Development of urban geothermal systems: how to promote a sustainable approach?

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ABSTRACT

Labelled Ecocity, Grenoble Presqu'île is a large urban development project (265 hectares) located at the confluence of the Drac and Isère Rivers. With regard to energy aspects, the city council wanted the buildings to meet precise environmental objectives, namely 30% below low-energy building standard requirements, and connection to a shallow geothermal energy system to cover heating, domestic hot water and summer cooling requirements.

The Presqu'île district environment is characterized by a high energy demand, various other subsurface uses and a constantly changing neighbourhood. Within this context the development of very low-temperature geothermal energy in a sustainable and optimized manner was made possible mainly through a specific planning procedure (ZAC), a relevant tool (groundwater and heat transpirt modelling) to assess the impacts of present and future geothermal systems and underground uses and the political will from Grenoble municipal council.

1. INTRODUCTION

Cities emit the majority of anthropogenic greenhouse gases [1, 2]. Their carbon footprint could be reduced by establishing sustainable energy systems that are more energy-efficient and use on-site renewable energy sources [3].

With this regard, and with a view to keeping operating costs relatively low and promoting a good environmental image, there is growing interest in using geothermal resources accessible at shallow depths beneath cities, as a number of recent developments have shown.

The city environment is characterized by high demand for energy, limited space available for installing geothermal systems, and the existence of other potentially interacting subsurface uses. In addition, cities are constantly being built and regenerated as part of a continuous process.

In light of these factors, the sustainable development of low temperature geothermal resources in urban areas is called into question.

According to various authors [3-6] the main issues to be addressed relate to:

- Scientific research, to gain a better understanding of the impact on the groundwater environment,
- Regulation, which is deemed to be insufficient, to control the increasing use of shallow geothermal resources while minimizing adverse effects on the groundwater environment,
- Subsurface planning, to minimize conflicts between geothermal systems and other subsurface uses.

Drawing on the specific case of the Presqu'île district of Grenoble, France, we will show that subsurface planning is the key factor in the sustainable development of shallow geothermal resources.

The Presqu'île urban development project is presented hereafter, along with its potential adverse impacts. The paper then briefly overviews the French present geothermal energy regulation framework, before moving on to discuss the subsurface planning approach implemented.

2. THE GRENOBLE PRESQU'ILE URBAN DEVELOPMENT PROJECT

Grenoble is located in the northern part of the French Alps, at the confluence of the Drac and Isère rivers.

The confluence area is called the "Presqu'île" (the French word for "peninsula").

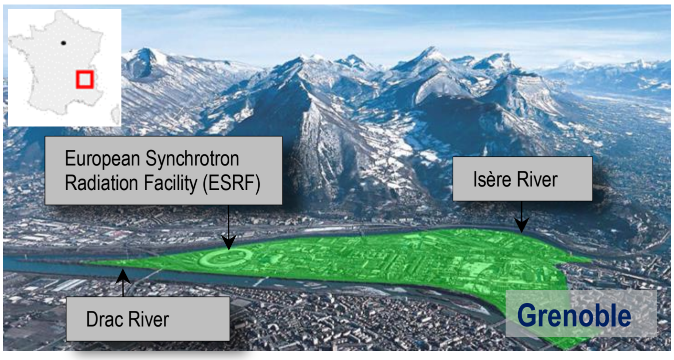

Figure 1: Grenoble Presqu'île District

This flood-prone area has been progressively developed thanks to the construction of embankments.

It was initially occupied by the French army as a firing range, before being the site of significant development for scientific purposes, notably through the building of the Grenoble Nuclear Research Centre (CENG) by the French Atomic Energy Authority (CEA) from 1956 onwards. Since then there has been continuous development of what has now become the Grenoble science park (nuclear research and nanotechnology).

Grenoble Presqu'île is a large-scale urban development project that aims to transform this sector into a new neighbourhood, intended for a variety of different uses (work, research, leisure and housing).

Covering a total area of 265 ha, it will comprise a research and innovation campus (GIANT), a new tramway line, offices, family and student accommodation, businesses and new public spaces. It is broken down as follows:

- 250 000 m^2 of tertiary-sector buildings
- 230 000 m^2 of research laboratories
- 50 000 m^2 of buildings for higher education
- 2 500 m^2 of family housing units
- 1 000 m^2 of student accommodation
- 9 000 m^2 of businesses and services
- 20 000 m^2 of public facilities

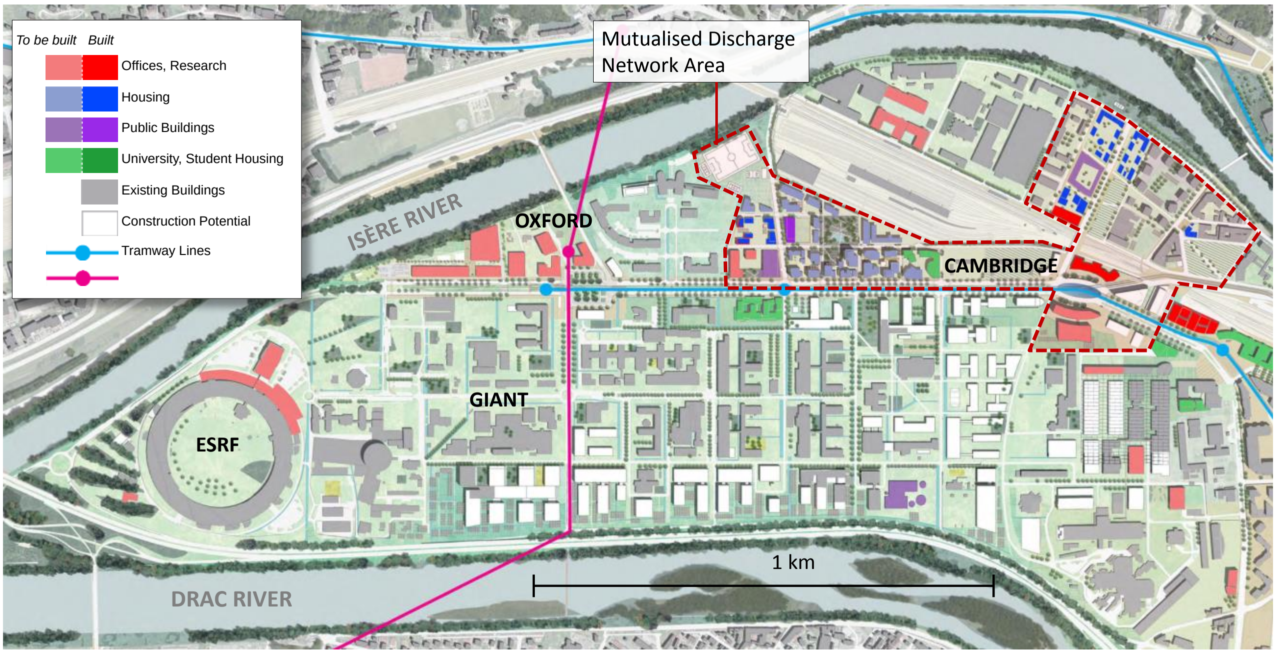

Figure 2. The Presqu'île Urban Development Project

The development works are scheduled to continue up to 2035.

With regard to energy aspects, the city council wanted the buildings to meet precise environmental objectives, namely 30% below low-energy building standard requirements, and connection to a shallow geothermal energy system to cover heating, domestic hot water and summer cooling requirements.

These requirements are in line with Grenoble's goal of being at the very forefront of sustainable development and renewable energy in France. The Presqu'île project, which has been given Ecocity label, was able to draw on lessons learnt with the development of Grenoble's Bonne district, the first eco-district in France, which is self-sufficient from the energy standpoint.

3. POTENTIAL IMPACTS OF DEVELOPMENT OF GEOTHERMAL ENERGY IN AN URBAN SETTING

For a shallow (very low temperature) geothermal development project to be sustainable, it is essential to take into account interactions with other subsurface uses.

Potential impacts linked to modification of the aquifer temperature

Groundwater is abstracted from a shallow aquifer via a borehole. After passing through a heat exchanger coupled with the heat pump (where the heat is extracted or dissipated), all the water – which has become warmer after being used for cooling or cooler after being used for heating – is pumped back into the aquifer via an injection borehole (open loop system).

From the thermal point of view, the reinjected water locally changes the temperature of the groundwater, by creating thermal plumes that propagate in the direction of groundwater flow.

In the case of a constrained space (e.g. the construction of a geothermal doublet on a small plot of land), if the distance between the point of abstraction and the point of discharge is insufficient, water may recirculate (some of the water injected into the aquifer will be captured once again by the abstraction well), and this will reduce the efficiency of the system.

Modifying the temperature of the aquifer at the discharge point may also disturb the operation of other doublets located nearby.

Lastly, injection of warm-hot water could modify the chemistry and biology of the groundwater and cause problems such as biological clogging, corrosion of the pump (this effect is usually minimal).

Long term thermal impact on groundwater quality is still to be addressed but this question is not specific to urban areas.

Potential impacts linked with aquifer hydrodynamics (flow rates, levels)

First of all, the specifications for a doublet are based on the requirements of the building concerned, expressed in terms of the flow rates and difference in temperature between the abstraction point and the discharge point.

It is necessary, therefore, to determine whether the aquifer is locally able to "supply" the flow rate required. This flow rate depends in particular on the hydrodynamic characteristics of the aquifer and may be affected by other pumping wells situated in the immediate vicinity (large-scale pumping nearby will reduce the possibility of developing new pumping facilities). Similarly, other abstraction wells situated in the vicinity may be affected by the construction of new ones.

Lastly, the presence of existing or future buried structures may cause local disturbance of subsurface flows and lead to a reduction in the productivity of the wells.

The construction of a doublet will produce a local drop in the water table close to the abstraction well and a rise in the water table close to the injection well.

These modifications in the water table level may affect buried structures, in terms of either their stability or through the arrival of unwanted water from outside. This is the case of the following structures in the Presqu'île district:

- Car parks (risk of flooding due to extraneous water);
- Wastewater and stormwater sewerage networks (stability and arrival of extraneous water);
- Diaphragm wall of the Institut Laue-Langevin – ILL nuclear reactor (stability);
- European Synchrotron Radiation Facility (ESRF) (stability and arrival of extraneous water in the drainage system surrounding the site).

Modifications in the water table level may also affect flow directions and, for example, modify the directions in which a pollution plume spreads.

The following figure illustrates the main current subsurface uses that may interfere with the development of geothermal systems.

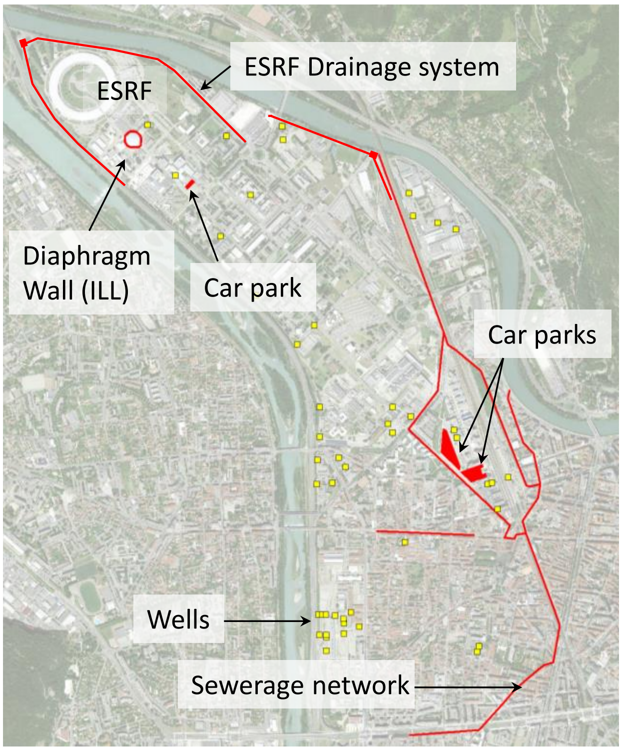

Figure 3: Underground Structures that May Potentially Interfere with Geothermal Systems

In this context, where there are other subsurface uses and the neighbourhood is constantly changing, how is it possible to develop very low-temperature geothermal energy in a sustainable, optimised manner?

4. BRIEF SUMMARY OF THE REGULATORY CONTEXT CONCERNING GEOTHERMAL SYSTEMS IN FRANCE

The following texts are the main ones that apply to the development of geothermal systems in France:

- The Mining Code;
- The Environment Code.

According to the French system, a mine belongs to nobody (res nullius). The State awards the right to use a mine and determines the conditions in which it is to be exploited [7].
The notion of mine covers fuels, metals, mineral and chemical resources and subsurface heat.

As a result, in order to obtain authorisation to exploit a mining resource, it is necessary to obtain authorisation to carry out investigations, to start construction work and a permit to exploit it, both of which are issued by the State. The associated documents must include an impact assessment (relating to the project itself or to the project works, depending on the procedure), which describes in detail the measures taken to attenuate or eliminate such impacts.

Current changes in the regulatory context surrounding geothermal system concern only small operations (systems of minor importance, power capacity < 500 kW).

In the framework of an urban development project covering several years, the regulations relating to geothermal systems would be ill-adapted to making allowance for future systems, even if they should become more stringent. The notion of future damage exists in French law, but it implies on the one hand that future urban development would have to be known in detail, and also that the associated damage could be defined as certain, and that it could be quantified. In other words, French regulations evaluate current projects on a case-by-case basis and cannot regulate future geothermal projects nor help in optimising them (indeed, that is not their role).

Thus, the only possible approach for sustainable, optimised development of geothermal systems in an urban environment is one based on urban planning. The following section describes to what extent existing planning procedures can be used for such development.

5. URBAN DEVELOPMENT ZONES (“ZAC”): POWERFUL TOOLS FOR THE LONG-TERM AND OPTIMISED DEVELOPMENT OF GEOTHERMAL ENERGY IN URBAN ENVIRONMENTS

We have seen that current and future interactions between the different uses of the subsoil can result in conflicts of use. Hence, it is necessary to plan urban developments, on the one hand by taking into account potentially incompatible uses and, on the other hand, by imposing guiding principles for development projects, which must be in line with the city’s development policy. This process can be achieved by using the “ZAC” approach.

A “ZAC” (French acronym for Urban Development Zone) is a legal framework that allows the public sector to delimit an area for future development and to negotiate the programme with the potential developers (either public or private).

A ZAC can be considered as the framework with which local authorities handle the development process while taking on the financial risks of the operation [8].

These zones are often an opportunity for a local authority and the potential developer and concession operator to introduce other criteria than mere property cost optimisation when selecting property operators. Hence, this process creates competition between property developers by forcing them to respond to a series of requirements laid down by the local authority and then formalised during the sale in the specifications.

The constraints associated with the specifications can result in additional costs for property developers (sale price control policy for social housing, additional costs resulting from energy-related choices required by the municipal council, etc.). The resulting approach consists in proposing reduced prices on the land to compensate for these additional costs and thereby make this type of programme interesting for property developers. In this case, political choices have an obvious cost (lower revenue from the sale of land, but control over the resulting urban development).

The creation of relatively strict rules implemented by local authorities is not only a constraint: it also represents an opportunity for land or property developers. Firstly, this reflects the objectives of the development authorities and the property developers, not to tend towards deregulation and the most open competition between players, but rather to setting clear and stable rules (with regard to land rights or how the costs related to the operations are borne). Furthermore, this allows them to switch their focus from the financial aspects of the programmes to what they define as the core of their business lines, i.e. the construction of high-quality property complexes. Property developers do not strive for complete freedom of action. On the contrary, they prefer local authorities to set clear and stringent urban development rules so that the competition between promoters can be limited to certain precise aspects. This limits the amount of uncertainty that must be borne, and therefore the resources (financial or other) that need to be mobilised to deal with this uncertainty.

Furthermore, local authorities have assets that allows them impose their policy:

- They own plots of land that can sometimes represent significant sizes;
- They have pre-emptive rights to purchase plots of land, and can even use expropriation procedures in certain cases;
- They can exert their influence on land law.

For the specific case of the Presqu’île de Grenoble project, we will see in the next section how the municipal council managed to promote the long-term and optimised development of geothermal energy.

6. A FRAMEWORK FOR THE LONG-TERM AND OPTIMISED DEVELOPMENT OF GEOTHERMAL ENERGY FROM GROUNDWATER ON THE PENINSULA

InnoVia Grenoble durablement (INNOVIA), a Grenoble urban planning semi-public company, is in charge for supervising the ZAC Presqu’île development.

The development of geothermal energy is based on two pillars:

- Restrictive specifications that provide a framework for the development of geothermal energy;

- A tool to assess the impacts of the projects while taking into account all the uses that are being made of the subsoil.

Specifications [9,10]

An entire section of the specifications for the ZAC is dedicated to the management of the aquifer ("fiche monographique" sheet).

In its introduction, the sheet provides a reminder on the need to monitor geothermal resources on the scale of the district in order to allow their long-term exploitation.

"In a deep sedimentary zone that also contains the confluence between the rivers Drac and Isère, the aquifer is large but it is already the subject of significant exploitation. The development of the Presqu'Ile project is going to result in a major modification of needs. Given the planned energy flow pooling and balancing processes, the subsoil and the aquifer in this part of the city are now at the heart of the available renewable energy resources. The sensitivity of this invisible resource requires good knowledge and monitoring in order to allow its use in the long term."

depths that can overlap the maximum groundwater level, must be declared prior to their launch; any dewatering operations must be specified and must receive prior approval in coordination with the ZAC before being carried out […];

2. Operations to drill new wells or boreholes for pumping or reinjection purposes, even on a temporary basis, must be the subject of an impact assessment prior to their implementation, using the tool developed by Innovia on the scale of the ZAC, in order to check their feasibility, the lack of interference with the other structures, and the limitation of their impact. At a later stage, this impact will be tracked using the monitoring system implemented (measurements using piezometers) and the regular calibration of the model. It will also be incorporated in the thermal flow and material balances. The specifications for the structures and the precise operating conditions will be provided with a view to being used for the model, which will be taken into account by the requestor"

Assessment tool of Geothermal Projects

A model of groundwater flows and heat propagation has been developed for a zone that covers the Presqu'île district.

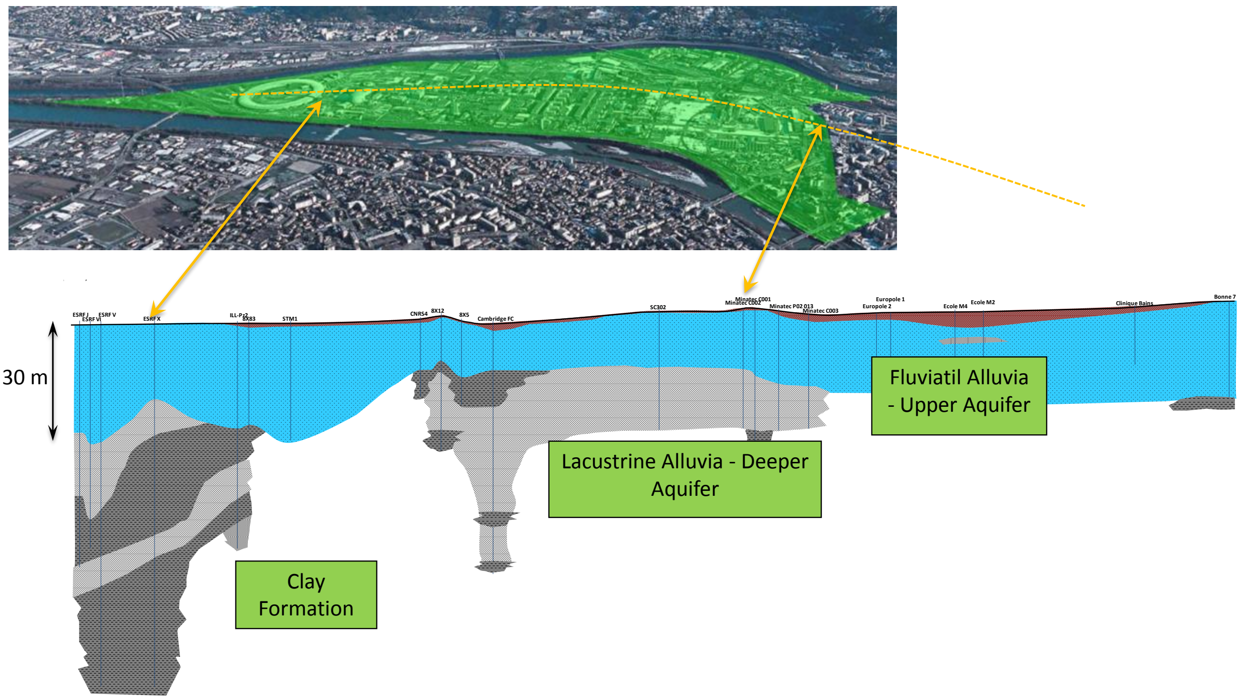

Figure 4: Hydrogeological Context

Hence, all the actions that have an impact on this strategic aquifer will be supervised, whether they are one-off or permanent actions.

The sheet then specifies the obligations of the property developers with regard to any works that may have an impact on the aquifer (involving geothermal energy or other types of works):

1. "Any works involving infrastructure in the subsoil and that have an impact on the aquifer (foundations, diaphragm walls), i.e. structures that are located at

It takes into account a hydrogeological context characterized by two aquifers at different depths (Cf. Figure 4):

• An upper aquifer consisting of fluviatile alluvia and controlled mainly by the Drac and Isère rivers. At present, all water pumping and reinjection operations take place in this aquifer;

• A deep aquifer flowing very slowly through the fine lacustrine alluvium. There are no boreholes tapping this aquifer, although its thermal potential could be interesting in view of these hydrodynamic characteristics, in particular for heat storage.

The fluviatile deposits are approximately 20-30 meters thick with hydraulic conductivity of 4.10^{-3} m^2/s-1. The groundwater table is around 4 m below the surface and the main direction of the flow is from the river Drac to the river Isère.

The average groundwater temperature is approximately 14°C and seasonal variations are relatively small.

The 3D groundwater model was developed in 2012 to assess the impacts of existing and future geothermal schemes. The model covers a surface area of 500 ha and has been divided into three layers defined on the basis of geological characteristics. The mesh designed takes all the site singularities (wells, drains, carpark, diaphragm wall, etc.) into account. The model extent and the mesh are presented on the figure below.

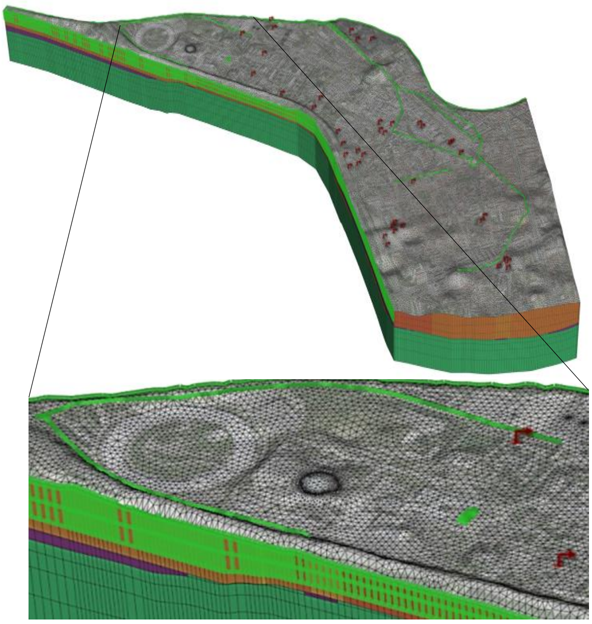

Figure 4: Mesh and Model Extent

Since 2012, there is a regular survey of the groundwater in order to collect enough data to understand the thermal diffusion inside the aquifer and to calibrate the model.

The aquifer is monitored by 23 observation boreholes with temperatures and water levels (at a fixed depth) being recorded automatically. Monthly thermal logs are also recorded.

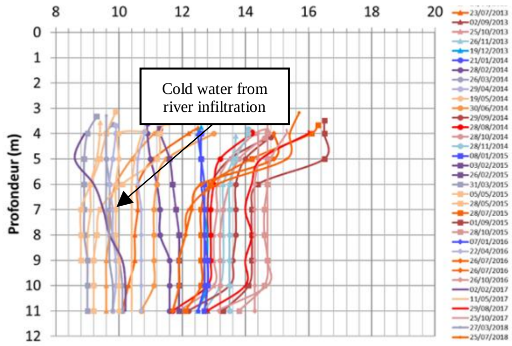

Figure 5: Upper Aquifer Thermal Logs

The data show:

- no vertical temperature gradient in the upper aquifer;
- spatial temperature variations, generated by inflows infiltrating from the river Drac to the aquifer, heat transfers within the aquifer and groundwater being warmed as it flows under the urban area;
- seasonal temperature distribution within a range of 1°C to 6°C.

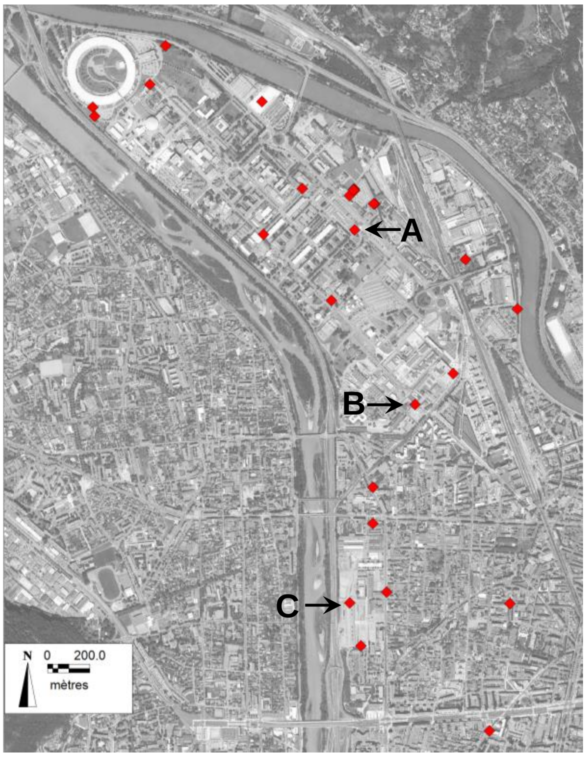

Figure 6: Groundwater Level and Temperature Monitoring Network

This continuous survey of the aquifer allows the present impacts to be modelled and the numerical model to be calibrated regularly.

This calibration consists mainly in adjusting the hydrodynamic data and the spatial distribution of thermal dispersivity and porosity.

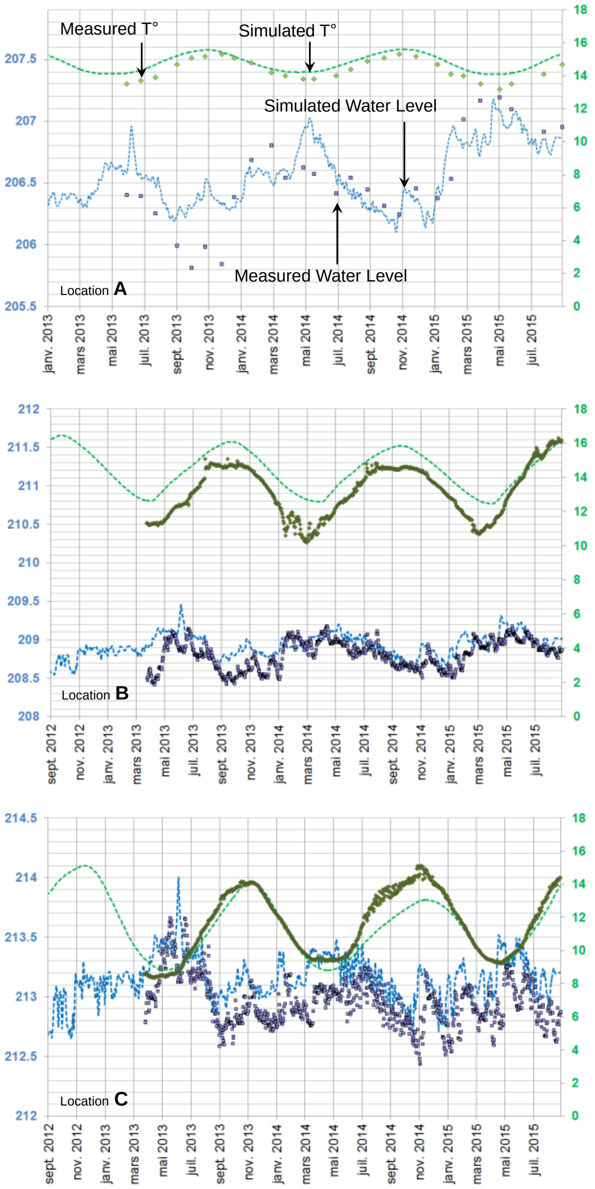

Figure 8: Hydrogeological Model Calibration (Water Level and Temperature). Borehole Locations are indicated at Figure 7.

The model is updated regularly and recalibrated when necessary.

7. ILLUSTRATION OF THE DEVELOPED APPROACH

The value of the approach is that it relies on:

- A groundwater and heat transport model which is regularly updated, and, the case being, recalibrated;
- The consideration of, not only all present underground uses, but also planned projects (not yet built).

Since 2014, impacts of 12 geothermal projects were assessed at the request of developers or the planner. For each new project, a numerical simulation is realised and covers a period of 30 years consistent with the period requested for a geothermal permit.

Some examples here-below illustrate the overall approach.

A doublet project

The project relates to the cooling, all year round, of a data center. Temperature differences vary between +4°C and +7°C and well discharge rates vary from 100 to over 700 m^3/h.

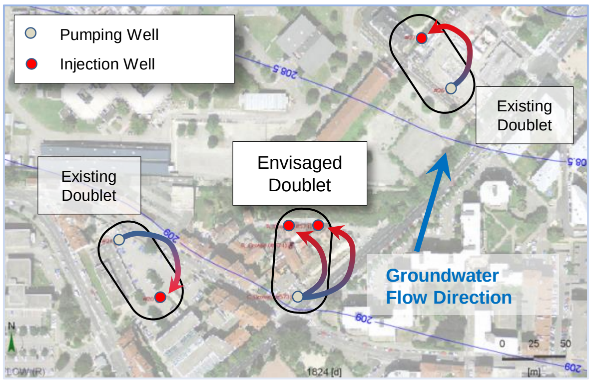

Figure 7: Doublet Project (End of Summer Context)

The project includes a pumping well and two reinjection wells. Two wells were used for reinjection in order to reduce the water table rise close to a carpark located close by.

To take groundwater flow direction into account, the pumping well is situated upstream from the two reinjection wells.

The model simulation shows that the envisaged project does not have a negative impact on existing doublets in the vicinity.

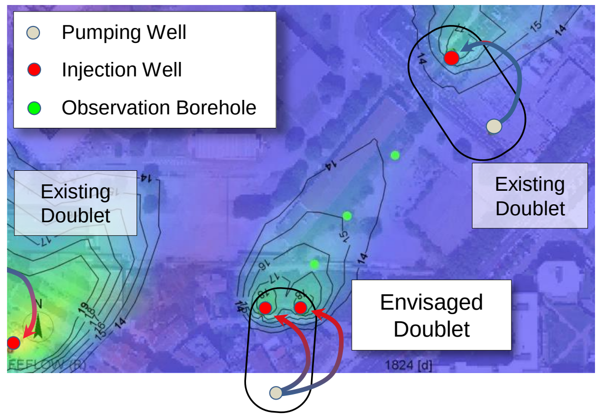

Figure 10: Evolution of Heat Plume around New Injection Wells (End of summer)

A more complex project: The Cambridge Project

It was planned to build 50 buildings within the Cambridge Area. first, Innovia wanted to know the feasibility of a scheme where each developer would have its own open-loop system for heating and cooling.

The impact of such a scheme was assessed the groundwater model.

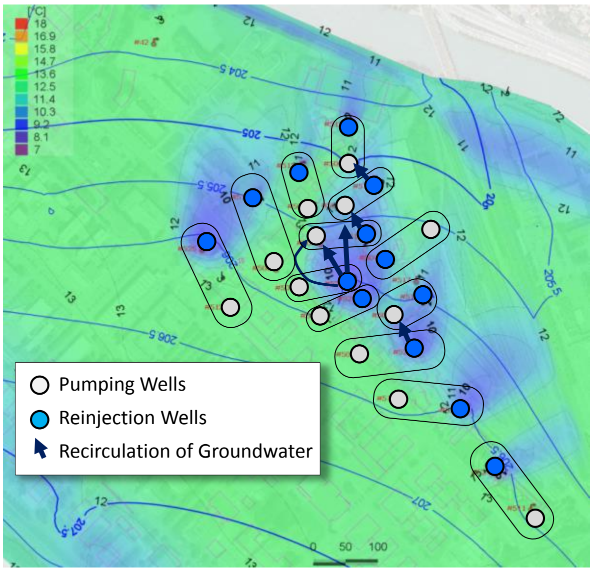

Figure 11: Reinjected Water Recirculation (Winter Conditions)

In the previous figure groundwater is supposed to be pumped from the aquifer at a 14°C temperature. Water then goes through a heat exchanger to produce heat. As a result reinjected water is cooler (blue colour in previous figure) than abstracted water (green colour).

Due to closeness of geothermal systems, part of the cooler reinjected water flows towards some abstraction wells. This is detrimental to the concerned geothermal systems as heat exchanger will spend more energy to meet the heating demand.

Thus the technical solution was to pump in the aquifer and to create a mutualised discharge network which would reject the water to the Isère River. This solution could only be feasible through the ZAC procedure. Indeed the construction of a mutualised discharge network was designed and financially supported by the Public Planner whereas such a common system would have been difficult to fund with private developers.

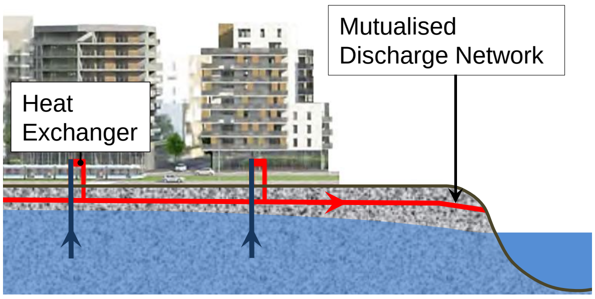

Figure 10: Principle of the Mutualised Discharge Network

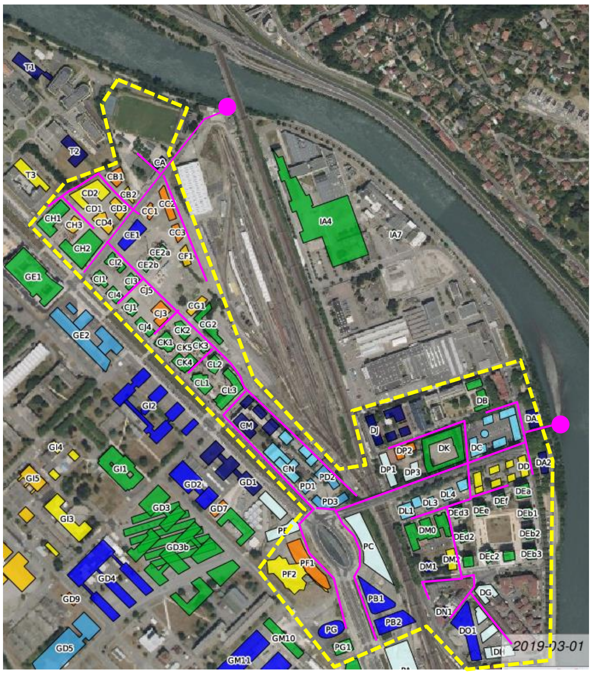

Figure 13: Cambridge Mutualised Discharge Network

7. CONCLUSION

An optimized and sustainable development of geothermal energy was made possible on the Presqu'île district mainly through a specific planning procedure (ZAC), a relevant tool to assess the impacts of geothermal systems and underground uses and the political will from Grenoble municipal council.

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