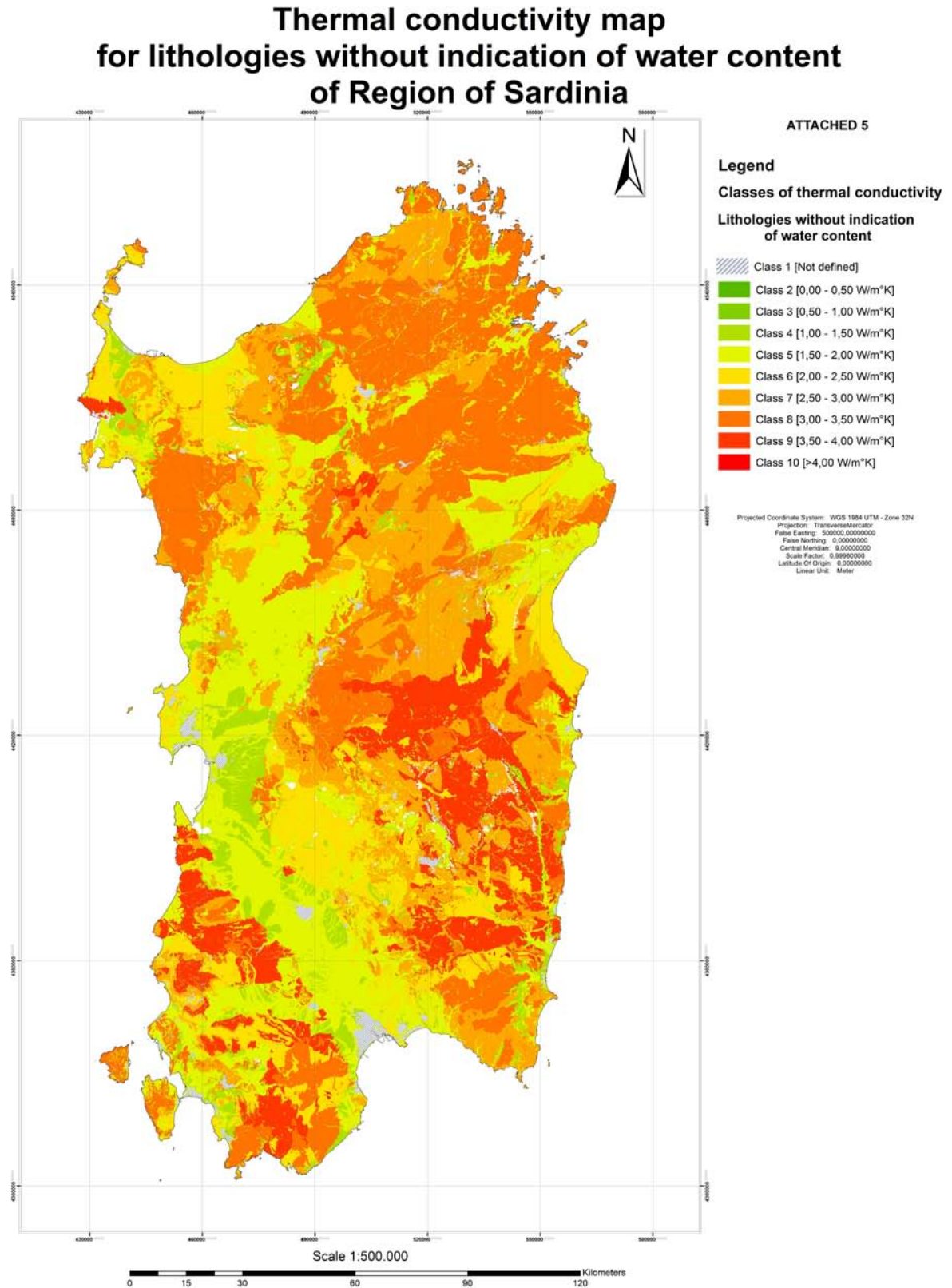


Figure 5.3 - Thermal conductivity map for lithologies without indication of water content of the Sardinia Region (scale 1: 500000).

The thermal conductivity values assigned to each lithostratigraphic unit derived from a literature research and shown in "Attachment 2". The assignment of these values was carried out by averaging the values of thermal conductivity weighted based on the percentages of abundance of individual lithologies. The "Attachment 1" shows the values of thermal conductivity allocated to each lithostratigraphic unit of Geological Territorial Continuum of Sardinia Region in according to the methodology described above. Subsequently were assigned, for each type of map, of the classes of thermal conductivity divided as follows:

- Class 1 – Thermal conductivity value not defined;
- Class 2 – Value between 0.00 – 0.50 W/mK;
- Class 3 – Value between 0.50 – 1.00 W/mK;
- Class 4 – Value between 1.00 – 1.50 W/mK;
- Class 5 – Value between 1.50 – 2.00 W/mK;
- Class 6 – Value between 2.00 – 2.50 W/mK;
- Class 7 – Value between 2.50 – 3.00 W/mK;
- Class 8 – Value between 3.00 – 3.50 W/mK;
- Class 9 – Value between 3.50 – 4.00 W/mK;
- Class 10 – Value greater than 4.00 W/mK.

6 Development of a thematic map of the thermal conductivity in a pilot site: Baratz Lake (Sassari)

The geologic characterization in the planning of a system of geoexchange is of fundamental importance for the corrected realization of the same one from the energetic, technical and economic point of view.

The corrected definition of the thermal properties of a ground must prescind from the correct reconstruction of the surrounding geologic model a any site of plan. In this chapter will be shown the geological study conduct in the area of the Baratz Lake (SS), tourist area and important communitarian site, where it is possible to realize the construction of a system of geoexchange to service of buildings for turistic and residential use.

6.1 Geological setting

The area object of this study is situated in around of the Baratz Lake, localized in the municipality of Sassari (SS), near Poro Ferro and Baratz in the municipality of Sassari, and near the fractions of Villa Assunta and Santa Maria La Palma in the municipality of Alghero.

The area is localized between the beach of Poro Ferro and the western side of the carbonatic massif of Monte Zirra, an isolated morphologic relief which extends over a length of approximately 2.5 km in North-South direction and 4 km towards East-West. The study area is placed in a sector of internal nappe zone, and occupies the south central region of Nurra (Figure 6.1).

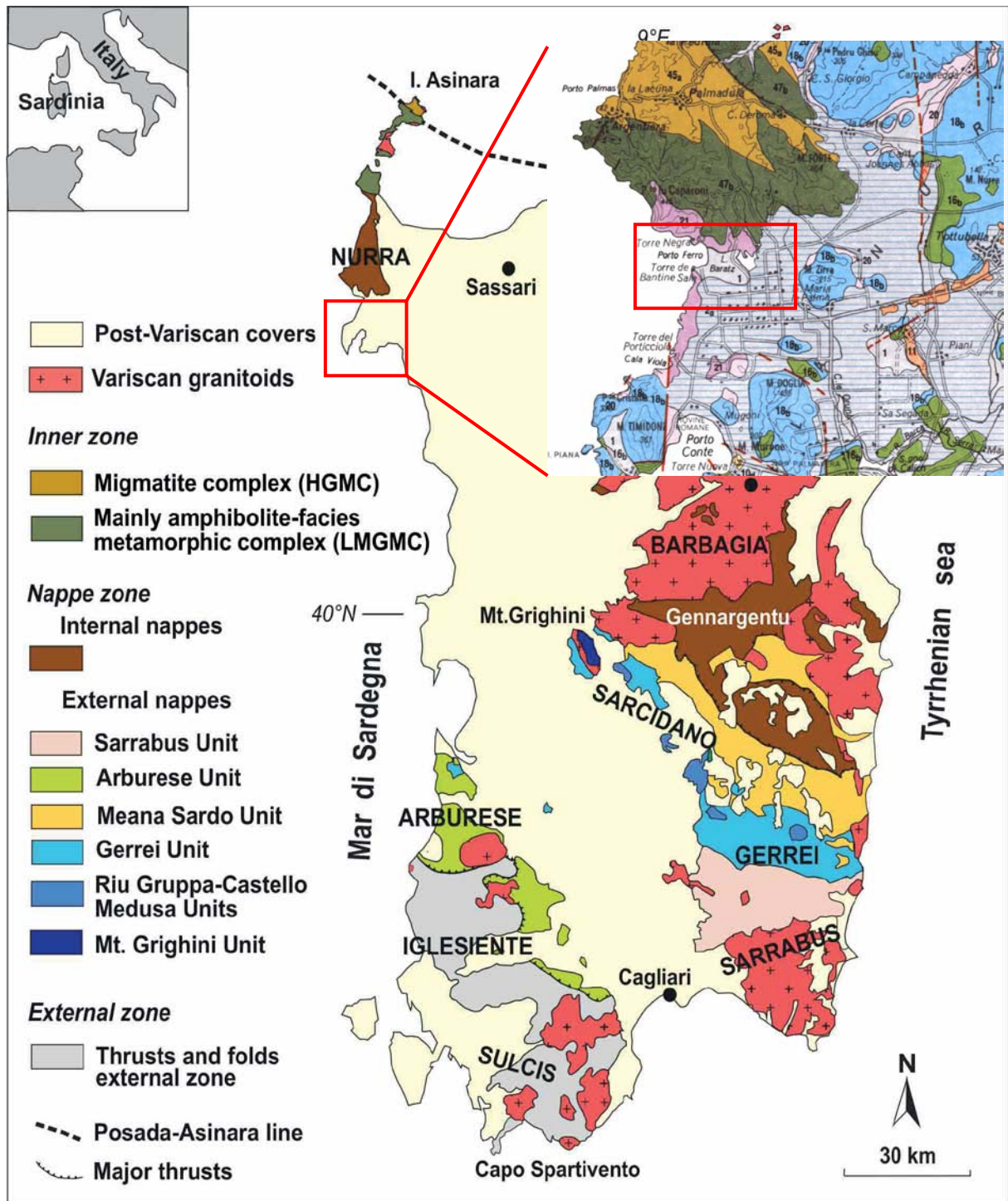


Figure 6.1 - In the red polygon is located the examined area (from Carmignani et al., 2001).

The metamorphic basement of Sardinian is a segment of the European Variscan chain, separated from Europe only in the early Miocene (Burdigalian). Restoring the position of Sardinian-Corse block pre-drift of the Miocene, the fundamental structures

of the two islands find their continuation in Provence and Catalonia (Alvarez, 1972; Arthaud & Matte, 1966; 1977; Cherchi & Montadert, 1982; Edel et al., 1981; Gattacceca et al., 2007; Matte, 2001; Ricci & Sabatini, 1978; Westphal et al., 1976). The various reconstructions of the pre-Mesozoic geometry of this chain (Matte, 1986; Vai & Coccozza, 1986) are generally agreed to outline a curved orogenic belt that reaches from Spain to the Central French Massif (Ibero-Armorican Arc). The Variscan orogeny affected the entire basement of Sardinia with intense deformation, metamorphism syn-kinematic and an important post-collisional magmatism. The age of the Variscan deformation is well defined on both bases, stratigraphic that radiometric.

According to the classic model of evolution proposed by Carmignani et al. (1994), the Sardinian Variscan chain can be divided, from south to north, in three major tectono-metamorphic complex:

- **External Zone** (the foreland of the Variscan belt), wich consisting of units substantially autoctonous affected by a very low metamorphic degree;
- **Nappe zone**, with alloctonous nappe affected by a sense of movement towards SW, a polyphased tectonic with a D2 phase which tends to increase in intensity moving towards NE and barrovian metamorphism which showing an increase in metamorphic grade in the same direction;
- **Inner zone**, which is the "axial zone" of the chain and occupying the northern portion of the island. This area can be divided into two portions: a medium grade metamorphic complex, in the southernmost portions and a migmatitic complex in north-eastern regions of the island. These two metamorphic complexes are separated from the Posada-Asinara line (Cappelli et al., 1992; Carmignani et al., 1994): an important mylonitic band with kilometric thick and right sense of shear, which extends through the entire of Sardinia from Asinara island, to the west, to the valley of the Posada river, to the east. For the presence of bodies to eclogitic affinity along its entire length Caps et al. (1992) and Carmignani et al. (1994), interpreted this feature as a paleosuture of South-Armorican Ocean present during the Early Paleozoic, between the edge of Gondwana (represented in

this model by the high grade metamorphic complex) and Armorica (represented by the medium and low metamorphic complex). As they observe the evolution of the Variscan chain of Sardinia can be divided into two phases: the collisional phase, related to the development of the D1 event (approximately 350 Ma, Di Vincenzo et al., 2004) and blastesis of the barrovian minerals (M1: Bt Grt, St, Ky; Kretz, 1983) and a long extensional phase, leading to the collapse of the chain (D2 and D3 phases) and the major exhumation of of medium and high grade metamorphic rocks. The emplacement of the Sardinian batholith finally binds the final stage Variscan orogeny. In a recent years, however, detailed work carried out along the western and eastern transects of the Posada-Asinara line, would seem to present a more complex tectonic evolution. According Carosi & Palmeri (2002), Carosi & Oggiano (2002) and Carosi et al. (2004), in fact, the post-collisional phase would be characterized by a transpressive regime responsible for the major exhumation of the medium and high grade metamorphic rocks. In this reconstruction, therefore, the extensional tectonics play a secondary role limited only in the final stages of deformation.

The post-Variscan evolution of Sardinia has always been interpreted as that of a stable craton, subject to periodic transgressions and regressions without implications in collisional events that have affected all neighboring areas during the Alpine cycle. This evolution, well described by Cocozza et al. (1974), it was only interrupted during the setting of the Tertiary rift ("Sardinian rift") related with the opening of the Balearic Basin.

Several unconformity in the Mesozoic and tertiary succession have been chronologically correlated with orogenic events of the Alpine cycle (Iaramica phase, Austrian phase, etc.), without it being clearly detected in Sardinia a regional structuring correlated, from a geodynamic point of view, with Alpine collision zones (Cherchi & Barberi, 1980; Cherchi & Montadert, 1982; 1984; Cherchi & Tremolieres, 1984; Oggiano et al., 1987; Tremolières, 1988).

Recent works (Carmignani et al., 1994a, Oggiano et al., 2009, Oggiano et al., 2011) have shown that, like the "Variscan Corse", as well as Sardinia has been affected by tertiary tectonic collision, with the development of a system of strike-slip faults that induce important transpressioni (Carmignani et al., 1992a; 1994a; 2004; Feed, 1997), with thrusting of the Paleozoic basement on the post-Variscan coverage (eg. Supramonte), and transtensioni (Chilivani-Berchidda basins, Ottana) (Oggiano et al., 1995).

In the Oligo-Miocenic succession are intercalated calcalkaline volcanic products (oligo-Miocene calcalkaline volcanic cycle) related to subduction of northern Apennines and the relative post-collisional distension (Beccaluva et al., 1994; Carmignani et al., 1994a, 1994c; Lecca et al., 1997).

The latest volcanic products recognized in the island are represented by intraplate basalts associated with the opening of the southern Tyrrhenian Sea (Plio-Pleistocene alkaline and sub-alkaline transitional affinity volcanic cycle). In the post-Variscan succession of Sardinia are "registered" with different intensity all the movements associated with the evolution of the Alps and Apennines. This is well-known for some time in Provence, a region with which the Sardinia has shared the geological evolution until the early Miocene.

6.2 Detailed geological survey

In order to define the geological and thermal parameters of the land needed for the construction of the geothermal heat pump, it was conducted a detailed geological survey on area of about 4 km² around the project site (Baratz Lake).

For the cartographic representation of the geological survey it was used as the base the Technical Map of Sardinia Region (CTR) in scale 1:10000, published by the Geographic Military Institute, specifically the sheet 458110. The original scale has been increased to 1:5000, to represent the geological features with greater detail.

The investigated area is formed by a portion of Variscan basement represented by the Monte Forte Formation (FTE) belonging to the Argentera Tectonic Unit.

This formation consists of an irregular alternation of levels, from metric to decimetric in thick, of quartz and mica metasandstones, quartzite, quartzitic phyllite and phyllites, with color from light gray to purple and green (Figure 6.2). In some areas the lithological similarity with the Cambro-Ordovician succession of the outer nappes (St. Vito Sandstones, Solanas Formation) is very strong; in other places prevail instead terms like quartzite or metasandstones and metasiltsstones. The Cambrian-Lower Ordovician attribution to the has never palaeontologically and the attribution were made on the basis of lithologic similarities with Cambro-Ordovician succession of the outer nappes.



Figure 6.2 - Outcrop of metasandstones and phyllites of the Monte Forte Formation.

The metamorphic basement is covered, in a discontinuous manner, by a continental post-Variscans uccession (PID) represented by terrigenous deposits intercalated with volcanoclastic products. This stratigraphic sequence, as redefined by Durand & Ronchi (2001) and Cassinis et al. (2002, 2003), has been divided into three major cycles or depositional sequences, characterized by sedimentary facies and volcanic episodes that reflect a deposition related to a very different structural-geodynamic environments very different from each other and who have succeeded in the long time between Lower Permian and Middle Triassic. The entire series consists

of continental deposits of fluvial and lacustrine environment associated with alkaline volcanites. The deposits are generally made up of layers of sandstone, more or less coarse, with interbedded conglomerate, ranging in color from gray to red violet (Figure 6.3), with subordinate levels of mudstones, often silicified. The volcanites that are interspersed within this sequence are generally very discontinuous and have thicknesses of several tens of meters. They consist of ignimbrites and "porphyry" with phenocrysts of quartz and red brick feldspar, surrounded by a light-colored groundmasses. These volcanites usually appear discontinuous and thickness slightly above ten meters.



Figure 6.3 - Outcrop of conglomerates and sandstones of the post-Variscan continental succession of Nurra.

In the study area are well represented the Pleistocene deposits attributable to Portoscuso Subsynthem (PVM₂) which covering unconformably the Variscan metamorphic basement and post-Variscan continental succession of Nurra. This

subsynthem is represented in the interest area of alluvial fan and flood plain deposits (PVM_{2a}) and aeolian deposits (PVM_{2b}).

The deposits of alluvial fan and flood plain (PVM_{2a}) crop out discontinuously in the northern part of the examined area, and with good continuity throughout the western sector up to the slopes of Zirra Mount. These deposits mainly consist of coarse gravel, pebbles from sub-angular to sub-rounded shape, subordinated medium-fine sands and local levels of mudstones (Figure 6.4). The aeolian deposits (PVM_{2b}), marginally outcropping in the southern part of the area, are represented by medium-fine sands extremely-sorted with planar cross-bedding and obvious erosion surfaces and reactivation. The age of these sediments is fixed, based on fossil remains of mammals, to the Upper Pleistocene (Malatesta, 1954; Vardabasso, 1956 Comaschi Caria, 1965).



Figure 6.4 - Outcrop of terraced Pleistocene alluvial deposits.

The Holocene deposits in the area are represented by current sediment and which derived from Holocene changes in the physical environment, and therefore characterized by varying degrees of inactivity and burial. The most represented

deposits are those post-Thyrranean aeolian (d) which forming the coastal dunes, consist of sand with silicic grains, medium to fine, with cross-bedding.

Locally, in the northeastern part of the study area, there are eluvial-colluvial deposits (b₂) consisting of varying percentages of fines fractions (sand and silt) more or less pedogeized and enriched in organic matter. Are generally associated with coarser sediments, usually debris from medium to fine, always subordinate.

Along the northern side of Baratz Lake are found marsh deposits (e₅) which consisting of very plastic clay sediments, probably resulting from weathering of the bedrock consists mainly of the sediment of the post-Variscan succession of Nurra. This type of deposit is found mainly at extended stagnant water where the water remains in some cases until the early summer months.

Along major rivers, however, it is found present alluvial deposits (b) consisting primarily of sands and gravels with subordinate levels of silt and clay.

Completing the geological framework of the examined area the beach deposits (g₂) formed of coarse sandy sediments, as well sorted in extremely sorted that crop out along the Porto Ferro beach.

The geological map resulted from the interpretation of the data is shown in Figure 6.5.

A.A. 2014 - 2015

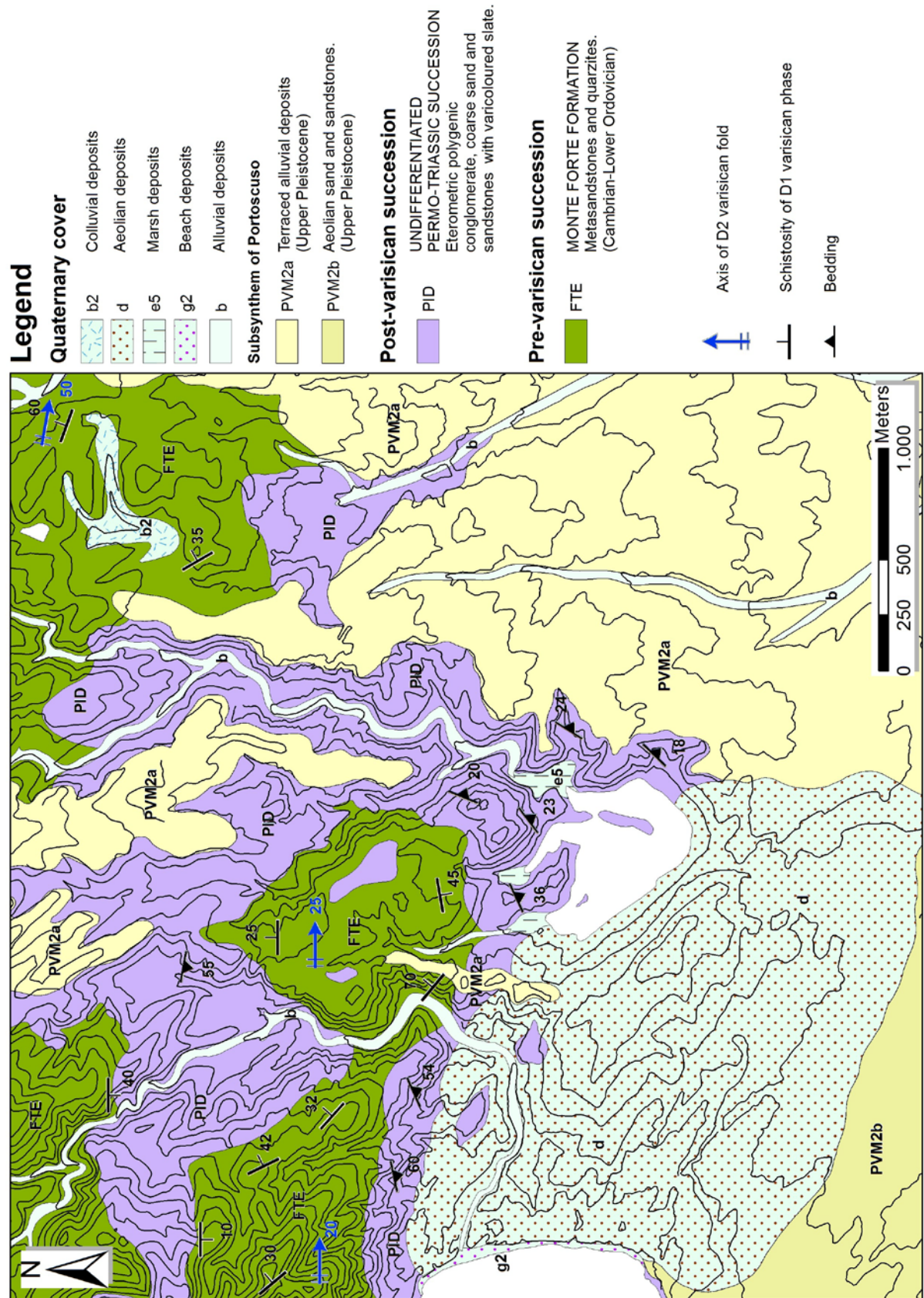


Figure 6.5 - Geological map of the study area.

6.3 Hydrographic and hydrogeological settings

The hydrographic basin of Baratz Lake (Figure 1.8) extends mainly to the north of the lake, with a total area of 12,32 km² and has the following boundaries: to the North-East border rises to Punta Canistreddu (413,6 meters above sea level); to the north, towards the East-West direction, the border affects the relief of Lu Ferru Mount (228,6 meters above sea level), to Punta Signadoggiu (379,5 meters above sea level); towards the south-west the border descends through to Domo l'Eremita (102,4 meters above sea level) up to Cuile Puddighinu (76,8 meters above sea level); to the South the border consists mainly of a barrier dune, with interests ranging from 40 and 70 meters above sea level

The hydrographic basin consists of a single main river, the Rio Bastianeddu, steady markedly torrential flowing from North to South. The network also includes a number of smaller watersheds that flow into the main river.

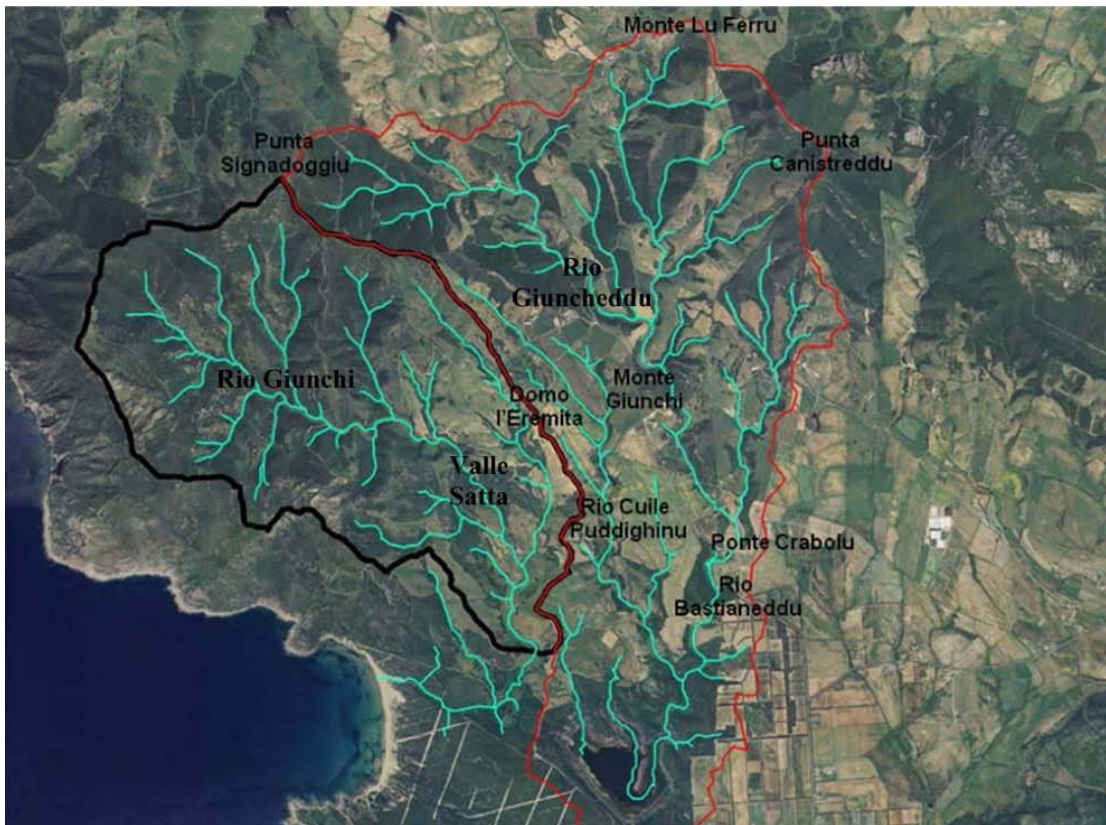


Figure 6.6 - The hydrographic basin of Baratz Lake (in red) and Valle Satta (in black) with the drainage network (in blue).

The basin is hydrogeologically characterized by a substantially waterproof bottom constituted by phyllites and quartzites in the northern field, Varicoloured sandstone in that meridional, and from the overlying permeable formations including Pleistocene alluvial terraces and post-thyrrenean sand deposits. The permeable formations of the basin are represented by detrital layers that cover the valley floor often subject to agricultural, the sandy and gravelly terms of terraced floods and sands of the dunes that separate the lake from Porto Ferro.

The hydrogeology of the catchment basin of the area of the Baratz Lake is expressed through a rapid sub-supeficial circulation of the water precipitation on the slopes of the valleys, with accumulation and stagnation of water in the end zones of the valleys characterized by thicker blanket of debris. With reference to the regional typical pluviometrici regimes, also as a result of persistent and intense precipitations, the water course that feed the lake can introduce very meager capacities and evidence a modest increase of the levels of the lake. The permeable formations of the alluvial sediments that cover the valley, in fact, absorb for infiltration also the more intense rains and slowly drain towards the lake in according to the pressure gradient. Only when the water table levels are close to the ground surface the volumes of precipitation, not being able to infiltrate, flowing rapidly increasing in the downstream direction just as quickly the levels of the lake.

These observations, in reference to historical data available on the lake, and to the emphasized the lowering level of the lake of the last years, seem to above all delineate a crisis situation of the Baratz Lake determined from environmental imbalances and variations in the conditions of use of the ground in the catchment basin. There is a close correlation between the annual rainfall, especially in the 50s and 60s, and the water levels of the lake. Beginning from the half of 60s years but the average of annual rains has been maintained substantially stable, so showing the existence of other causes that must have determined the ulterior lowering of the levels in years 2000. The fraction of basin occupied from the forest cover gradually has been reduced from years '60 in then, until current 20%. It is famous that deforestation produces, between the various negative consequences, also a reduction of the water resources available. The soils of the basin of the Baratz,

mostly cultivated to autumn-winter cereals, remain exposed to the direct radiation for all the summery period. The radiation fluxes are transformed almost entirely in sensitive heat that the temperature increases, and in latent heat that the evaporation increases. The water levels of the acquifer endure therefore a progressive reduction because of the evaporativa forcing increment of. The infiltrated volumes of precipitation more do not succeed to compensate this member, the superficial outflows are cancelled and the levels of the lake are reduced in parallel with being reduced of the levels of the acquifer.

Such situation has demanded therefore the start of a detailed investigation on the causes that ingender the situation of above-mentioned water deficit, is natural or anthropic origin. The relative informative historical framework to the levels of lacustrine waters has turned out strongly incomplete and inconsistent. Never the precipitations in the area of the lake and their relation with the levels of the acquifer and the lake with a sufficient temporal detail are not found. By a point of view of the quality of waters, one of the characteristics details of the lake is given by the remarkable chlorinity (documented in approximately 500-600 ppm of Cl) derived in part from the weathering of the rocks of the basin (post-varisican continental succession) that have an elevated salt content, in part by the minute particles escaped the salt waters of the sea that the mistral spills on the basin, on vegetation and on the same lake water (marine spray effect).

Even the hardness of the water of the lake is remarkable, given that the presence of CaCO_3 in various sizes ranging between 250 and 400 ppm. As to the pH, the most frequent values have been documented around 8, however, never below to 7. As regards the superficial temperature, the maximum recorded is about 28.3 °C and the minimum of 9.4 °C. Conductivity data (at 25 °C) of Lake Baratz are available for the following periods:

- 1978-79, presented by Sechi & Cossu (1980), Marcasciano (1983) and Cella (1985);
- 1994, presented bu University of Sassari, Department of Botany and Plant Ecology (1994);
- 1995-96, collected by the Environment Consortium Sardinia.

In 1978-79 it has values of the order of 2 $\mu\text{S}/\text{cm}$, with typical increases and decreases in the surface layer in correspondence, respectively, of the increased evaporation and increased rain. In 1994, the conductivity is practically doubled, with values of the order of 4 $\mu\text{S}/\text{cm}$; in 1995-96, there was another significant increase, reaching stable values of the order of 5.5 $\mu\text{S}/\text{cm}$.

In the absence of an emissary of the lake water losses are due mainly to evaporation which causes, in addition to the decrease in the level of the lake, also a gradual concentration of the solutes present in its waters that affects the life of the species found in the lake (progressive decrease species of freshwater in favor of the typical species of salt water). The conductivity values detected show a high ionic content, and then a strong brackish nature lake (typical values of fresh waters are of the order of a tenth of those detected).

6.4 Important geological characteristics for the design

In the Chapter 2 have been defined defined the geological parameters that must be known in order to a correct design of geothermal heat pump system. The properties studied for geological deposits and rock outcrops in the area of interest are the fracturing degree, porosity, permeability and density. They were regarded both during discovery, that by using the bibliographical data.

6.4.1 Fracturing degree

The knowledge of the degree of fracturing of a rock mass is important because it allows to have an idea of the possible direction of flow of the ground water, since the presence of it has an influence on the thermal conductivity of the ground.

The study of fracturing was conducted both in outcrops of metamorphic basement than in the post-Variscan continental succession of Nurra.

All giacitura collected data and fracturing in the examined area were represented in stereographic projections (Figure 6.7).

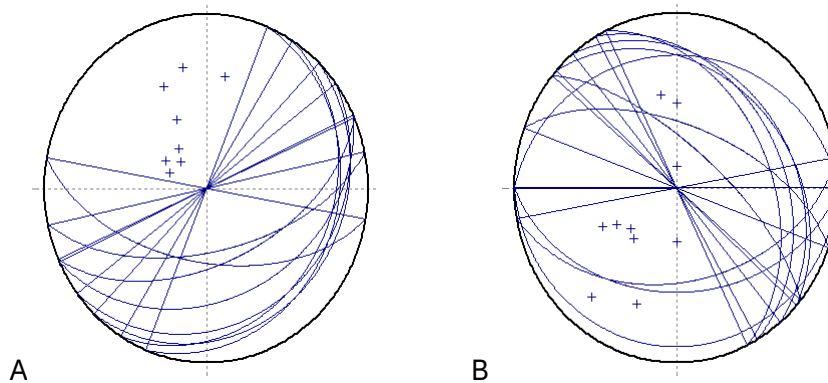


Figure 6.7 - Stereographic projections of the measures of bedding in the post-Variscan sedimentary sequence of Nurra (A) and measures of the first Variscan phase schistosity in the Monte Forte Formation (B).

The examination of stereonet allowed to verify a general dip towards South-East of the bedding and the main schistosity of the metamorphic basement. The most representative family of measures is oriented approximately 150° - 180° with variable inclination between 20° and 40° .

As for the systems fracturing detected in this study are oriented approximately NW-SE and NE-SW compatible with a wider system of normal faults at the regional scale which led to the opening of the Balearic basin and the current structure. Locally it is found portions of substrate characterized by intense and pervasive fracturing that can lead to transit or storage water.

6.4.2 Porosity

In the esteem of the porosity it is proceeded under consideration of all present lithologies in the area, because all play an important role in the infiltration of meteoric waters and in the water circulation in the ground.

Regarding the rocks of the metamorphic basement, phyllite and quartzite, due to the very fine particle size inherited from the mother rock and the conditions of pressure and temperature to which were subjected, have a very low porosity, which rises to an average degree when the rock is very fractured. The post-Variscan continental succession of Nurra has a primary porosity medium-low to low due to the

intercalation of pelitic sediments and the high degree of diagenesis. The secondary type porosity, however, is moderately high because of the fracture systems involving the succession.

The porosity estimation of the eluvio-colluvial deposits, however, must take into account two factors: the high clay content is indicative of a very high total porosity, but also an effective porosity almost nothing; inside this clay matrix are present heterometric phyllitic and/or arenitic elements that determine a slight increase in the total effective porosity. The marsh deposits in the area, being mainly composed of silt and clay, have a very high total porosity, but an effective porosity almost nothing.

Finally, the aeolian and alluvial deposits, both of which Pleistocene and Holocene, have a very high total porosity due to coarse particle sizes that make up these deposits.

6.4.3 Permeability

The definition of the permeability degree has been made for all lithologies and deposits present in the area, on the basis of the two previous estimates of fracturing and porosity.

The permeability of the metamorphic basement, both for the phyllite and quartzite that for metasandstones attributable to the Monte Forte Formation, has a value from low to very low, both for the metamorphic action which greatly reduced the empty spaces of the rock types originating, both for the scarce fracturing. Only locally, where fracturing is more pervasive, can reach values of medium permeability. For this training you can estimate a value of permeability in the range of $K = 10^{-6} \div 10^{-9}$ cm/s.

The post-Variscan continental succession of the Nurra is characterized by a medium to medium-low permeability for porosity but the moderate fracturing degree and the large number of internal voids causes the porosity of the secondary type is medium. It is conceivable a permeability value in the range of $K = 10^{-6} \div 10^{-8}$ cm/s.

The recent deposits, represented by the marsh and eluvio-colluvial deposits, are characterized by a permeability from low to very low, because in them prevails a component of clayey nature that limits or prevents the infiltration of rainwater and the circulation of underground water. It is conceivable a permeability value in the range of $K = 10^{-7} \div 10^{-9}$ cm/s.

Finally, aeolian deposits and alluvial deposits, both of which Pleistocene and Holocene, have a permeability from medium-high to high, because of the presence of numerous hollow to enable good infiltration of rainwater, which reach a certain speed the underlying bedrock. For these deposits the coefficient of permeability can be estimated with an interval of $K = 10^{-6} \div 10^{-4}$ cm/s.

6.4.4 Density

The knowledge of the density of a soil is important, as already mentioned in the previous chapters, to calculate the apparent thermal conductivity; It is shown in the table below the ranges reported in the literature (Farmer, 1968; Goodman, 1989).

<i>Lithotype</i>	Phyllites	Metasandstones and Quarzites	Sandstones and Conglomerate	Aeolian deposits	Marsh and eluvio-colluvial deposits	Alluvial deposits
<i>Density [KN/m³]</i>	25 – 28	26 - 27	23 - 28	14 - 18	10 - 20	15 - 22

Table 6.1 - Estimate of density values for the rocks and deposits outcropping in the detection area (from Farmer, 1968; Goodman, 1989).

6.5 Pedological survey

In order to define in detail the eluvio-colluvial deposits in the area it was decided to perform a detailed pedological sampling, through which were characterized in terms of textural and grain size, 30 sample.

The sampling was carried out in a systematic way, trying to cover evenly the entire area examined.

The sampling was performed by drilling the ground with a special hand tool and analyzing the sample before analysis with expeditious in the country, by filling in the evaluation form (Figure 6.8). The pH measurements were carried out by reacting a portion of each sample with a color reagent and then comparing the color obtained with a chromatic scale notes.

To estimate the percentage of lime content of the horizons of each sample, these have been reacted with an aqueous solution with 10% HCl.

SCHEDA RILEVAMENTO PEDOLOGICO

Data:	Località:	Formazione geologica 10k:	STS:
Rilevatore:	Comune:	Erosione:	Drenaggio interno:
Codice osservazione:	Quota:	Ghiaia (<7,5 cm):	
Numero osservazione:	Pendenza:	Ciottoli (7,5-25 cm):	
Coordinata X:	Esposizione:	Pietre e massi (>25 cm):	Profondità utile (classe):
Coordinata Y:	Natura della forma:	Rocciosità:	
UDP di riferimento:	Elemento morfologico:	Uso del suolo:	

DESCRIZIONE SUOLO (trivellata e/o osservazione speditiva)

Prof. cm	Sigla orizzonte	Colore masse	Screziature		Stime tessiturali percentuali		Classe Tessitura USDA	Scheletro >2,0 mm	pH	Eff. HCl	Concrezioni		NOTE
			colore	quantità (%)	Argilla <0,002 mm	Sabbia 0,050-2,0 mm					Fe-Mn (%)	CaCO ₃ (%)	
10													
20													
30													
40													
50													
60													
70													
80													
90													
100													
110													
120													

* Gradi di reazioni all'HCl: 0-nessuna; 1-molto debole; 2-debole; 3-notevole; 4-violenta.

Figure 6.8 - Description of a sample for soil survey.

The survey has allowed the implementation of 30 sampling points in total, and has allowed the recognition of two main types of soil that differ between them for the highest content of sand or clay.

The northern part of the basin, to the limit roughly located between the alignments of Ponte Crabolu, M. Giunchi and C. l'Eremita, has soils that are going to set in part on metamorphic basement and partly on the post-Variscan continental succession of Nurra. These soils are made up of soil profiles type AC, A-Bw and

subordinate A-Bt-C, and are low to medium deep, from franco sandy to franco clay, from permeable to medium permeable, sub-acid and partially desaturated.

The southern part of the basin, the alignment above the southern edge, is set mainly of Quaternary deposits characterized by aeolian cemented sandstones and flood deposits. The soils in this area are made up of soil profiles type A-Bt-C, A-Bt-Cg and subordinate AC, are deep, and have a texture ranging from sandy to franco sandy and clay in surface, a predominantly sandy in depth, from permeable to medium permeable, from sub-acid to acids, from saturated to desaturated.

6.6 Geophysical surveys

The geoelectric surveys supply a areal vision of the underground investigated, with a resolution that is function of the Inter-elettrodico step. At the same time the tomografica elaboration affords to obtain resistivity models that contain a topographic reference with adequately resolved which allowing it to report to the tomographic evidence on the morphological profile. It is possible moreover to obtain useful information in relation to the presence of fractures, faults, or discontinuity in general terms.

The specific objectives of these geoelectric surveys can be summarized as follows:

- identification of tomographic evidence in relation to the surface morphology;
- stratigraphic reconstruction aimed at the definition of the geotechnical and thermal units;
- identification of evidence of significant breaks, particularly fractures, dikes or cavities;
- identification of any underground water movement of, closely related with the thermal properties of levels of interest.

Achieving these objectives will provide, together with the results arising from the geological survey of detail, a cognitive framework adequate for the purposes of labor.

6.6.1 *Equipment used*

For exploration has been used a georesistivity meter Terrameter LS built by Abem AB (Sweden), equipped with two rolls of multi-cable with 32 sends, in order to handle the 64 electrodes indifferently used as the inlet points of the current and how the measurement points of potential difference.

The georesistivity meter consists of an internal control unit and an internal switch, both housed inside a casing of aluminum with dimensions 39x21x32 cm and weighing 12 kg.

The control unit allows you to program the automatic management of the electrodes of the stringing, connected through multielectrode cables to the switch. On the basis of the chosen array, the switch select the pairs of electrodes through which energize and performs a set of measurements that are repeated automatically for a fixed number of times (referred to as stack or cycle) to lower the statistical error acquisition.

The unit also has the function to simultaneously connect two cables which are connected to the electrodes and has the task is to configure the input parameters (intensity of current fed, electrode distance, the number of electrodes used, the allowable error in measurements, the number of measurements for a same configuration and the protocol or the sequence with which measurements are carried out) that of real-time monitoring of the acquisitions.

The Terrameter LS is equipped with an internal battery 12 V, required for the functioning of the internal software Firmware. In order to realize geoelectrical surveys however, must be connected to the instrument an external battery from 12-18 V. The georesistivity meter has an electrical output power of 250 W, it can dispense a maximum intensity of current of 2500 mA, and has the ability to change instantly polarity. As for receiving data it is provided with 4 channels and can measure an input voltage of between ± 600 volts; sampling the data with a frequency of 30 kHz. It has an internal memory of 4 GB and comes with integrated GPS receiver SiRFstar III.

The instrument is based on the use of metal electrodes for galvanic coupling and is designed to carry a full set of stendimenti geoelectric: vertical electrical survey, resistivity profiles, measurements for multi-electrode, electric tomography 2D and 3D, measurements of induced polarization and potential spontaneous. It is also able to automatically manage up to 64 electrodes but in the specific case, both the first stringing both in the second stringing, were not used all the electrodes due to logistical problems.

The software Terrameter LS can display real-time readings representing a pseudosection of the investigated ground according to the apparent resistivity measured up to that point.

After an investigation, the data collected from georesistivity meter can be quickly downloaded to a computer via USB connection.

At the multitaken cable of georesistivity meter all electrodes are connected simultaneously through appropriate connectors.

6.6.2 Analytical methods

In this phase it is necessary to set a methodology of analysis such as to allow an immediate understanding of the interpretations derived from it. The first phase involves defining the range of resistivity that must be weighed against the geological data in our possession. From this point of view it will be crucial to select a single map scale of representation that allows the correct interpretation of tomographs.

The scale of values defined has been calibrated for a more rapid and easy identification of possible classes of resistivity.

The interpretation of the resistivity models can not disregard the resistivity values that are commonly reported in the literature (Table 6.2) for the soils and rocks that characterize the investigated area.

	<i>Sand</i>	<i>Gravel</i>	<i>Clay and sand</i>	<i>Gravel and sand</i>	<i>Conglomerate</i>	<i>Limestone</i>	<i>Dolostone</i>	<i>Schist</i>	<i>Marble</i>
<i>Norinelli, 1996</i>	100-1000	-	-	-	-	100-5000	500-10 ²	-	-
<i>Musset, 2003</i>	500-5000	100-5000	-	-	-	-	-	-	-
<i>Telford, 1990</i>	10-800	-	30-215	-	2000-10 ⁴	50-10 ⁷	-	-	-
<i>Loke, 2004</i>	-	-	-	-	-	-	-	-	-
<i>Peltoniemi, 1998</i>	500-1000	1000-2000	-	-	-	-	-	-	-
<i>Ward, 1990</i>	-	-	50-300	200-5x10 ³	-	-	-	-	-
<i>Culley, 1975</i>	-	100-10	-	-	-	-	-	-	-
<i>Carrara, 1992</i>	-	-	-	70-700	-	300-10 ⁴	-	-	-
<i>Zanichelli, 1988</i>	500-5000	-	-	-	-	50-10 ⁷	-	10-10 ⁴	100-10 ⁸
<i>Boyd, 2003</i>	1-1000	100-5000	-	-	-	100-10 ⁴	-	-	-

Table 6.2 - Resistivity intervals of soils and rocks by different authors.

Beyond the single contexts, there is a substantial agreement between the orders of magnitude of the intervals of resistivity values for different authors.

The acquired results in the country through the geoelectric spreadings have been all elaborated with the software Res2Dinv (Geotomo Software) which has allowed us to realize 2D resistivity models relatable to the geological and geomorphological discussed in the preceding paragraphs. It should be remembered as the electric tomography is a tool of fundamental importance for the geological interpretation of the subsurface characteristics when associated with a proper geological context of the site, the past geological assumptions are well corroborated by changes in resistivity measured.

To facilitate reading of the tomograms you chose to introduce and justify the scale of values used for all the resistivity sections. For the purposes of interpretation a functional representation scale holds in fact an essential role. The high variability of the readings and the many features to consider in interpretation have made that were chosen four different layers of interpretation: the physical, lithology, saturation and compositional. The physical layer refers to the choice of range and classes of resistivity to be used in this paper: the choice to attribute such variability range is

reflected in the data shown above in Table 6.2. It has therefore been chosen to use a variable range between 5 and 1300 Ωm , then divided into sixteen classes plus a seventeenth tending to higher values: to them have been associated color gradations useful to isolate chromatically the different characteristics of the various layers. As regards the lithological layer should be stated that this is characterized by a considerable overlap of the resistivity values (there is in fact uniqueness between the lithological characteristics and the relative values of resistivity): this is further corroborated by the presence or less for each lithology of a saturation component which tends to greatly lowering the resistivity. The resistivity values below 80 Ωm can be associated, depending on the area and the geological context: levels of clay, silt-loam layers and thicknesses sandy-gravelly. These last thicknesses are also characterized by higher values in fact, in the absence of saturation, can reach 300 Ωm . The resistivity values greater than 300 Ωm are attributable to the conglomeratic covers and aeolian sandstones: within that range to Higher numbers indicate a greater fraction of quartz. Finally, between 225 and 450 Ωm , between these two levels, there is an intermediate range due to well-cemented sands and sandstones altered. Of fundamental importance to the study conducted for this research project was to define the layer referred to saturation: it was reported to the values of resistivity of less than 80 Ωm . To values close to 80 Ωm will correspond to a lower degree of saturation vice versa, to the minimum values, it corresponds to a major component saturates. Very important for the interpretation is the compositional layer, in fact, a greater fraction of silty lithologies, correspond to lower values of resistivity and an increased presence of quartz fraction correspond values increasing. In light of these considerations, the color scale is designed to easily connect the values of resistivity at the geological context described and facilitating the reading of tomography (Figure 6.9).

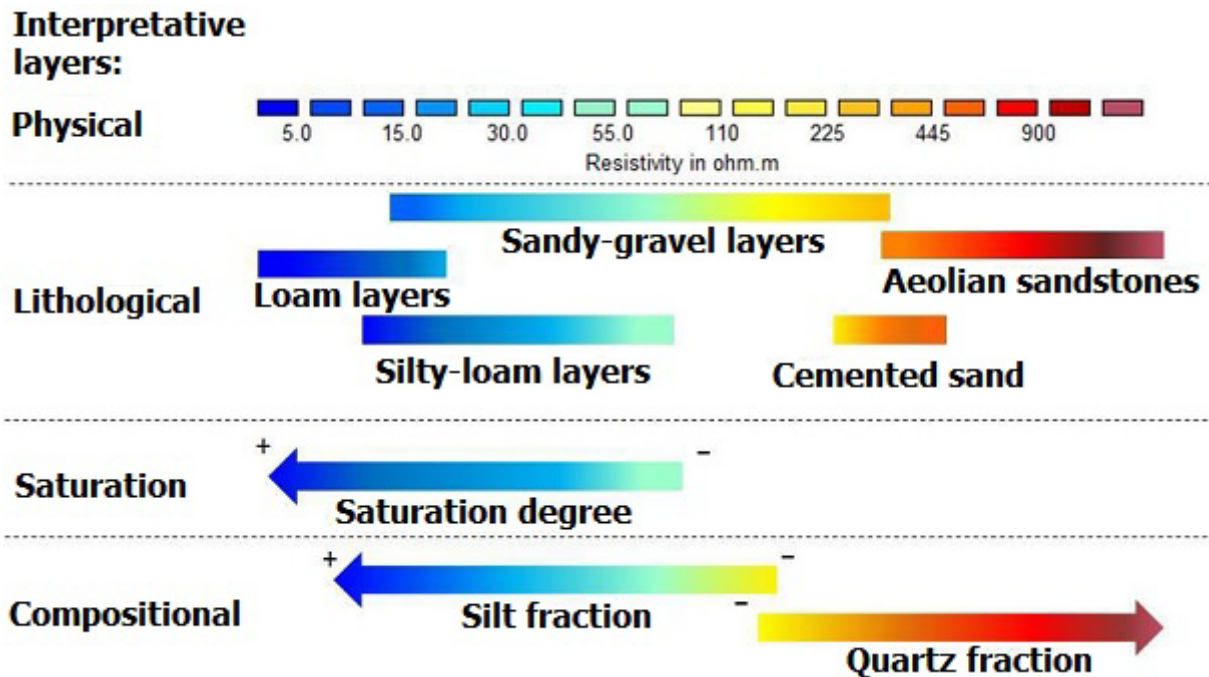


Figure 6.9 - Color scale used for the interpretation in this work.

In every tomography were inserted the topographical references, to give a better contextualization morphological, were highlighted levels refer to the portion of the sea level and the lake, help us understand better the hydrogeological dynamics. The topographic data were obtained from the CTR 1:10000 available for the direct surveys carried out in the country.

The resistivity models, finally, have all been reversed with a refined model that allowed us to have a better degree of resolution especially at the thickness surface, characterized by aeolian sands making up the dunes and the conglomerate covers.

The next few paragraphs then collect the technical details of any survey, the associated electrical tomography and the interpretation.

6.6.3 GPS surveys

The need to locate the surveys within the context of available cartography has suggested to carry out the acquisition of the field reference points, useful for a correct positioning of the geoelectrical lines. Supported by a mapping in scale

1:10000, it was decided to acquire at least two points for each geoelectrical line in order to localize later the investigation into the cartographic base. With the exception of only one relief (geoelectrical line number 4), we were measured relative coordinates to the points of the first electrode, the center of the geoelectrical line and the last electrode.

In order to properly position the points earned with GPS was necessary to have the Regional Technical Numerical Map of the Autonomous Region of Sardinia in scale 1:10000 (section 458110 "Baratz") containing the study area (Figure 6.10).

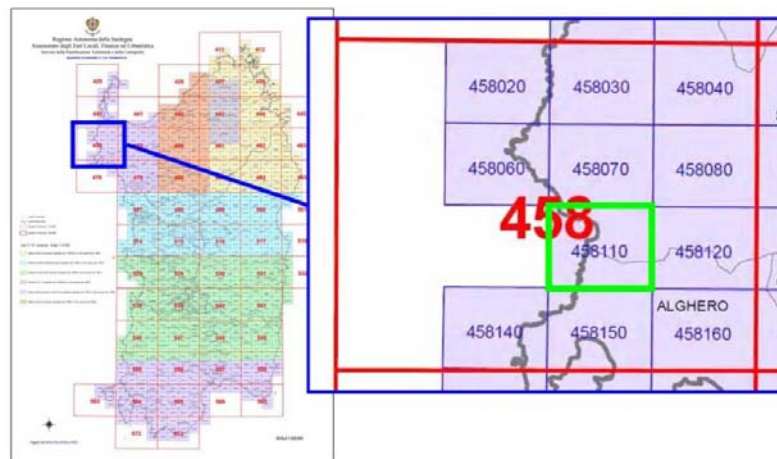


Figure 6.10 - Union framework of the CTR 1: 10000 of the Autonomous Region of Sardinia with its positioning in the section 458110 "Baratz".

The instrument used for the acquisition of the coordinates of the points is a handheld GPS (Garmin) with 12-channel receiver SiRFstar III.

The data was acquired by International System WGS84 coordinate system and then transformed in reference Gauss-Boaga through software Traspunto V.2.6.

The Table 6.3 shows the geographical coordinates of the GPS points and the accuracy provided by the instrument in the acquisition phase on the plane (x, y). The analysis of the acquired points can evaluate the reliability of the measures. As is evident, most of the errors of the points acquired by the GPS is less than 6 m. For a specific purpose you may be considered appropriate accuracy of the positioning of the geoelectric surveys.

<i>ID_Point</i>	<i>Location throughout the survey</i>	<i>WGS84 latitude</i>	<i>WGS84 longitude</i>	<i>GB latitude</i>	<i>GB longitude</i>	<i>Quality positioning (m)</i>
Inizio Stendimento 1 (Baratz)	0	N 40°40'50.1"	E 08°13'14.3"	4503599.619	1434167.623	5
Metà Stendimento 1 (Baratz)	315	N 40°40'43.0"	E 08°13'24.1"	4503378.652	1434395.740	6
Fine Stendimento 1 (Baratz)	630	N 40°40'35.7"	E 08°13'32.2"	4503151.876	1434583.908	5
Inizio Stendimento 2 (Baratz)	0	N 40°40'38.3"	E 08°13'31.0"	4503232.296	1434556.443	6
Metà Stendimento 2 (Baratz)	315	N 40°40'30.6"	E 08°13'38.6"	4502993.294	1434732.773	5
Fine Stendimento 2 (Baratz)	630	N 40°40'23.2"	E 08°13'47.8"	4502763.217	1434946.760	4
Inizio Stendimento 3 (Baratz)	0	N 40°40'32.6"	E 08°13'38.4"	4503055.006	1434728.620	4
Metà Ste 3 (Bartaz)	315	N 40°40'36.3"	E 08°13'50.3"	4503166.642	1435008.984	4
Fine Ste 3 (Baratz)	630	N 40°40'37.4"	E 08°14'03.4"	4503197.873	1435316.813	4
Inizio Stendimento 4 (Baratz)	0	N 40°40'42.9"	E 08°14'06.3"	4503366.873	1435386.367	5
Metà Stendimento 4 (Baratz)	315	N 40°40'43.8"	E 08°14'19.9"	4503391.851	1435705.869	4

Table 6.3 - The Cartesian coordinates of the points acquired along four surveys carried out in the work area.

6.6.4 Positioning of the surveys and operative choices

The work area includes the areas to the South and Southeast of the lake: in the first sector, at the lake barrier dune, the area extends for the entire length of the dune up to about 300 m south of it. In the second sector, starting from the lower limit of the dune, the area extends eastward for about 1500 m (Figure 6.11).

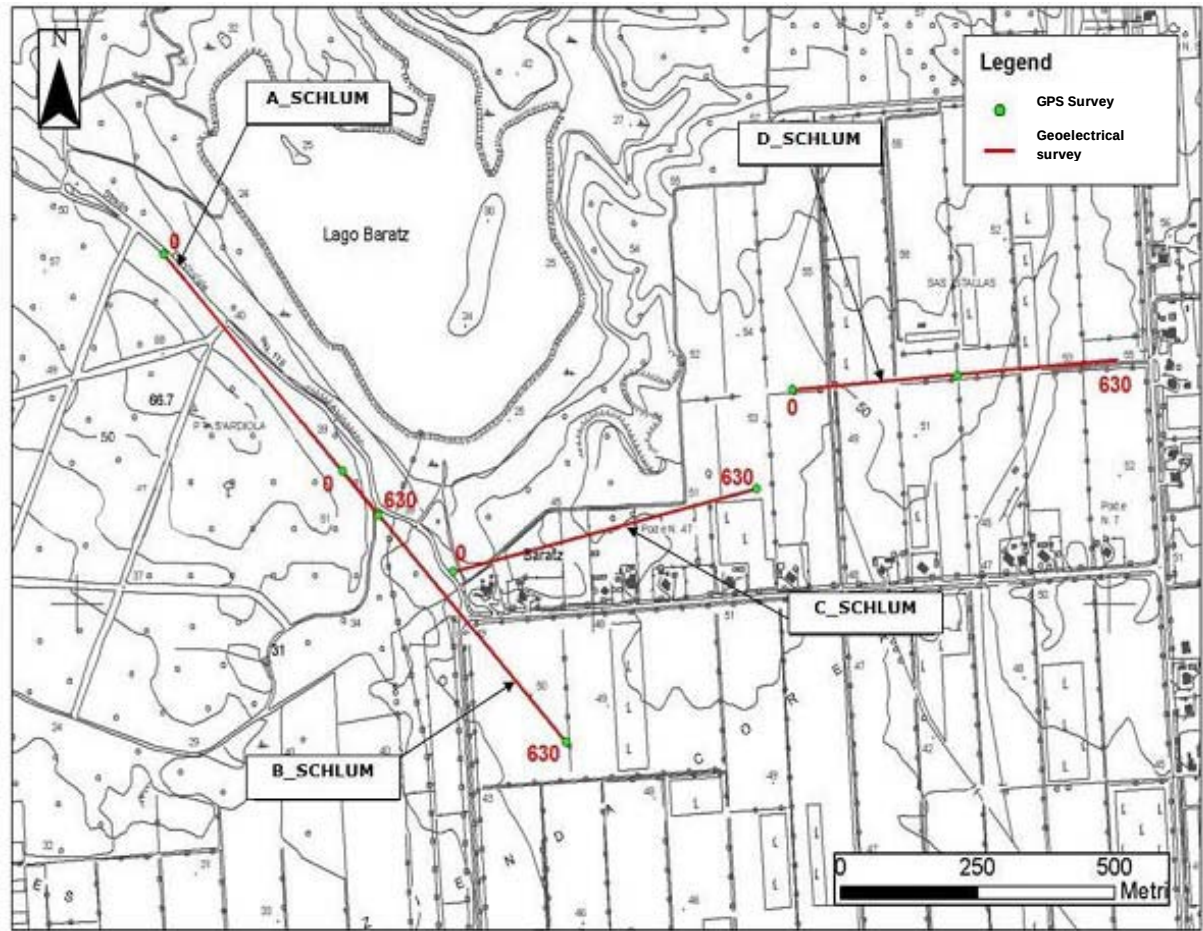


Figure 6.11 - Geographical location of geoelectrical survey lines (in red).

In order to obtain a more exhaustive picture of the hydrogeological characteristics of the lake (see section 1.3), the geoelectrical investigation is proposed to analyze the following problematics:

- determination of the course of the superficial aquifer present in the zone, in relation to the functional characteristics of the dune barrier;
- search of eventual evidences of lowering of the level of stratum in order to estimate possible repercussions, on the dynamics of the geoexchange systems, of the numerous present wells in pumping phase;
- appraisal of eventual logons between the deep aquifer and the superficial groundwater table;
- determination of eventual evidences tied to the presence of a North-South faults, than isolates the coastal system from the external system;

- determination of the possible intrusion of the salt wedge in the eventual “loss” zones below of the dune, concrete hypothesis date the remarkable vicinity of the basin to the coast.

The carried out inspection has afforded to observe directly the dune barrier placed in the south-west of the lake (about 800 m long): This looks characterized by aeolian sands, often in outcrop, with a dense of vegetation cover coinciding with 200 m further south.

In correspondence of the same one were made realized A_SCHLUM and B_SCHLUM reliefs (Figure 6.12 and Figure 6.13), both of length 630 m, with electrodic spacing of the 10 m and maximum depths of investigation of approximately 120 m. Both reliefs have direction from North-West to South-East and are located on the left side of the road along the East side of the lake (Provincial road n.118). In particular, the first electrode of relief A_SCHLUM is placed 150 m to South regarding the end of the asphalted tract of the of the above-mentioned road. The first electrode of the relief B_SCHLUM is located in correspondence of electrode 54 of relief A_SCHLUM, having obtained therefore an overlap of 90 m with this last relief. At last, the center of relief B_SCHLUM is placed in proximity of the crossing street, place immediately to south of the lake (electrode 35 is excluded own because in correspondence of such crossing); the last 280 m of the geoelectrical line are placed in correspondence of a cultivated field (Figure 6.13).

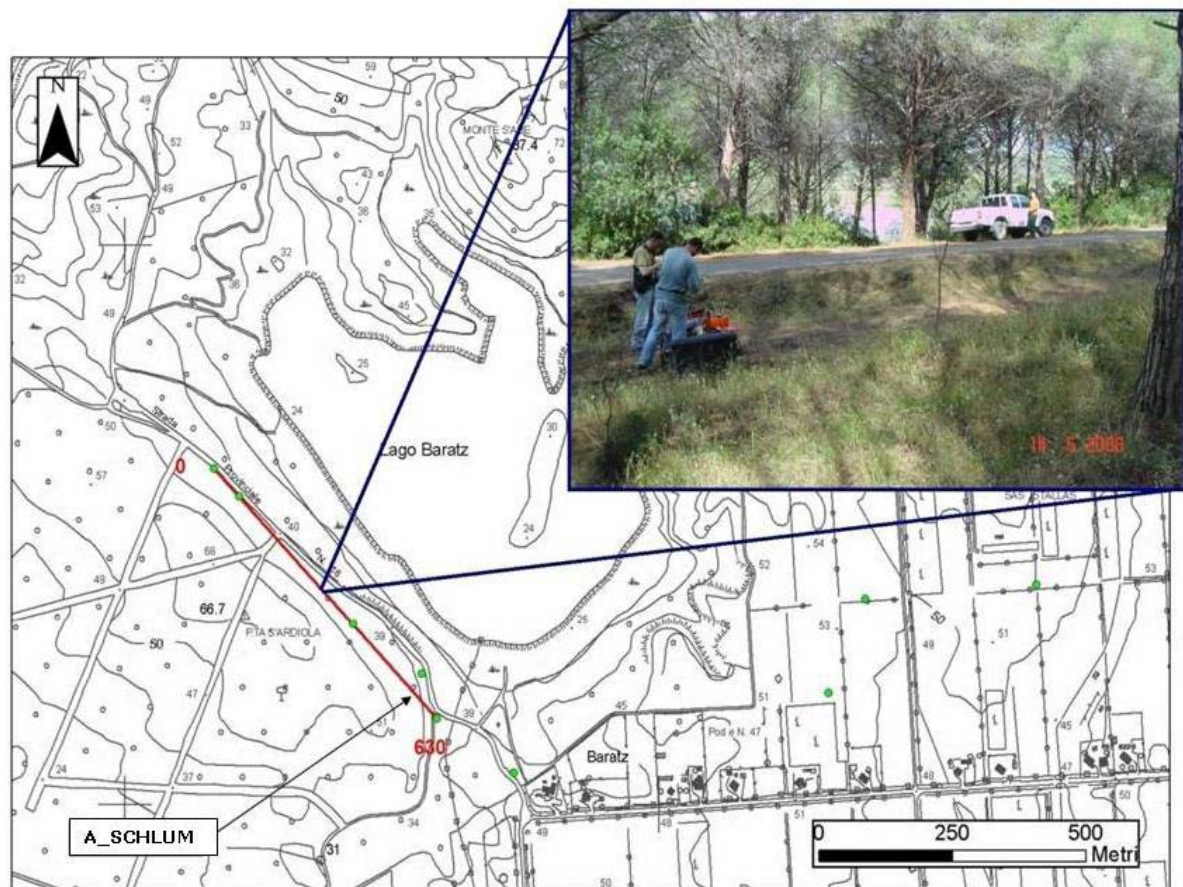


Figure 6.12 - Workspace of the relief A_SCHLUM.

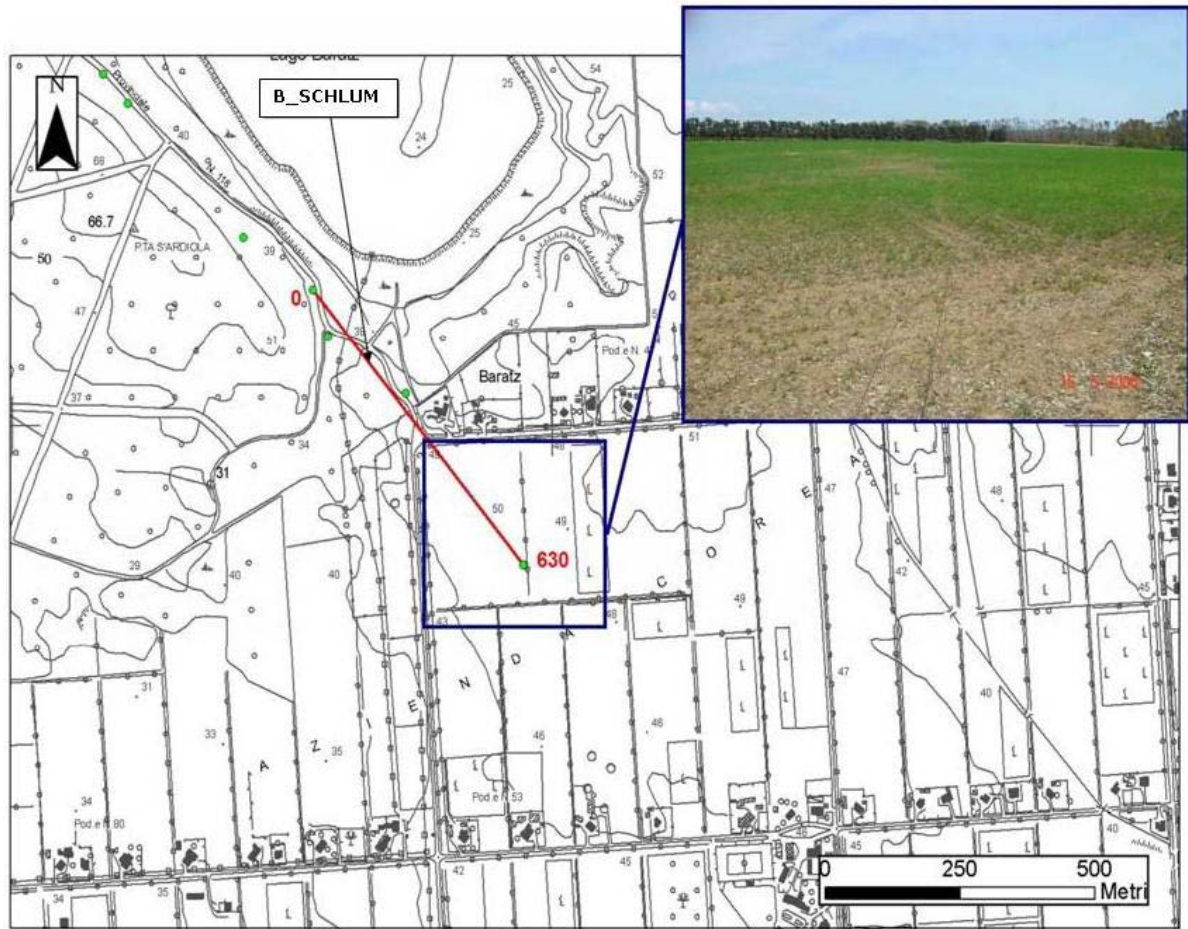


Figure 6.13 - Workspace of the relief B_SCHLUM.

The objective of this series of reliefs is that to monitor the dune with the aims of the determination of the effective effectiveness produced from the obstruction. In particular the thickness of aeolian sands that is developed from the campaign plan will be studied trying to characterize of the power and the geometric development. Below it the investigation is proposed to find eventual saturates levels , center of preferential water passage directly connected with dynamics of the lake. These characteristics afford to optimize the study; furthermore, the available literature and the direct country observation seem to indicate the presence of silty deposits from the bottom of the old lake, but do not provide an indication of the presence of significant thickness.

The reliefs C_SCHLUM and D_SCHLUM (Figure 6.14 and Figure 6.15) are realized in correspondence of the field in the center-meridional part of the basin, and cover

the area that is extended from the lower end of the dune towards the Northeast. Both reliefs, are arranged according to West-East direction, have length of 630 m, electrodic spacing of the 10 m and maximum depths of investigation of approximately 120 m. The first electrode of relief C_SCHLUM is placed to South of the lake, in correspondence of the provincial road n.118, on the opposite side regarding reliefs A_SCHLUM and B_SCHLUM. The first electrode of the D_SCHLUM is placed 75 m to East regarding the last electrode of relief C_SCHLUM.

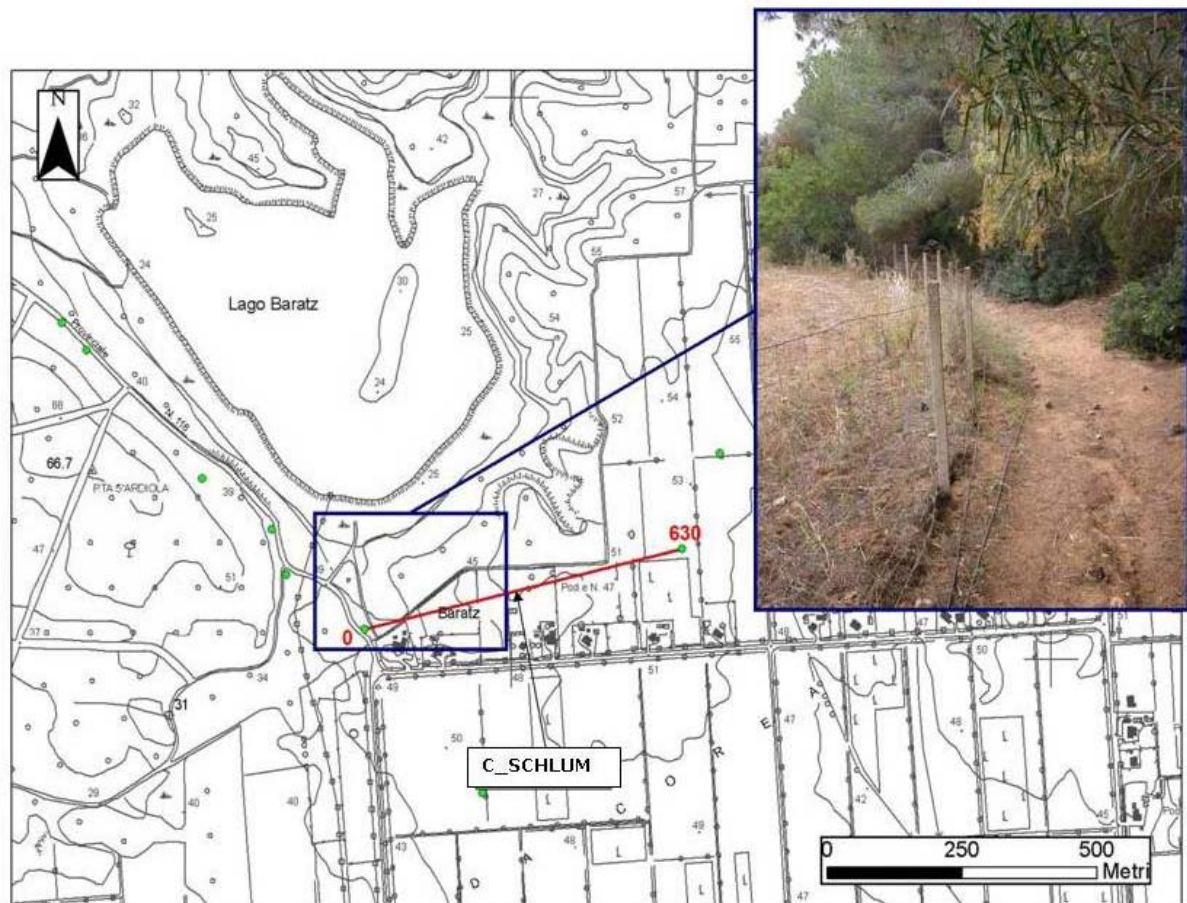


Figure 6.14 - Workspace of the relief C_SCHLUM.

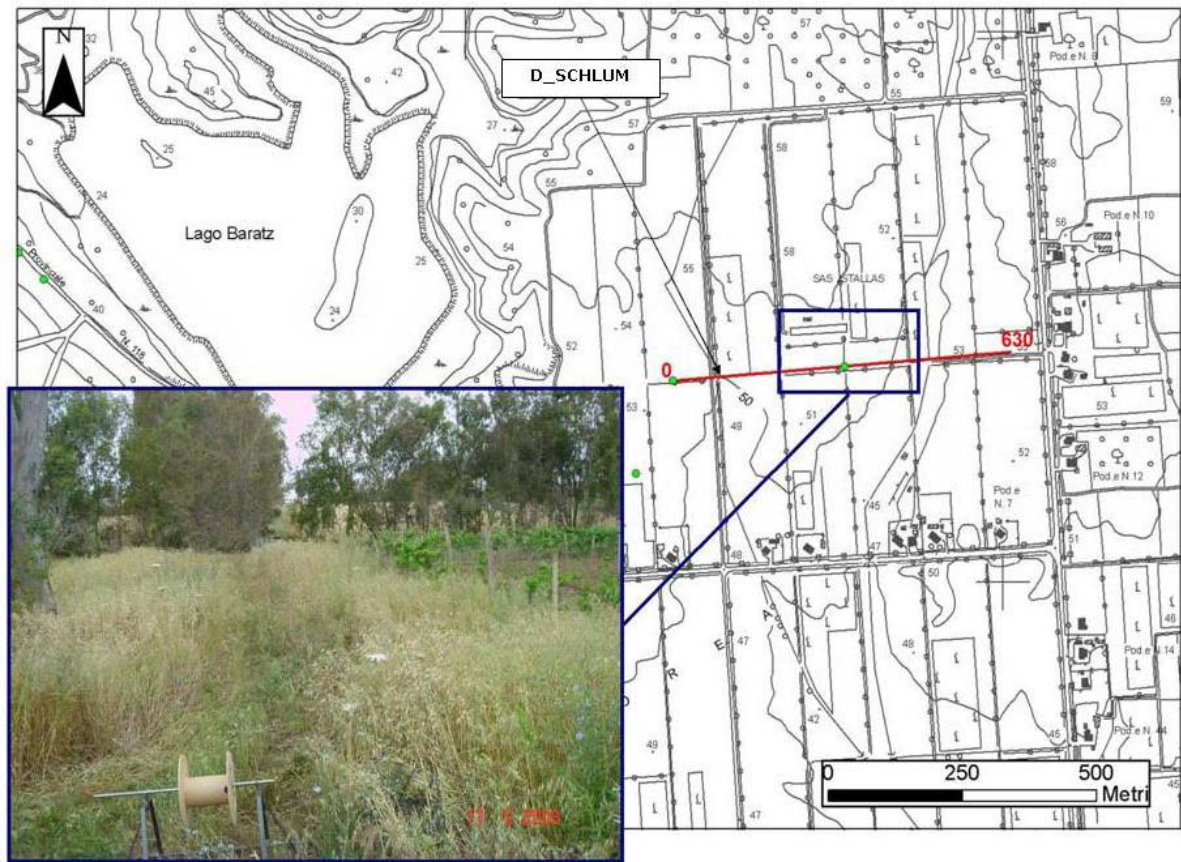


Figure 6.15 - Workspace of the relief B_SCHLUM.

These two reliefs are realized with the objective to find eventual discontinuities inside of the bedrock and to put in evidence the trend of the more superficial aquifer, from which reach numerous wells of the zone. In addition, the same, are designed to analyze any evidence of autonomy of the coastal system, compared to the external system.

Considered the targets to reach and their variability (power and geometry of sands and aeolian sandstones that constitute the dune, depth and extension of the levels saturate and possible discontinuities of the substrate) are chosen to elaborate and to interpret the measures realized with Array Schlumberger, own for the greater sensibility that such method of acquisition anticipates for the survey of variable orders (anticipates optimal resolution is vertical that horizontal). The Schlumberger method has permission, moreover, to reach a lateral cover more wide.

6.6.5 *Results*

In this paragraph the results of the geoelectrical reliefs will be introduced. In addition to briefly summarize the technical specifications of each survey will be represented the electrical tomography with univocal color scale and adequately determined for the purposes of interpretation.

All the tomographies have been inverted, by means of Res2Dinv™ Geotomo Software, using a refined model of reversal, with width of the cells equals to half of the electrode spacing. Like described in literature (Loke, 2004), this arrangement is particularly apt to a context like that object of study, in which a good variability of resistivity is present, caused mainly from the fratturazione of the substrate and different type of deposits.

The interpretation of the following models of resistivity is based on the geologic characteristics found during the campaign of measures.

Regarding the resistivity values it is necessary to make reference to the values searched in literature and from the campaign survey, to the aim to estimate the thickness of the layers, the presence of eventual saturated zones and lines of fractures.

6.6.5.1 TOMOGRAPHY A_SCHLUM

TECHNICAL DATA	
File name	Tomografia_1S.dat
Acquisition method	Schlumberger (n=3)
Protocol used	64SC3V
Length of geoelectrical line	630 m
Number of electrode	64
Interelectrode spacing	10 m
Maximum depth of investigation	120 m

Table 6.4 - Technical data of the A_Schlum tomography.

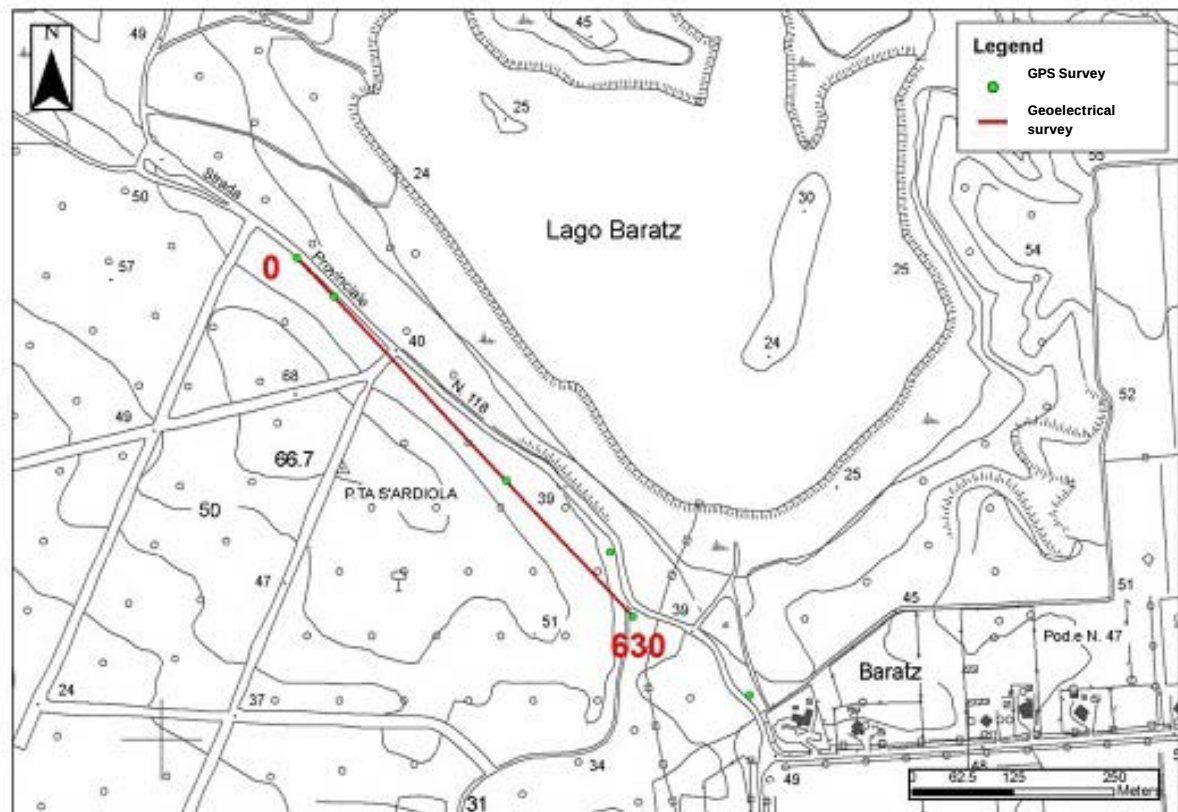


Figure 6.16 - Geographical location of the relief A_SCHLUM and point location GPS-based mapping georeferenced 1: 10000.

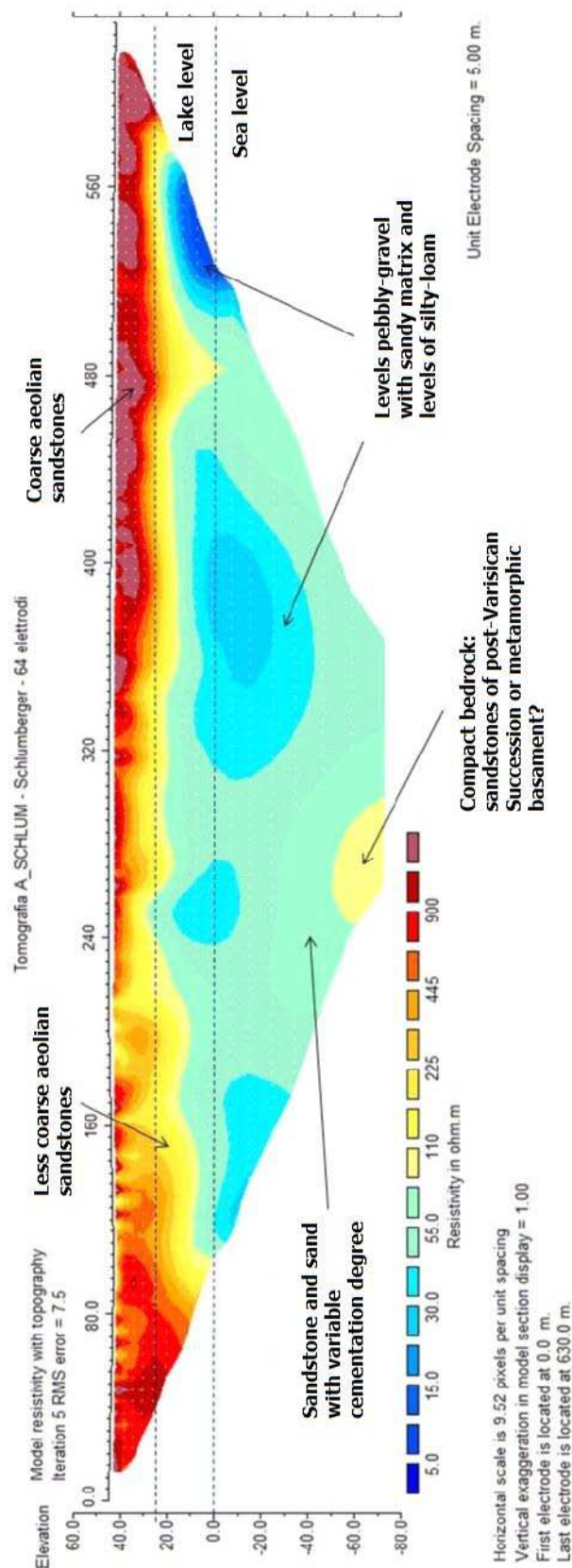


Figure 6.17 - Electrical tomography A_Schlum.

The A_SCHLUM tomography is carried out along the provincial road n.118 in correspondence of the coastal dune situated along the south-western margin of the lake. The measures collections during the survey electrical worker in campaign have been affette from inferior instrumental errors to 5%, this have afforded a clear geologic interpretation. The layer more superficial of the tomography it is characterized by a very distinguishable layer, sub-horizontal, of variable thickness between the 10 and 30 meters from campaign plan, that it is situated to approximately 45 meters s.l.m. This level has values of resistivity comprised between the 500 and 2000 Ωm related, also according to the geological context of the area, in aeolian sands (d) dry. These ranges are reflected in the bibliographic data available (Table 6.2).

Under such layer a horizon of 15 m with values of resistivity comprised between the 100 and the 500 Ωm is present, due to aeolian sandstones but to less coarse grain size. Note how the resistivity decreases with depth: this is due to the progressively lower degree cementation of sandstones, to pass to assimilable values to very cemented sandstones (PVM_{2b}). The underlying layer has a thickness ranging between 10 and 55 m, with resistivity values below 80 Ωm , due to terms pebbly-gravelly with sandy matrix and levels silty loam soils attributable to the alluvial deposits of the Pleistocene Subsintheme of Posrtoscuso (PVM_{2a}).

Going down of quota we find instead values of increasing resistivities (until 100 Ωm) riconducibili to sandstones with presence interbedded and silty-loam and sands with increasing of cementation degree with the depth, justifiable from the values of always greater resistivities. At last in the central feature to the depth of approximately 100 m from the flat campaign are found the 150 advanced values to Ωm , such increase of resistivity are from leading back to the presence of the below substrate the dune: the information in our possession us do not allow a clear interpretation of such lithology. The resistivity values make to presuppose the presence of arenaceous substrate, but the considerable depth that has intercepted the high resistive tends to recommend an interpretation on the metamorphic substrate.

6.6.5.2 TOMOGRAPHY B_SCHLUM

TECHNICAL DATA	
File name	Tomografia_2S.dat
Acquisition method	Schlumberger (n=3)
Protocol used	64SC3V
Length of geoelectrical line	630 m
Number of electrode	64
Interelectrode spacing	10 m
Maximum depth of investigation	120 m

Table 6.5 - Technical data of the B_Schlum tomography.

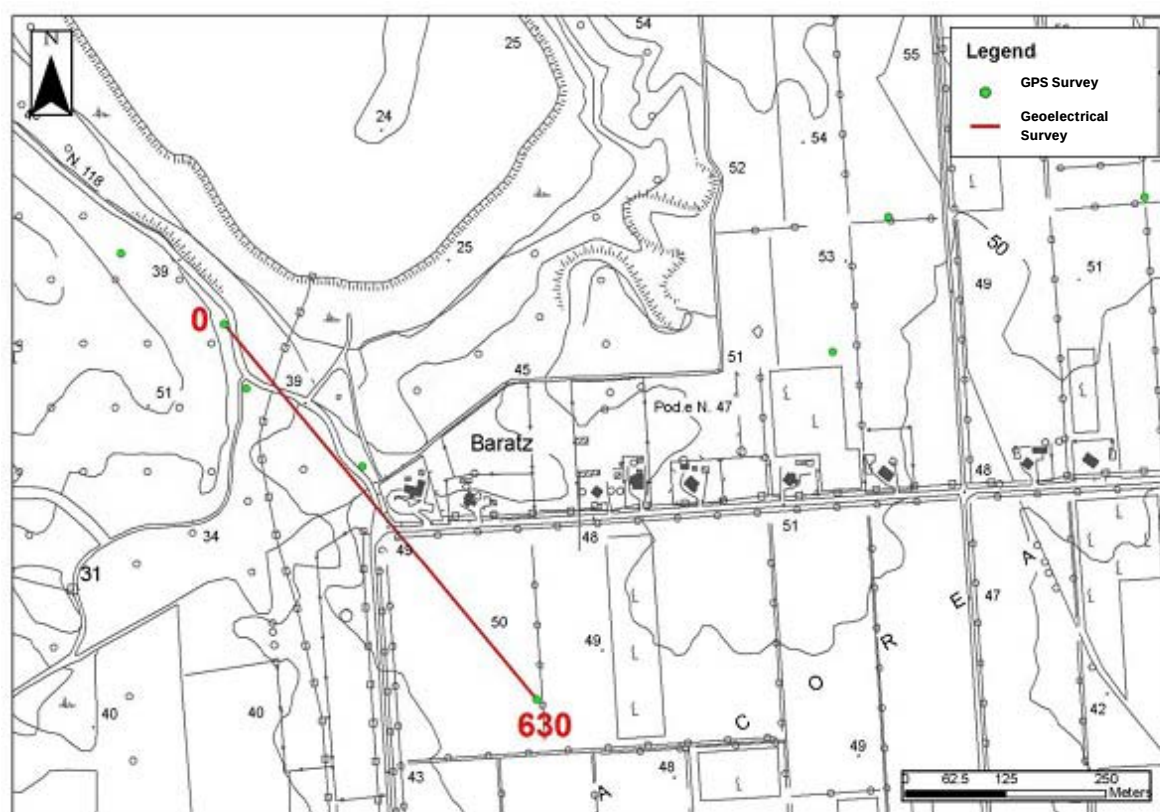


Figure 6.18 - Geographical location of the relief B_SCHLUM and point location GPS-based mapping georeferenced 1:10000.

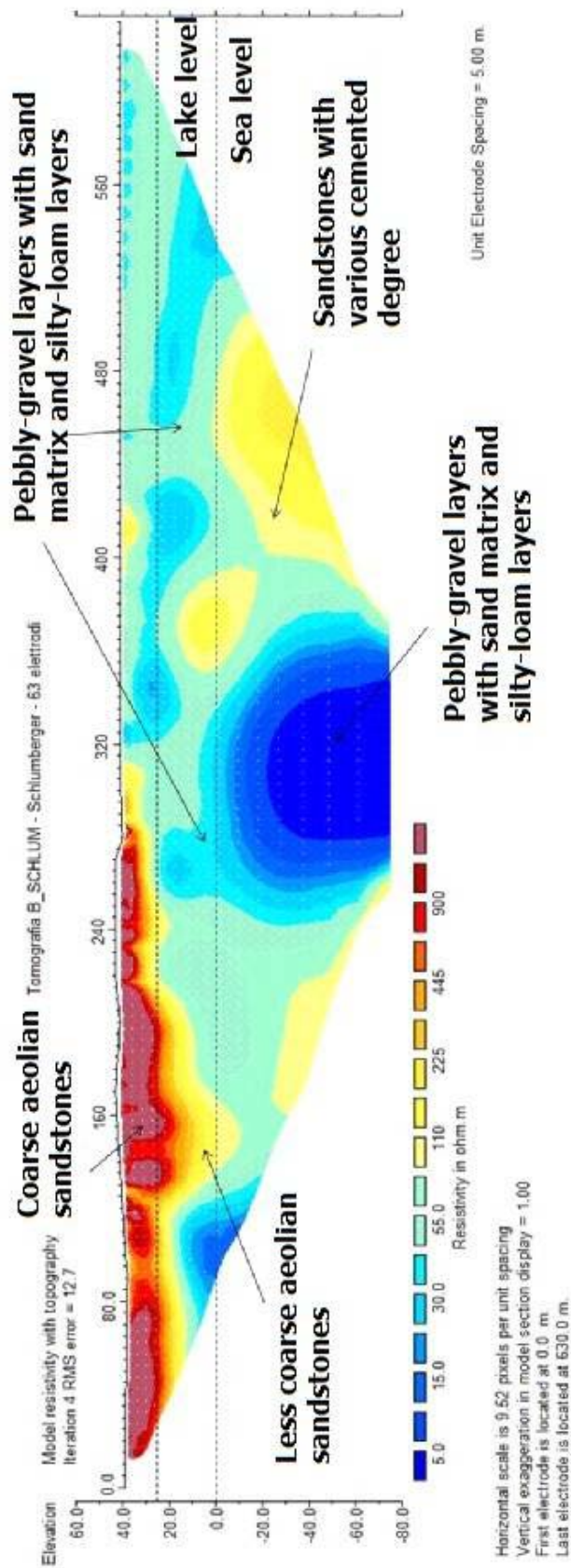


Figure 6.19 - Electrical tomography B_Schlum.

The tomography B_SCHLUM is carried out partially overlapped to tomography A_SCHLUM in order to afford to complete the study of the barrier dune investigated to the southern field of the basin. Also in this case the intercepted layers and relative values of resistivity allow to a clear geological interpretation.

The apex part is characterized by a superficial layer to high gradient of resistivity (from 500 to 2000 Ωm), due to dry aeolian sands (d) constituent of the superficial part of the dune. This level, however, is limited to 285 meters, which corresponds to the extreme south of the dune. This layer is in a position above with respect to a level of approximately 10 m, also noted in the previous tomography, corresponding to less coarse aeolian sands up to well-cemented sandstones (PVM_{2b}) in the deepest part (resistivity values ranging from 500 to 100 Ωm).

Below it is instead present a level to which the geometry and resistivity values presuppose passages between areas with a different degree of saturation: this level starting from the meter of 290 comes to surface. The latter is therefore composed of alternating lithologies of pebbles, gravel with sandy matrix and silty-loam fractions (PVM_{2a}). In the specific areas related to possible levels saturated are located along tomography between 60 and 125 m at a depth of 25 m from the ground level; between 255 and 360 m, this level is characterized by considerable extension and depth, reaching up to 100 m depth from the ground level, the homogeneity and the considerable extent of such low values of resistivity, they may also be due to a considerable fraction clay deposit. Finally, there are 3 levels of saturated surface between 320 and 360 m, between 380 and 425 m and between 470 and 560 m, approximately 20 m depth from ground level.

Just below is then present a level with higher resistivity values gradually up to 200 Ωm , due to sandstones with increasing of cementation degree up to sandstones probably characterized by brittle discontinuity. Finally, between 400 and 500 m and at the depth of 80 m, is present or identifiable thickness as a compact bedrock (PID or FTE).

In reference to the levels low resistivity above mentioned can be seen as they are located in an intermediate position between the sea level and the lake: the geometric

arrangement lets assume the absence of saline intrusions. These levels are definitely areas saturated with water from fresh to salty.

It is also noted as the 350 meter of the tomography has been detected a well not drilled (Figure 6.20): not noticed however evidence of exploitation that might affect in any way the level of the water.

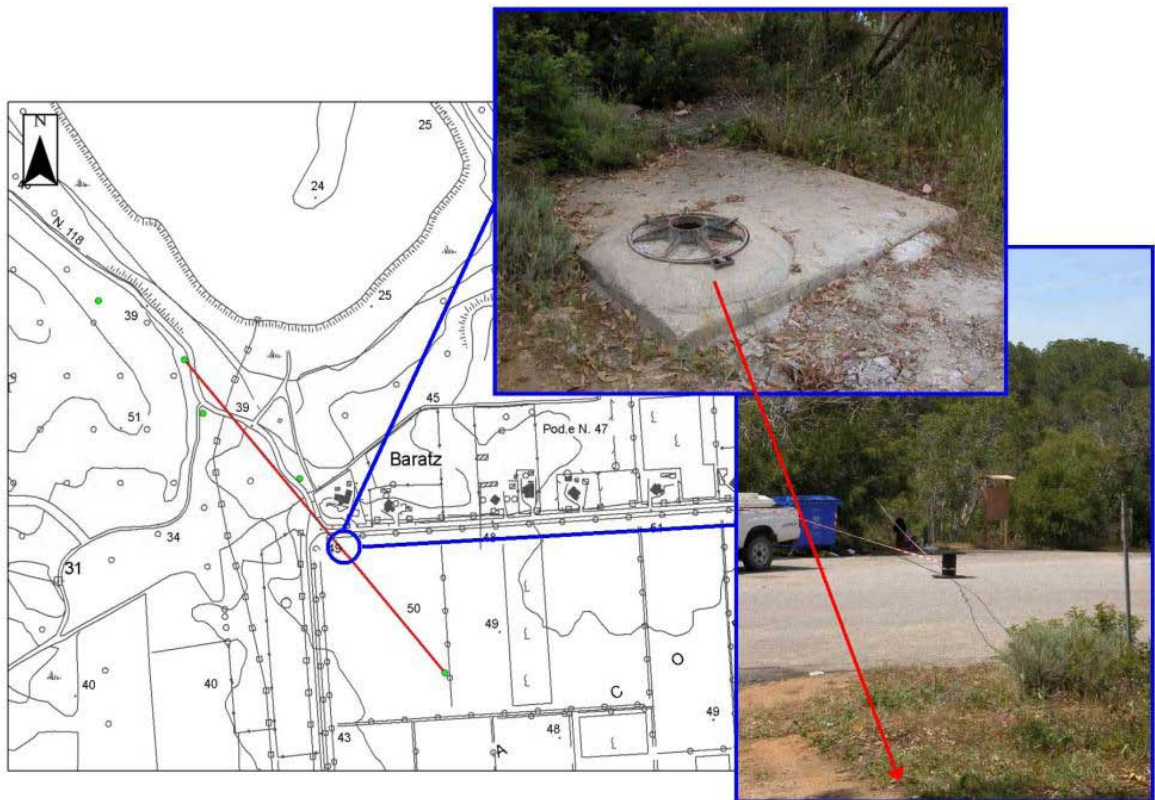


Figure 6.20 - Location of the well intercepted with the B_SCHLUM relief.

6.6.5.3 TOMOGRAPHY C_SCHLUM

TECHNICAL DATA	
File name	Tomografia_3S.dat
Acquisition method	Schlumberger (n=3)
Protocol used	64SC3V
Length of geoelectrical line	630 m
Number of electrode	64
Interelectrode spacing	10 m
Maximum depth of investigation	120 m

Table 6.6 - Technical data of the C_Schlum tomography.

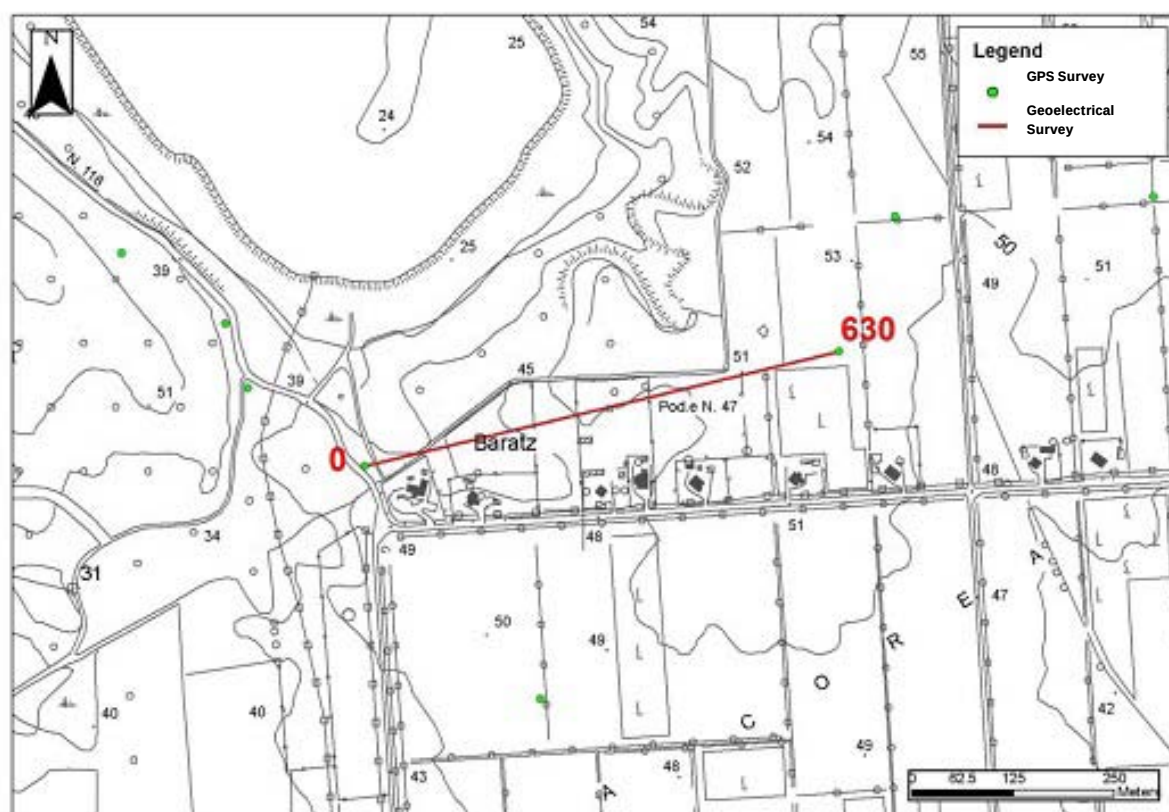


Figure 6.21 - Geographical location of the relief C_SCHLUM and point location GPS-based mapping georeferenced 1:10000.

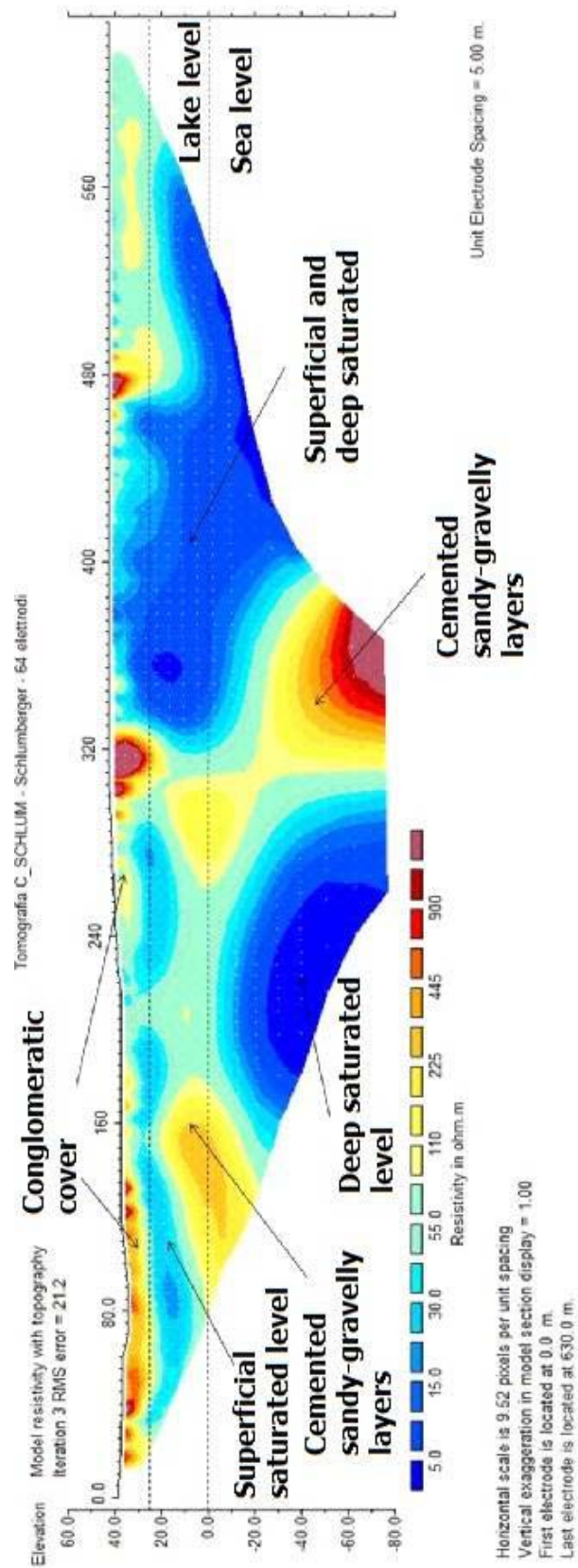


Figure 6.22 - Electrical tomography C_Schlum.

The C_SCHLUM tomography investigates the South-East side of the basin of the Baratz lake. In the first place, the upper part of the tomography is constituted by a non-continuous layer, with resistivity values greater than 500 Ωm , which are compatible with a lithology consisting of dry sands (d) and/or conglomerates rich in quartz (PVM_{2a}). This is supported by direct observation of this lithology during the geoelectric surveys. The greater thickness is located in the first 190 meters of tomography, with depths up to 15 m from the ground level, subsequently the superficial conglomeratic layer is reduced in thickness (about 5 m), and then thicken again to the meter 335. The high values of resistivity detected at the 320 meters and 480 meters are due to some technical problems during data acquisition: in fact were recorded particularly high values (above 10000 Ωm) totally incompatible with the asphalt surface. These data were considered during the processing result of a distortion of the electric field that the phases of post-processing, the analysis and the handling have eliminated the influence only partially.

The below level is present a thick, enough continuous, characterized by extremely low resistivity, less than 40 Ωm , due to saturated layers. This thickness is interrupted for about 35 meters in the central part of the geoelectrical line, and from the meter 470 to the end of the relief. The shallow aquifer is lower confined in the first 320 meters by a more resistive with values between 50 and 80 Ωm due to silty-clay layers and with values between 100 and 300 Ωm due to terms gravelly-sandy well cemented. In greater depths always in the first 320 meters are found very low resistivity values below 30 Ωm : this is explained by the presence of an important ground water, probably hosted in the post-Variscan continental succession of Nurra. These values are also found in the second portion of tomography with a depth slightly less: this stretch is characterized by a zone with passages of a different saturation degree in that the superficial and deep aquifer are interconnected.

In the central section that isolates the deep aquifers there is a zone significantly more resistive with increasing values going down in depth: this area is due to levels stony-gravelly until the presence of the substrate compact that appears at about 100 meters from the ground level. In relation to the target of the investigation should be stated how it was detected a borehole to the meters 540 (Figure 6.23): this is a

further proof of the exact geological interpretation of the area. Moreover it can be assumed that the drilled well being located in a portion of the area where the superficial aquifer is absent, sometimes captures from deeper acquifer. From experience, however, are not as apparent also in this case variations in the water table level attributable to it. At the conclusion of this analysis it can be seen as the lithological and geological structure is very different than previous geoelectrical line, this can be assumed a structural arrangement that isolates the coastal system by the external system, as suggested during the inspection.

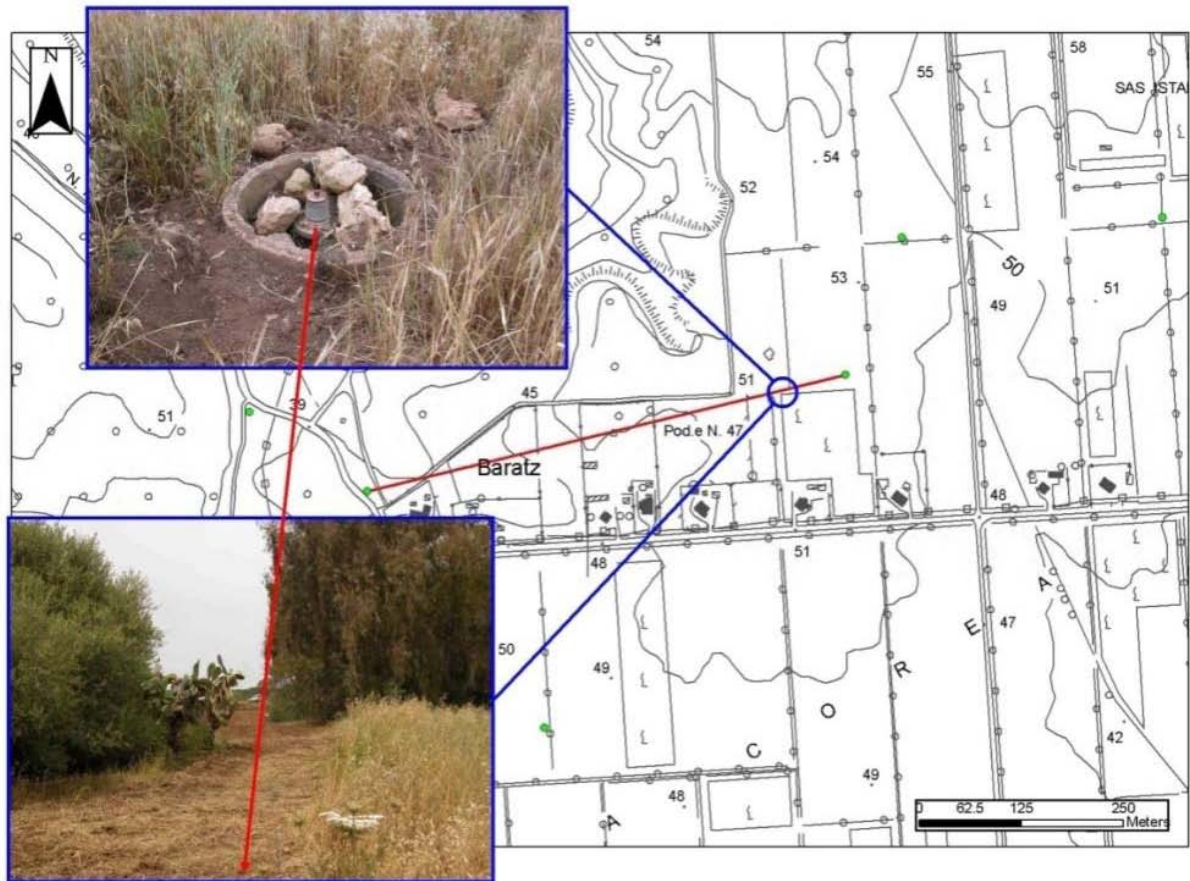


Figure 6.23 - Location of the well intercepted with the C_SCHLUM relief.

6.6.5.4 TOMOGRAPHY D_SCHLUM

TECHNICAL DATA	
File name	Tomografia_4S.dat
Acquisition method	Schlumberger (n=3)
Protocol used	64SC3V
Length of geoelectrical line	630 m
Number of electrode	64
Interelectrode spacing	10 m
Maximum depth of investigation	120 m

Table 6.7 - Technical data of the D_Schlum tomography.

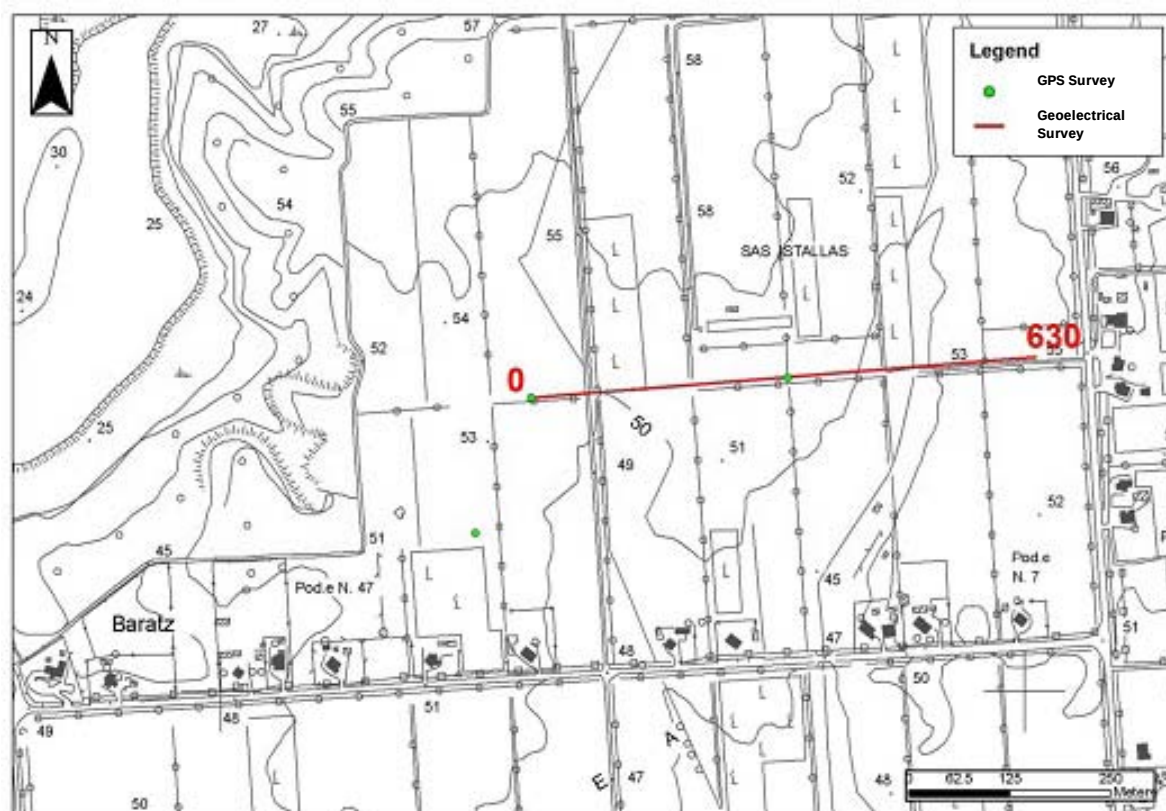


Figure 6.24 - Geographical location of the relief D_SCHLUM and point location GPS-based mapping georeferenced 1:10000.

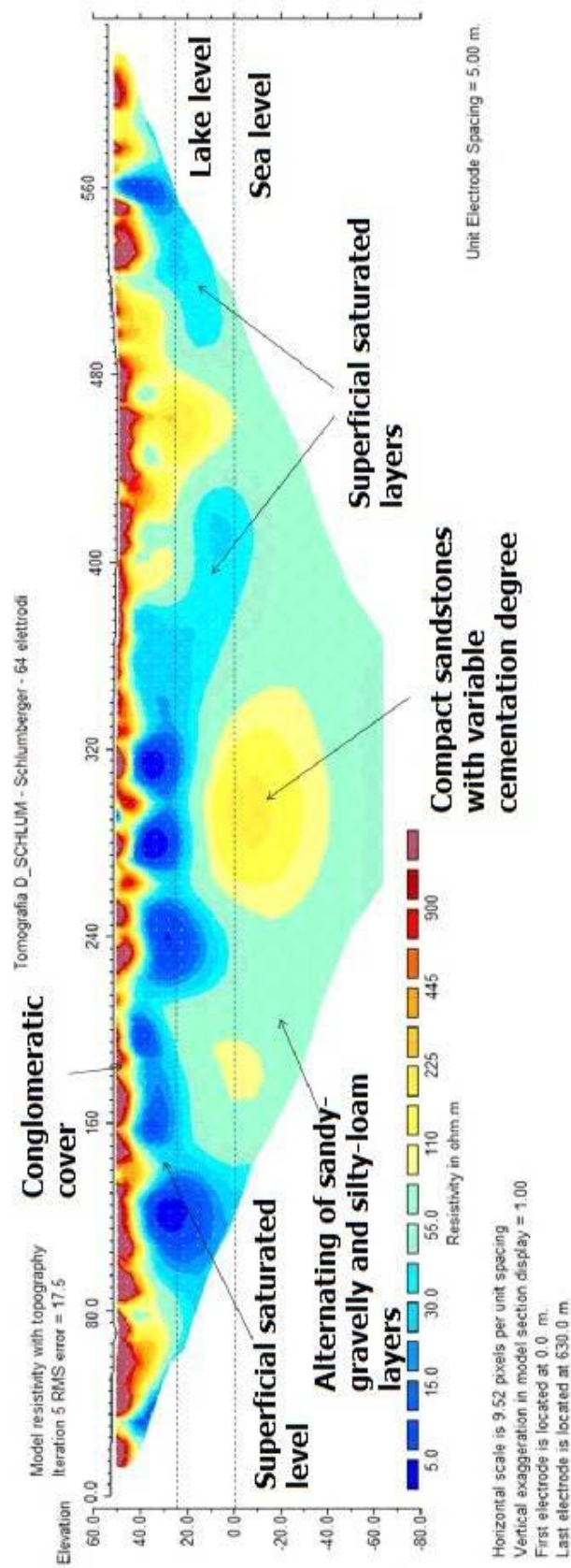


Figure 6.25 - Electrical tomography C_Schlum.

The D_SCHLUM tomography is located in the southern sector of the basin and, compared to previous geoelectrical line is located approximately 50 m to the east, which is useful to continue the investigation of this area of the basin.

The most superficial part is characterized by a level conglomeratic (PVM_{2a}) of constant thickness of 10-15 meters, with resistivity values greater than 500 Ω m. In a position below it is instead values less than 40 Ω m, as for the previous tomography: this is due to a level predominantly saturated, with good lateral continuity, interrupted only between the meters 400 and 510 of the relief, in which prevail values greater referable at one level comprising of pebbles, gravel and silty-loam (PID), (values respectively of 100-300 Ω m and 50-80 Ω m). These levels are also found below the superficial aquifer with thicknesses varying between 10 and 50 m.

The deepest part of tomography presents variable values between 100 and 500 Ω m: the most resistive portion, positioned at the center at a depth of 60-70 m, is attributable to sandstones with greater of cementation degree, with side gradual passages toward sandstones less cemented.

Also in this area were recognized boreholes: in particular at the 565 meters was found a drilled well (Figure 6.26). From the resistivity model in this passage we see a rising levels associated to the saturated thicknesses: it is not possible to determine if the well draws from the most superficial acquifer or from a deeper aquifer (this due to the location in the marginal area of tomography with relative limited depth of investigation).

Like the previous survey, this tomography is oriented West-East, and allows you to investigate the eastern sector of the basin. Again the general characteristics are significantly different compared to the results of the A_SCHLUM and B_SCHLUM reliefs made in the western sector. It is not ruled out a structural setting which isolates the coastal system by the external system.

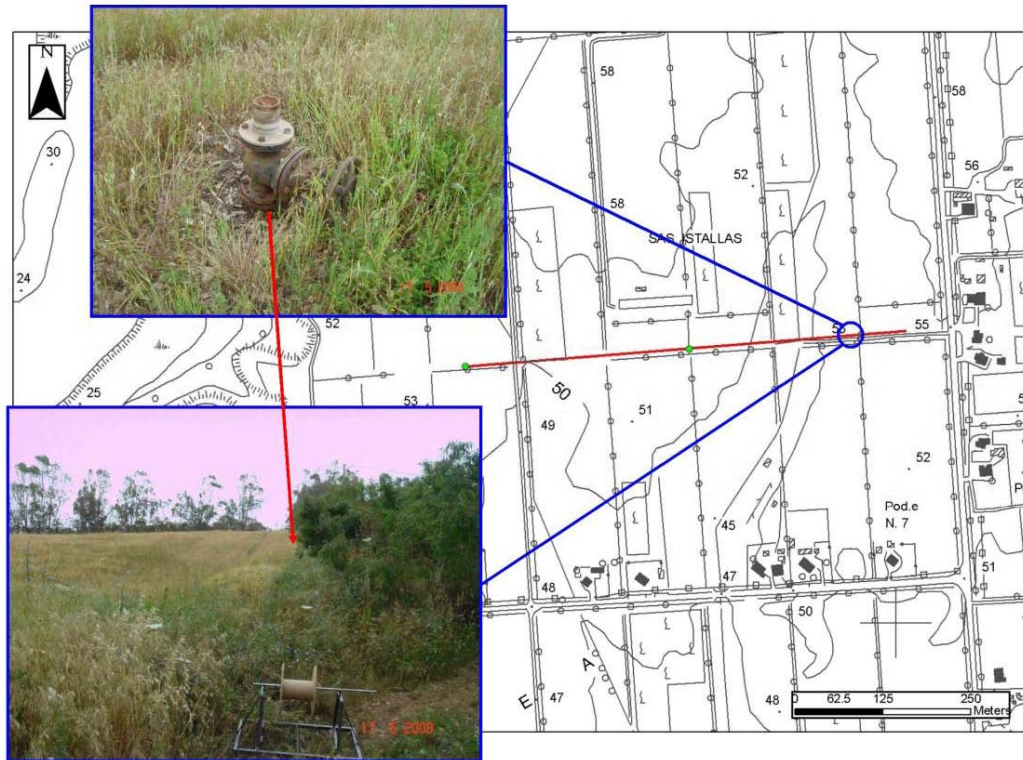


Figure 6.26 - Location of the well intercepted with the D_SCHLUM relief.

6.7 Thermal characterization of the site

The detailed geologic characterization of the site aims to provide thermal parameters necessary for the correct sizing of geothermal probes, because, depending on the range of values that we are going to estimate the length of the perforations will vary to a greater or lesser degree, affecting then on installation costs.

The definition of thermal values was divided respectively in indirect estimation of the thermal conductivity, heat capacity and thermal diffusivity; with these parameters was carried out the evaluation of the thermal yield of the soil.

6.7.1 Estimation of the thermal conductivity of the subsurface and processing of thermal conductivity map

The estimation of the thermal conductivity of the ground may be carried out through three different methods:

- using a valuation based on bibliographic data;
- by analytically estimating from the knowledge of the thermal properties of the constituents of rocks and deposits, and the water content;
- by a direct measurement, on site or in the laboratory.

On the one hand the characterization would require an investigation punctual that in principle should lead to build a four-dimensional function (spatial position and time) able to fully describe each thermal property of the subsoil and the probes; on the other hand, this practice is evidently impossible and is inevitably limited to a statistical analysis which leads to a subdivision in homogeneous areas, which may where appropriate be characterized by values of conductivity, heat capacity and density dependent on time and temperature.

In this case, according to information obtained through the geological survey, geoelectrical surveys and soil survey it has been possible to estimate the thermal conductivity of the superficial deposits and of the bedrock. This estimate was made using the formula of Kersten (Section 2.1 "Thermal conductivity") and using the coefficients in Table 2.1 and the density values indicated in Table 6.1.

As for the rest of the lithologies identified in the area the estimate was made of bibliographic data associating the lithology a thermal conductivity value from the table in "Attachment 2".

The estimates obtained (Table 6.8) have allowed the realization of a mapping of the study area, indicating the average thermal conductivity value (Figure 6.27). The coloring more "ignited" indicates the higher thermal conductivity.

Cartographic label	Lithology	Thermal conductivity estimated [W/mK]
b2	Eluvio-colluvial deposits	0,26
d	Aeolian deposits	0,80
e5	Marsh deposits	0,61
g2	Beach deposits	0,51
b	Recent alluvia deposits	0,53
PVM2a	Terraced alluvial deposits	1,30
PVM2b	Aeolian deposits	1,18
PID	Undifferentiated volcano-sedimentary succession of Nurra	2,25
FTE	Monte Forte Formation	3,54

Table 6.8 - Estimation of the thermal conductivity for the lithologies outcropping in the studied area.

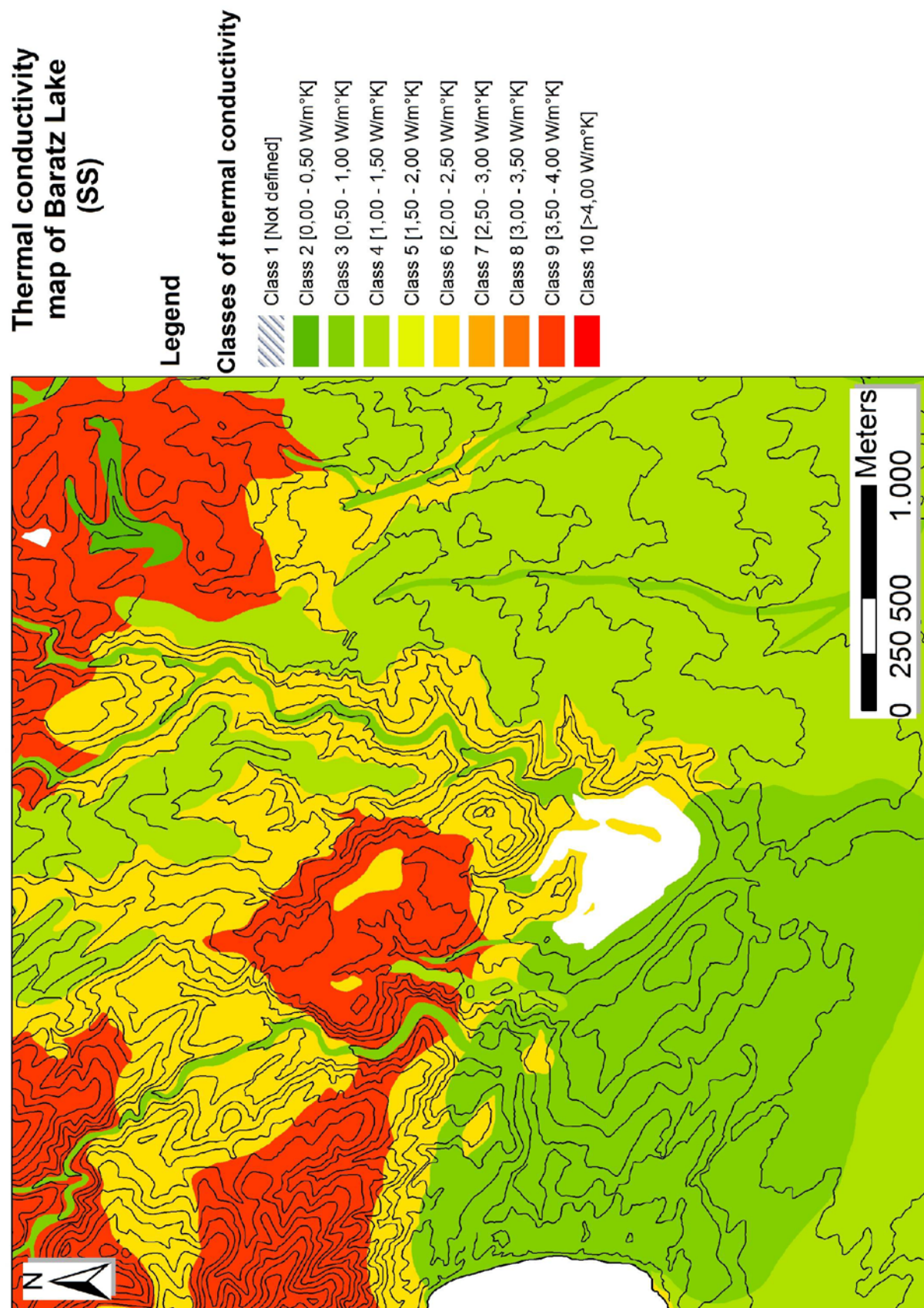


Figure 6.27 - Thermal conductivity map of the study area.

As reconstructed by synthesizing the survey work carried out in the study area, we can say that the strata, in the south-west of Baratz Lake, a first portion from ground level up to 25 meters deep is formed by holocenic aeolian deposits. Going down into the depths, between 25 and 50 meters, are present aeolian sands of Pleistocene age, locally cemented, then followed by 50 to 80 meters of Pleistocene alluvial deposits. The aquifer was detected at a depth of about 25/30 meters from ground level leading to saturation of the aeolian and/or alluvial deposits.

The southeastern part of the lake presents a first portion extending from ground level up to a maximum depth of 15 meters, and consists of holocenic aeolian deposits and Pleistocene alluvial deposits. Going down into the depths, between 15 and 70 meters, are presents alluvial deposits of Pleistocene age, followed, at more than 70 meters deep, by the bedrock which consists of the continental succession of Nurra or metamorphic basement of the Argentera Unit. The groundwater are detected at a depth of about 20/25 meters from ground level leading to saturation of the aeolian and/or flood deposits.

Then were estimated values of thermal conductivity of lithologies present in the study area (Table 6.9).

Lithology	Depth from ground level [m]	Thermal conductivity [W / mK]
Holocenic aeolian deposits	0 - 25	0,80
Pleistocenic aeolian deposits (water presence)	25 - 50	1,34
Pleistocenic alluvial deposits (saturated)	50 - 80	2,47
Beedrock (Continental succession of Nurra?)	80 - 120	2,82

Table 6.9 - Thermal conductivity of lithologies traversed by the geothermal heat pump system.

Whereas for each identified level, the thermal conductivity and thickness, can be calculate the weighted mean total which is equal to 1,86 W/mK.

6.7.2 *Estimation of the thermal capacity and thermal diffusivity of the ground*

The calculation of the volumetric thermal capacity [$\text{MJ}/\text{m}^3\text{K}$] has been obtained on the bibliographical basis.

The mean value obtained for the entire stratigraphic column, weighed for each thickness it is equal to $7,1 \cdot 10^6 \text{ MJ}/\text{m}^3\text{K}$. With the knowledge of both the thermal conductivity data (λ), and the thermal capacity data (C_s), it was possible to estimate the thermal diffusivity, making the ratio $D_t = \lambda/C_s$, which provided a value of $D_t = 2,6 \cdot 10^{-7} [\text{m}^2/\text{s}]$.

In Table 6.10 are summarized the geological- thermal parameters estimated for the study area.

Lithology	Depth from ground level [m]	Thickness of the layers [m]	Thermal conductivity [W/mK]	Thermal capacity [$\text{MJ}/\text{m}^3\text{K}$]	Thermal diffusivity [m^2/s]
Holocene aeolian deposits	0 - 25	25	0,80	$7,1 \cdot 10^6$	
Pleistocene aeolian deposits (water presence)	25 - 50	25	1,34	$7,1 \cdot 10^6$	
Pleistocene alluvial deposits (saturated)	50 - 80	30	2,47	$7,1 \cdot 10^6$	
Bedrock (Continental succession of Nurra?)	80 - 120	40	2,82	$7,1 \cdot 10^6$	
Weighted average	120 (tot. from ground level)	-	1,86	$7,1 \cdot 10^6$	$2,6 \cdot 10^{-7}$

Table 6.10 - Summary of estimated thermal data.

6.7.3 *Estimation of the thermal efficiency of the ground*

The calculation of the thermal efficiency of the land was made indirectly using the equation of Eskilson's infinite linear source (Delmastro & Noce, 2009) that occurs in the following forms:

$$q = \frac{T_{f1} - T_g}{Rb + \frac{\left[\ln \frac{4 \cdot \alpha \cdot t_1}{r_b^2} - \gamma \right]}{4 \cdot \pi \cdot \lambda}} \quad (\text{cooling mode})$$

$$q = \frac{T_g - T_{f2}}{Rb + \frac{\left[\ln \frac{4 \cdot \alpha \cdot t_2}{r_b^2} - \gamma \right]}{4 \cdot \pi \cdot \lambda}} \quad (\text{heating mode})$$

where:

- R_b : thermal resistance of the well $\left[\frac{K}{\left(\frac{W}{m} \right)} \right]$;
- T_g : temperature of the undisturbed ground [$^{\circ}\text{C}$] ;
- T_{f1} : mean temperature of the fluid expected (summer) [$^{\circ}\text{C}$] ;
- T_{f2} : mean temperature of the fluid expected (winter) [$^{\circ}\text{C}$] ;
- γ : Eulero's number [dimensionless] ;
- r_b : radius of the well planned [m] ;
- α : thermal diffusivity $\left[\frac{m^2}{\text{sec}} \right]$;
- t_1 : 1800 hours of operation of the system [s];
- t_2 : 2400 hours of operation of the system [s].

These parameters have been assigned the following values shown in Table 6.11, calculated on the basis of estimates made in previous paragraphs and on the data provided by the designer.

Parameter	Value
R_b [K/Wm]	0,1
T_g [°C]	14
T_{f1} [°C]	30
T_{f2} [°C]	0
γ [dimensionless]	0,5772
t_1 [s]	6480000
t_2 [s]	8640000
r_b [m]	0,075
α [m ² /s]	$2,6 \cdot 10^{-7}$

Table 6.11 - Parameters used for the calculation of the thermal yield of the ground.

At this point we were able to estimate the thermal efficiency of the ground (Table 6.12) both in winter and in summer, considering an operation of 1800 hours and 2400 hours.

	1800 operating hours	2400 operating hours
Cooling performance [W/m]	42,32	41,02
Heating performance [W/m]	36,93	35,89

Table 6.12 - Thermal yield of the ground for the project site.

7 Test of verification of procesing of the data of thermal conductivity from the stratigraphic information for the Arezzo Province

Being the objective of the thesis that of to be able to obtained from a detailed investigation than that obtained from an evaluation of the information available, it was decided to carry out an initial test using data available of the Geological Survey of the Tuscany Region for the Arezzo Province.

In the present chapter will be illustrated the main passages that allowed to elaborate a thermal conductivities map beginning from the stratigraphic information for the three depths of interest: 30, 60 and 100 meters.

This criteria allowed to check in before analysis if this approach could provide useful results to the objectives.

7.1 Input data

As previously mentioned for the development of the thermal conductivity maps have been used information obtained from the stratigraphy in the database "WEB_BDSRI_8.2". The tables presents are 37, and the information contained in them are described in Table 5.2.

Table	Description
App_Tab_Nomi	Tables designation
ARN_DEC_USI	Type of use of the well
Arn_per	Arno basin area (polygonal)
Arn_poz	Mapping location of all drilling in the Arno basin (punctual)
Arn_poz_Clip	Clip of Arn_poz
Bdsri	Reference table with the borehole code (punctual)
BDSRI_DEC_AFC	Derivation of the borehole
BDSRI_DEC_CPT	Description of the catchment type
BDSRI_DEC_CPZ	Description of the well field
BDSRI_DEC_FNT	Provenance of the information
BDSRI_DEC_ISL	Type of lifting system
BDSRI_DEC_MTR	Material of the lining tube
BDSRI_DEC_ORD	Absent
BDSRI_DEC_PPQ	Description the power of pump

BDSRI_DEC_SDP	Absent
BDSRI_DEC_SNO	Identification of the type of technical data
BDSRI_DEC_SPO	Probe type
BDSRI_DEC_STA	Status of the well activity
BDSRI_DEC_TDR	Type of derivation
BDSRI_DEC_TID	Type of hydropower
BDSRI_DEC_TMP	Measurement of the piezometric duration
BDSRI_DEC_TRP	Type of the well coating
BDSRI_DEC_TSC	Drilling mode
BDSRI_DEC_USO	Type of use
BDSRI_DEC_VAL	Technical data
BDSRI_LEGA_DB_GEO	Code and description of wells
BDSRI_LEGA_IDROGRAFO	Identificative code and description of wells
BDSRI_LEGA_PIEZ_OMBRONE	Identificative code and description of wells in the area of the Ombrone basin
BDSRI_LEGA_PIEZ_T_COSTA	Identificative code and description of wells along the Tyrrhenian coast
BDSRI_LEGA_PIEZ_T_NORD	Identificative code and description of wells in the area of north Tuscany
BDSRI_LEGA_POZZI_ARNO	Identificative code and description of wells of the Arno Basin area
BDSRI_LEGA_TUTTI	List of all the values in the tables BDSRI_LEGA_xxx previously described
BDSRI_TAB_AFC	Meters depth from the ground level
BDSRI_TAB_CPQ	Period in which it was made the piezometric measure
BDSRI_TAB_CPZ	Type of catchment
BDSRI_TAB_PIE	It contains the values of the piezometric recorded
BDSRI_TAB_PIV	Synthesizes with 1:1 relationship the derivation of the wells
BDSRI_TAB_STR	It contains a description of each lithological layer
BDSRI_TAB_VAL	Indication relating to technical derivations
Ciss	Areas of some Tuscan aquifers
CISS_BDSRI	Absent
CISS_DEC	Names of Aquifers

Table 7.1 - Description of the tables inside the WEB 8.2 BDSRI and BDSRI_TOSCANA database.

In this database are present data relatives to 12566 wells characterized by depth of a few meters to over 600. Many of the tables in "WEB_BDSRI_8.2" not contain information relevant to the implementation of the thermal conductivity map of the Arezzo Province. The only tables that contain useful information for the achievement of our objectives are:

- "bdsri"
- "BDSRI_TAB_STR"

The relationships between these tables are shown in Figure 7.1.

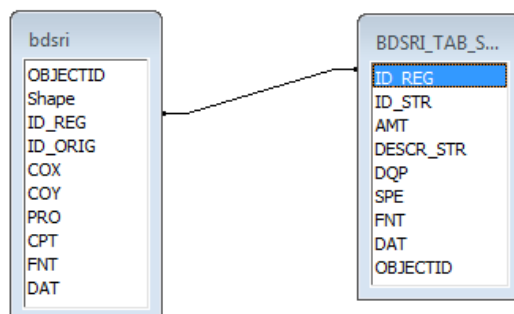


Figure 7.1 - Relationship between the "bdsri" table and "BDSRI_TAB_STR" table.

In the table "bdsri" there are 185674 records each of which contains information about a wells, although only 12566 of these have stratigraphic information. The table structure is shown in Table 7.2.

Field	Type	Description
id_reg	Bigint	Unique Regional identifier
id_orig	Character varying (254)	ID database source
coord_x	Double precision	Coordinate x (Gauss Boaga, Monte Mario 32 N)
coord_y	Double precision	Coordinate y (Gauss Boaga, Monte Mario 32 N)
prov	Character varying (254)	Province in which falls the derivation
cpt	Integer	Type of catchment Dec.: bdsri_dec_captazione
fonte	Integer	Source of data origin Dec.: bdsri_dec_fonte
data	Date	Date of release of the data

Table 7.2 - Fields description of the "bdsri" table.

It is related with the "BDSRI_STR" table with 1:M cardinality through the primary key "id_reg". The latter contains 63739 records, each of which identifies a layer and is characterized by a unique value of the field "ID_STRAT". The description of the fields of the table "BDSRI_STR" is shown in Table 7.3.

Field	Type	Description
id_reg	Bigint	Unique Regional identifier
id_stratig	Integer	Progressive ascending order within the stratigraphy of a single derivation
amt	Double precision	Meters depth from the ground level
descrizione	Character (254)	Description of the stratigraphy
da_qpc	Double precision	Distance in meters from the altitude above the sea level
spessore	Double precision	Layer thickness in meters
fonte	Integer	Source of data origin Dec.: bdsri_dec_fonte
objectid	Bigint	Progressive number necessary for Personal Geodatabase ESRI
data	Date	Progressive necessary for

Table 7.3 - Fields description of the "BDSRI_STR" table.

7.2 Realization of the tables used for the calculation of the thermal conductivity

In this paragraph are described the phases of construction of the tables that will subsequently be used for the calculation of the mean thermal conductivity of the stratigraphy contained in the database "WEB_BDSRI_8.2". In particular, wanting to realized three maps of the thermal conductivity characterized by different depths of interest of respectively 30, 60 and 100 meters, are realized 3 tables named:

- "Tab_0_30"
- "Tab_0_60"
- "Tab_0_100"

Initially was exported the BDSRI_TAB_STR table containing 63739 records and has been saved in the table "Dati_input". Later, have been standardized the descriptions of each lithological layer which constitutes a stratigraphy following the geotechnical terminology. To do this have been preserved descriptions only purely lithological, omitting specifications such as: color, shades, deposition zone, and so on. Being a database implemented by different operators, at different times there has been some inconsistency in the lithological classification, which is why it was necessary, standardize all lithological descriptions. Below is reported an example of

the change (Table 8.1). In the column "Description_layers" is preset the original description while the column "Thermal lithotype" show the changed description.

ID_REG	ID_STR	AMT	Description_layers	Thermal lithotype
21001423	1	3,90	Vegetable soil	Peat
21001423	2	6,50	Ash-gray compact clay	Clay
21001423	3	11,40	Dirty medium gravel	Gravel
21001423	4	13,50	Dark gray compact clay	Clay
21001423	5	17,80	Yellowish sandy-clay	Sandy-clay
21001423	6	25,10	Medium size gravel and sand with clay layers	Gravel and sand with clay
21001423	7	29,30	Yellowish compact clay	Clay
21001423	8	31,80	Medium size pebbles and gravel	Gravel
21001423	9	35,30	Yellowish clay mixed with gravel	Clay with gravel
21001423	10	38,80	Yellowish compact clay	Clay
21001423	11	43,80	Medium and coarse gravel, gravel and sand	Gravel and sand
21001423	12	44,70	Yellowish compact clay	Clay
21001423	13	47,60	Dark gray compact clay	Clay
21001423	3	11,40	Dirty medium gravel	Gravel

Table 8.4 - Example of information nomenclature.

To the aims of the calculation of the thermal conductivity of each stratigraphy, it was considered appropriate to add two fields to the table "Dati_input":

- "Tetto";
- "Base".

To derive the value in the "Tetto" have been copied by value of the "AMT" shifted of one row down. It was assigned the value "0" to all the top layers of the wells. In order To go back to the correct values in the "Base" were copied the values of the field AMT. In Figure 8.1 is shown as an example the survey with "id_reg" 10000145.

	A	B	C	D	E	L	M
1	ID_REG	ID_STR	AMT	DESCR_STR	Litotipo termico	Tetto	Base
2	10000145	1	2,00	Limi Sabbiosi	Limo Sabbioso	0	2,00
3	10000145	2	12,00	Argilla	Argilla	2,00	12,00
4	10000145	3	20,00	Argilla Limosa	Argilla Limosa	12,00	20,00
5	10000145	4	24,00	Argilla	Argilla	20,00	24,00
6	10000145	5	42,00	Argilla	Argilla	24,00	42,00
7	10000145	6	46,00	Argilla Limoso Sabbiosa	Argilla Limosa-Sabbiosa	42,00	46,00
8	10000145	7	47,00	Limi Argillosi	Limo Argilloso	46,00	47,00
9	10000145	8	50,00	Argilla Limosa	Argilla Limosa	47,00	50,00
10	10000145	9	51,00	Ghiaia, Ciottolami con Salsi	Ghiaia con Sabbia	50,00	51,00
11	10000145	10	52,00	Argilla	Argilla	51,00	52,00
12	10000145	11	53,00	Sabbia	Sabbia	52,00	53,00
13	10000145	12	54,00	Argilla Limosa	Argilla Limosa	53,00	54,00
14	10000145	13	59,00	Argilla	Argilla	54,00	59,00
15	10000145	14	60,00	Sabbia	Sabbia	59,00	60,00
16	10000145	15	62,00	Argilla	Argilla	60,00	62,00
17	10000145	16	68,00	Argilla Limosa	Argilla Limosa	62,00	68,00
18	10000145	17	69,00	Argilla	Argilla	68,00	69,00
19	10000145	18	70,00	Brecce e Ciottolami	Ghiaia	69,00	70,00
20	10000145	19	74,00	Argilla	Argilla	70,00	74,00
21	10000145	20	87,00	Argilla Limosa	Argilla Limosa	74,00	87,00

Figure 8.2 - Operation to get the value of the fields "Tetto" and "Base".

Subsequently, although present in the database, was obtained the field thickness (m) of each layer. The new field is called "Spessore_calcolato" and its value has been calculated using the "FIELD CALCULATOR" ArcGIS®, setting the following formula:

$$\text{"Spessore_calcolato"} = \text{"Base"} - \text{"Tetto"}$$

The field "Spessore" and "Spessore_calcolato" are different. After a review, it was noted that the field "Spessore" contained negative values, and incorrect values. The presence of such errors is due, in the first case to typing errors in the second case failure to take account of the decimals of the field "AMT". In order not to eliminate the stratigraphy containing at least one of the layers with a thickness wrong, it was necessary to control them one by one. First, the stratigraphy presenting thicknesses <0 and that developed for a depth less than 30 m have been eliminated regardless of the possibility of their correction, as not useful for the achievement of the end. In the case of stratigraphy that reached depths > 30 m has been identified the error and, subsequently corrected case by case.

Unfortunately, in some cases (especially for stratigraphy that have more than one layer thick negative) it was not possible to identify the error, and we proceeded to eliminate them.

From the table "Dati_input" were created only 3 tables by exporting the records characterized by minimum values of the field "Base" of the last layer under 30 in "Tab_0_30"; "60" in "Tab_0_60" and "100" in "Tab_0_100" as shown in Table 8.2.

Table name	Minimum values of the "Tetto" field in the last layer	Total records
Tab_0_30	30	47784
Tab_0_60	60	24606
Tab_0_100	100	7487

Table 8.5 - Tables of depth and relatives records.

In this way they are eliminated all stratigraphy that do not reach the desired depth. Wanting to be considered in the calculation of the thermal conductivity only in the of the layers present in the thickness of interest it was necessary to removed from the three tables the layers that developed throughout its thickness over the depth of interest, or those who had records to the "Tetto" higher values or equal to:

- "30", for the Table "Tab_0_30";
- "60", for the Table "Tab_0_60";
- "100", for the Table "Tab_0_100".

For example, considering the table "Tab_0_30", deleting records with the "Tetto" values ≥ 30 led to the cancellation of all those layers that develop entirely below the 30 m deep (D layer in Figure 8.2a). In these tables, however, are still present the layers which develop in part above and in part below 30 m, or those records that have "Tetto" < 30 and "Base" > 30 (layer C in Figure 8.2a). Entering the value "30" in to the field "Base" of such records it was possible to obtain stratigraphy as in Figure 8.2b, which give information only up to 30m depth without having any loss of information.

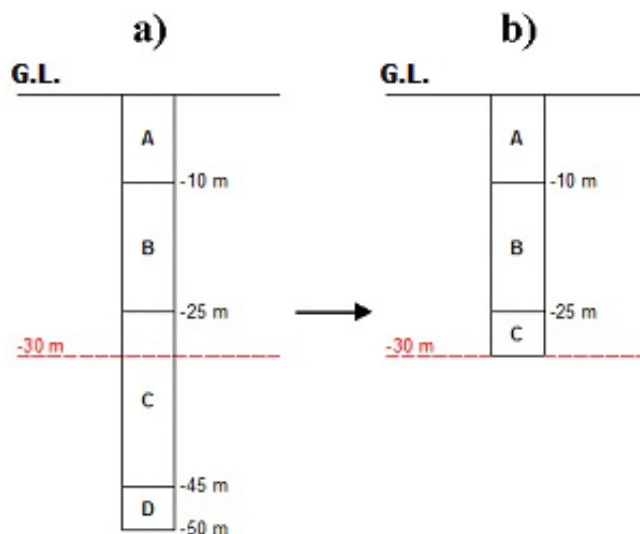


Figure 8.3 - a) Example of a stratigraphy with a layer which extends entirely below the 30 m depth (D layer), and one that develops only partially under at such a depth (layer C). b) Stratigraphy obtained by removing the D layer and modifying the base of layer C (from Del Ciondolo, 2010).

The same was done for table records "Tab_0_60" and "Tab_0_100" but considering the deep interest respectively of 60 and 100 m. Changing these values has made it necessary to recalculate the values of the field "Spessore_calcolato" via the "FIELD CALCULATOR" for all three tables, using the following formula:

$$\text{"Spessore_calcolato"} = \text{"Base"} - \text{"Tetto"}$$

After eliminating these layers, the three tables had total (Table 5.15):

Table name	Minimum values of the "Tetto" field in the last layer	Total records
Tab_o_30	30	29741
Tab_0_60	60	18629
Tab_0_100	100	5911

Table 8.6 - Tables of depth and relatives records.

At this point it was necessary to determine the procedure to follow in order to develop a "significant" cartography. It was decided to calculate the thermal conductivity of each layer considering the bibliographical values, table in "Attachment

2", which not contained indications of water content, since the data concerning the percentage of water of the area considered, were insufficient.

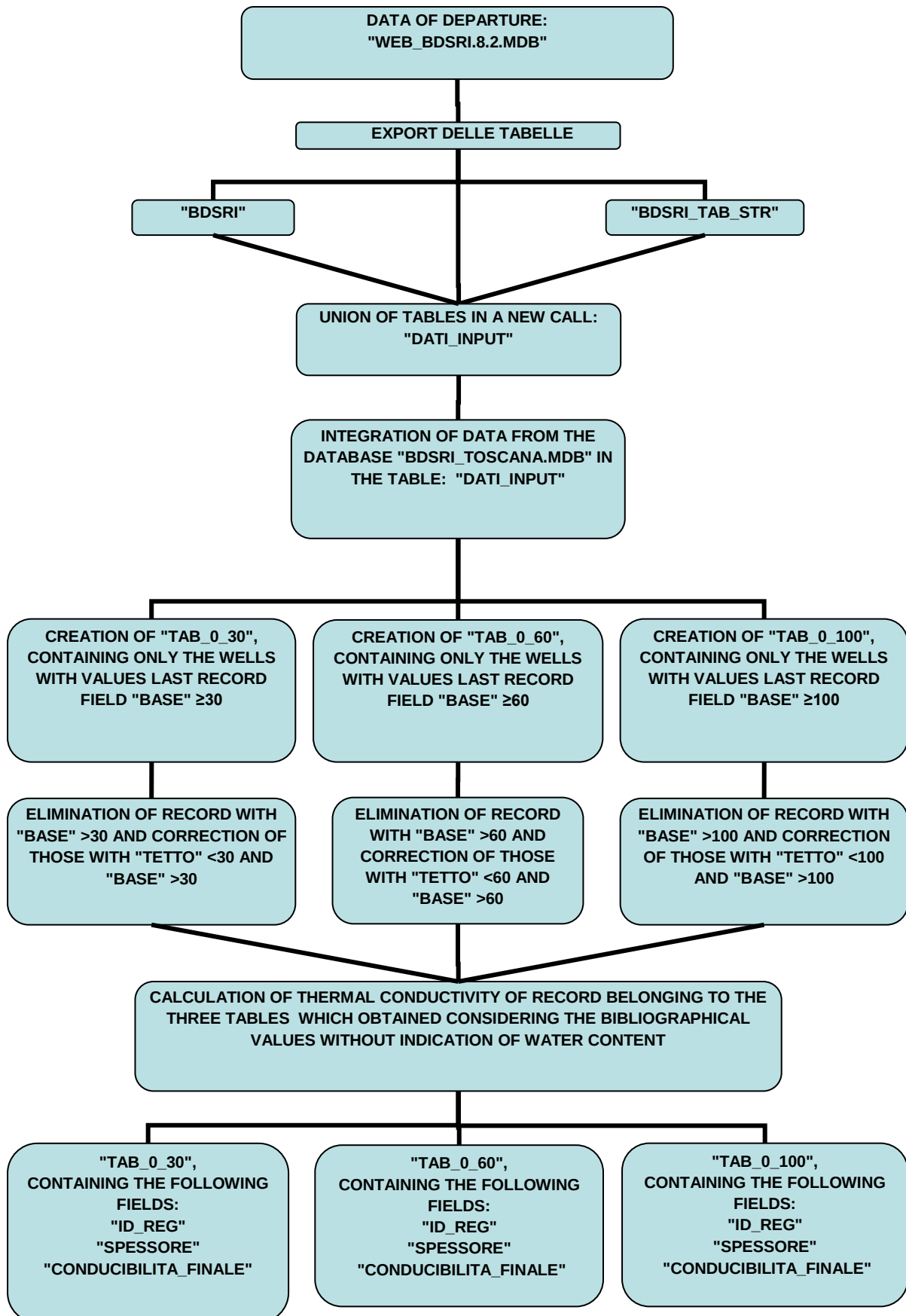
As shown in Table 5:16 has been attributed to the layers a thermal conductivity according to the lithology, in the case where it is not present the value of thermal conductivity Bibliographic has been assigned the value "-9999".

Id_reg	Id_str	"Litotipo_termico"	"Tetto"	"Base"	"Spessore"	Thermal conductivity (W / mK)
10034817	1	Sandstone	0,00	32,00	1,00	2,71
10034817	2	Siltstone	32,00	39,00	2,00	1,95
10034817	3	Marlstone	39,00	54,00	25,00	2,49
10034817	4	Sandstone	54,00	75,00	2,00	2,71
10034817	5	Sandstone and marlstone	75,00	100,00	45,00	2,60

Table 8.7 - Input data of the stratigraphy with "id_reg" equal to 10034817 used for the calculation of the thermal conductivity.

Below is reported a flow chart which summarized the main steps taken towards attaining the final datum, indispensable for the statistical processing illustrated in the next paragraph.

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7.3 Calculation of the thermal conductivity of the Arezzo Province

After to have realized the tables "Tab_0_30", "Tab_0_60" and "Tab_0_100" through the procedures described in the paragraph precedence, it has been necessary to calculate for every wells the weighed thermal conductivity, calculated considering the contribution that every layer, of a determined stratigraphy, supplies in terms of thermal conductivity. In order to carry out this calculation it is necessary to know the thickness of every layer, the value of thermal conductivity attributed to everyone of they and the field "id_reg" (Primary Key). In order to calculate the weighed thermal conductivity of every stratigraphy it was realized a software called "geotermia_RER_per_PESO_v18", in the programming language of "Fortran 95". This software carries out in automatic rifle the following operations:

- calculation of the total length of each stratigraphy adding the thickness of all the layers of the same value to the field "id_reg";
- calculation of the weighing thermal conductivity for each stratigraphy, by summing the contributions of each layer, obtained by multiplying the value of thermal conductivity to the layer attributed to the relationship between, the layer thickness and the total length of the stratigraphy.

After to have executed for all stratigraphy in table the calculations as soon as described, the software gives back output data like .txt formed from two columns: "id_reg" and "med_conduc". The first shows the "id_reg" identification of the stratigraphy and in the second the value of thermal conductivity calculated.

The thermal conductivities values calculated from the software, through the ArcGis® program, are correlated to punctual shapefile "BDSRI" of database "WEB_BDSRI_8.2" and to shapefile "BDSRI" of database "BDSRI_TOSCANA" which containing the coordinates of the surveys. Were realized for each interest depths three different shapefile:

- "Tab_0_30_coordinate"
- "Tab_0_60_coordinate"
- "Tab_0_100_coordinate"

7.4 Processing using geostatistics software ISATIS®

"The geostatistic offers with of determinist instruments and statistical faces to the understanding and modeling of the spatial variability"; so, it would be opportune to rerun to such discipline in all those situations for which the spatial continuity of the phenomenon under investigation is considered the main aspect, or at least one of the main ones. The literature often refers to the geostatistica like to the theory of the "variable ones regionalized", that is given that they turn out spatially distributed and spatially structured. It was Matheron, in 1963, to introduce for first this term, in order to bring to light the two main aspects that characterize this type of data: on one side, "the accidental" aspect, that it realizes of the spatial variability on small scales and of eventual local irregularities; from the other, an aspect more "structured", that it realizes of the variability on large-scale and can evidence the presence of tendencies, like trend and/or details directionality of the phenomenon. Regarding the traditional statistical approach, the geostatistica offers the possibility of dealing at the same time both contrasting aspects; moreover it supplies the adequate instruments in order to manage the intrinsic characteristics of this type of data, than which can some complicate in sensitive way the treatment:

- generally you have access to a unique achievement of the phenomenon for each location sampled;
- the spatial data can not be considered independent of each other and extracts from the same probability distribution.

The geostatistic is based on the traditional spatial correlation based on a "two-point" statistics; however, lately are developing approaches that consider a statistic to more than two points and approaches related to the Bayesian theory of maximum entropy. First of all it is necessary to have a tool suitable to recognize, describe and possibly model the variability of the data; among all the analytical measurements of the correlation/spatial continuity available nowadays, the traditional and historically most used is the variogram $\gamma(h)$, that from the physical point of view describes, varying the h distance, as two measures are among their uncorrelated. Once in possession of an analytical model for the spatial correlation, this will be implemented

in according to the instrument an action to the estimation/prediction of the variable of interest in localizations that are not sampled. Limiting itself however to the linear models, the geostatistics has developed to an entire family of estimators, called in jargon "Kriging", that belong to the BLUE (p) estimators - Best Linear Unbiased Estimators/Predictors, where "Best" indicates that the estimator is chosen so as to diminish the variance of the esteem, "Linear" that draft of linear models, "Unbiased" that, in the sense of the "expectation value", is not affection from systematic errors. The weights that the procedure of kriging assigns to the measures employed in the esteem are determined to the aim to consider in explicit way the local spatial distribution of the same measures around the esteem point; moreover they are influenced by the analytical model of variogram chosen in the first phase of the study on the base of the analysis of the samplings available.

7.4.1 Processing

Found a good spatial distribution of the data in the Arezzo Province it has been passed to the effective geostatistical elaboration of the data. The first step has been that to analyze the data from a purely statistical point of view.

VARIABLE	Count	Minimum	Maximum	Mean	Std.Dev.	Variance
MED_CODUC	4212	1.03	4.28	1.97	0.56	0.31

Table 8.8 - Main parameters of statistical data in the dataset TAB_0_30.

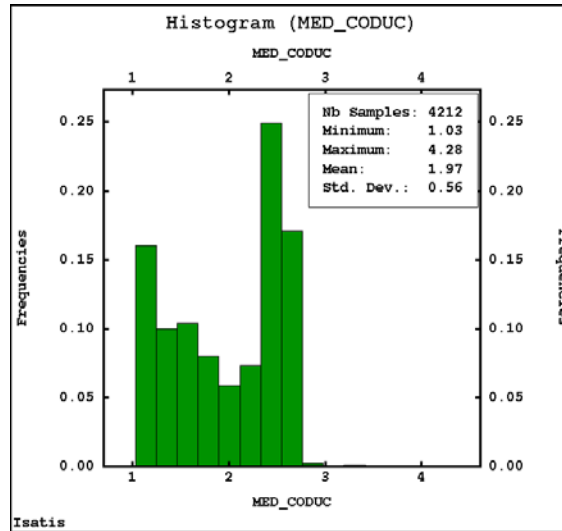


Figure 8.4 - Frequency histogram data of the dataset TAB_0_30.

VARIABLE	Count	Minimum	Maximum	Mean	Std.Dev.	Variance
MED_CODUC	2342	1.03	4.93	2.15	0.53	0.28

Table 8.9 - Main parameters of statistical data in the dataset TAB_0_60.

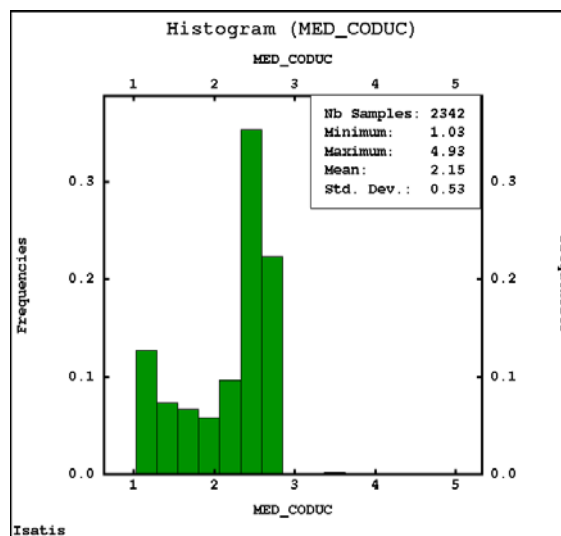


Figure 8.5 - Frequency histogram data of the dataset TAB_0_60.

VARIABLE	Count	Minimum	Maximum	Mean	Std.Dev.	Variance
MED_CODUC	548	1.03	3.40	2.29	0,46	0.21

Table 8.10 - Main parameters of statistical data in the dataset TAB_0_100.

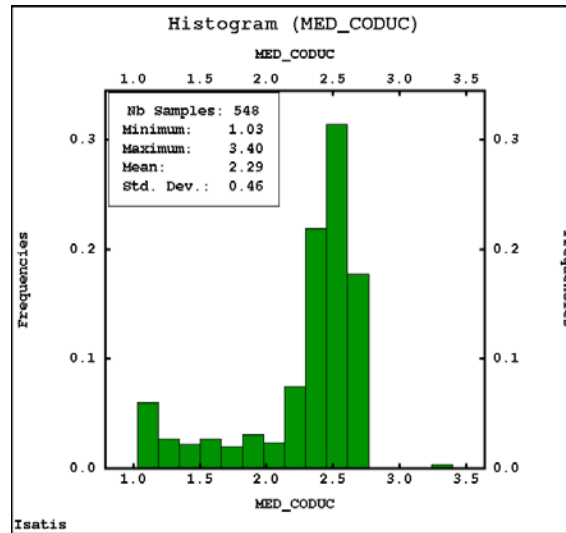


Figure 8.6 - Frequency histogram data of the dataset TAB_0_100.

Following have been created different variograms for each distribution, for each of them was chosen the curve which best could fit the distribution of data. To choose the best combination was performed cross validation, which allows us to compare the interpolated values to the actual values, was therefore selected the model that produced more accurate predictions, as shown in Figure 8.6, Figure 8.7, Figure 8.8, Figure 8.9, Figure 8.10 and Figure 8.11.

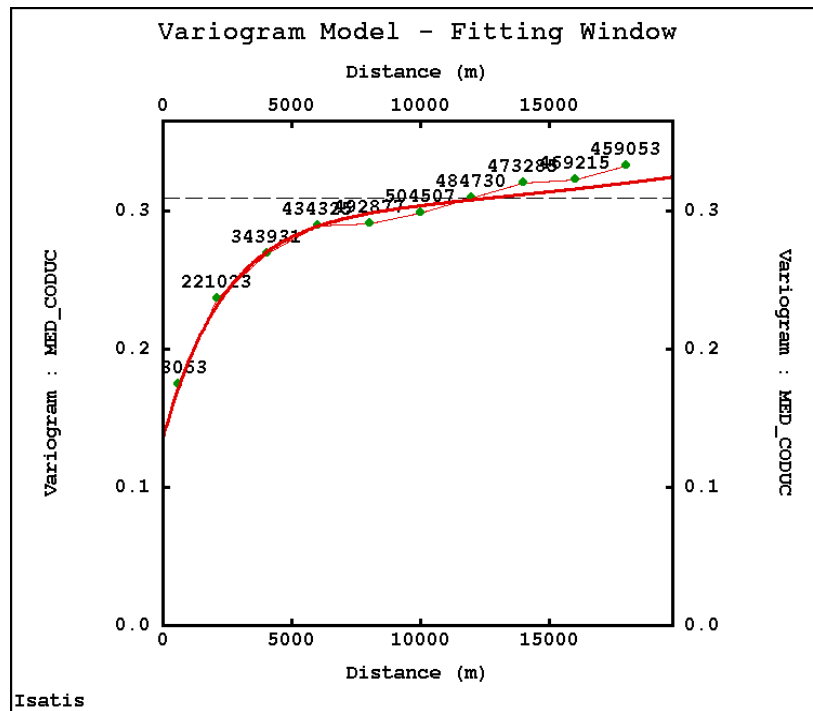


Figure 8.7 - Variogram data of the dataset TAB_0_30.

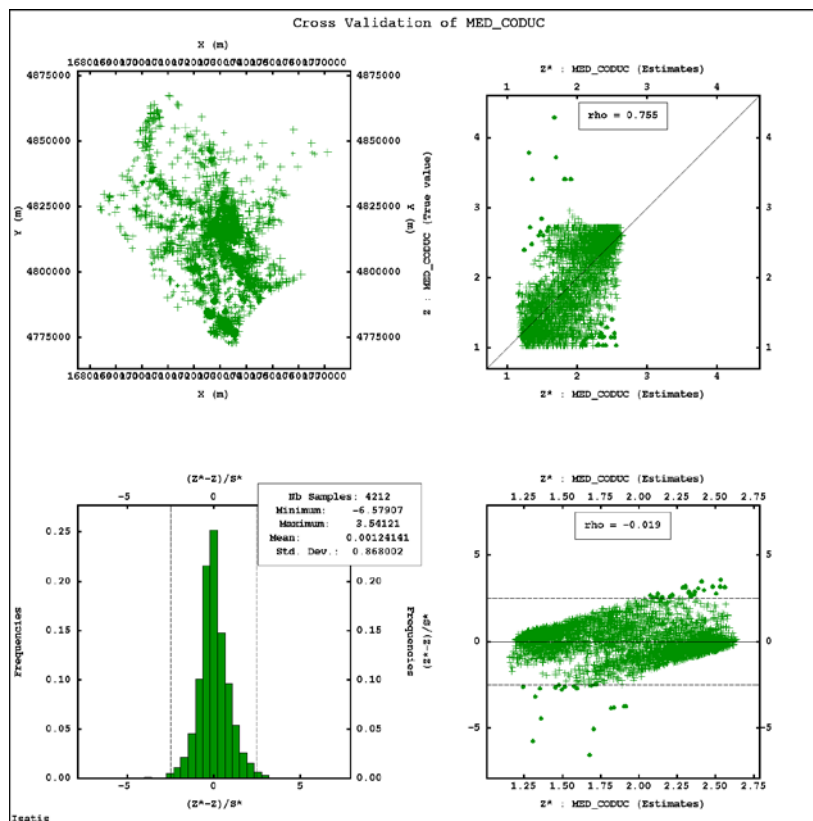


Figure 8.8 - Cross validation variogram of the dataset TAB_0_30.

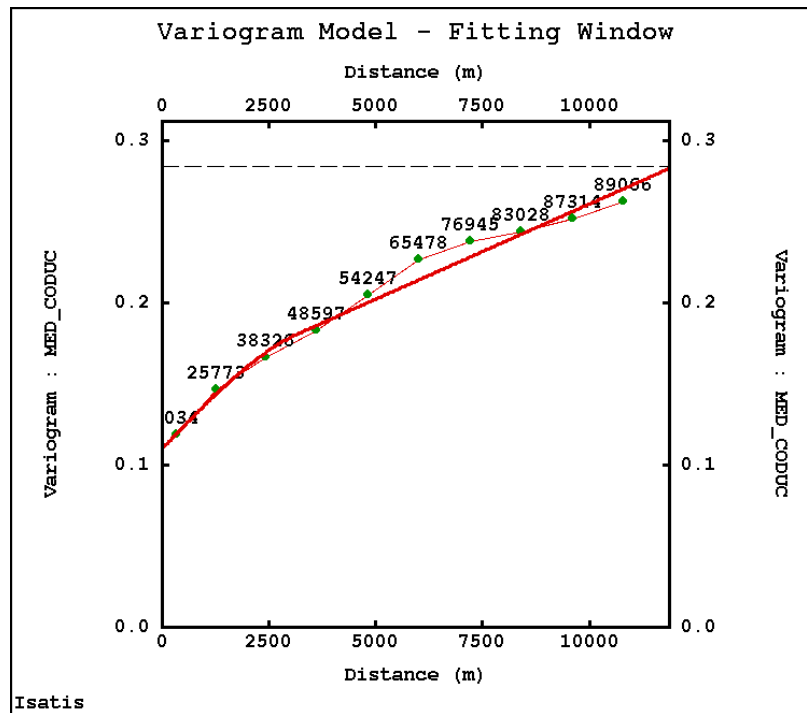


Figure 8.9 - Variogram data of the dataset TAB_0_60.

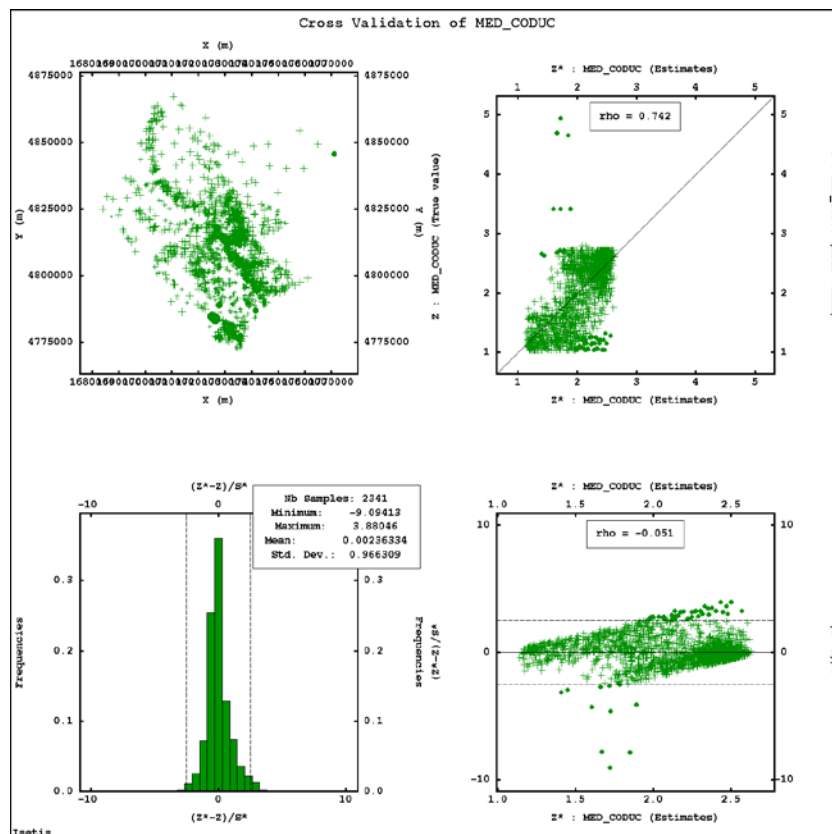


Figure 8.10 - Cross validation variogram of the dataset TAB_0_60.

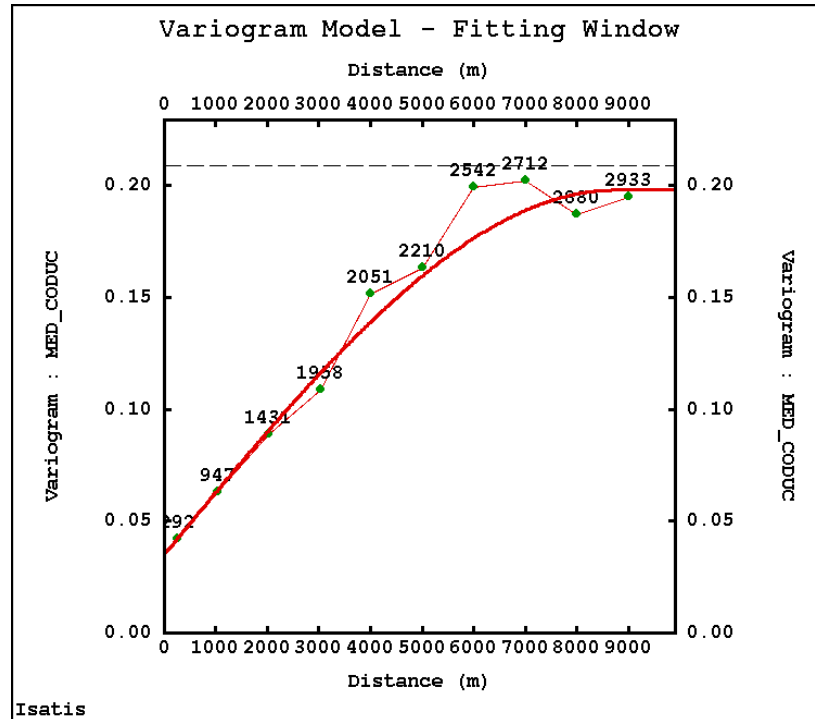


Figure 8.11 - Variogram data of the dataset TAB_0_100.

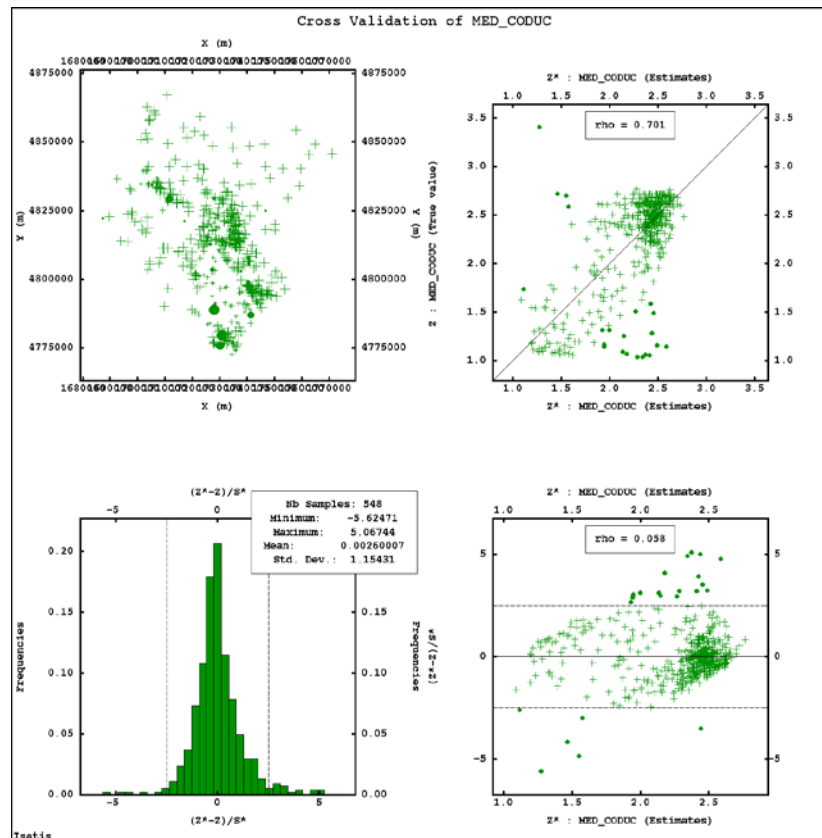


Figure 8.12 - Cross validation variogram of the dataset TAB_0_100.

The objective of the previous passages has been essentially of descriptive type. At this point are not interested to describe the champions of the datasets under investigation, but it is important to understand like estimating the values of the thermal conductivity in the sampled zones not respecting the statistics and geostatistics description. To such fine the Ordinary Kriging interpolator (OK) has been chosen, because, being a interpolator stocastic, holds in consideration the chance variations of variable of data (thermal conductivity), supplying also an esteem of the amount of potential error of the output.

For being able to elaborate an interpolated map, it has been necessary to construct a grill. The chosen step for it has been of 100 meters, as a good compromise between the medium distance of the data and the cells of the map is considered reclassified (step of 10 meters) with which it will be confronted. Through program ISATIS® the procedure is executed in order to create the interpolated map of the esteem of the thermal conductivities of the Arezzo Province to the depths of 30, 60 and 100 meters (respectively Figure 8.12, Figure 8.13 and Figure 8.14) and maps of the relative errors (respectively Figure 8.15, Figure 8.16 and Figure 8.17).

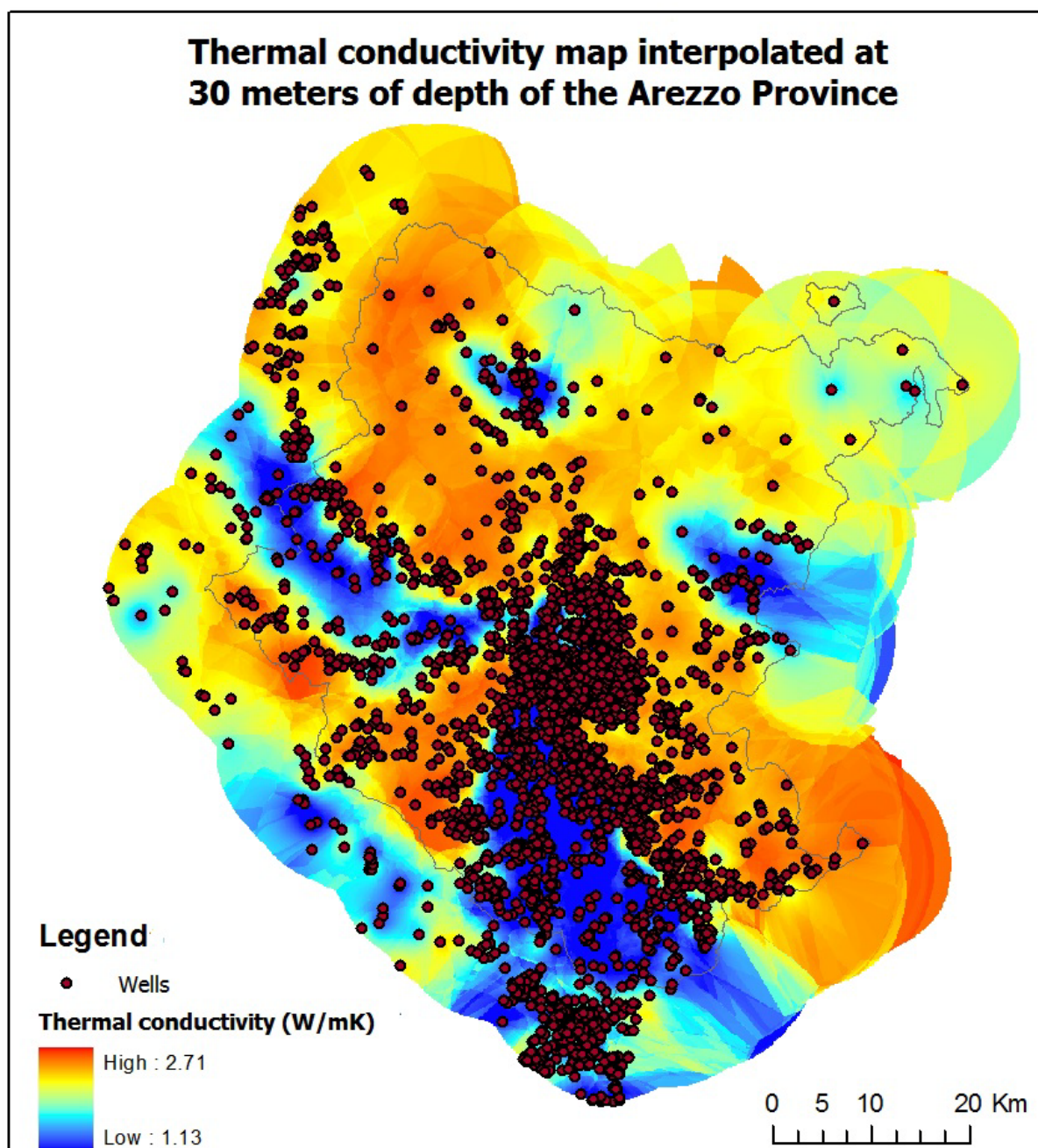


Figure 8.13 - Thermal conductivity map interpolated at 30 meters of depth of the Arezzo Province.

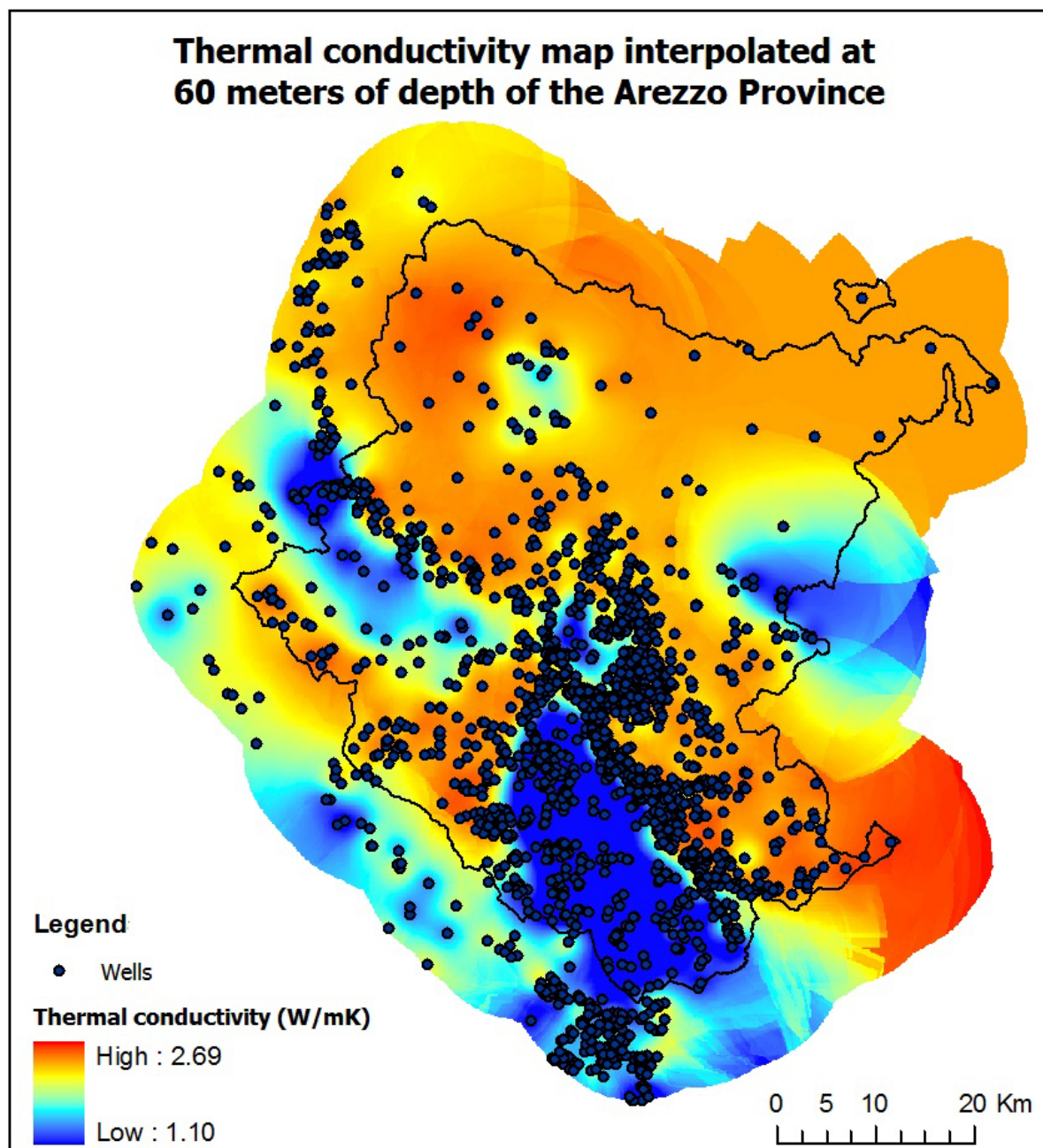


Figure 8.14 - Thermal conductivity map interpolated at 60 meters of depth of the Arezzo Province.

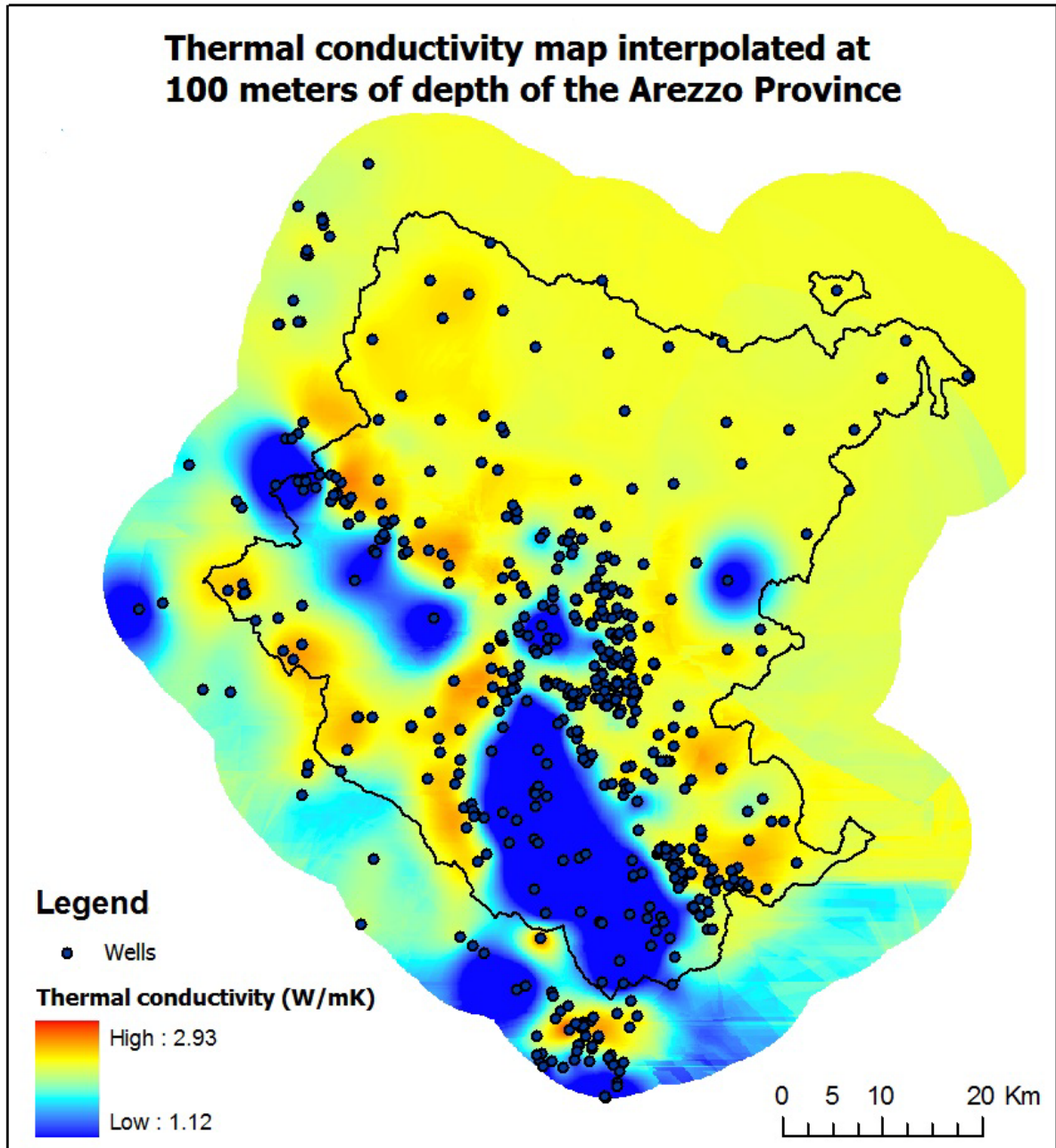


Figure 8.15 - Thermal conductivity map interpolated at 100 meters of depth of the Arezzo Province.

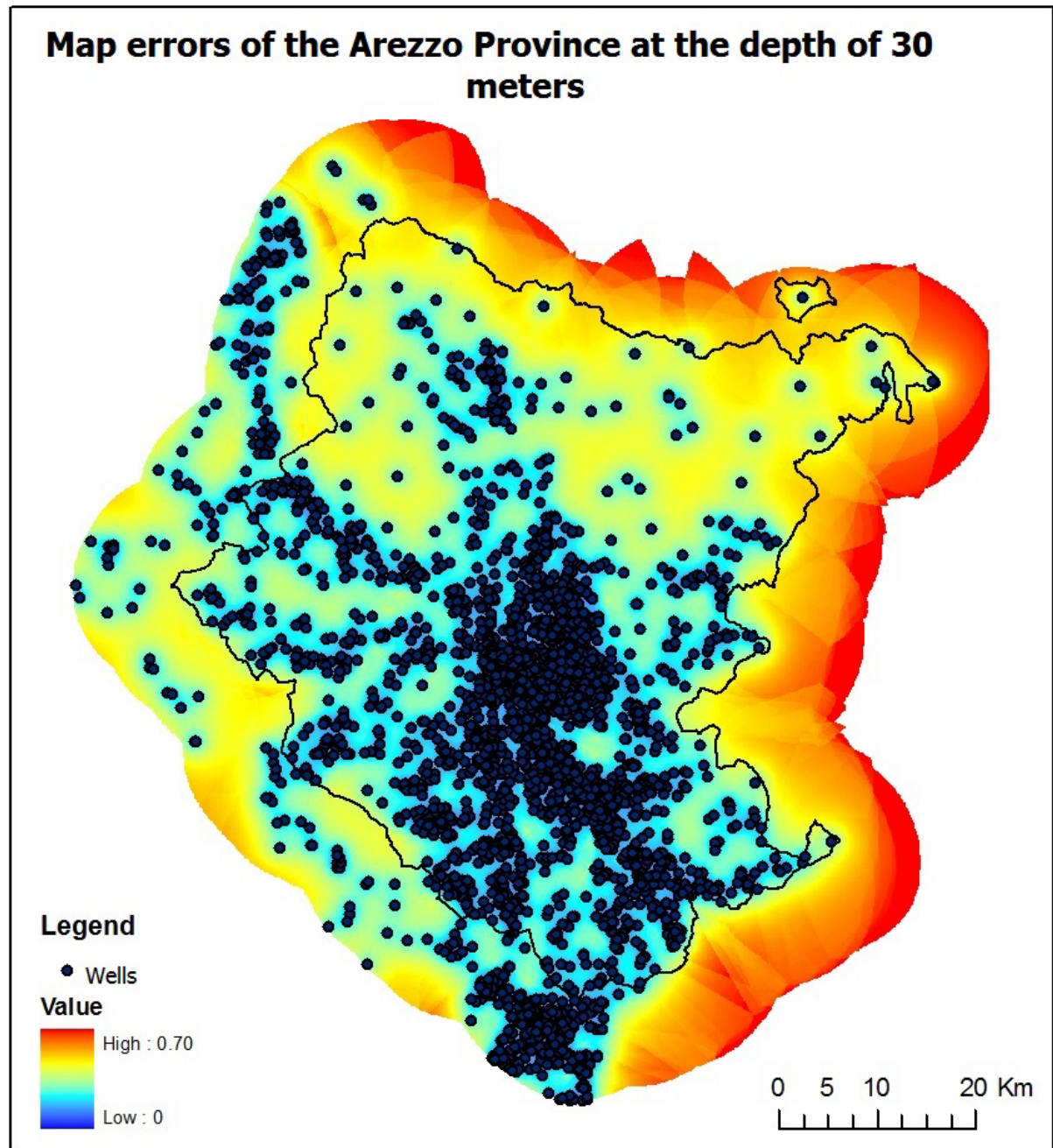


Figure 8.16 - Map errors of the Arezzo Province at the depth of 30 meters.

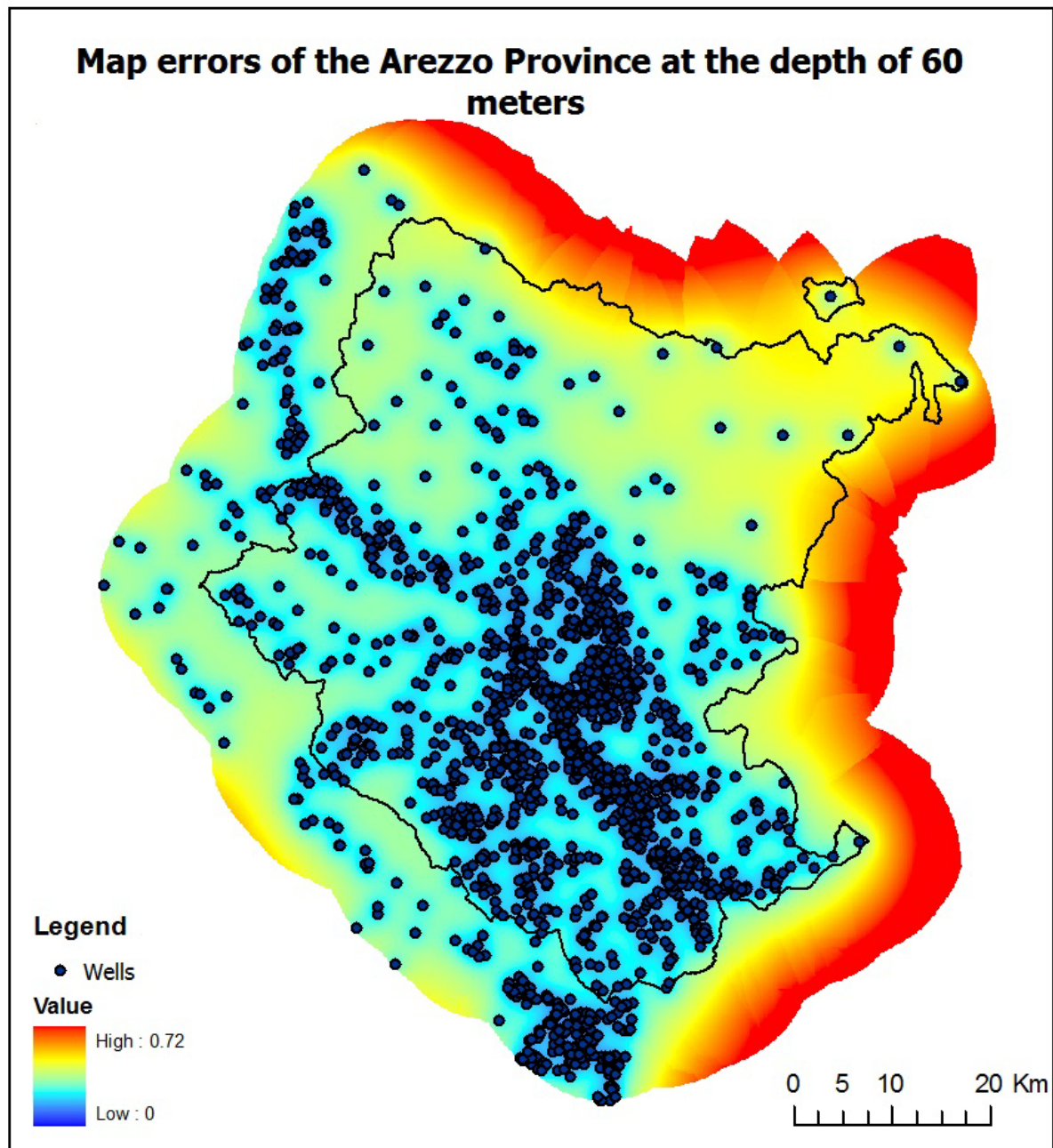


Figure 8.17 - Map errors of the Arezzo Province at the depth of 60 meters.

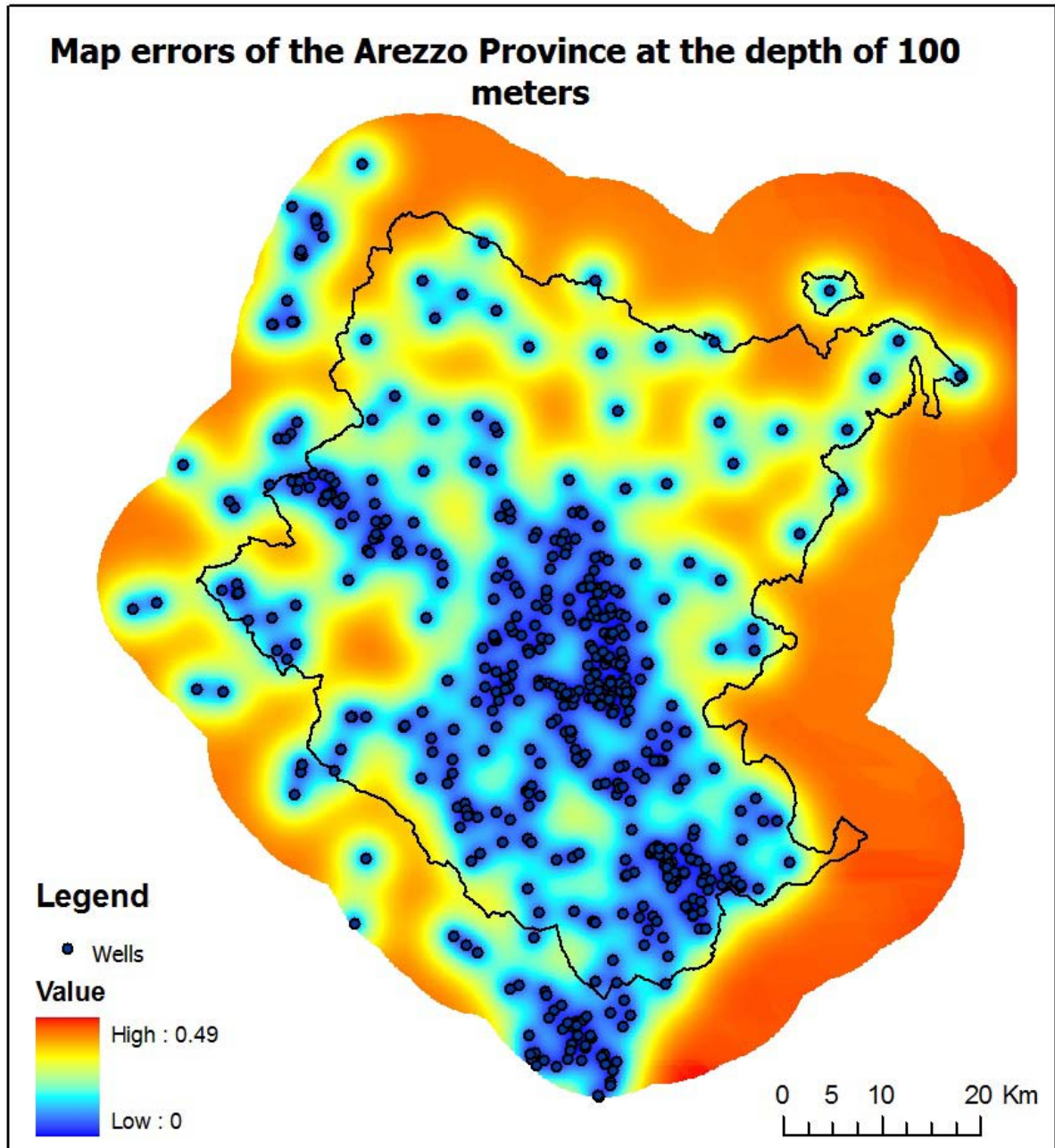


Figure 8.18 - Map errors of the Arezzo Province at the depth of 100 meters.

8 Procedural Iter and criteria of address in sensitive sites

The study of the international and national norms that make reference to the geoechange systems sure represents an important reference for the drafting up of a proposal of procedural iter. This obviously, cannot prescind from the acquaintances of the specification of the various configurations that, own for their different properties, afford to characterize the various procedures.

In this paragraph, it shows the synthesis of a possible procedural initially defining the parts that come into play in the process of construction of a plant. Follow some specifications related to the criteria to be applied in sensitive areas, for the study and control of a thermal point of view, of a site potentially suitable for installation of a plant.

In the first place define the parts that enter in cause in the realization of a system:

- The **private** (the single individual or society), that it wants to realize a geothermal system, closed cycle or open cycle, of small or great dimensions;
- The **"planner"**, that it takes in cargo the definition of the conceptual model of the site (idrogeologica and geologic-thermal relation), the dimensioning and the planning of the geothermal system (study of thermal yield and planning of the system – technical relation), the direction works in realizzativa phase and the relationships with the agencies you premail during the authorization process;
- The **enterprise**, that it realizes the intense activities of borehole and the putting in work of the probes and the geothermal systems;
- The **agencies of control and the public administrations**, that receive and they manage the demands for the access to the stratigraphic, hydrogeologic and environmental data of the site and estimate the authorization questions stipulating the concession of use.

Each of the parties has specific responsibilities and must meet all the requirements necessary to carry out the tasks entrusted to it.

In particular, the **"planner"** will be represented by a professional team, able to respond to the many aspects that accompany the design of an installation of geothermal heat pump; in particular, will be responsible for:

- define the hydrogeological and geological-thermal site arrangement (geologist);
- define the "environmental status" of the site (or Professional Geologist Environmental);
- define the possible critical environmental (water contamination and/or the ground) and, at the same time, the technical features necessary to resolve these issues and to prevent any possible impact related to the installation of the geothermal system itself (Professional Environmental specialist);
- define the thermal output of the system and the system design (Professional specialized);
- check work (Works Manager, Professional specialized);
- define and manage the monitoring plan (environmental and thermal efficiency) during operation (if necessary/required);
- maintain relationships with regulatory bodies throughout the authorization process, and realization of concession.

All the relations managed from the "Planner" will be signed by the relative Specialized Professional, than will be the responsible.

The **"enterprise"** will be responsible for the realization of the boreholes, the armament of the wells of taken and/or restitution, the installation of the geothermal probes, mixtures of cementation and the isolation of the systems. The enterprise must have all requirement (certifications) that of it they demonstrate to the ability and the technical experience in the field, guaranteeing that the workings answer to the fixed qualitative standards. At the end of the work the firm will provide a certificate, signed and authenticated, to describe the type of work performed, the characteristics and quantities of materials used, the results of any tests performed.

The private will be responsible for both economic project that subsequently manage geothermal plant in the planning phase, realization, operation and final disposal.

The **Public Administration** will have the role of providing the necessary technical support for capture of stratigraphic, hydrogeological and environmental data may be available for the site; It will have to indicate the presence of any "environmental problems" existing in the site, or in a neighborhood significantly; It will also assess the technical documentation provided by the designer, to approve the project, with an indication of any changes/restrictions; and define the concession.

The following flow chart (Chart 8.1) summarizes the responsibilities and relationships between the parties involved.

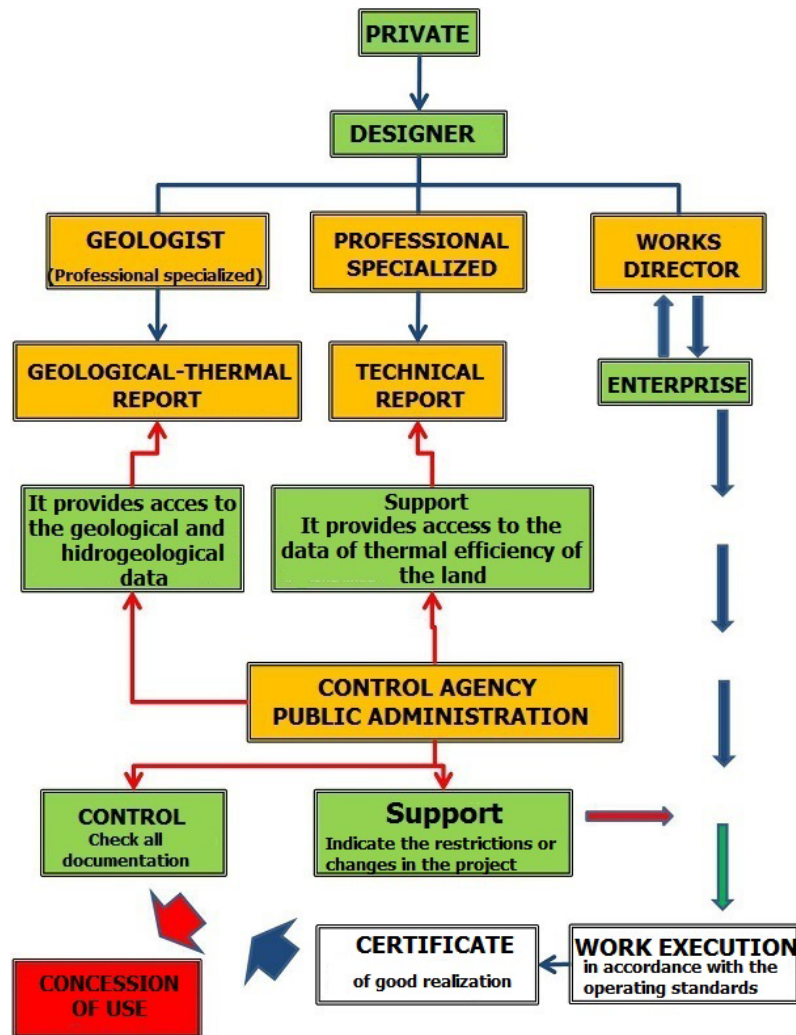


Chart 9.1 - Summary of responsibilities of the parties involved in the construction of a geothermal heat pump system.

Identify the different professionals involved in the various phases of design, installation and testing of a geothermal heat pump system, and knowledge of the regulatory approach (chapter 4) which follow the main countries which use this technology, it possible to get ideas for writing a possible procedural approach when requesting installation of a geothermal heat pump system.

The example of authorization procedure proposed is aimed at centralizing the authorization request to the Regional level, and has been divided into:

- general provisions;
- methods of installation, operation and characteristics of the plants;
- materials allowed during installation and operation of the plant;

- drilling mode;
- laying of the probe;
- testing of the geothermal probes;
- ambiental monitoring;
- security tools;
- authorization process;
- controls.

8.1 General provisions

In according to the study carried out and the matured experience it is possible to define some general provisions to make the first considerations referred only closed loop systems. It is important to identify different procedures depending on not only the type of system but also to some specific technical configuration. Is therefore essential in the general provisions specified depending on the type of plant and the technical characteristics which procedural agency or whoever it has to follow.

In according to the study of the specification of the systems, and in particular based on the configuration (vertical probes, reach depth of approximately 100 meters; horizontal probes, are installed to a depth of approximately 2 meters), is opportune to indicate two different approaches, in particular:

- vertical geothermal probes – in this case it is necessary to demand the authorization to the competent Agency, in this case the Region;
- horizontal geothermal probes – for the installation of these types of probes is not necessary any type of authorization if not in particular areas.

The installation of geothermal probes can not always be granted but must be assessed case by case, any limitations. Own for their configuration (above all for vertical geothermal probes) and the type of installation, is important lend attention to possible pollution causes provoked in some cases, from connection of more acquifer or from the damaging of the same probe with consequent spillage of thermovector liquid. For these reasons surely, the installation of a geothermal system must be always prohibited in the zones of absolute protection while, they must be assessed

case by case, some limitations to refer to the area in which it will go to fall back a system:

- vulnerable areas (Legislative Decree no. 152/06);
- recharge areas/reserve of the aquifer (Legislative Decree no. 152/06);
- areas that fall within the buffer zone of public wells used for drinking water (Legislative Decree no. 152/2006);
- contaminated or potentially contaminated areas as defined by art. 240 of Legislative Decree n°. 152/06;
- contaminated areas subject to remediation, putting in safety or putting in permanent safety;
- areas with exceedances of threshold concentrations of contamination in which was conducted a risk analysis that has defined the risk threshold concentrations tolerable without subsequent remediation;
- areas including artesian aquifers;
- areas including aquifer water very mineralized;
- areas where the geological structure and hydrogeological subsoil is poorly understood.

Moreover, the perforations must respect the legal distances from the edge of the property of the applicant with the neighboring property established by the Civil Code (minimum distance of 4 meters).

8.2 Modality of installation, management and characteristics of the systems

In according to the information in chapter 4 "Normative Criteria" is to be referred to within this possible authorization process an inherent part of the method of installation, operation and characteristics of the different systems.

In order to dimension correctly a geothermal heat pump system it is necessary to initially define the geothermal reservoir, knowing the following information:

- any geothermal probes already installed in order to evaluate possible interference;
- stratigraphy of the ground involved;

- quantitative and qualitative characteristics of the water to prevent and avoid possible contamination during installation;
- thermal characteristics of the subsoil to assess in principle the thermal yield that that type of soil is able to provide.

It is necessary to guarantee that, it is during the phases of installation that of management of the geothermal probes, does not happen the proliferation of the bacterial flora or the dissolution of heavy metals in waters basements, pollution cause.

An aspect a lot important not to underrate in phase of planning of a system of geoexchange is surely the esteem of the thermal yield. Knowing stratigraphy, the quota interception of eventual acquifer and the mechanical characteristics of the various crossed thicknesses it is possible to go back to this parameter. In some cases this esteem can be only indicative in particular, for power systems ≤ 50 kW. The cost of a continuous core perforation, to trace in detail the stratigraphy, would go to heavy weigh on the final costs of the system, penalizing the development of this technology. In these case is opportune beginning from to estimate the thermal parameters of the bedrock from the reconstructed stratigraphy by means of methods of geophysical investigation. On the base of these information it can be proceeded therefore, to the dimensioning second the norms ONES and ISO.

For the dimensioning of great systems (power > 50 kW), instead, is necessary to determine in detailed way stratigraphy, eventual intercepted aquifers and main mechanical characteristics. In this case, the cost of a borehole does not go to weigh on the all in cost of the system. Moreover, it is opportune to estimate the course of the temperatures of the geothermal exchanger to the aim to guarantee that the temperature in income and escape from the heat pump and the system remains coherent with the plan values.

In order to define the termo-physical properties of the ground it is necessary to execute the Ground Response Test, as defined in paragraph 3.2. The test must have a minimal duration of 50 hours and must necessarily supply the following output datas:

- thermal resistance of the geothermal exchanger;

- medium thermal conductivity of the underground;
- medium temperature of the undisturbed underground.

In order to guarantee the collection of sufficient data to allow the elaboration statistics of the same ones, is necessary that the number of acquisitions is not inferior to one for minute. The measure of the capacities in the circuit must be carried out with a sensor of not inferior precision to 2% while, the sensor for the temperature measures must at least have a precision 0,02°C.

8.3 Materials authorized in phase of installation and operation of the system

All the materials used in phase of installation of the geothermal probe must be certified and they cannot in some case to alter the properties physicist-chemistries of the ground and the water-bearing neither to create pollution phenomena of some genre. It is necessary to such care to characterize a material able to not only resist to determined pressures to which he will be subordinate (in reference to the systems to vertical probes) but also to the bending, the corrosion and the breakage. The materials mainly indicated in literature make reference to geothermal probes in polyethylene to high density. This material is surely echo-compatible, not subject to corrosion, flexible and breakage.

The probes used in geothermal energy must therefore have certain characteristics including:

- they must be in polyethylene or reticulated polyethylene;
- high density in the class of pressure of 16 bars (PN 16).

They are from avoiding, for all the reasons mentioned over, the pipelines in PVC.

An other aspect not to underrate is the choice of the heat-transfer fluid. The probability that a geothermal probe can be damaged during the phases of installation is lowland, but in some critical conditions (winding of the same, perforation executed correctly) could cause the breach of the same one and therefore to afford the spillage of the heat-transfer fluid. Starting from the assumption that during the installation phase of the geothermal probe should be filled with water alone is difficult to understand that, in this case, the criticality largest is excluded. In fact, the

breakage of the probe may cause only the leakage of water, thus not causing any pollution. Discarded this problematic one it remains however the possibility that during their operation they can be damaged and deteriorate the probes and in this case, would be the heat-transfer fluid to being released in the ground. For this reason it is therefore necessary to search a fluid to low environmental impact, rather drinkable water added with ethylene glycol or non-toxic and biodegradable propilenico for alimentary use. It is necessary to avoid the inhibitor use of the corrosion.

8.4 Drilling mode

The phase of installation of the geothermal probes is surely that most problematic from an environmental point of view.

During the perforation it is necessary to guarantee determined indispensable precautions in order particularly not to bring pollution of the ground and of groundwaters. The installation of a system of geoexchange to vertical probes sure very more is complicated than a system to horizontal probes, own for the various depths that are reached by the various employed probes. While the system to vertical probes, reaching depth of approximately 100 meters, can cross various aquifers with different characteristics, the horizontal system reaching depth of approximately 2 meters would not have to interest the groundwater and therefore, its installation would have to guarantee the greater safety. Obviously, the fact remains that, in both cases, the damage of a probe could cause leakage of the coolant that, by percolating in the subsoil could intercept different aquifer levels causing , depending on the characteristics of the liquid, pollution. It is therefore necessary to pay the maximum attention in both cases in the installation phase, but for systems having vertical probes is appropriate to know in detail the grounds that will be crossed and the aquifer crossed in such a way as to define what type of drilling technique adopting, coatings and cementing materials best suited to the situation. It must be absolutely guaranteed that any aquifer crossed are not put into communication with each other.

From all the observations brought back over is therefore necessary to specify which attentions must be adopted to the aim to avoid any possible pollution of the ground and groundwaters. To such care they must be adopted some safeguards measures, between which:

- to eg. avoid losses of oil from the car of perforation, specific products (fuel, lubricant, hydraulic oils, additives). The ground below the perforation car must be protected by means of teli waterproof or bathtubs of collection;
- the yard must be endowed of headmasters of emergency in order to contain spillages of potentially contaminating liquids; must be used fluid of perforation that does not involve some negative consequence for the ground.

Regarding the perforation methods, that to prefer are:

- to percussion;
- to rotation with nucleus destruction;
- to rotation with continuous drilling;
- to rotopercussion.

The perforation mixture must answer to the following minimal characteristics:

- specific weight of 1200 kg/m^3 ;
- characteristics of the cementation: permeability factor of $K_f \leq 1 \cdot 10^{-7} \text{ m/s}$ without cracking neither sedimentation. The withdrawal of the suspension does not have to exceed 2% of the length of the hole for a maximum of 5 m, otherwise must be completed the filling. The mixture standard for the filling must follow these conditions: for 1 m^3 of suspension, 100 Kg of bentonite, 200 Kg of concrete and 900 Kg of water. Are only admitted of not dangerous additives for the atmosphere, and must be annotated the amount of injected suspension.

To such purpose, to the action of the presentation of the request of use licence, the certificate of regulating execution, to signature of the Director of the Intense activities and of an Geologist, will have to be accompanied from certificates of tests that attest the quality of the mixture employed for sealing. These tests are: test of

viscosity with viscometer of Marsh; test of withdrawal with graduated cylinder for the volumetric yield, and test of density with balance of Baroid.

The perforation fluid that can be used are water, compressed air and bentonitic mud.

Before the pumping of bentonite mixture into the hole is need to perform a pressure test on the probe filled with water. The test will have to be extended for a time of 60 minutes, to a pressure at least 6 bars, with a maximum loss of the permissible cargo of 0.2 bar. Finished the test it is begun to inject, from the low towards the high, the bentonitic mixture through the grooves inside of the hole. It is fundamental that the mixture which injected succeeds to maintain in the time a good thermal conductivity between the probe and the surrounding land of way such to guarantee the same yield.

During the perforation, in relation to the characteristics of the ground, it is necessary puts down it of temporary tubes of covering. In particular these coverings will have to be adopted in the following cases:

- when there is risk of landsliding of the walls of the hole with consequent loss of verticality of the probe or the formation of empty and/or discontinuities in the phase of sealing of the hole with the bentonitica mixture;
- when there is in the ground the presence of overlapped aquifers, in order to avoid intercommunications between the superficial aquifer and the deep aquifer to the drinkable use.

The position of the perforation must be guaranteed to the aim to avoid possible buried underground utilities. It must be compiled a relationship of perforation for every carried out hole, this must contain:

- stratigraphic composition of the subsurface by applying at least the following categories:
 - Loose soil permeability;
 - Loose soil impermeable;
 - Rock;
 - Contamination of the subsoil;

- Inflow of groundwater;
- Groundwater level measured.
- inflows of ground water and water loss of drilling;
- type of drilling and technical data;
- use of coatings;
- additives used;
- quantities of suspension injected pressure to backfill the hole;
- special events.

Every 6 meters and at each change of formation must be performed to representative samplings of land in the first drilling performed. The samples should be collected and stored in suitable containers for at least 60 days from the end of the work for inspection by the competent authorities.

8.5 Installation of the probe

Once finished the phase of perforation must be proceeded with the insertion of the probe. Obviously, the diameter of perforation must be such to allow the insertion of the probe without large difficulties let alone, to allow the breaking of the cementation tube in the borehole. The probes before being descents in foro must be filled up of water to the aim to increase of their weight and therefore to avoid possible windings. For their insertion they must be used of the used the rotors that facilitate the installation and avoid rubbing and squeezing of the tubes.

8.6 Testing of the geothermal probes

In Italy, today, there is no national legislation which specifies, at the end of the putting in pose of the probe, the need to perform the acceptance tests of the system, only some regions such as Lombardy in its rules it indicated this stage between those essential to ensure the smooth operation of an installation.

At European level, Germany and Switzerland consider in their legislation the testing phase as a "guarantee" of a successful system. Assuming that these nations

have created a list of certified installers (in Switzerland has been created the "Swiss for heat pumps Group" where, by accessing the website, you can consult the certified companies) which, at the end of installation of the geothermal heat pump system and testing of the same, are authorized to issue a certificate of guarantee of proper operation. This guarantee is generally lasting 30 years. It is from specifying that such guarantee can be maintained only if is guaranteed, to regular intervals in the time, a continuous maintenance of the system. Moreover, the system is guaranteed for this period on condition that the hours of operation are always the same ones in summery modality that winter and above all considering the thermal characteristics of the ground at the moment of the installation. The thermal characteristics are surely the more important parameter as, through the esteem of the same ones it is possible to go back and to calculate the thermal yield that a determined system, is able to supply for those determined conditions. Here because in case in the immediate vicinities of a system already existing had to be installed a geoexchange system the guarantee 30-year-old could not be more valid. In fact the two systems, if not very planned and installed to a distance not adapted one from the other, can be damaged not succeeding to guarantee of the good yields. Here because turns out fundamental to establish of the respect areas within which cannot be installed a certain number of systems.

In order to release a guarantee document is necessary to the term of the intense activities and before commissioning the plant is necessary to proceed with the testing phases by:

- estate test: on each probe it must be followed a test of hydraulic estate using water, for a not inferior duration to 2 hours, with pressure of not advanced to 1.5 times that of exercise and never higher than 500 kPa. The test is positive when the pressure inside of the probe does not drop in meaningful way (tolerated decrease of 0,5 bar);
- testing of flow: in order to assess any possible ovalization or crushing that the probe may have undergone during transport or installation, must be performed on each probe a dynamic flow test involving the measurement of the pressure drop measured across the probe at different flow rates.

If an acceptance test produces a negative result is necessary to abandon the probe sealing in a definitive manner with a suspension of cement, water and bentonite.

The safety of the well provides for a system of support and closing of the same, in the initial part and in all those that pass through the aquifer levels, so as to prevent any pollution of the water cross.

For each test it must be compiled a protocol.

8.7 Environmental monitoring

For the great systems (power >50 kW) recommends an environmental monitoring that verifies the efficiency and environmental integrity of the thermal tank. Therefore, It must be provided a plan of monitoring in which are defined not only the parameters to measure but also the number and localization of the instrumentations that will come employees. Particularly it will have to be estimated the number of holes that will be employed in order to lodge the useful instrumentation for the monitoring in phase of exercise of the system. The parameters to monitor are:

- groundwater quality: for this purpose it is necessary to install a piezometric tube with windows corresponding at the aquifers to be monitored. The wells must be made before work to determine the "zero" initial and to be able to monitor the entire construction phase of the plant. To take samples of ground water should be used samplers (bailer) disposable consist of a cylindrical transparent PVC, HDPE or Teflon. The bailer should be equipped with a bottom valve consists of a sphere free to slide inside the sampler that allows the entry of water from the bottom in the phase of immersion and guarantees tightness during the ascent phase. The sphere will facilitate the operations of emptying of the bailer allowing water to escape from the bottom to be entered into the collection container without excessive aeration. The diameter of the bailer should be at least 1.5 "and such as to allow its introduction into the piezometer with a length of at least 1 meter. The containers for the collection of samples must be sterile. The

receptacles shall be sent to the laboratory performing the analyzes which must ensure perfect sterility of all material submitted. Should be sent also a control sample of known nature called trip blank (white of transport) in a sealed container on which the laboratory will perform the same analysis to verify that there has been no contamination of the samples during transportation to and from the site investigation. Before starting the filling of the receptacle or receptacles intended to each sample, these must be rinsed with water coming from the piezometer. This operation ensures that the sample is not in contact with foreign substances possibly present in the receptacle or is not diluted by the rinse water used for its cleaning. The rinsed will have to be repeated for at least 3 times for each container. From all piezometers installed must be periodically removed samples of water upon which perform specific laboratory tests such as microbiological testing standards under the Legislative Decree no. 31/2001 aimed to detect the presence of bacteria in the waters which interested the geoexchange system and to highlight a any increase of pathogens. The tests should be performed at the completed system, prior to commissioning and during operation in order to determine the bacterial load in the waters affected by geothermal probes and to highlight any increase of pathogens potentially attributable to changes in the temperature field produced by plant. The parameters to be analyzed are listed in Table 9.1:

Parameter
<i>Escherichia coli</i>
Enterococchi
<i>Pseudomonas aeruginosa</i>
Colony count at 22 °C
Colony count at 37°C

Table 9.1 - Microbiological parameters to check before starting up the system and during operation.

The monitoring of the bacterial charge must be carried out at least once before the putting in exercise of the system and it must be repeated every

3 months during the first year of exercise and every 6 months for successive the 4 years.

- Control of the thermal field: must be realized of the pales equipped with thermocouple probes which placed to the center of the acquifer levels (if presents). The thermocouple probes will have to be positioned to various depth to decide based on the depth in which the acquifer will be intercepted.
- Control of efficiency of the system: it must be carried out by means of the employment of the cetralized system of digital regulation that supplies to the management of the heat pumps, to the compensation of the set-point according to the external temperature, to the night reduction, the extinction of the heat pumps and the relative circulating pumps in case of necessity (reduction of the cargo or application of energetic programs). At the same time the digital system controls the temperature of the geoexchager (side evaporation) varying the capacity of the fluid by means of the frequency shifters of which the circulating pumps of the circuit are equipped. The monitoring is executed by means of the control and the survey of the following values: thermal energy supplied from the heat pumps (winter operation); cooling energy supplied from the heat pumps (summery operation); supplied cooling energy from the refrigeration unit; electrical absorption of the heat pumps (summery and winter operation); electrical absorption of the refrigeration unit (summery and winter operation); overall power consumption of the pumping station.

The trend of these parameters allows to highlight the daily trend of the COP and EER plant and so to enhance the seasonal average parameter.

The following is a summary of the monitoring activities (Table 2.1).

Type of control	Control action	Frequency of measurements		Communication data
		Construction phase	Operating phase	
Checks during the realization of the plant	Stratigraphy control	Before works	-	Before works
	Drilling control	In continuous	-	At least every month
	Control of cementing mixture	In continuous	-	Before works
	Pipes control	Before works	-	At least every month
	Leakage test of the piping	After the realization of the first 8 probes	-	Within 15 days from the execution of the tests
	Control of the efficiency of the cementation for the isolation of the aquifers	After the realization of the first 8 probes	-	Within 15 days from the execution of the tests
		At the end of the realization of the field probes		
Quality control of groundwater	Sampling and microbiological analysis	Before works	Every 3 months during the first year and every 6 months for the next 4 years	Before work. Within 15 days execution of the analyzes in the operating phase
Thermal control	Bearings temperature	Before the commissioning of the plant	With daily frequency	Every 15 days in the first 3 years of operation; then every 3 months
Control of efficiency of the system	Traceability of the probes and the collectors	At the end of realization of the plant	-	-
	Controls of refilling system	Performing leak testing pressure	Continuously from specific counter	Every 30 days in the first three years of operation; then every 3 months
	Plant performance	-	In continuous	Every 3 months

Table 9.2 - Synthesis phase of collection and communication of the monitoring actions.

The monitoring data should be stored by the owner of the system to make them available for inspection in the Region, the Provinces and the competent authorities.

8.8 Security Tools

Another aspect not to be underestimated during the design phase of the system is the security tools. This instrumentation is fundamental in order to avoid, for example, possible leakage of heat transfer fluid from the probes or even damage of the horizontal collectors. In particular, the system must be equipped with:

- each individual probe must be equipped with its own gate valve (flow and return);

- the system must be fitted with a safety valve (calibrated to prevent the foot of the probe the pressure sensor exceeds the rated);
- on each probe must be present balancing valves;
- on the circuit probes must be mounted a flow switch which interrupts the circulation of fluid in the probes in the presence of anomalies such as the drop of pressure that could be indicative of loss in the circuit.

They can be also installed other control instruments, such as:

- thermometer;
- pressure gauge;
- flowmeter;
- electric meter.

8.9 Authorization procedure

Once designed the plant and study the geological, hydrogeological and geotechnical site that will go to host the same, you must start the authorization procedure.

As previously mentioned, it is considered appropriate to centralize the authorization request to the Region, leaving the possibility of release or no the authorization. Additionally, it should be able to provide users a tool that allows you to view the installed systems in the area concerned and their technical characteristics. This tool should enable the on-line compilation of information necessary for authorization from the Region.

For the Region a tool with these characteristics is very important as a source by managing on-line you can know in real time the situation of the equipment installed in the territory, release with a much shorter time of the project authorization and especially to have a digital archive consulted easily.

The authorization procedure includes:

- the submission of the application;
- the authorization;
- the on-line register for the authorized plant.

The owner must provide to forward the authorization request to the province territorial jurisdiction. Documentation submitted in support of the authorization shall contain the elements necessary to show that the creation of the probes, at every stage of construction, does not constitute a risk factor for the soil and subsoil, nor pollution factor of water quality.

The authorization must be granted by the Region responsible for the area within the period of sixty days from the date of the notice of commencement of work. This period may be suspended in the event it becomes necessary, from the competent administration, the acquisition of additional information or even information on the plant.

The application for the installation of a geothermal system consists of two different parts: a more general, it consists of the application for authorization to the installation of geothermal probes; the other of a more specialized, made up of a technical documentation to be attached to the application installation.

From the procedural point of view, depending on the different types of systems which is intend to realize, you will need to submit two different technical administrative instances that will be summarized below.

It will be task for the relevant authorities, assessed the technical documentation provided by the applicant, to decide whether and how to restrict (number and type of sensors, depth reached, type of materials used) to grant permission to the realization of the geothermal system.

Useful tool for public administrations that have to operate in the field of geothermal energy would be the possibility of having a specific authorization process that allows to authorize and require certain specifications depending on the area in which the authorization is sought. In particular, information is identified in the territory of the main areas of interest and to specify for each of them whether or not to grant an authorization, and even what kind of documents are necessary for the granting of an authorization.

In this regard we have been identified three main areas that are characterized for geological, structural, hydrogeological and of exploitability:

- **Zone A:** fall in this area, the catchment zones of surface water intended for drinking water; areas affected by geothermal, hydrothermal and minerals events already exploited or exploitable; areas affected by landslides and tectonic zones of interest, seismic zones of interest; contaminated sites;
- **Zone B:** falling in this areas of water supply (wells and springs used for drinking water); areas with quiescent landslides; karst areas and areas with evaporites rocks; site remediation;
- **Zone C:** includes all the areas not subject to any restrictions. As far as special cases, refer to the zones comprising contaminated sites, catchment areas and open loop systems, reference is made to some subsequent considerations reported in the following pages.

It shows instead, a summary scheme of the main steps to follow when issuing authorization for the areas listed above, for the type of facility for which authorization is requested same. In particular for closed circuit systems having vertical probes it has divided the authorization procedure according to the type of installations to be undertaken (Chart 9.2) by identifying:

- small uses (power <50 kW): the conditioning part of single-family buildings;
- large uses(> 50 kW) fall within this type of use include industrial units, public or private buildings that have the need for high energy requirements (higher than that of single dwelling).

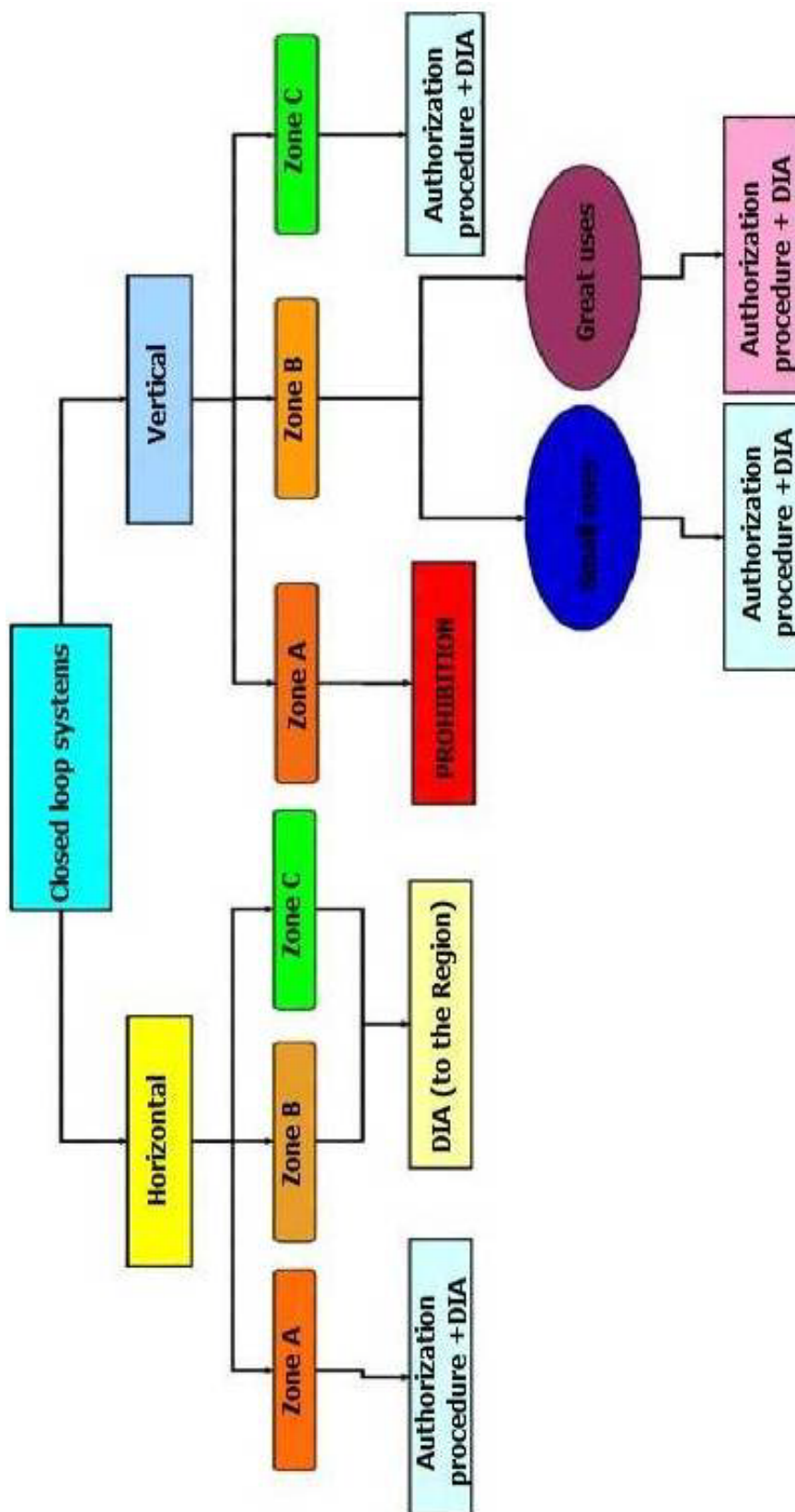


Chart 9.2 - Flowchart for the procedure for authorization of a geothermal plant.

As it regards the more specific cases are reported the flow schemes of synthesis, representatives of any limitations to the realization of a geothermal plant and its procedural iter to follow.

In particular will be discusses the following "special" cases and potentially "problematic":

- request for installation of closed loop geothermal probes in industrial areas potentially contaminated (Diagram 8.2);
- request for installation of closed loop geothermal probes within the buffer zone of a public well for drinking water (Diagram 8.3);
- request for the re-entry of the water pumped from an open loop geothermal probes in groundwater, surface waters or underground (Diagram 8.4).

In this regard it is recalled that in the vicinity of existing water utilities installation of geothermal probes shall be granted only if they can be excluded negative consequences for the latter. This must be clarified by the client through appropriate hydrogeological inquiries(possibly supported by numerical modeling of flow). In any case, you must observe the following safety distances:

- within a radius of 30 m from any well and 100 m from the drinking water wells private;
- within 30 m downstream and 200 m upstream of captured sources.

The maximum depth to which the probes can be installed coincides with the base of the traditional aquifer. Only in exceptional cases to be individually examined at the valley of a hydrogeological study in depth, and only in the presence of safeguards for the protection of groundwater resources, is allowed a greater depth.

It seems clear that the collection of spatial information and subsoil is an essential element of a good design of geothermal plants.

The Environmental Specialist (Geologist) should gather all the information needed to file the application for authorization. In particular it will have to collect data on the physical environment from the surface down to a depth where you have to drill the holes. If the data are inaccurate, incomplete or relatively old, you will need to make further inquiries for the acquisition of input parameters needed for the project

definition (geognostic and environmental, always necessary in cases potentially "problematic" or for the realization of geothermal systems of "large" size).

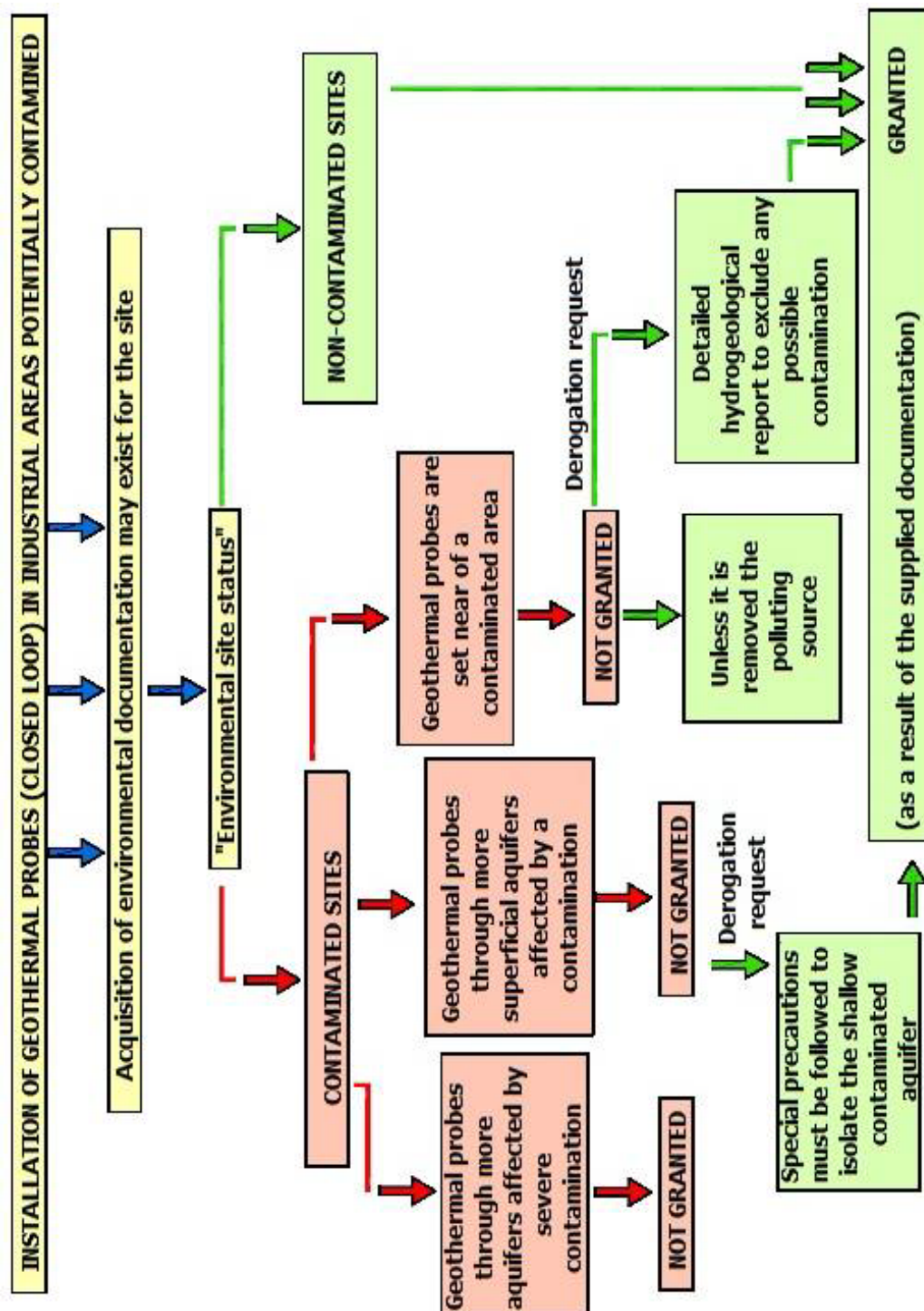


Chart 9.3 - Procedure for the request for installation of geothermal closed loop systems in potentially contaminated industrial areas.

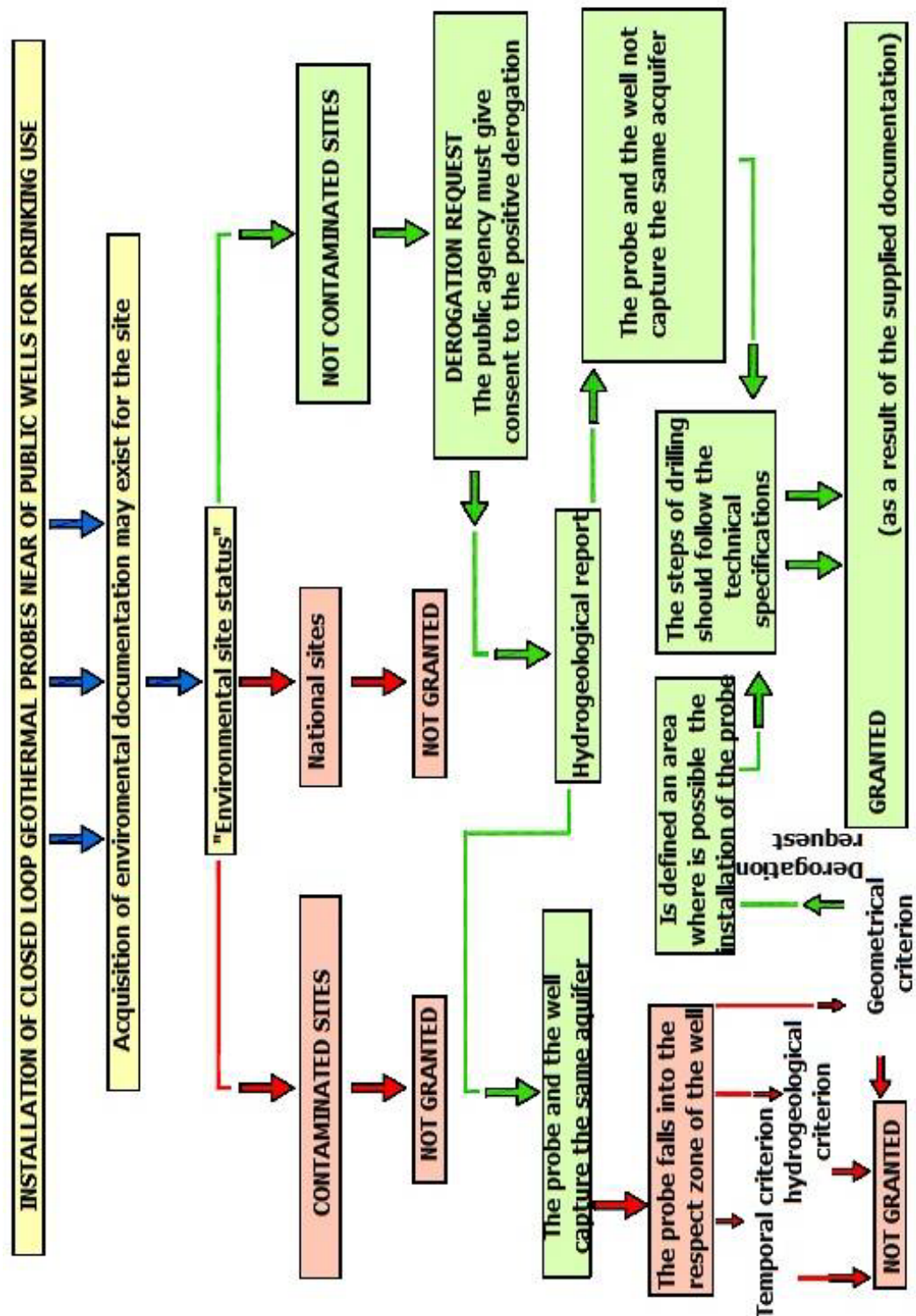


Chart 9.4 - Procedure for the request for installation of closed loop geothermal system within the buffer zone of a public well for drinking uses.

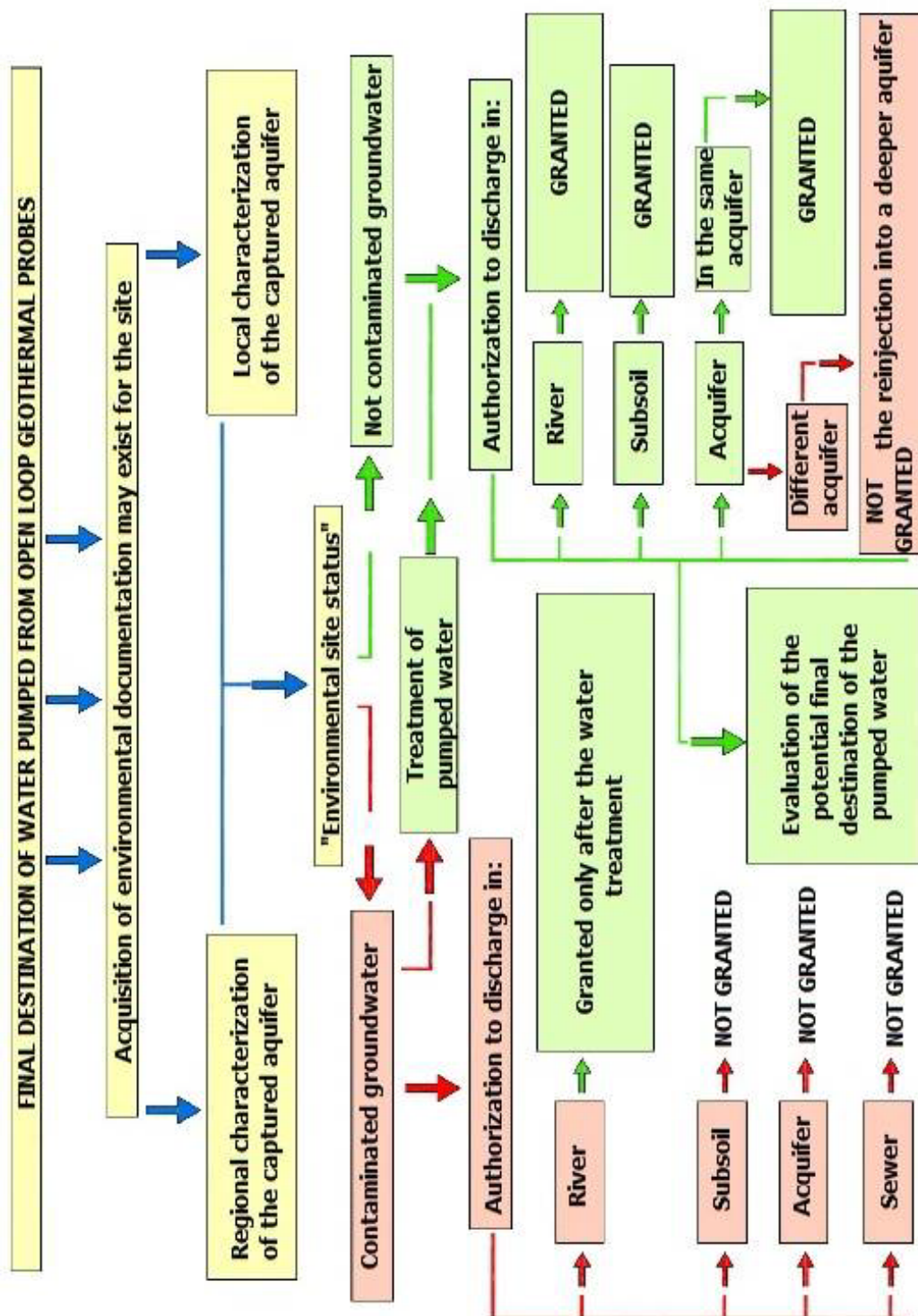


Chart 9.5 - Procedure for the request for installation of geothermal open loop system with reinjection of the water pumped into the groundwater, surface waters or underground.

8.10 Procedure for installation of the geothermal probes

By accessing the database on-line the owner is obliged to enter all the data related to the system before the opening of the construction site and soon after the release of the authorization.

This procedure can be divided into two main phases:

- notice of start works;
- notice of completion of work.

The registration is obligatory and must be made online at least 30 days before the date of the opening drilling site.

The owner must provide the following information:

- personal data of the owner;
- cadastral data of the Site;
- project data of the plant;
- the number of geothermal probes expected and their depth in the case of vertical probes or length in the case of horizontal probes;
- materials that will be used for cementing the borehole;
- constituent materials of the geothermal probes;
- geometry of geothermal probe;
- type of heat transfer fluid that circulates inside of the probes;
- stratigraphy deduced;
- main hydrogeological aspects;
- date of the opening drilling site.

The owner must also submit a declaration by which assumes full responsibility for compliance with the restrictions and prohibitions, and the veracity of the information transmitted.

The owner is also required to provide a statement of consent from the owner of the land in the case of a person other than the person who installs the system.

Once entered all the information, the system releases automatically an identification code that is the certificate of registration. The identification code is valid for one year. The period of one year is intended as a deadline for

implementation of the system. Upon expiry of this period, the owner is required to re-register and obtain a new identification code. After completing the installation work is required by the database on-line notify the successful conclusion of the work.

To this end, it shall present a certificate containing the following information:

- statement of completion of work or certificate of regular execution or testing;
- number of probes actually realized with relative depth in case of vertical probes, or length, in case of horizontal probes;
- the data and information relating to the perforations made and the stratigraphy obtained;
- elements necessary to show that the realization of the probes, in each phase of construction, had not been a risk factor of pollution of the soil or subsoil, or factor of deterioration of groundwater quality, in relation of the same uses.

The owner as well as the communication of completion of work needs to convey to the Region, again through the on-line insertion data, the following information extracted from the execution of the Ground response test, or rather:

- average thermal conductivity of the subsoil;
- average temperature of the undisturbed ground;
- thermal resistance of the geothermal probe.

When all the data of the work order system automatically closes the communication procedure.

8.11 Controls

The last phase of the authorization process is not possible without an inspection by the competent authorities on the matter.

The Provinces must provide for the control of the respect of the content in the database on-line. It would be important, especially for large facilities (power > 50 W/m), which the responsible agency possessed a campaign of monitoring the

resource by providing for the execution of Ground Response Test at regular intervals to be defined in according to the particular criticalities.

The audit must be carried out by verifying in situ, and the results must be sent to the Region at least once every six months.

9 Conclusion

The research work has been centralized on the identification of a procedural iter to follow in phase of thermal characterization, starting from an analysis of the normative elements that regulate the phases of authorization, planning and installation of the heat pumps systems in the various international and national contexts. Successively, two methods of elaboration of the thermal conductivity data are compared: investigations of detail that have afforded to reconstruct the relative stratigraphic order of a pilot site, and elaboration of the heat conductivity data from the regional stratigraphic information.

Initially, the technical-engineering parameters that characterize the geothermal heat pump systems were studied, with reference to their operating principle. In a second phase the geological, geophysical, hydrogeological and geotechnical parameters that influence the heat exchange between the probe and the ground were identified. In particular, the study saw the research and definition of the thermal conductivity bibliographical data and of the main tools for its measurement.

Therefore, it was made a table of the main bibliographic lithologies that allowed to assign a thermal conductivity value for each lithostratigraphic unit of the geological legend, in scale 1:10000, of the Sardinia Region. Almost 778 units have been studied, an "equivalent thermal litotype" has been assigned to each of these units, from which it is go back to the allocation of an appropriate thermal conductivity value. It should be noted that whenever it has not been possible to identify a single litotype we proceeded with the calculation "weighed" of the thermal conductivity through the calculation of prevalences lithological.

The research, therefore, has seen a detailed study of the pilot site located in proximity of Baratz Lake (Municipality of Sassari) that through the investigations in situ, it has allowed first to characterize from a geologic point of view identifying a representative stratigraphy and, at a later time, to elaborate this information in thermal key.

Therefore, it has been possible to calculate the value of heat conductivity for the single formations that constitute the stratigraphy of the area, and the relative thermal yield on the operation hours of the system (1800 – 2400 hours) in modality heating and cooling. In particular, for the depth of 0 - 25 meters has obtained a value of 0,80 W/mK, for the depth of 25 - 50 meters 1,34 W/mK while, for the depth of 50 - 80 meters 2,47 W/mK and for the depth of 80 - 120 meters 2,82 W/mK. Moreover, from the calculation of the thermal conductivity for the depth of 0 - 30 meters has been possible to estimate the relative thermal yield on 1800 hours of operation (cooling 42,32 W/m; heating 36,93 W/m) and on the 2400 hours of operation (cooling 41,02 W/m; heating 35,89 W/m).

Subsequently the attention was paid to the development of the data of thermal conductivity from the regional stratigraphic information. A test on the Arezzo Province was performed, where, through the geostatistical elaboration of the regional stratigraphic information were produced three maps of the thermal conductivity at depths of 30, 60 and 100 meters. The thermal conductivity values obtained for the depth of 30 meters are between 1,13 to 2,71 W/mK, for the depth of 60 meters are between 1,10 to 2,69 W/mK, and finally for the depth of 100 meters are between 1,12 to 2,93 W/mK.

In particular, from the elaboration of the three maps it can be noted as the data of heat conductivity tend to rise more with increasing depth.

This increasing reports mainly to the insertion in the calculation of elaboration of stratigraphies that reach greater depths (30, 60 and 100 meters) and from the geological variability of the site.

For the obtained thermal conductivity maps, the respective maps of standard deviations of the esteem of the thermal conductivity value were elaborated from the elaboration of the regional stratigraphic information. It can be noticed that the standard deviation values of the estimations anticipate a high reliability of the same ones near the stratigraphic points, in which the values of heat conductivity are calculated, and high errors committed by the estimator used (Ordinary Kriging) far from the aforesaid points, especially in the peripheral zones of the considered dominions. The study places the bases in order to estimate the reliability, in the

zones discovered from the stratigraphic information, of the elaborated thermal conductivity data.

A future objective of the search will be that to obtain new obtainable punctual information from the stratigraphy or installations of future geoexchange systems own in these areas.

The study showed that in areas where there are no stratigraphic information is therefore advisable to perform in situ investigations, in order to characterize the thermal characteristics of the area of interest. Importantly, the approach to follow is highly dependent on the power of the system to be installed. For systems with inferior power to 30 kW and for those areas where there are no stratigraphic information, it turns out important to fix some control points and to execute in these sites a stratigraphic, geological and hidrogeological investigation deriving at first from the reading of the maps and successively, from the collection of information in situ. Therefore, from the in situ investigations it will be possible to reconstruct a type stratigraphy through which, defined the tickness of various crossed lithologies, using the thermal conductivity data which deriving from a bibliographical analysis, it is possible to calculate the heat conductivity for the depths of interest. The investigation in this case is completed through the first perforations going to eventually correct the dimensioning, optimizing the depth of perforation according to the parameters eventually measured.

In the case where it is intended to install a power exceeding 30 kW it is however always duty to perform a test of thermal yield in situ on the first probe installed, in order to characterize from a thermal point of view in a precise way, the entire probe system.

For complex systems and then with powers greater than 150-200 kW it is appropriate to carry out a series of thorough investigations: one or more drilling in continues core in order to determine the stratigraphy and with good accuracy even hidrogeology. On the probes are also necessary to execute, even in this case, the test of thermal efficiency for the determination of the thermal properties of soils and the measurement of the average temperature of the soil in depth.

Although these procedures are expensive from an economic standpoint, it is clear that they are applied precisely in view of a sharp increase in installations in our country, mainly because countries like Germany and Switzerland have developed energy policies in this direction that favored in the years the growth of these systems.

In addition, it has tried to indicate three possible procedure to be followed when requesting the installation of a plant for specific cases, such as:

- vertical geothermal probes in industrial areas potentially contaminated;
- closed loop probes systems within the buffer zone of a public well for drinking water;
- re-entry of water pumped from the open loop system in groundwater, surface waters or underground.

Based on the experience, the research project has shown some possible approaches to follow as a guide for professionals working in this field that are trying to characterize from a geological-thermal point of view a particular site. The methods described can also be applied to various territories, except some measures relating mainly to the types of information that each agency can provide.

It is essential being able to count on a given stratigraphic spatialized data stored in a database, in order to perform calculations such as those outlined in this thesis.

At completion than produced in this thesis, the future of the research will regard the hydrogeological numerical modelling and the study of its influence on the thermal conductivity of interesting rock types.

10 Acknowledgments

The contribution of many people was fundamental to complete the research described in this dissertation. They have all helped me in different ways during the past years, but everyone of them was important.

A special thanks go to my parents who gave me the opportunity to study and leaning in more all my choices.

Thank you to Prof. Antonio Funedda and Prof. Luigi Carmignani that in these years have followed me with much patience proving a good tutors as well as a good persons. I had no previous experience in geothermal energy and they helped me to become productive with useful suggestions and wise comments.

Thank you to Prof. Marcello Franceschelli for the valuable suggestions during these years of research.

Doct.Tommaso Colonna is thanked for his interest in all of the different aspects related to this project. He assisted me from the initial planning of the dissertation to the final interpretation of the experimental results.

Thank you to Prof. Taj-Eddine Kamal for his warm welcome and help when i first arrived in Marrakech in March 2015 to begin my research.

Thanks to Prof. Giacomo D'Amato Avanzi who accepted to revise the final draft of my dissertation. His comments helped me to improve the last rough edges of this research and his positive feedback was indispensable to face peacefully the academic discussion.

A special thanks go to Doct. Enrico Guastaldi for his interest in all of the different aspects related to this project.

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- Erdgekoppelte Wärmepumpenanlagen, Parte II.

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12 Attachments

- Attachments 1: equivalent thermal lithotype from Territorial Geological Continuum of the Regione Sardegna (staircase 1:10000);
- Attachments 2: Bibliographical references of thermal conductivity;
- Attachments 3: Thermal conductivity map for saturated lithotype of Regione Sardegna (staircase 1:500000);
- Attachments 4: Thermal conductivity map for unsaturated lithotype of Regione Sardegna (staircase 1:500000);
- Attachments 5: Thermal conductivity map for lithotype without information of water content of Regione Sardegna (staircase 1:500000).

12.1 Equivalent thermal lithotype from Territorial Geological Continuum of the Region Sardinia (staircase 1:10000)

Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
a	Slope deposits	Ghiaia	0,49	1,96	1,14
a1	Landslides	N.D.	N.D.	N.D.	N.D.
a1a	Landslides	N.D.	N.D.	N.D.	N.D.
AAZ	Atzori Andesite	Andesite	N.D.	N.D.	2,87
AAZa	Lithofacies Atzori Andesite	Andesite	N.D.	N.D.	2,87
ab	Anfibolite	Anfibolite	2,46	2,78	3,03
ABS1a	La Vedetta Facies (Capo Pecora intrusive Subunit)	Gabbro	2,13	2,54	2,22
ABS1b	Corru Longu Facies (Capo Pecora intrusive Subunit)	Granodiorite	2,29	2,73	2,83
ABS2a	Riu Mudaregu Facies (Gonnosfanadiga intrusive Subunit)	Gabbro	2,13	2,54	2,22
ABS2b	Facies Monte Omu (Gonnosfanadiga intrusive Subunit - Arbus intrusive Unit)	Granodiorite	2,29	2,73	2,83
ABS3	Rio Terra Maistus intrusive Subunit (Arbus intrusive Unit)	Granite	2,79	3,22	3,30
ACN	Rio Canoni Slate	Slate with metalimestone	2,05	2,83	2,09
ACNa	Lithofacies of Rio Canoni Slate	Marble	3,41	4,09	2,48
ACNc	Lithofacies of Rio Canoni Slate	Micaschist and quartzite	4,13	5,51	3,85
ADGa	Stazzo Pione Facies (S. Antonio di Gallura Intrusive Unit)	Gabbro	2,13	2,54	2,22
ADGb	S. Antonio di Gallura Facies (S. Antonio di Gallura Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ADGc	Stazzo Pittaru Facies (S. Antonio di Gallura Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ADGd	S. Antonio di Gallura Facies (S. Antonio di Gallura Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ADGe	Nalbina Facies (S. Antonio di Gallura Intrusive Unit)	Granite	2,79	3,22	3,30
ADP	Pirri Sandstone	Sandstone with silty shale	N.D.	2,82	2,24
AFA	Fangario Clay	Clay and marly clay	N.D.	N.D.	1,76
ag	Eclogite	Eclogite	N.D.	N.D.	3,08
AGU	Monte Argentu Formation	Slate and sandstone	2,05	2,83	2,09
AGU1	Punta Sa Broccia Member (Monte Argentu Formation)	Metaconglomerate	3,22	3,59	2,79
AGU2	Rio Is Arrus Member (Monte Argentu Formation)	Metapelite and metasandstone	N.D.	2,58	2,59

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
AGU3	Medau Murtas Member (Monte Argentu Formation)	Metapelite and metasandstone	N.D.	2,82	2,24
ALJ	Allai Unit	Ignimbrite	N.D.	N.D.	3,12
ap	Aplitic dikes	Granite	2,79	3,22	3,30
AQC	Acqua Sa Canna Dacite	Ignimbrite	N.D.	N.D.	3,12
ARX	Aragixi Formation	Tuff	N.D.	N.D.	1,37
ASNa	Fornelli Facies (Asinara Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ASNb	Cala del Turco Facies (Asinara Intrusive Unit)	Granite	2,79	3,22	3,30
ASU	Asuni Marble	Marble	3,41	4,09	2,48
ATU	Cuccuru Pirastu Unit	Basalt	N.D.	2,60	2,00
ATZ	Pardu Atzei Unit	Basalt	N.D.	2,60	2,00
AZN	Arzachena Intrusive Unit	Granodiorite	2,29	2,73	2,83
AZN1a	Punta de Lu Focu Facies (Punta La Ettica Intrusive Subunit - Arzachena Intrusive Unit)	Granodiorite	2,29	2,73	2,83
AZN1b	Punta La Ettica Facies (Punta La Ettica Intrusive Subunit - Arzachena Intrusive Unit)	Granodiorite	2,29	2,73	2,83
AZN2a	Punta Candela Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2b	Punta Lisandru - Monti Biancu Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2c	Monte Cupalchiata Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granito	2,79	3,22	3,30
AZN2d	Punta Balbarichinu Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2e	Arzachena Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2f	Castel Cervo Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2g	Monte Moro Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2h	San Pantaleo Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2i	Punta di La Banderitta Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
AZN2l	Monte Pulcheddu Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
AZN2m	Miriacheddu Facies (Monte Tiana Intrusive Subunit - Arzachena Intrusive Unit)	Granite	2,79	3,22	3,30
b	Alluvional deposits	Gravel, snd and silt	0,53	2,02	1,56
b2	Eluvial-colluvial deposits	Sand and silt	0,53	2,05	1,78
ba	Alluvional deposits	Gravel and sand	0,50	2,22	1,52
BAO	Barisone Unit	Andesite	N.D.	N.D.	2,87
BAO1	Punta de Libezzu Subunit (Barisone Unit)	Ignimbrite	N.D.	N.D.	3,12
BAO1a	Calchinadas Facies (Punta de Libezzu Subunit - Barisone Unit)	Silt and clay	0,61	1,64	1,34
bb	Alluvional deposits	Sand, silt and clay	0,58	1,92	1,53
BBAa	Barrabisa Facies (Barrabisa Intrusive Unit)	Granodiorite	2,29	2,73	2,83
bc	Alluvional deposits	Silt and clay	0,61	1,64	1,34
BDD	Berchidda Intrusive Unit	Granite	2,79	3,22	3,30
BDDa	Errianoa Facies (Berchidda Intrusive Unit)	Granite	2,79	3,22	3,30
BDDb	Punta S'Elighe Entosa Facies (Berchidda Intrusive Unit)	Granite	2,79	3,22	3,30
BDDc	Monte Gasparru Facies (Berchidda Intrusive Unit)	Granite	2,79	3,22	3,30
BDDd	Monte Rasu Facies (Berchidda Intrusive Unit)	Granite	2,79	3,22	3,30
BDDe	Sa Corona Facies (Berchidda Intrusive Unit)	Granite	2,79	3,22	3,30
BDU	Bauladu Unit	Andesite	N.D.	N.D.	2,87
BGA	Bortigali Unit	Ignimbrite	N.D.	N.D.	3,12
BGD	Logudoro Basalt	Basalt	N.D.	2,60	2,00
BGD1	Thiesi Subunit (Logudoro Basalt)	Basalt	N.D.	2,60	2,00
BGD2	Semestene Subunit (Logudoro Basalt)	Basalt	N.D.	2,60	2,00
BGD3	Monte Ruju Subunit (Logudoro Basalt)	Basalt	N.D.	2,60	2,00
BGD4	San Matteo Subunit (Logudoro Basalt)	Basalt	N.D.	2,60	2,00
BGD5	Monte Poddighe Subunit (Logudoro Basalt)	Basalt	N.D.	2,60	2,00
BGD6	Punta Sos Pianos Subunit (Logudoro Basalt)	Basalt	N.D.	2,60	2,00
BGFa	Il Catalano Facies (Oristano Gulf Basalt)	Basalt	N.D.	2,60	2,00
BGFb	Conc'ailloni Facies (Oristano Gulf Basalt)	Basalt	N.D.	2,60	2,00

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
BGFc	Costa Randada Facies (Oristano Gulf Basalt)	Basalt	N.D.	2,60	2,00
BGO	Gollei Basalt	Basalt	N.D.	2,60	2,00
BGOa	Nuraghe Su Cungiadu Facies (Gollei Basalt)	Basalt	N.D.	2,60	2,00
BGOB	Biristeddi Facies (Gollei Basalt)	Basalt	N.D.	2,60	2,00
BGOc	Rio Osalla Facies (Gollei Basalt)	Ignimbrite	N.D.	N.D.	3,12
BGR	Giare Basalt	Basalt	N.D.	2,60	2,00
BGRa	Lithofacies of Giare Basalt	Basalt	N.D.	2,60	2,00
BIR	Biancareddu Formation	Slate	2,05	2,83	2,10
BIRa	Lithofacies of Biancareddu Formation	Metaconglomerate	3,22	3,59	2,79
BIRb	Lithofacies of Biancareddu Formation	Granite	2,79	3,22	3,30
BIRc	Lithofacies of Biancareddu Formation	Basalt	N.D.	2,60	2,00
BLA1a	Molimentu Facies (Monte Isalle Intrusive Subunit - Monte San Basilio Intrusive Unit)	Gabbro	2,13	2,54	2,22
BLA1b	Sa Mendula Facies (Monte Isalle Intrusive Subunit - Monte San Basilio Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BLA1c	Monte Su Da'Varu Facies (Monte Isalle Intrusive Subunit - Monte San Basilio Intrusive Unit)	Granite	2,79	3,22	3,30
BLA1d	Riu Chindamu Facies (Monte Isalle Intrusive Subunit - Monte San Basilio Intrusive Unit)	Granite	2,79	3,22	3,30
BLA2a	Punta Lunavera Facies (Punta Biriai Intrusive Subunit - Monte San Basilio Intrusive Unit)	Gabbro	2,13	2,54	2,22
BLA2b	Ponte S'Archimissa Facies (Punta Biriai Intrusive Subunit - Monte San Basilio Intrusive Unit)	Granite	2,79	3,22	3,30
BLA2c	S'Argustariu Facies (Monte Isalle Intrusive Subunit - Monte San Basilio Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BLA3a	Cantoniera Noce Secca Facies (Oddoene Intrusive Subunit - Monte San Basilio Intrusive Unit)	Granite	2,79	3,22	3,30
BLA3b	Punta Su Briliottu Facies (Oddoene Intrusive Subunit - Monte San Basilio Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BLA4	Monte Nieddu di Ottana Intrusive Subunit (Monte San Basilio Intrusive Unit)	Granodiorite	2,29	2,73	2,83

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
BME	Borta Melone Intrusive Unit	Granite	2,79	3,22	3,30
bn	Terraced alluvional deposits	Sand and silt	0,53	2,05	1,78
bna	Terraced alluvional deposits	Gravel and sand	0,50	2,22	1,52
bnb	Terraced alluvional deposits	Sand and silt	0,53	2,05	1,78
bnc	Terraced alluvional deposits	Silt and clay	0,61	1,64	1,34
BNF1a	Punta Falcone Marazzino Facies (Bocche di Bonifacio Intrusive Unit - Punta Falcone Intrusive Subunit)	Granodiorite	2,29	2,73	2,83
BNF2a	Moneta Facies (Giardinelli Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BNF2b	Garibaldi Facies (Giardinelli Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BNF3a	Marazzino Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BNF3b	Punta de la Balcaccia Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF3c	Monte Martino Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF3d	Capo Testa Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF3e	Santa Teresa di Gallura Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF3f	Cala Sambuco - Conca Verde Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF3g	Punta del Faro - la Licciola Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF3h	Baia Lu Caloni - Punta Campanile Facies (Monte Colba Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF4a	Palau Facies (Palau Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF4b	Porto Rafael Facies (Palau Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30

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BNF4c	Capo d'Orso Facies (Palau Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF4d	Monte Altura Facies (Palau Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BNF5a	Baia Trinita Facies (La Gatta - Teialone Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF5b	Spalmatore Facies (La Gatta - Teialone Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF5d	Monte Arbuticci Facies (La Gatta - Teialone Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF5e	Punta Coticcio Facies (La Gatta - Teialone Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF5f	Punta La Crucitta Facies (La Gatta - Teialone Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF5g	Abbatoggia Facies (La Gatta - Teialone Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF6a	Punta Tegge Facies (Guardia Vecchia Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF6b	Padule Facies (Guardia Vecchia Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF6c	Cala Francese Facies (Guardia Vecchia Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF6d	Porto Lungo Facies (Guardia Vecchia Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNF6e	Punta De Li Colmi Facies (Guardia Vecchia Intrusive Subunit - Bocche di Bonifacio Intrusive Unit)	Granite	2,79	3,22	3,30
BNN	Bono Unit	Ignimbrite	N.D.	N.D.	3,12
BNS	Bruncu Mois Unit	Basalt	N.D.	2,60	2,00
BNTa	Lithofacies of Brunestica Formation	Marlstone and limestone	N.D.	N.D.	2,45
BNTb	Lithofacies of Brunestica Formation	Limestone	3,48	3,80	2,40
BPL1	Campeda Subunit (Campeda-Planargia Basalt)	Basalt	N.D.	2,60	2,00
BPL2	Dualchi Subunit (Campeda-	Basalt	N.D.	2,60	2,00

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	Planargia Basalt)				
BPL3	Funtana di Pedru Oe Subunit (Campeda- Planargia Basalt)	Basalto	N.D.	2,60	2,00
BPL4	Sindia Subunit (Campeda- Planargia Basalt)	Basalt	N.D.	2,60	2,00
BRD	Monte Bardia Formation	Limestone	3,48	3,80	2,40
BRDa	Lithofacies of Monte Bardia Formation	Dolostone	3,50	3,64	2,99
BSAa	Anela Facies (Bono Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BSAb	Santa Restituta Facies (Bono Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BSAc	Bolotana Facies (Bono Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BSU	Piroclastite of Bruncu Su Sensu	Ignimbrite	N.D.	N.D.	3,12
BSUa	Lithofacies of Bruncu Su Sensu	Basalt	N.D.	2,60	2,00
BSUb	Lithofacies of Bruncu Su Sensu	Ignimbrite	N.D.	N.D.	3,12
BTH	Bithia Formation	Micaschist	2,72	3,51	2,13
BTHa	Lithofacies of Bithia Formation	Marble	3,41	4,09	2,48
BTI	Bitti Intrusive Unit	Granodiorite	2,29	2,73	2,83
BTUa	Nule Facies (Benetutti Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BTUb	Orune Facies (Benetutti Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BTUc	Nuraghe Pira Facies (Benetutti Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BUDa	Nuraghe Oddastra Facies (Buddusò Intrusive Unit)	Granodiorite	2,29	2,73	2,83
BUDb	S. Reparata Facies (Buddusò Intrusive Unit)	Granite	2,79	3,22	3,30
BUI	Burcei Intrusive Unit	Gabbro	2,13	2,54	2,22
BUN	Buntsandstein <i>Auct.</i>	Slate and sandstone	1,74	2,33	1,87
ca	Blackish phyllites	Phyllite	N.D.	N.D.	1,67
CAB	Cabitza Formation	Slate and sandstone	2,76	2,95	2,48
CAB1	Punta Camisonis Member (Cabitza Formation)	Slate and sandstone	2,76	2,95	2,48
CAB2	Punta Su Funu Member (Cabitza Formation)	Slate and sandstone	2,76	2,95	2,48
CAB3	Riu Cea de Mesu Member (Cabitza Formation)	Slate and sandstone	2,76	2,95	2,48
Canali	Channel	N.D.	N.D.	N.D.	N.D.
CBU	Monte Crobu Rhyolite	Ignimbrite	N.D.	N.D.	3,12
CDT	Comenditi <i>Auct.</i>	Ignimbrite	N.D.	N.D.	3,12

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CDT1	Cala Vinagra Subunit (Comenditi <i>Auct.</i> ("Commenditi C" <i>Auct.</i> <i>P.P.</i>))	Rhyolite	N.D.	N.D.	3,12
CDT2	Becco Nasca Subunit (Comenditi <i>Auct.</i> ("Commenditi C" <i>Auct.</i> <i>P.P.</i>))	Rhyolite	N.D.	N.D.	3,12
CDT3	Genarbi Subunit (Comenditi <i>Auct.</i> ("Commenditi C" <i>Auct.</i> <i>P.P.</i>))	Ignimbrite	N.D.	N.D.	3,12
CDT4	Punta Senoglio Subunit (Comenditi <i>Auct.</i> ("Commenditi C" <i>Auct.</i> <i>P.P.</i>))	Ignimbrite	N.D.	N.D.	3,12
CDT5	Ventrischio Subunit (Comenditi <i>Auct.</i> ("Commenditi C" <i>Auct.</i> <i>P.P.</i>))	Ignimbrite	N.D.	N.D.	3,12
CDT6	Monte Tortoriso Subunit (Comenditi <i>Auct.</i> ("Commenditi C" <i>Auct.</i> <i>P.P.</i>))	Rhyolite	N.D.	N.D.	3,12
CDT7	Sepoltura Subunit (Comenditi <i>Auct.</i> ("Commenditi C" <i>Auct.</i> <i>P.P.</i>))	Rhyolite	N.D.	N.D.	3,12
CGIa	Lithofacies of Cagliari Limestones	Malstone and sandstone	N.D.	N.D.	2,17
CGIb	Lithofacies of Cagliari Limestones	Limestone	3,48	3,80	2,40
CGIc	Lithofacies of Cagliari Limestones	Limestone	3,48	3,80	2,40
CGU	Monte Cugutada Unit	Andesite	N.D.	N.D.	2,87
CIF	Cala D'inferno Formation	Marlstone and marly limestone	N.D.	N.D.	2,48
CIX	Cixerri Formation	Claystone and sandstone	0,67	2,05	1,71
CIXa	Lithofacies Cixerri Formation	Breccia	3,56	3,78	2,95
CLS	Sinis Laminated Limestones	Limestone	3,48	3,80	2,40
CMU	Capo Mannu Formation	Sand	0,51	2,47	1,90
CNM	Corona Maria Dacite	Ignimbrite	N.D.	N.D.	3,12
CPI	Campo Pisano Formation	Marl and marly limestone	N.D.	N.D.	2,48
CPT	San Pietro Conglomerate	Conglomerate and sandstone	1,87	3,03	2,35
CRU	Correboi Marble	Marble	3,41	4,09	2,48
CSA	Sa Lilla Complex	Slate and sandstone	2,76	2,95	2,48
CSAa	Lithofacies of Sa Lilla Complex	Marble	3,41	4,09	2,48
CSAb	Lithofacies of Sa Lilla Complex	Conglomerate and sandstone	1,87	3,03	2,35
ct	Mylonitic-cataclastic bands	Breccia	3,56	3,78	2,95

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CTS	Torre del Sevo Limestone	Limestone	3,48	3,80	2,40
CUG	Cuga Unit	Ignimbrite	N.D.	N.D.	3,12
CUL	Cuglieri Unit	Ignimbrite	N.D.	N.D.	3,12
CUR	Cuccuru 'E Flores Conglomerate	Conglomerate	3,22	3,59	2,79
CURa	Lithofacies of Cuccuru 'E Flores Conglomerate	Limestone	3,48	3,80	2,40
CZS	Candelazzos unit	Ignimbrite	N.D.	N.D.	3,12
d	Eolic deposits	Sand	0,51	2,47	1,90
DAL	Dualchi Sandstones	Sand and gravel	0,50	2,22	1,52
df	Phyllonite	Phyllite	N.D.	N.D.	1,67
dg	Olistolite of "Dolomie Gialle" (Punta Sa Broccia Member - Monte Argentu Formation)	Dolostone	3,50	3,64	2,99
di	Diatexites	Granite	2,79	3,22	3,30
DIU	Piroclastite of Bruncu De Didus	Ignimbrite	N.D.	N.D.	3,12
DMV	Domusnovas Formation	Metasandstone	4,13	5,51	3,85
DMV1	Maciurru Member (Domusnovas Formation)	Metasandstone	4,13	5,51	3,85
DMV2	Punta S'Argiola Member (Domusnovas Formation)	Slate	N.D.	2,15	2,47
DMV2a	Lithofacies of Punta S'Argiola Member (Domusnovas Formation)	Slate	N.D.	2,15	2,47
DOR	Dorgali Formation	Dolostone	3,50	3,64	2,99
dr	Olistolite of Punta Sa Broccia Member (Monte Argentu Formation)	Dolostone	3,50	3,64	2,99
DUL	Ardauli Unit	Ignimbrite	N.D.	N.D.	3,12
dv	Lithofacies of Pala Manna Formation	Marble	3,41	4,09	2,48
e	Lacustrine/marsh deposits	Silt and clay	0,61	1,64	1,34
e2	Lacustrine deposits	Limestone	3,48	3,80	2,40
e3	Marsh deposits	Clay and peat	0,43	1,26	N.D.
e5	Marsh deposits	Silt and clay	0,61	1,64	1,34
ea	Lacustrine/marsh deposits	Clay and peat	0,43	1,26	N.D.
eb	Lacustrine/marsh deposits	Sand	0,51	2,47	1,90
ECI	Nureci Unit	Gabbro	2,13	2,54	2,22
EDD	Andesites of Punta Marturedda	Andesite	N.D.	N.D.	2,87
EDI	Sedilo Unit	Ignimbrite	N.D.	N.D.	3,12
EGI	Monte Enturgiu Unit	Andesite	N.D.	N.D.	2,87
ELS	Castelsardo Formation	Sandstone and slate	N.D.	2,58	2,59
ENZ	Basaltic Andesite of Monte Ennazza	Andesite	N.D.	N.D.	2,87
ENZa	Lithofacies of Basaltic	Ignimbrite	N.D.	N.D.	3,12

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	Andesite of Monte Ennazza				
ENZb	Lithofacies of Basaltic Andesite of Monte Ennazza	Andesite	N.D.	N.D.	2,87
ERI	Monte Eri Formation	Conglomerate	3,22	3,59	2,79
ERU	Erula Limestone	Limestone	3,48	3,80	2,40
ESEa	Punta Colovros Facies (Monte 'E Senes Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ESEb	Cuile Furros Facies (Monte 'E Senes Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ESEc	San Michele Facies (Monte 'E Senes Intrusive Unit)	Gabbro	2,13	2,54	2,22
ESEd	Punta Su Grabellu Facies (Monte 'E Senes Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ESEe	Punta Abba Vritta Facies (Monte 'E Senes Intrusive Unit)	Granite	2,79	3,22	3,30
ESEf	Sant'elena Facies (Monte 'E Senes Intrusive Unit)	Granite	2,79	3,22	3,30
ESS	Andesitic Basalt of Monte Essu	Basalt	N.D.	2,60	2,00
f1	Travertine	Travertine	N.D.	N.D.	1,96
fa	Undifferentiated Aplopegmatite	Granite	2,79	3,22	3,30
FAU	Monte Filau Ortogneiss	Granite	2,79	3,22	3,30
fb	Basaltic dikes of transitional series	Basalt	N.D.	2,60	2,00
fd	Dykes of intermediated composition (Dioritic and Quarzoandesitic)	Diorite	2,21	2,48	2,71
fg	Gabbro dykes	Gabbro	2,13	2,54	2,22
FGU	Sa Funtaneda Unit	Igimbrite	N.D.	N.D.	3,12
fi	Dykes of intermediated to basic composition, Andesitic or Basaltic	Andesite	N.D.	N.D.	2,87
FIS	Flumin'alis Formation	Metasandstone	4,13	5,51	3,85
fi	Dykes of intermediated composition	Andesite	N.D.	N.D.	2,87
FLU	Fluminimaggiore Formation	Slate and limestone	N.D.	2,98	2,44
FLZ	Lu Falzu Conglomerate	Conglomerate	3,22	3,59	2,79
fm	Dykes of basic composition	Basalt	N.D.	2,60	2,00
FMCa	Lithofacies of Monte Cardiga Formation	Sandstone and conglomerate	3,03	3,30	2,75
FMCb	Lithofacies of Monte Cardiga Formation	Slate	N.D.	2,15	2,47
FMCc	Lithofacies of Monte Cardiga Formation	Sandstone	2,84	3,00	2,71
fn	Alkaline dykes	Basalt	N.D.	2,60	2,00

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fo	Aplopegmatitic dykes	Granite	2,79	3,22	3,30
fp	Porphyry granite	Granite	2,79	3,22	3,30
fq	Idrothermal dykes of Quartz, often mineralized with Barite and Fluorite, and metalliche sulphydes (Pb, Zn, Cu, Fe, etc)	Granite	2,79	3,22	3,30
fr	Dacitic/Rhyolitic dykes	Rhyolite	N.D.	N.D.	3,12
FSI	Monte Frusciu Unit	Dacite	N.D.	3,73	2,58
ft	Alkairhyolitic dykes	Rhyolite	N.D.	N.D.	3,12
FTE	Monte Forte Formation	Metasandstone	4,13	5,51	3,85
FUA	Fiume Santo Formation	Slate and conglomerate	0,54	1,79	1,40
FUI	Fuile Formation	Sand	0,51	2,47	1,90
fz	Monzogranitic dykes	Granite	2,79	3,22	3,30
g	Ancient beach deposits	Sand and gravel	0,50	2,22	1,52
g2	Beach deposits	Sand and gravel	0,50	2,22	1,52
ga	Olistolite of Punta Sa Broccia Member (Monte Argentu Formation)	Metasandstone	4,13	5,51	3,85
GBA	Giba Andesite	Andesite	N.D.	N.D.	2,87
GEA	Geremeas Intrusive Unit	Granite	2,79	3,22	3,30
GEAa	Facies Serra Paulis (Geremeas Intrusive Unit)	Gabbro	2,13	2,54	2,22
GEAb	Facies Bruncu De Su Procu (Geremeas Intrusive Unit)	Gabbro	2,13	2,54	2,22
GEAc	Facies Is Mortorius (Geremeas Intrusive Unit)	Granodiorite	2,29	2,73	2,83
GEAd	Facies of Geremeas Intrusive Unit	Granodiorite	2,29	2,73	2,83
GEAe	Nicola Bove Facies (Geremeas Intrusive Unit)	Granite	2,79	3,22	3,30
GEAf	Bruncu Su Casteddu Facies (Geremeas Intrusive Unit)	Granite	2,79	3,22	3,30
GEI	Monte Genis Intrusive Unit	Granite	2,79	3,22	3,30
GEN	Gennargentu Formation	Metasandstone	4,13	5,51	3,85
GGO	San Gregorio Intrusive Unit	Granite	2,79	3,22	3,30
GGOa	Baccu Scardu Facies (San Gregorio Intrusive Unit)	Granite	2,79	3,22	3,30
GGOb	S. Gregorio Facies (San Gregorio Intrusive Unit)	Granite	2,79	3,22	3,30
GGOc	Cuccuru Nuraxi Baiocca Facies (San Gregorio Intrusive Unit)	Granite	2,79	3,22	3,30
GGT	Gneiss Migmatitici di Santa Maria	Granite	2,79	3,22	3,30
GHE	Samugheo Unit	Ignimbrite	N.D.	N.D.	3,12
GIN	Monte Grighini Intrusive	Granite	2,79	3,22	3,30

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	Unit				
GMN	Guardia Manna Andesite	Andesite	N.D.	N.D.	2,87
GMNa	Lithofacies of Guardia Manna Andesite	Ignimbrite	N.D.	N.D.	3,12
GMNb	Lithofacies of Guardia Manna Andesite	Andesite	N.D.	N.D.	2,87
gn	Olistolite of Punta Sa Broccia Member (Monte Argentu Formation)	Marble	3,41	4,09	2,48
GNI	Geniò Rhyolite (Lipariti <i>Auct. P.P</i>)	Ignimbrite	N.D.	N.D.	3,12
GNN	Gonnesa Formation	Limestone	3,48	3,80	2,40
GNN1	Dolomia Rigata Member (Gonnesa Formation)	Dolostone	3,50	3,64	2,99
GNN2	Calcare Ceroide Member (Gonnesa Formation)	Limestone	3,48	3,80	2,40
GNN2a	Lithofacies Calcare Ceroide Member (Gonnesa Formation)	Dolostone	3,50	3,64	2,99
GNN2b	Lithofacies of Calcare Ceroide Member (Gonnesa Formation)	Dolostone	3,50	3,64	2,99
GNR	Monte Genere Conglomerate	Conglomerate	3,22	3,59	2,79
GNS	Genna Selole Formation	Conglomerate	3,22	3,59	2,79
GOL	Genna Ollastus Basaltic Andesite	Andesite	N.D.	N.D.	2,87
GOLa	Lithofacies of Genna Ollastus Basaltic Andesite	Breccia	3,56	3,78	2,95
GPA	Genna Spina Unit	Rhyolite	N.D.	N.D.	3,12
GPAa	Cuccuru Is Abis Facies (Genna Spina Unit)	Glass	N.D.	N.D.	1,20
GPI	Guardia Pisano Formation	Sandstone and slate	N.D.	2,58	2,59
GPU	Gorropu Formation	Limestone	3,48	3,80	2,40
GRX	Sa Gruxita Andesite	Andesite	N.D.	N.D.	2,87
GRXa	Lithofacies of Sa Gruxita Andesite	Ignimbrite	N.D.	N.D.	3,12
GST	Gesturi Marlstone	Marl	N.D.	N.D.	2,49
GSTa	Lithofacies Gesturi Marlstone	Tuff	N.D.	N.D.	1,37
GSTb	Lithofacies Gesturi Marlstone	Sandstone	2,84	3,00	2,71
GSTc	Lithofacies Gesturi Marlstone	Sandstone	2,84	3,00	2,71
GTN	Gora Terras Nieddas Basaltic Andesite	Basalt	N.D.	2,60	2,00
GTU1	Bruncu Mura Gessa Intrusive Subunit (Gennargentu Intrusive Unit)	Andesite	N.D.	N.D.	2,87
GTU2	Monte Genna 'E Ruxi Intrusive Subunit	Granodiorite	2,29	2,73	2,83

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
	(Gennargentu Intrusive Unit)				
GTU3	Punta Paulinu Intrusive Subunit (Gennargentu Intrusive Unit)	Granodiorite	2,29	2,73	2,83
GTU4	Monte Terrarba Intrusive Subunit (Gennargentu Intrusive Unit)	Granodiorite	2,29	2,73	2,83
GUB	Guardia Sa Barracca Formation	Limestone	3,48	3,80	2,40
GUD	Nuraghe Genna Uda Unit	Andesite	N.D.	N.D.	2,87
GXL	Graxioleddu Formation	Bauxite	N.D.	N.D.	N.D.
h	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
h1i	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
h1m	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
h1n	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
h1r	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
h1u	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
h2	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
ha	Anthropic deposits	Anthropic deposits	N.D.	N.D.	N.D.
HRM	Chiaromonti Unit	Ignimbrite	N.D.	N.D.	3,12
HVN	Chilivani Unit	Ignimbrite	N.D.	N.D.	3,12
HVNa	Lithofacies of Chilivani Unit	Ignimbrite	N.D.	N.D.	3,12
ICO	Riu Bicole Sandstone	Sandstone and conglomerate	3,03	3,30	2,75
ILV	Monte Sa Silva Unit	Ignimbrite	N.D.	N.D.	3,12
IOI	Monte Ironi Unit	Ignimbrite	N.D.	N.D.	3,12
IRU	Case Cilirus Unit	Ignimbrite	N.D.	N.D.	3,12
JOR	Monte Majore Unit	Andesite	N.D.	N.D.	2,87
KEU	Keuper <i>Auct.</i>	Marl	N.D.	N.D.	2,49
L	Lakes	N.D.	N.D.	N.D.	N.D.
LAB	Calabona Unit	Andesite	N.D.	N.D.	2,87
LBG	Lu Bagnu Unit	Ignimbrite	N.D.	N.D.	3,12
LCD	Funtana Su Lacheddu Unit	Andesite	N.D.	N.D.	2,87
LCDa	Lithofacies of Funtana Su Lacheddu Unit	Shale	N.D.	2,15	2,47
LCP	Monte Lu Caparoni Formation	Conglomerate	3,22	3,59	2,79
LDU	Formazione di Pianu Ladu	Conglomerate	3,22	3,59	2,79
LGF	Punta Ischia Longa Leucogranite	Granite	2,79	3,22	3,30
LGI	Santu Lussurgiu Unit	Trachite	N.D.	N.D.	2,87
LGN	Lignitifero <i>Auct.</i>	Limestone	3,48	3,80	2,40
LGNa	Lithofacies Lignitifero <i>Auct.</i> Formation	Conglomerate	3,22	3,59	2,79
LGNb	Lithofacies Lignitifero <i>Auct.</i>	Dolostone	3,50	3,64	2,99

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
	Formation				
LGS	Monte Longos Unit	Ignimbrite	N.D.	N.D.	3,12
LGTa	Monte Franchinu Facies (Luogosanto Intrusive Unit)	Granite	2,79	3,22	3,30
LGTb	Monte Agliu Facies (Luogosanto Intrusive Unit)	Granite	2,79	3,22	3,30
LGTc	Monte Pulchiana Facies (Luogosanto Intrusive Unit)	Granite	2,79	3,22	3,30
LGTd	Contramazzone Facies (Luogosanto Intrusive Unit)	Granite	2,79	3,22	3,30
LGT e	Monti di Cognu Facies (Luogosanto Intrusive Unit)	Granite	2,79	3,22	3,30
LGTf	Montiggiu Santu Facies (Luogosanto Intrusive Unit)	Gabbro	2,13	2,54	2,22
LGU	Logulentu Unit	Ignimbrite	N.D.	N.D.	3,12
LIR	Li Corti Formation	Shale	N.D.	2,15	2,47
LML	Nuraghe Salamattile Unit	Basanite	N.D.	N.D.	2,58
LNR	San Leonardo Unit	Ignimbrite	N.D.	N.D.	3,12
LNS	Florinas Formation	Sand	0,51	2,47	1,90
LNSa	Lithofacies of Florinas Formation	Sand	0,51	2,47	1,90
LNSb	Lithofacies of Florinas Formation	Limestone	3,48	3,80	2,40
LNU1	Ilbono Intrusive Subunit (Lanusei Intrusive Unit)	Granite	2,79	3,22	3,30
LNU1a	Baccu Longu Facies (Ilbono Intrusive Subunit - Lanusei Intrusive Unit)	Granite	2,79	3,22	3,30
LNU1b	Punta Moros Facies (Ilbono Intrusive Subunit - Lanusei Intrusive Unit)	Granodiorite	2,29	2,73	2,83
LNU1c	Punta Genna Stulas Facies (Ilbono Intrusive Subunit - Lanusei Intrusive Unit)	Granodiorite	2,29	2,73	2,83
LNU1d	Cardedu Facies (Ilbono Intrusive Subunit - Lanusei Intrusive Unit)	Granodiorite	2,29	2,73	2,83
LNU1e	Barisardo Facies (Ilbono Intrusive Subunit - Lanusei Intrusive Unit)	Granodiorite	2,29	2,73	2,83
LNU2a	Brunco Maoro Facies (Quirra Intrusive Subunit - Lanusei Intrusive Unit)	Granite	2,79	3,22	3,30
LNU2b	Monte Arista Facies (Quirra Intrusive Subunit - Lanusei Intrusive Unit)	Granite	2,79	3,22	3,30
LNU2c	Santorù Facies (Quirra Intrusive Subunit - Lanusei Intrusive Unit)	Granite	2,79	3,22	3,30
LNU2d	Monte Tarè Facies (Quirra Intrusive Subunit - Lanusei Intrusive Unit)	Granite	2,79	3,22	3,30
LNZ	Lenzu Dacite	Ignimbrite	N.D.	N.D.	3,12

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
LOC	Salto di Lochele Unit	Ignimbrite	N.D.	N.D.	3,12
LOCa	Lithofacies of Salto di Lochele Unit	Ignimbrite	N.D.	N.D.	3,12
LPE	La Pedraia Formation	Shale	N.D.	2,15	2,47
LRL	La Reale Ortogneiss	Granite	2,79	3,22	3,30
LRM	Rio Minore Formation	Silt and Clay	0,61	1,64	1,34
LRS	Monte Presa Metagranite	Granite	2,79	3,22	3,30
LRT	Monte Larenta Unit	Andesite	N.D.	N.D.	2,87
LUD	Rio Su Luda Formation	Limestone	3,48	3,80	2,40
LUDa	Lithofacies of Rio Su Luda Formation	Conglomerate	3,22	3,59	2,79
LUDb	Lithofacies of Rio Su Luda Formation	Conglomerate	3,22	3,59	2,79
LUDc	Lithofacies of Rio Su Luda Formation	Silt and Clay	0,61	1,64	1,34
LUDd	Lithofacies of Rio Su Luda Formation	Limestone	3,48	3,80	2,40
LUL	Lula Phyllite	Phyllite	N.D.	N.D.	1,67
LULa	Lithofacies of Lula Phyllite	Phyllite	N.D.	N.D.	1,67
LULb	Lithofacies of Lula Phyllite	Marble	3,41	4,09	2,48
ma	Azoic Marble and Dolomitic Marble	Marble	3,41	4,09	2,48
MAB	Monte Arrubiu Andesite	Andesite	N.D.	N.D.	2,87
MABa	Lithofacies of Monte Arrubiu Andesite	Andesite	N.D.	N.D.	2,87
MAZ	Matzaccara Dacite ("Lipariti Biotitiche T3" <i>Auct.</i>).	Ignimbrite	N.D.	N.D.	3,12
MAZa	Lithofacies of Matzaccara Dacite	Ignimbrite	N.D.	N.D.	3,12
mc	Undifferentiated Micaschist and Paragneiss	Micaschist	2,72	3,51	2,13
MCA	Mitza Corona Arrubia Epilastite	Ignimbrite	N.D.	N.D.	3,12
md	Metadolerite	Metabasite	N.D.	2,60	2,00
MDD	Medadeddu Conglomerate	Conglomerate	3,22	3,59	2,79
MDM	Medau Mereu Formation	Calcare	3,48	3,80	2,40
MDV	Mal di Ventre Intrusive Unit	Granodiorite	2,29	2,73	2,83
mg	Microgranite dykes	Granite	2,79	3,22	3,30
MGD	Cala Capra Diatexite	Granite	2,79	3,22	3,30
MGM	Genna Mesa Metarkose	Metasandstone	4,13	5,51	3,85
MGMa	Lithofacies of Genna Mesa Metarkose	Metaconglomerate	3,22	3,59	2,79
MGT	Punta della Volpe	Granite	2,79	3,22	3,30
MGTa	Lithofacies of Punta della Volpe Metatexite	Anfibolite	2,46	2,78	3,03
MHN	Mandrachina Formation	Limestone	3,48	3,80	2,40

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
mi	Micaschist	Micaschist	2,72	3,51	2,13
MIA	Schina Serra Miana Unit	Basalt	N.D.	2,60	2,00
MIAa	Lithofacies of Schina Serra Miana Unit	Tuff	N.D.	N.D.	1,37
MIR	Monte Ibera Ignimbrite	Ignimbrite	N.D.	N.D.	3,12
MIRa	Lithofacies of Monte Ibera Ignimbrite	Ignimbrite	N.D.	N.D.	3,12
MLI	Miliolitico <i>Auct.</i>	Limestone	3,48	3,80	2,40
MLIa	Lithofacies of Miliolitico <i>Auct.</i> Formation	Conglomerate	3,22	3,59	2,79
MLN	Monte La Noce Rhyolite	Rhyolite	N.D.	N.D.	3,12
MLO	Villanova Monteleone Unit	Ignimbrite	N.D.	N.D.	3,12
MLR	Monte Lerno - Punta Senalonga Intrusive Unit	Granite	2,79	3,22	3,30
mm	Silicate Fels	N.D.	N.D.	N.D.	N.D.
MMN	Monte Mannu Anfibolic Andesite	Andesite	N.D.	N.D.	2,87
MNU	Montiggiu Nieddu Metabasite	Granite	2,79	3,22	3,30
mo	Metagabbro and Metadolerite	Gabbro	2,13	2,54	2,22
mp	And, Sill, Crd, Micaschist and Paragneiss	Micaschist	2,72	3,51	2,13
MPL	Monte Palmas Andesite	Andesite	N.D.	N.D.	2,87
MPLa	Lithofacies of Monte Palmas Andesite	Ignimbrite	N.D.	N.D.	3,12
MPLb	Lithofacies of Monte Palmas Andesite	Andesite	N.D.	N.D.	2,87
MPR	Monte Perda Andesite	Andesite	N.D.	N.D.	2,87
MPS	Mason Porcus Formation	Marble	3,41	4,09	2,48
MPSa	Lithofacies of Mason Porcus Formation	Marble	3,41	4,09	2,48
MPSb	Lithofacies of Mason Porcus Formation	Shale	N.D.	2,15	2,47
mr	Rhyodacitic Porphyroid	Granite	2,79	3,22	3,30
MRH	Monte Rughe Unit	Andesite	N.D.	N.D.	2,87
MRI	Monte Orri Formation	Metasandstone	4,13	5,51	3,85
MRN	Monte S Andesite	Andesite	N.D.	N.D.	2,87
MRNa	Lithofacies of Monte S Andesite	Ignimbrite	N.D.	N.D.	3,12
MRV	Muravera Metaconglomerate	Metaconglomerate	3,22	3,59	2,79
MRVa	Lithofacies of Muravera Metaconglomerate	Quarzite	5,53	7,51	5,56
ms	Undifferentiated Metatexite	Granite	2,79	3,22	3,30
MSOa	Lithofacies of Monte S'orcu Intrusive Unit	Granite	2,79	3,22	3,30
MSOb	Lithofacies of Monte S'orcu	Breccia	3,56	3,78	2,95

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
	Intrusive Unit				
MSU	Conca De Mesu Unit	Dacite	N.D.	3,73	2,58
MSV	Monte Santa Vittoria Formation	Metavulcaniti acide	2,84	3,00	2,71
MSVa	Lithofacies of Monte Santa Vittoria Formation	Metasandstone	4,13	5,51	3,85
MSVb	Lithofacies of Monte Santa Vittoria Formation	Metasandstone	4,13	5,51	3,85
MSVc	Lithofacies of Monte Santa Vittoria Formation	Metavulcanite	2,84	3,00	2,71
mt	Metavulcanite	Metavulcanite	2,84	3,00	2,71
MTD	Pala Mantedda Unit	Andesite	N.D.	N.D.	2,87
MTR	Mataracui Andesite	Andesite	N.D.	N.D.	2,87
MTS	Capo Testa Limestone	Limestone	3,48	3,80	2,40
MUC	Monte Uccari Formation	Limestone	3,48	3,80	2,40
MUK	Muschelkalk <i>Auct.</i>	Limestone	3,48	3,80	2,40
MUK1	Su Grifoneddu Member (Muschelkalk <i>Auct.</i>)	Clay and Marl	N.D.	N.D.	2,59
MUK2	Su Passu Malu Member (Muschelkalk <i>Auct.</i>)	Breccia	3,56	3,78	2,95
MUX	Genna Muxerru Formation	Slate	2,05	2,83	2,10
MUZ	Su Muzzioni Metasandstone and Quarzite	Metasandstone	4,13	5,51	3,85
MUZa	Lithofacies of Su Muzzioni Metasandstone and Quarzite	Metaconglomerate	3,22	3,59	2,79
MUZb	Lithofacies of Su Muzzioni Metasandstone and Quarzite	Quarzite	5,53	7,51	5,56
mv	Lithofacies of Pala Manna Formation	Metabasite	N.D.	2,60	2,00
NBB	Nuraghe Baboe Formation	Conglomerate	3,22	3,59	2,79
nc	Not classifiable area	ND	N.D.	N.D.	N.D.
NCA	Nuraghe Casteddu Formation	Shale	N.D.	2,15	2,47
NDD	Campanedda Formation	Limestone	3,48	3,80	2,40
NDU	Capo Nieddu Unit	Basalt	N.D.	2,60	2,00
NEB1	Matoppa Member (Nebida Formation)	Metasandstone	4,13	5,51	3,85
NEB1a	Lithofacies of Matoppa Member (Nebida Formation)	Marble	3,41	4,09	2,48
NEB2	Punta Manna Member (Nebida Formation)	Metarenaria	4,13	5,51	3,85
NEB2a	Lithofacies of Punta Manna Member (Nebida Formation)	Marmo	3,41	4,09	2,48
NGS	Punta Mingosa Rhyolite (Lipariti "T" <i>Auct.P.P.</i>)	Ignimbrite	N.D.	N.D.	3,12

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
NIA	Punta Niassa Unit	Rhyolite	N.D.	N.D.	3,12
NIEa	Punta Micalotto Facies (Monte Nieddu Intrusive Unit)	Granite	2,79	3,22	3,30
NIEb	Loiri Facies (Monte Nieddu Intrusive Unit)	Granite	2,79	3,22	3,30
NIEc	Concas Facies (Monte Nieddu Intrusive Unit)	Granite	2,79	3,22	3,30
NIEd	Monte Nieddu Facies (Monte Nieddu Intrusive Unit)	Granite	2,79	3,22	3,30
NLI	Santa Giulia Unit	Andesite	N.D.	N.D.	2,87
NLL1	Conglomerato Di Duidduru (Formazione di Nurallao)	Conglomerate	3,22	3,59	2,79
NLL1a	Lithofacies of Duidduru Conglomerate (Nurallao Formation)	Conglomerate	3,22	3,59	2,79
NLL2	Serra Longa Sandstones (Nurallao Formation)	Sandstone	2,84	3,00	2,71
NLL2a	Lithofacies of Serra Longa Sandstones (Nurallao Formation)	Sandstone	2,84	3,00	2,71
NMC	San Marco Unit	Ignimbrite	N.D.	N.D.	3,12
NNA	S.Anna Gneiss	Granite	2,79	3,22	3,30
NNE	Colonne Vulcanoclastite (Lipariti "T" <i>Auct.P.P.</i>)	Ignimbrite	N.D.	N.D.	3,12
NNIa	Pratobello Facies (Fonni Intrusive Unit)	Granodiorite	2,29	2,73	2,83
NNIb	Gavoi Facies (Fonni Intrusive Unit)	Granodiorite	2,29	2,73	2,83
NNIc	Lodine Facies (Fonni Intrusive Unit)	Granodiorite	2,29	2,73	2,83
NNN	Punta dei Cannoni Rhyolite	Ignimbrite	N.D.	N.D.	3,12
NOL	Nuraghe Ola Intrusive Unit	Granite	2,79	3,22	3,30
NPI	Nuraghe Pitzienti Andesite	Andesite	N.D.	N.D.	2,87
NRC	Monte Narcao Andesite	Andesite	N.D.	N.D.	2,87
NRR	Monte Nurra Formation	Dolostone	3,50	3,64	2,99
NRRa	Lithofacies of Monte Nurra Formation	Sandstone	2,84	3,00	2,71
NRU	Capo Negru Formation	Metasandstone	4,13	5,51	3,85
NRUa	Lithofacies of Capo Negru Formation	Metavulcanite	2,84	3,00	2,71
NST	Monte Santo Formation	Calcare	3,48	3,80	2,40
NTA	Nuraghe Giuntas Unit	Ignimbrite	N.D.	N.D.	3,12
NTIa	Sos Preigadores Facies (Monti Intrusive Unit)	Gabbro	2,13	2,54	2,22
NTIb	Monti Facies (Monti Intrusive Unit)	Granodiorite	2,29	2,73	2,83
NTIc	Stazzo Alinedu Facies (Monti Intrusive Unit)	Granodiorite	2,29	2,73	2,83

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
NTId	Monte Chilchiritanos Facies (Monti Intrusive Unit)	Granito	2,79	3,22	3,30
NTIe	Stazione di Monti Facies (Monti Intrusive Unit)	Granite	2,79	3,22	3,30
NUO1	Ottana Intrusive Subunit (Nuoro Intrusive Unit)	Granite	2,79	3,22	3,30
NUO2	Monte Cuculio Intrusive Subunit (Nuoro Intrusive Unit)	Granodiorite	2,29	2,73	2,83
NUR	Nuraxi Rhyolite(Lipariti "T4" <i>Auct.</i>)	Igimbrite	N.D.	N.D.	3,12
NVT	Nughedu S. Vittoria Unit	Igimbrite	N.D.	N.D.	3,12
NVTa	Lithofacies of Nughedu S. Vittoria Unit	Sand and Clay	0,55	2,05	1,78
nx	Lithofacies of Pala Manna Formation	Granite	2,79	3,22	3,30
NXS	Serra Nuaxis Andesitic Basalt	Basalt	N.D.	2,60	2,00
NXSa	Lithofacies of Serra Nuaxis Andesitic Basalt	Igimbrite	N.D.	N.D.	3,12
NXSb	Lithofacies of Serra Nuaxis Andesitic Basalt	Andesite	N.D.	N.D.	2,87
oa	Oligo-Miocenic dykes	Andesite	N.D.	N.D.	2,87
OBN1a	Marrerri Facies (Su Redentore Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granodiorite	2,29	2,73	2,83
OBN1b	Caparedda Facies (Su Redentore Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
OBN1c	Fàrcana Facies (Su Redentore Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
OBN1d	Jacu Piu Facies (Su Redentore Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
OBN1e	Ordolai Facies (Su Redentore Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
OBN1f	Cuccuru Nigheddu Facies (Su Redentore Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
OBN2a	Crastu Longu Facies (Olzai Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
OBN2b	Monte Lutz Facies (Olzai Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
OBN3a	Monte Pranu Facies (Irgoli Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30

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OBN3b	Capo Comino Facies (Irgoli Intrusive Subunit - Monte Ortobene Intrusive Unit)	Granite	2,79	3,22	3,30
oc	Oligo-Miocenic dykes	Granite	2,79	3,22	3,30
ODO	Modolo Formation	Sandstone	2,84	3,00	2,71
OER	Macomer Unit	Ignimbrite	N.D.	N.D.	3,12
OERb	Lithofacies of Macomer Unit	Ignimbrite	N.D.	N.D.	3,12
og	Ortogneiss	Granite	2,79	3,22	3,30
OIA	Monte Olia Unit	Ignimbrite	N.D.	N.D.	3,12
OLD	Monte Oladri Andesite	Andesite	N.D.	N.D.	2,87
OLE	Olmedo Unit	Ignimbrite	N.D.	N.D.	3,12
OMN	Romana Unit	Ignimbrite	N.D.	N.D.	3,12
ONE	Lodè-Mamone Ortogneiss	Granite	2,79	3,22	3,30
ONEa	Lithofacies of Lodè- Mamone Ortogneiss	Granite	2,79	3,22	3,30
ONI	Punta Macciaroni Andesite	Andesite	N.D.	N.D.	2,87
OPN	Oppia Nuova Formation	Sand	0,51	2,47	1,90
oq	Oligo-Miocenic dykes	Quartzite	5,53	7,51	5,56
ORGa	Monte Nieddu Facies (Orgosolo Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ORGb	Monte Locoe Facies (Orgosolo Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ORGd	Ponte Gorinnaru Facies (Orgosolo Intrusive Unit)	Granodiorite	2,29	2,73	2,83
ORR	Orroledu Formation	Metasandstone	4,13	5,51	3,85
ORRa	Lithofacies of Orroledu Formation	Metasandstone	4,13	5,51	3,85
ORRb	Lithofacies of Orroledu Formation	Metabasite	N.D.	2,60	2,00
ORRc	Lithofacies of Orroledu Formation	Marble	3,41	4,09	2,48
ORS1	Cala Gonone Subsintheme ("Panchina Tirreniana" <i>Auct.</i>) (Orosei Sintheme)	Gravel and Sand	0,50	2,22	1,52
ORS2a	Lithofacies of Su Gologone Subsintheme (Sintema di Orosei)	Gravel and Sand	0,50	2,22	1,52
ORS2c	Lithofacies of Su Gologone Subsintheme (Orosei Sintheme)	Gravel, Sand and Silt	0,53	2,02	1,56
ORS2d	Lithofacies of Su Gologone Subsintheme (Orosei Sintheme)	Gravel, Sand and Silt	0,53	2,02	1,56
ORU	Orudè Formation ("Orizzonte di Orudè" <i>Auct.</i>)	Limestone	3,48	3,80	2,40
OSA	Bosa Unit	Ignimbrite	N.D.	N.D.	3,12
OSCa	Punta Gomoretta Facies (Sos Canales Intrusive Unit)	Granite	2,79	3,22	3,30

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
OSCb	Sos Sonorolos Facies (Sos Canales Intrusive Unit)	Granite	2,79	3,22	3,30
OSCc	Loelle Facies (Sos Canales Intrusive Unit)	Granite	2,79	3,22	3,30
OSCd	Punta Tepilora Facies (Sos Canales Intrusive Unit)	Granite	2,79	3,22	3,30
OSCe	Bultei Facies (Sos Canales Intrusive Unit)	Granite	2,79	3,22	3,30
OS Cf	Tres Montes Facies (Ozieri Intrusive Subunit - Sos Canales Intrusive Unit)	Granite	2,79	3,22	3,30
OSDa	Badu Luras Facies (Osidda Intrusive Unit)	Gabbro	2,13	2,54	2,22
OSI	Undifferentiated Upper Ordovician	Metarenaria e argilloscisto	4,13	5,51	3,85
OSL	Osilo Unit	Andesite	N.D.	N.D.	2,87
OSLa	Lithofacies of Osilo Unit	Gravel, Sand and Silt	0,53	2,02	1,56
OTG	Golfo Aranci Ortogneiss	Granite	2,79	3,22	3,30
OTL	Orotelli Unit	Ignimbrite	N.D.	N.D.	3,12
OTUa	Ponte Becciu Facies (Mandrolisai Intrusive Unit)	Granodiorite	2,29	2,73	2,83
OTUb	Ortuero Facies (Mandrolisai Intrusive Unit)	Granite	2,79	3,22	3,30
OTUc	Atzara Facies (Mandrolisai Intrusive Unit)	Granite	2,79	3,22	3,30
OTUd	Ponte Araxisi Facies (Mandrolisai Intrusive Unit)	Granodiorite	2,29	2,73	2,83
OTUe	Case Figu Facies (Mandrolisai Intrusive Unit)	Granite	2,79	3,22	3,30
OTUf	Monte Occelei Facies (Mandrolisai Intrusive Unit)	Granite	2,79	3,22	3,30
OVA	Ortogneiss di Cala d'Oliva	Granite	2,79	3,22	3,30
OVOa	Lago Benzone Facies (Ovodda Intrusive Unit)	Granodiorite	2,29	2,73	2,83
OVOb	Teti Facies (Ovodda Intrusive Unit)	Granodiorite	2,29	2,73	2,83
OVOc	Tiana Facies (Ovodda Intrusive Unit)	Granite	2,79	3,22	3,30
OZS	Monte Ozzastru Unit	Andesite	N.D.	N.D.	2,87
pa	Porfidi Quarziferi <i>Auct.</i>	Rhyolite	N.D.	N.D.	3,12
PAM	Monte Pramas Unit	Andesite	N.D.	N.D.	2,87
pb	Andesite	Andesite	N.D.	N.D.	2,87
PBNa	Lithofacies of Monte Sa Pibionada Dacite and Andesite	Dacite	N.D.	3,73	2,58
PBNb	Lithofacies of Monte Sa Pibionada Dacite and Andesite	Andesite	N.D.	N.D.	2,87
PDDa	Lithofacies of Monte Porceddu Piroclastite	Ignimbrite	N.D.	N.D.	3,12
PDDb	Lithofacies of Monte	Ignimbrite	N.D.	N.D.	3,12

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
	Porceddu Piroclastite				
PDF	Monte Perdas De Fogu Andesite	Andesite	N.D.	N.D.	2,87
PDFa	Lithofacies of Monte Perdas De Fogu Andesite	Breccia	3,56	3,78	2,95
PDFb	Lithofacies of Monte Perdas De Fogu Andesite	Breccia	3,56	3,78	2,95
PDL	Palmadula Formation	Shale	N.D.	2,15	2,47
PDR	Monte Santu Padre Unit	Ignimbrite	N.D.	N.D.	3,12
PDRa	Lithofacies of Monte Santu Padre Unit	Ignimbrite	N.D.	N.D.	3,12
PDU	Riu Pireddu Intrusive Unit	Granodiorite	2,29	2,73	2,83
pe	Pegmatitic dykes	Granite	2,79	3,22	3,30
PED	Monte Pedru Unit	Andesite	N.D.	N.D.	2,87
PEDa	Lithofacies of Monte Pedru Unit	Clay	0,64	1,65	1,03
PEU	Monte Perdedu Rhyolite	Ignimbrite	N.D.	N.D.	3,12
PFDa	Lithofacies of Sa Fossada Piroclastite	Ignimbrite	N.D.	N.D.	3,12
PFDb	Lithofacies of Sa Fossada Piroclastite	Ignimbrite	N.D.	N.D.	3,12
PFI	Sa Perda Firma Andesite	Andesite	N.D.	N.D.	2,87
pg	Olistolite of Pala Manna Formation	Metavulcaniti acide	2,84	3,00	2,71
PGI	Pogolina Unit	Ignimbrite	N.D.	N.D.	3,12
PGS	Sarrabus Gray Porphyroids	Metavulcanite	2,84	3,00	2,71
PID	Undifferentiated Permo- Trias	N.D.	N.D.	N.D.	N.D.
PMN	Pala Manna Formation	Slate	2,05	2,83	2,10
PMNa	Lithofacies of Pala Manna Formation	Metaconglomerate	3,22	3,59	2,79
PMNb	Lithofacies of Pala Manna Formation	Quarzite	5,53	7,51	5,56
PMNc	Lithofacies of Pala Manna Formation	Metabasite	N.D.	2,60	2,00
PMNd	Lithofacies of Pala Manna Formation	Quarzite and slate	N.D.	3,37	2,76
PMNe	Lithofacies of Pala Manna Formation	Metaconglomerate	3,22	3,59	2,79
PMNf	Lithofacies of Pala Manna Formation	Slate	2,05	2,83	2,10
pn	Paragneiss	Micaschist	2,72	3,51	2,13
POC	Capo Caccia Formation	Limestone	3,48	3,80	2,40
pp	Poligenic Breccia	Breccia	3,56	3,78	2,95
pr	Rhyolite	Ignimbrite	N.D.	N.D.	3,12
PRD	Cuccuru Porceddus Andesite	Andesite	N.D.	N.D.	2,87
PRDa	Lithofacies of Cuccuru	Breccia	3,56	3,78	2,95

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
	Porceddus Andesite				
PRDb	Lithofacies of Cuccuru Porceddus Andesite	Andesite	N.D.	N.D.	2,87
PRF	Porfiroidi <i>Auct.</i>	Metavulcanite	2,84	3,00	2,71
PRFa	Lithofacies of Porfiroidi <i>Auct.</i>	Metavulcanite	2,84	3,00	2,71
PRJ	Punta Ruja Unit	Ignimbrite	N.D.	N.D.	3,12
PRR	Pizzo Arrubiu Andesite	Andesite	N.D.	N.D.	2,87
PRRa	Lithofacies of Pizzo Arrubiu Andesite	Ignimbrite	N.D.	N.D.	3,12
PRRb	Lithofacies of Pizzo Arrubiu Andesite	Breccia	3,56	3,78	2,95
PRU	Paringianu Rhyolite (Lipariti "T1" <i>Auct.</i>)	Ignimbrite	N.D.	N.D.	3,12
PSR	Punta Serpeddi Formation	Metasandstone	4,13	5,51	3,85
PSR1	Bruncu Spollittu Member (Punta Serpeddi Formation)	Metasandstone	4,13	5,51	3,85
PSR2	Sa Murta Member (Punta Serpeddi Formation)	Metaconglomerate	3,22	3,59	2,79
PSR3	Is Mallorus Member (Punta Serpeddi Formation)	Metasandstone	4,13	5,51	3,85
PST	Perdas Stufaras Andesite	Andesite	N.D.	N.D.	2,87
PSTa	Lithofacies of Perdas Stufaras Andesite	Breccia	3,56	3,78	2,95
PTU	Porto Teulada Intrusive Unit	Granodiorite	2,29	2,73	2,83
PTX	Portixeddu Formation	Slate	2,05	2,83	2,10
PTXa	Lithofacies of Portixeddu Formation	Slate	2,05	2,83	2,10
PUF	Punta del Frara Limestones	Limestone	3,48	3,80	2,40
PUZ	Mandra Puzzones Unit	Ignimbrite	N.D.	N.D.	3,12
PUZa	Lithofacies of Mandra Puzzones Unit	Ignimbrite	N.D.	N.D.	3,12
PVM1	Calamosca Subsintheme ("Panchina Tirreniana" <i>Auct.</i> (Portovesme Sintheme)	Conglomerate	3,22	3,59	2,79
PVM2a	Lithofacies of Portoscuso Subsintheme (Portovesme Sintheme)	Gravel	0,49	1,96	1,14
PVM2b	Lithofacies of Portoscuso Subsintheme (Portovesme Sintheme)	Sand	0,51	2,47	1,90
PVM2c	Lithofacies of Portoscuso Subsintheme (Portovesme Sintheme)	Breccia	3,56	3,78	2,95
PVM2d	Lithofacies of Portoscuso Subsintheme (Portovesme Sintheme)	N.D.	N.D.	N.D.	N.D.
PVM2e	Lithofacies of Portoscuso Subsintheme (Portovesme Sintheme)	Limestone	3,48	3,80	2,40

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
qu	Quarzite	Quarzite	5,53	7,51	5,56
rc	Karst fillings	Breccia	3,56	3,78	2,95
RCP	Castello Pontes Rhyolite	Ignimbrite	N.D.	N.D.	3,12
RCU	Monte Arcuentu Unit	Andesite	N.D.	N.D.	2,87
RDS	Punta Tripides Unit	Andesite	N.D.	N.D.	2,87
RDU	Boroneddu Sandstone	Sand	0,51	2,47	1,90
REP	Mal Repos Formation	Limestone	3,48	3,80	2,40
RESa	Lithofacies of Mores Formation	Limestone	3,48	3,80	2,40
RESb	Lithofacies of Mores Formation	Sandstone and conglomerate	3,03	3,30	2,75
RESc	Lithofacies of Mores Formation	Conglomerate	3,22	3,59	2,79
RESd	Lithofacies of Mores Formation	Conglomerate	3,22	3,59	2,79
RGR	Rio San Giorgio Formation	Conglomerate	3,22	3,59	2,79
RGU	Capo Marargiu Unit	Andesite	N.D.	N.D.	2,87
RGUa	Porto Baosu Facies (Capo Marargiu Unit)	Ignimbrite	N.D.	N.D.	3,12
RIU	Su Colombariu Unit	Trachite	N.D.	N.D.	2,87
RML	Marmilla Formation	Malstone and sandstone	N.D.	N.D.	2,17
RMLa	Lithofacies of Marmilla Formation	Tuff	N.D.	N.D.	1,37
RMLb	Lithofacies of Marmilla Formation	Tuff	N.D.	N.D.	1,37
RMM	Monte Fromma Unit	Andesite	N.D.	N.D.	2,87
RRL	Barrali Intrusive Unit	Granite	2,79	3,22	3,30
RRTa	Lithofacies of Serrenti Epilastite	Limestone	3,48	3,80	2,40
RRTb	Lithofacies of Serrenti Epilastite	Argilla e marna	N.D.	N.D.	2,59
RRU	Nuraghe Furrù Unit	Ignimbrite	N.D.	N.D.	3,12
RSM	Rio San Marco Formation	Slate	2,05	2,83	2,10
RSM1	Punta Arenas Member (Rio San Marco Formation)	Metaconglomerato	3,22	3,59	2,79
RSM2	Cuccuruneddu Member (Rio San Marco Formation)	Metasandstone	4,13	5,51	3,85
RSM3	Serra Corroga Member (Rio San Marco Formation)	Metasandstone	4,13	5,51	3,85
RSM4	Girisi Member (Rio San Marco Formation)	Slate	2,05	2,83	2,10
RSR	Barisardo Basalt	Basalt	N.D.	2,60	2,00
RSU	Monte Rassu Unit	Basalt	N.D.	2,60	2,00
RTNa	Porto Rotondo Facies (Porto Rotondo Intrusive Unit)	Granodiorite	2,29	2,73	2,83
RTNb	Porto Cugnana Facies (Porto Rotondo Intrusive	Granite	2,79	3,22	3,30

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
	Unit)				
RTU	Borutta Formation	Marl	N.D.	N.D.	2,49
RUG	Monte Rugiu Unit	Dacite	N.D.	3,73	2,58
RUN	Ruinas Unit	Ignimbrite	N.D.	N.D.	3,12
RUNa	Lithofacies of Ruinas Unit	Clay	0,64	1,65	1,03
SBBa	S'Arriu De Sa Figu Facies (Santa Barbara Intrusive Unit)	Granodiorite	2,29	2,73	2,83
SBBb	S'arcu Varzia Facies (Santa Barbara Intrusive Unit)	Granite	2,79	3,22	3,30
sc	Contatùte	N.D.	N.D.	N.D.	N.D.
SDD	Sorteddatta Formation	Limestone	3,48	3,80	2,40
SDS	Serra De Su Pranu SintHEME	Gravel, sand and silt	0,53	2,02	1,56
SEI	Sedilo Sandstones	Sandstone and conglomerate	3,03	3,30	2,75
SEP	Serra di Paringianu Rhyolite (Lipariti "T" <i>Auct.P.P</i>)	Ignimbrite	0,00	0,00	3,12
sg	Lithofacies of Pala Manna Formation	Slate	2,05	2,83	2,10
SGA	Scisti a Graptoliti <i>Auct.</i>	Slate	2,05	2,83	2,10
sga	Lithofacies of Pala Manna Formation	Marble	3,41	4,09	2,48
SGAb	Lithofacies of Scisti a Graptoliti <i>Auct.</i>	Argilloscisto	2,05	2,83	2,10
sgb	Lithofacies of Pala Manna Formation	Radiolarite e argillite	N.D.	3,37	2,76
SGS	Monte Santa Giusta Vulcanite	Ignimbrite	N.D.	N.D.	3,12
SIO	Serra Is Ollastus Formation	Conglomerate	3,22	3,59	2,79
sm	Mylonitic schist	Phyllite	N.D.	N.D.	1,67
SMI	Monte Santu Miali Complex	Breccia	3,56	3,78	2,95
SMIa	Lithofacies of Monte Santu Miali Complex	Ignimbrite	N.D.	N.D.	3,12
SMR	Capo San Marco Formation	Clay, Sand and Limestone	N.D.	N.D.	2,45
SMRa	Lithofacies of Capo San Marco Formation	Marly clay	N.D.	N.D.	1,76
SMU	Scano Montiferro Unit	Basanite	N.D.	N.D.	2,58
SNLa	Lithofacies of Rocca Pischinale Unit	Breccia	3,56	3,78	2,95
SNR	Serra De Nuargius Andesite	Andesite	N.D.	N.D.	2,87
SPU	Su Pardu Vulcanoclastite	Ignimbrite	N.D.	N.D.	3,12
SQA	Siliqua Piroclastite	Ignimbrite	N.D.	N.D.	3,12
SRC	Seruci Rhyolite	Ignimbrite	N.D.	N.D.	3,12
SRCa	Lithofacies of Seruci Rhyolite	Ignimbrite	N.D.	N.D.	3,12

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SRM	Serra Coremò Andesite	Andesite	N.D.	N.D.	2,87
SSO	Montagna di Capo Rosso Rhyolite ("Tufi Liparitici" <i>Auct.</i>)	Ignimbrite	N.D.	N.D.	3,12
SSU	Su Suerzu Unit	Ignimbrite	N.D.	N.D.	3,12
STD	Rocca Sa Pattada Unit	Basalt	N.D.	2,60	2,00
STP	Serra 'E Tepuis Piroclastite and Epiclastite	Breccia	3,56	3,78	2,95
SVI	San Vito Sandstone	Metasandstone	4,13	5,51	3,85
SVIa	Lithofacies of San Vito Sandstone	Metaconglomerate	3,22	3,59	2,79
SVIb	Lithofacies of San Vito Sandstone	Marble	3,41	4,09	2,48
SXN	Monte Su Silixianu Tonalite	Granite	2,79	3,22	3,30
SZU	Monte Sotzu Unit	Tephryte	N.D.	N.D.	N.D.
TADa	Punta Pubugliema Facies (Pattada Intrusive Unit)	Granite	2,79	3,22	3,30
TADb	Bantine Unità Facies (Pattada Intrusive Unit)	Gabbro	2,13	2,54	2,22
TADc	Punta Sa Matta Facies (Pattada Intrusive Unit)	Granite	2,79	3,22	3,30
TDD	Tarra Padedda Intrusive Unit	Granite	2,79	3,22	3,30
TDI	Tadasuni Formation	Conglomerate	3,22	3,59	2,79
TEU	Sa Teula Unit	Ignimbrite	N.D.	N.D.	3,12
TGA1	Longone Subsinthema ("Panchina Tirreniana" <i>Auct.</i>) (S. Teresa di Gallura Sinthema)	Limestone	3,48	3,80	2,40
TGA2	Cannigione Subsinthema (S. Teresa di Gallura Sinthema)	Gravel	0,49	1,96	1,14
TGR	Monte Togoro Unit	Basalt	N.D.	2,60	2,00
TIL	Riu Tilisai Unit	Ignimbrite	N.D.	N.D.	3,12
TILa	Lithofacies of Riu Tilisai Unit	Sand and silt	0,53	2,05	1,78
TLR	Chelchedu-Tiloromo Unit	Andesite	N.D.	N.D.	2,87
TLTa	Scala di La Multa Facies (Telti Intrusive Unit)	Granite	2,79	3,22	3,30
TLTb	Rio Sa Raina Facies (Telti Intrusive Unit)	Granite	2,79	3,22	3,30
TMF	Monte Ferro Trachite	Trachite	N.D.	N.D.	2,87
TOO	Isola del Toro Trachite	Trachite	N.D.	N.D.	2,87
TOS	Bosa Tuff	Tuff	N.D.	N.D.	1,37
TOZ	La Tozza Basic Mass	Granite	2,79	3,22	3,30
TPS	Tempio Pausania Intrusive Unit	Granite	2,79	3,22	3,30
TPS1a	S. Lucia Facies (Bortigiadas Intrusive Subunit - Tempio Pausania Intrusive Unit)	Gabbro	2,13	2,54	2,22

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m°K)
TPS1b	S. Pancrazio Facies (Bortigiadas Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granodiorite	2,29	2,73	2,83
TPS1c	Punta Di Capragia Facies (Bortigiadas Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granodiorite	2,29	2,73	2,83
TPS1d	Stazzo Spina Facies (Bortigiadas Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS2a	Rio Pedralza Facies (Catala Intrusive Subunit - Tempio Pausania Intrusive Unit)	Breccia	3,56	3,78	2,95
TPS2b	Rinaggiu Facies (Catala Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS2c	Giacone Facies (Subunità Intrusiva di Catala - Tempio Pausania Intrusive Unit)	Granodiorite	2,29	2,73	2,83
TPS2d	Monte di La Jescia Facies (Catala Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS2e	Punta Lovia Avra Facies (Catala Intrusive Subunit - di Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS2f	Punta Paoleddu Facies (Catala Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS3a	Monte San Giorgio Facies (Monte Limbara Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS3b	Monte di Li Conchi Facies (Monte Limbara Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS3c	Valliciola Facies (Monte Limbara Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS3d	Punta Balistreri Facies (Limbara Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS3e	Punta Bozzico Facies (Monte Limbara Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPS3f	Monte La Eltica Facies (Monte Limbara Intrusive Subunit - Tempio Pausania Intrusive Unit)	Granite	2,79	3,22	3,30
TPU	Punta Trempu Intrusive Unit	Granodiorite	2,29	2,73	2,83
TRS	Tracasi Andesite	Andesite	N.D.	N.D.	2,87

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Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
TSU	Monte Traessu Unit	Rhyolite	N.D.	N.D.	3,12
TTL	Riu Trattalas Diorite	Diorite	2,21	2,48	2,71
TTR	S. Caterina di Pittinuri Formation	Limestone	3,48	3,80	2,40
TTS	Monte Settiballas Micaschist	Micaschist	2,72	3,51	2,13
TTZ	Tramatza Unit	Andesite	N.D.	N.D.	2,87
tu	Olistostrome of Pala Manna Formation	Limestone	3,48	3,80	2,40
TUL	Monte Tului Formation	Limestone	3,48	3,80	2,40
TUV	Tuviois Formation	Metasandstone	4,13	5,51	3,85
TUVa	Lithofacies of Tuviois Formation	Limestone	3,48	3,80	2,40
TVU	Punta Su Tuvu Unit	Ignimbrite	N.D.	N.D.	3,12
UBR	Monte Baranta Unit	Ignimbrite	N.D.	N.D.	3,12
UCU	Cuccuru Aspru Unit	Basalt	N.D.	2,60	2,00
ULA	Monte Mola Unit	Andesite	N.D.	N.D.	2,87
ULM	Monte Ulmus Hyperalkaline Rhyolite (Lipariti "T2" <i>Auct.</i>)	Ignimbrite	N.D.	N.D.	3,12
UMM	Monte Miale Spina Unit	Ignimbrite	N.D.	N.D.	3,12
UMP	Monte San Pietro Unit	Ignimbrite	N.D.	N.D.	3,12
UNV	Nuraghe Vittore Unit	Andesite	N.D.	N.D.	2,87
URA	Monte Mura Unit	Ignimbrite	N.D.	N.D.	3,12
URD	Casa Cardo Intrusive Unit	Gabbro	2,13	2,54	2,22
URG	Urgoniano <i>Auct.</i>	Limestone	3,48	3,80	2,40
URI	Is Urigus Basaltic Andesite	Andesite	N.D.	N.D.	2,87
USS	Ussana Formation	Conglomerate	3,22	3,59	2,79
USSa	Lithofacies of Ussana Formation	Breccia	3,56	3,78	2,95
USSc	Lithofacies of Ussana Formation	Sandstone	2,84	3,00	2,71
USSd	Lithofacies of Ussana Formation	Limestone	3,48	3,80	2,40
USSe	Lithofacies of Ussana Formation	Ignimbrite	N.D.	N.D.	3,12
USSf	Lithofacies of Ussana Formation	Limestone	3,48	3,80	2,40
USSg	Lithofacies of Ussana Formation	Limestone	3,48	3,80	2,40
UUI	Uri Unit	Ignimbrite	N.D.	N.D.	3,12
UZZ	Luzzana Unit	Ignimbrite	N.D.	N.D.	3,12
VGD1b	Lago Alto Flumendosa Facies (Villanova Intrusive Subunit - Villagrande Intrusive Unit)	Granodiorite	2,29	2,73	2,83
VGD1c	Genna Silana Facies (Villanova Intrusive Subunit - Villagrande Intrusive Unit)	Granodiorite	2,29	2,73	2,83

Analysis of geological parameters for optimization of geothermal probes applied to heat pumps:
individuation of a technical and procedural iter

A.A. 2014 - 2015

Map label (CARG)	Geological formation	Equivalent thermal lithotype	Thermal conductivity [Unsaturated] (W/m °K)	Thermal conductivity [Saturated] (W/m °K)	Thermal conductivity [Without definition of the water content] (W/m °K)
VG1e	Pedrabas Facies (Villanova Intrusive Subunit - Villagrande Intrusive Unit)	Granite	2,79	3,22	3,30
VG2a	Punta Nulai Facies (Monte Fenalbu Intrusive Subunit - Villagrande Intrusive Unit)	Granite	2,79	3,22	3,30
vi	Olistolite of Pala Manna Formation	Limestone	3,48	3,80	2,40
VLD	Villacidro Intrusive Unit	Granite	2,79	3,22	3,30
VLDa	Punta Mandaresus Facies (Villacidro Intrusive Unit)	Granite	2,79	3,22	3,30
VLDb	Punta De Peis De Pruna Facies (Villacidro Intrusive Unit)	Granite	2,79	3,22	3,30
VLDc	Monte Lattias Facies (Villacidro Intrusive Unit)	Granite	2,79	3,22	3,30
VLDd	Gutturu Derettu Facies (Villacidro Intrusive Unit)	Granite	2,79	3,22	3,30
VLD e	Punta Sa Cresia Facies (Villacidro Intrusive Unit)	Granite	2,79	3,22	3,30
VLG	Villagrecia Limestone	Limestone	3,48	3,80	2,40
VLL	Villasalto Limestone <i>Auct.</i>	Marble	3,41	4,09	2,48
VRM	Monte Lasana Rhyolite	Ignimbrite	N.D.	N.D.	3,12
VRS	Villarios Conglomerate	Conglomerate	3,22	3,59	2,79
vs	Metavulcanite	Prophyroid	2,84	3,00	2,71
VTT	S. Vittoria Unit	Andesite	N.D.	N.D.	2,87
ZAR	Monte Zara Andesite	Andesite	N.D.	N.D.	2,87
ZAV	Nuraghe Zavos Unit	Ignimbrite	N.D.	N.D.	3,12
ZEP	Cuccuru Zeppara Basalt	Basalt	N.D.	2,60	2,00

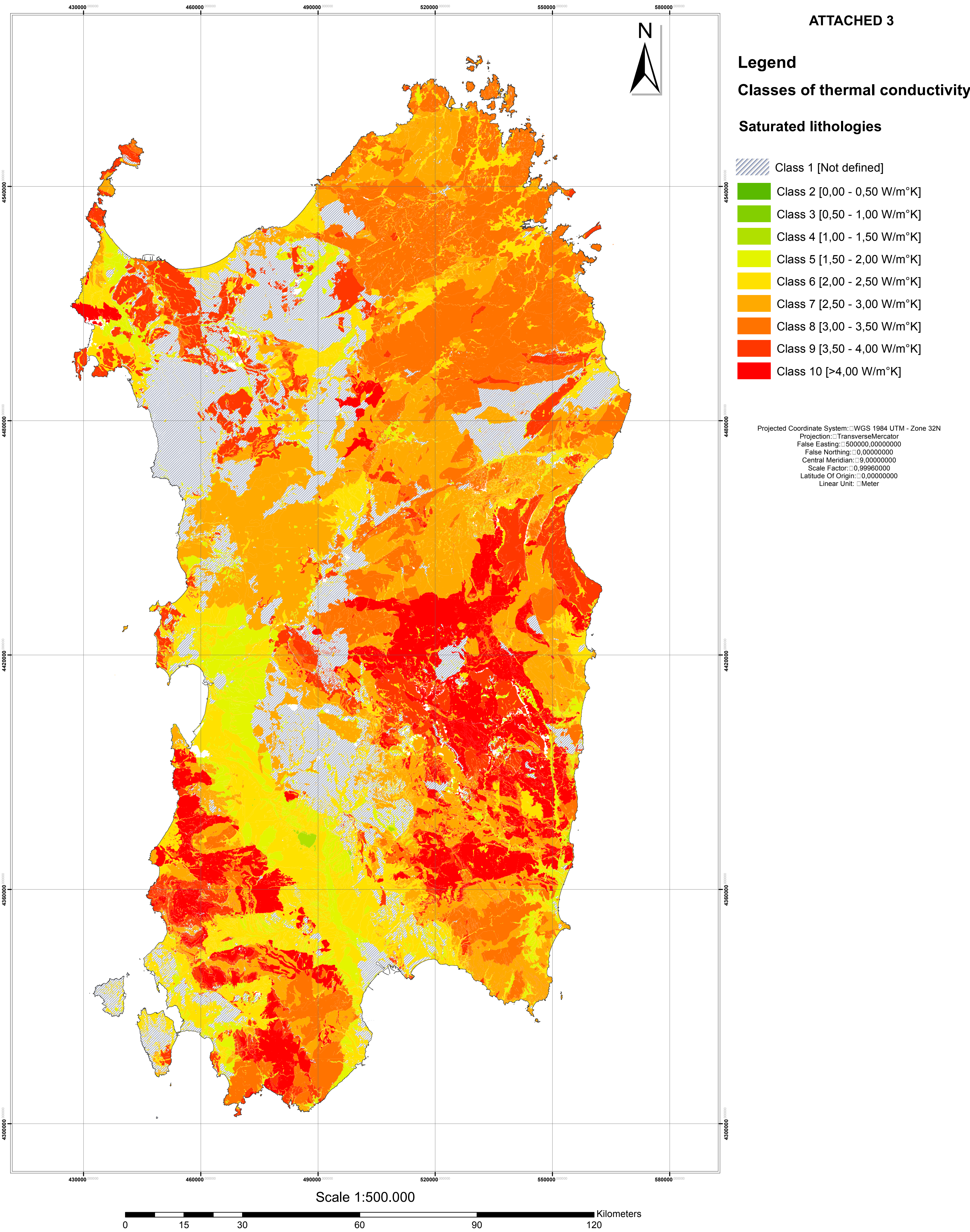
12.2 Bibliographical references of thermal conductivity

Litotype	Thermal conductivity (W/m ² K)
Clay	1.03
Dry clay	0.64
Saturated clay	1.65
Marly clay	2.00
Sandy clay	0.66
Wet silt and clay	1.70
Silt	1.65
Dry silt	0.58
Saturated silt	1.62
Sand	1.90
Dry sand	0.51
Compact dry sand	1.18
Thin sand	1.00
Coarse sand	0.80
Medium sand	1.67
Saturated sand	2.47
Wet sand	1.34
Gravel and sand	1.80
Gravel	1.14
Cemented gravel	2.00
Dry gravel	0.49
Saturated gravel	1.96
Marl	2.49
Dry marly limestone	2.29
Saturated marly limestone	2.35
Marly limestone	2.29
Peat	0.42
Limestone	2.40
Dry limestone	3.48
Saturated limestone	3.80
Limestone (1900 kg/m ³)	1.50
Limestone (2100 kg/m ³)	1.71
Limestone (2700 kg/m ³)	2.86
Calcare (2800 kg/m ³)	3.50
Limestone and dolostone	2.40
Dry limestone and dolostone	2.73
Saturated limestone and dolostone	2.81
Karstified limestone	3.40
Fine-grained saccharoid limestone	3.50
Coarse-grained saccharoid limestone	2.80
Grained limestone	0.95
Oolitic limestone	2.57
Dry oolitic limestone	2.53
Saturated oolitic limestone	2.85
Massive limestone	2.15
Dolostone	3.00
Dry dolostone	3.48
Saturated dolostone	3.60
Travertine	1.52
Gypsum	1.04
Dry gypsum	0.93

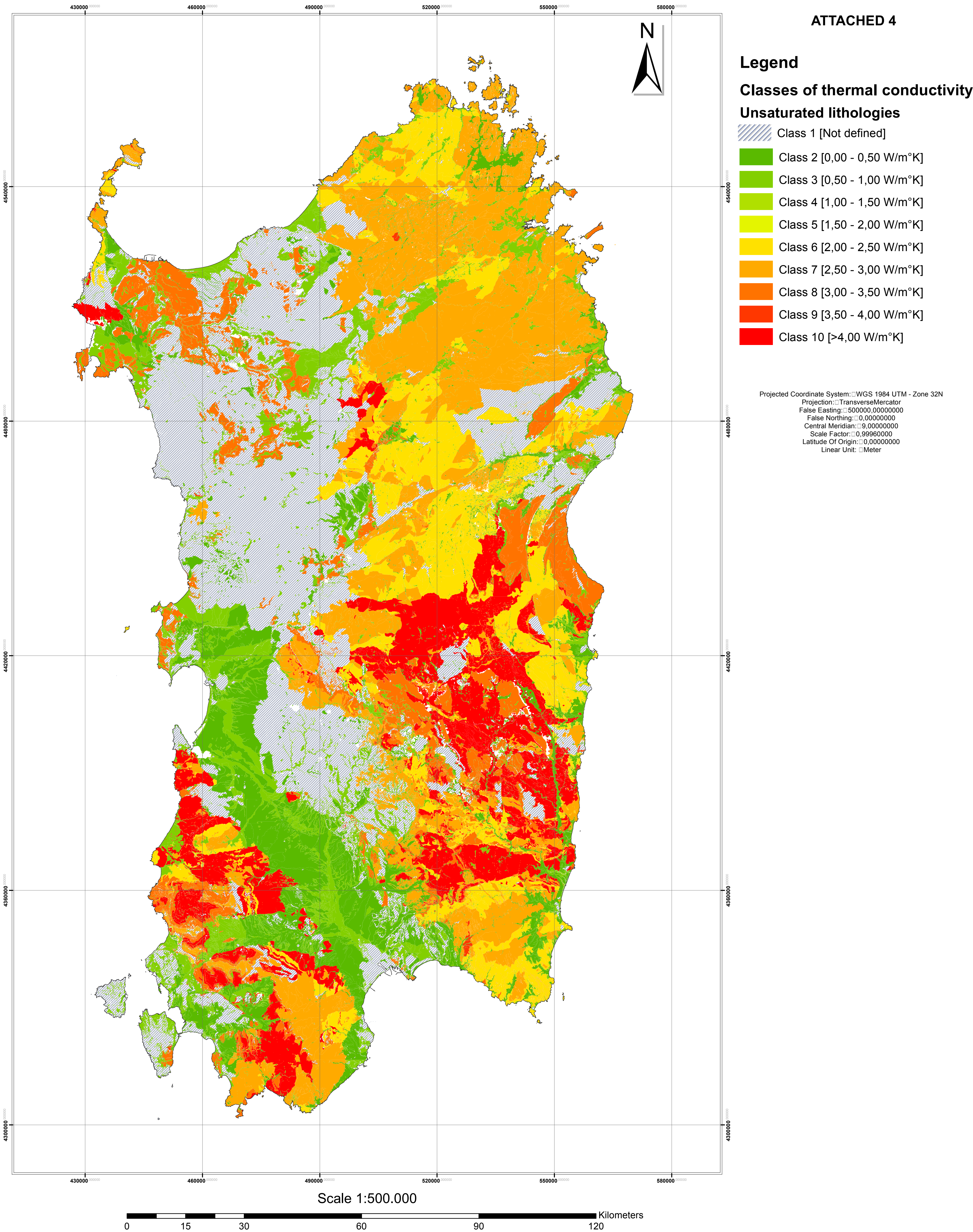
Wet Gypsum	0.80
Saturated gypsum	1.46
Salt	5.41
Anhydrite	4.93
Slate	2.47
Saturated slate	2.15
Siltstone	2.24
Dry siltstone	2.67
Saturated siltstone	2.90
Sandstone	2.71
Dry sandstone	1.60
Wet sandstone	2.84
Saturated sandstone	3.00
Conglomerate	2.79
Dry conglomerate	3.22
Saturated conglomerate	3.59
Dry dolomitic breccia	3.67
Saturated dolomitic breccia	4.04
Dry breccia	3.56
Saturated breccia	3.78
Breccia	2.95
Andesite	2.39
Basalt	2.00
Wet basalt	2.60
Trachite	2.87
Tuff (1550 Kg/m ³)	0.63
Tuff (2270 Kg/m ³)	1.70
Pumice	0.36
Rhyolite	3.12
Vulcanic tuff	1.37
Ingimbrite	3.12
Obsidian	1.20
Diabase or dolerite	1.86
Vetro	0.95
Alplite	3.20
Pegmatite	3.05
Dry pegmatite	3.72
Saturated pegmatite	4.78
Porphyry	2.50
Dunite	4.19
Peridotite	4.06
Gabbro	2.22
Dry gabbro	2.13
Saturated gabbro	2.54
Anortosite	2.35
Syenite	2.41
Diorite	2.71
Dry diorite	2.21
Saturated diorite	2.48
Saturated granodiorite	2.83
Dry granodiorite	2.29
Granodiorite	2.73
Granite	3.30
Granite (3000 Kg/m ³)	4.10
Granite (2500 Kg/m ³)	2.95
Shale	2.98
Schist	2.47
Dry schist	2.03
Saturated schist	2.94
Micaschist	2.13
Dry micaschist	2.72

Saturated micaschist	3.51
Clay slate	1.95
Serpentine	3.27
Dry serpentine	2.80
Saturated serpentine	3.81
Anfibolite	3.03
Dry anfibolite	2.46
Saturated anfibolite	2.78
Eclogite	3.08
Wet marble	2.50
Marble	2.48
Dry marble	3.41
Saturated marble	4.09
Gneiss	2.99
Dry gneiss	2.45
Saturated gneiss	3.64
Ardesia	3.09
Arkose	3.01
Quartzite	5.81
Dry quartzite	5.53
Saturated quartzite	7.51
Vulcanite	2.01
Dacite	2.58
Phyllite	1.67
Schist	3.88
Radiolarite	3.37
Dolomite	2.99
Saturated granite	3.22
Dry granite	2.79
Saturated marl	2.77
Saturated anhydrite	3.39
Saturated dacite	3.73
Saturated radiolarite	3.37
Schist	2.10
Coal	0.31
Monzonite	2.40
Dry peat	0.06
Wet peat (50 %)	0.29
Saturated peat	0.50
Saturated schist	1.86

Thermal conductivity map for saturated lithologies of Sardinia Region



Thermal conductivity map for unsaturated lithologies of Sardinia Region



Thermal conductivity map for lithologies without indication of water content of Sardinia Region

