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3.2.
USE AND MANAGEMENT OF SHALLOW GEOTHERMAL RESOURCES IN SWITZERLAND

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Introduction

The shallow geothermal resource –the heat content of the ground right below our feet– represents an immense and ubiquitous energy source. Nevertheless its tapping and use must be done in a controlled and –ideally– in a regulated manner.

In Switzerland the utilization of shallow geothermal resources by ground-coupled heat pumps systems (also termed geothermal heat pumps, GHP) develops at remarkably high speed: Presently there is about one GHP installation every 2 km^2.

Although it is obvious that some regulation is necessary to avoid an overuse of the re-source, so far there are no direct means of control by authorities, except from the view-point of groundwater protection. In this paper the present status of shallow resources utilization in Switzerland is summarized, followed by means and ways to manage the resource in a reasonable way, on the basis of special maps. Renewability and sustainability aspects are also covered.

Present status of the use of shallow geothermal resources in Switzerland

Presently there are various ground-coupled systems in use in Switzerland:

- Ground-coupled heat pumps with borehole heat exchangers and, to a limited extent of a few % of the total, buried, shallow (~1 m) horizontal pipes;
- Heat pumps using shallow groundwater as the heat source;
- “Geostructures”, building construction ele-ments equipped with heat exchanger pipes (e.g. foundation piles at the new terminal, Zurich airport).

In the following, the first two categories will be termed “geothermal heat pumps”, whereas “ground-coupled” means heat extraction by borehole heat exchanger (BHE) or by shallow horizontal pipes.

Installed thermal power

A recently performed statistical survey (Signo-relli et al. 2004a) reveals that in 2004 geothermal heat pumps (GHP) formed with 525 MW the largest part of installed capacity in Switzerland for direct use (90 % of installed geothermal capacity, Table 1). Total installed capacity for direct use was 585 MW.

Table 1: Direct use of geothermal heat in Switzerland: installed capacity in 2004 From Signorelli et al. (2004a).

Energy source / use	Capacity (MWt)	Percent of total (%)
GHP with borehole heat exchangers (incl. shallow horizontal pipes)	450.0	77.0
GHP with groundwater	75.4	12.9
Thermal springs/boreholes (balneology)	40.8	7.0
Deep aquifers	6.1	1.0
Tunnel waters	5.2	0.9

Deep borehole heat exchangers	0.2	0.03
Geostructures	7.0*	1.2
Total	584.7	100.0

*) Heating: 4.8 MWt, cooling: 2.2 MWt

Thermal energy used

The statistical survey reveals that GHPs contribute with 781 GWh in 2004 over 66 % to the total geothermal heat production (Table 2). Total energy produced was 1’190 GWh.

Table 2: Direct use of geothermal heat in Switzerland: heat production in 2004. From Signorelli et al. (2004a)

Energy source / use	Heat produced in 2004 (GWh)	Percent of total (%)
GHP with borehole heat exchangers (incl. shallow horizontal pipes)	666.3	56.0
GHP with groundwater	114.4	9.6
Thermal springs/boreholes (balneology)	341.5	28.7
Deep aquifers	37.2	3.1
Tunnel waters	13.7	1.2
Deep borehole heat exchangers	0.9	0.1
Geostructures	15.2*	1.3
Total	1’189.2	100.0

*) Heating: 12.2 GWh, cooling: 3.0 GWh

Rates and trends in development.

The installation of GHP systems in Switzerland proceeds since their introduction in the late 1970ties at high speed: Figures 1 and 2 show the impressive growth. The rapid spreading of GHPs calls for quality control. In 2002 the establishment of a quality label for the entire GHP system (heat source like borehole heat exchanger, heat pump (HP), circulation hydraulics, heating circuit) has been initiated.

The annual increase rates are remarkable: the number of newly installed systems increase with an annual rate > 10 %. With over 1 GHP units every 2 km^2 their areal density is the highest worldwide (Lund et al. 2003). As by the year 2004, a total of over 30’000 geothermal heat pump systems are operating in Switzerland.

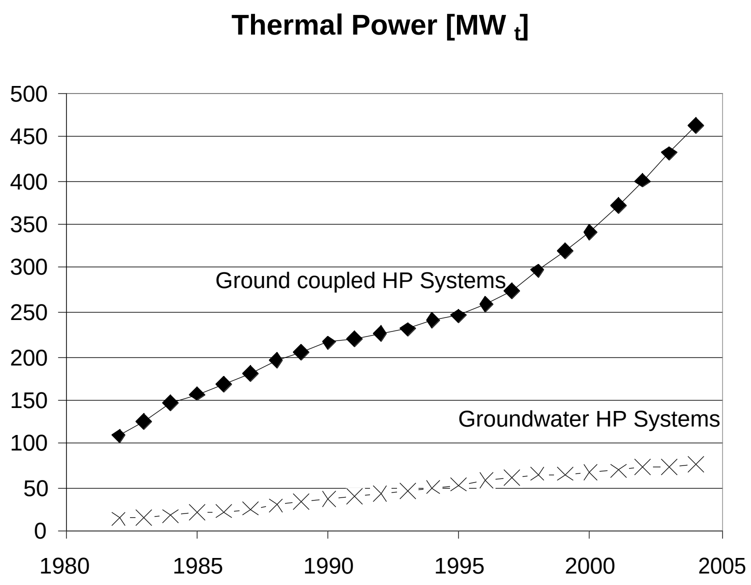

Figure 1. Development of installed capacities (MWt) of ground-coupled and groundwater-based geothermal heat pumps in Switzerland during the years 1982 – 2003. From Signorelli et al. (2004a).

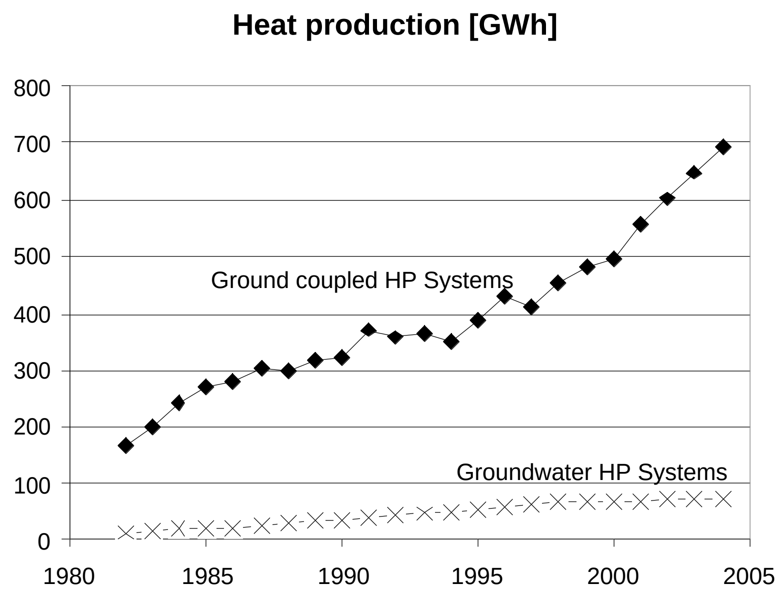

Figure 2. Development of heat production (GWh) by ground-coupled (upper symbols) and groundwater-based (lower symbols) geothermal heat pumps in Switzerland since 1982. From Signorelli et al. (2004a).

The average load factor, due to the climatic conditions is around 20 % and corresponds to a running time of 1'800 hours/year. A low capacity factor is not necessarily disadvantageous; in well-isolated buildings the heat pump runtimes (and thus electricity consumption) can be kept low. Essential in the establishment of GHP installations is the proper design and, especially, BHE dimensioning (see Rybach 2001)

Drilling activities

A large number of wells (several hundreds) are being drilled to install double U-tube borehole heat exchangers (BHE) in the ground. Average BHE drilling depth is now around 150-200 m; depths > 300 m become more and more common.

Average BHE cost (drilling, U-tube installation incl. backfill) is now around 40 € per meter. Figure 3 shows the increasing trend; in 2003 over 550 km (!) of drillholes have been deepened for BHE's. Since 2003 the drillings for the category of BHE arrays (=sites with > 10 BHEs and > 1000 m drilling) are separately registered (Signorelli et al. 2004a).

Limitations of GHP installations

The main aspect to be considered for new GHP installations is groundwater protection. Groundwater in Switzerland is not a private property; cantonal authorities are responsible for regulation. These authorities cover also the aspects of groundwater protection. In groundwater protection zones, as delimited in special maps, absolutely no GHP types can be established; the systems with shallow horizontal coils make no exception here. The basic concern of groundwater protection authorities is

a) the risk of leakage of circulated fluid (usually with some antifreeze) form BHE or horizontal pipes

b) the risk of establishing vertical hydraulic connections between separate aquifer layers through improper backfill of drillings.

The first priority in groundwater use is for drinking water. Domestic hot water is also produced from this supply. Much of the household water comes in Switzerland from extended gravel aquifers, mainly located at valley bottoms. Incidentally, such gravel layers (now often mapped as groundwater protection zones) have low thermal conductivity, which makes the heat extraction from the ground for energetic use inefficient: e.g the heat extraction rate for BHEs depends directly on the ground thermal conductivity (see e.g. Rybach and Eugster 1998). Therefore, it is technically unfeasible to establish vertical (BHE) or horizontal pipes in such formations and so a conflict situation between energy source and groundwater protection aspects does not exist.

Switzerland consists of 23 cantons; several cantonal water protection authorities have established maps for delimiting various zones. Here are some examples which demonstrate that so far there is no uniformity of such maps:

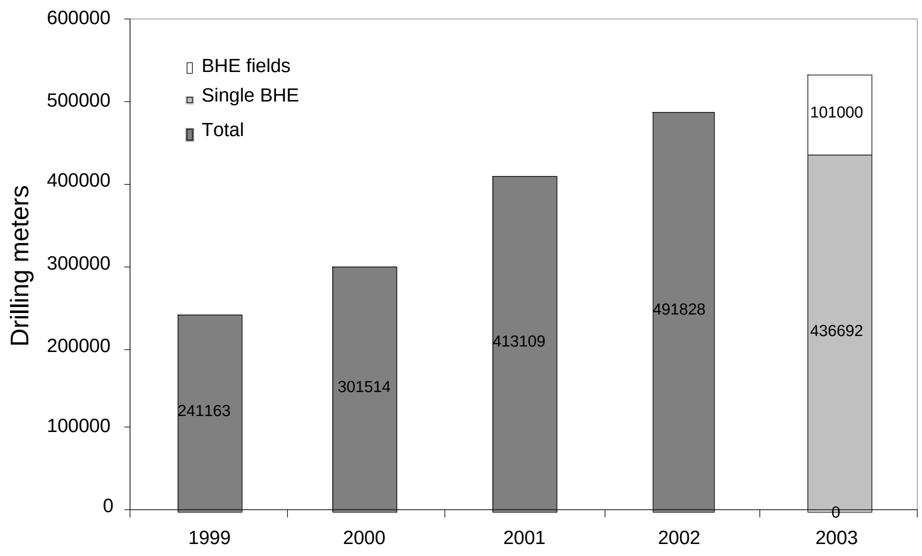

Figure 3. Development of drillings for borehole heat exchangers in Switzerland (total of drilled meters per year). From Signorelli et al. (2004a).

Canton Bern: A printed map on 1:100’000 scale has been published in 1998 by the *Wasser- und Energiewirtschaftsamt des Kantons Bern.* It shows

- groundwater protection zones where the installation of GHPs is prohibited
- zones where GHP with groundwater source can be installed
- zones where GHP with horizontal pipes and with BHE can be installed
- zones where GHP with horizontal pipes can be installed; BHE systems need special (mostly geologic) clarification
- zones where only GHP with horizontal pipes can be installed.

Canton Ticino: A synoptic geothermal map 1:100’000 in electronic format has been established, as well as local maps 1:25’000 which can be downloaded from the Internet (www.ist.supsi.ch). The map consists of different components:

- geologic map based on digital topography, lakes, rivers, roads, community borders
- terrestrial heat flow
- groundwater protection zones
- existing GHP installations.

Canton Zurich: A special map for GHP applications with BHE has been placed on the Internet (www.wasserwirtschaft.zh.ch/erdwaermenutzung/). The scale can be enlarged by browsing, from 1:500’000 through 1:200’000, 1:100’000, 1:50’000 down to 1:25’000. Figure 4 shows a detail map 1:25’000. The maps show

- topography, roads, rivers etc.
- groundwater protection zones, groundwater captures
- zones in which BHEs are permissible
- zones in which BHEs are permissible only with specific restrictions
- zones in which BHE installation needs further clarification
- zones in which BHEs are not permitted
- existing BHE installations, with/without geologic profile.

Most maps are being continuously updated. The cantonal authorities distribute also the necessary application forms in order to get the necessary installation permits.

Besides the groundwater protection aspects there have been no problems so far with the siting or the density of BHE installations. Of course, when the distance between individual neighboring drillings becomes small, conflicts with adjacent owners (“neighbor rights”) could emerge. Therefore, the issue of BHE spacing must be considered carefully. At the same time, the thermal conditions and processes in the influenced ground like the long-term behavior or the resource renewal must be understood and, if necessary, managed. In the following, these issues will be treated in some detail.

Renewability and sustainability aspects

Although the heat content of the top few hundred meters of the earth’s crust on continents is immense, the resupply of the extracted heat must be guaranteed. This refill can, to a certain extent, be provided by solar radiation and –to a limited extent– by the heat carried into the ground by rainwater. But most of the heat resupply must come from adjacent volumina. First the issue of heat extraction and its consequence, the ground cooling is addressed, and subsequently the aspects of heat resupply. In the following, the thermal processes and conditions in the ground will be treated by the example of BHEs, single as well as multiple (=BHE array).

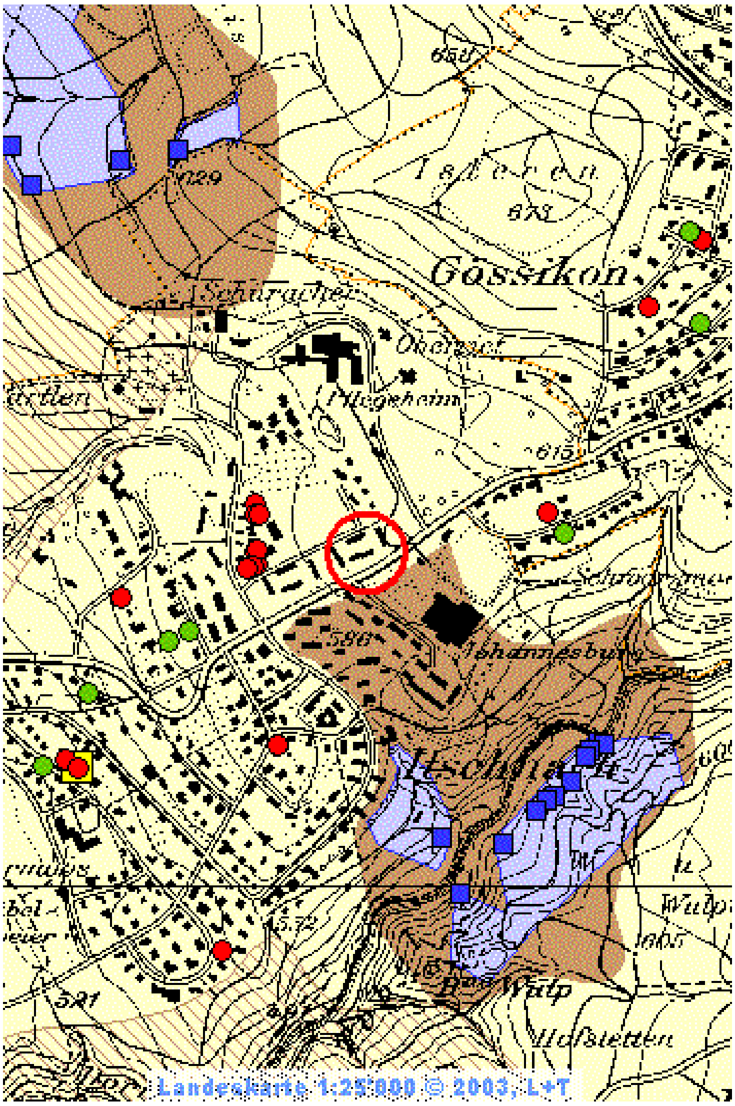

Figure 4. Detail of the BHE map of Canton Zurich. Blue and brown: groundwater protection zones, blue squares: groundwater captures; existing BHEs with (green) and without (red) geologic profiles. Hachure: no special geologic considerations needed.

Effects of heat extraction and regeneration

Continuous heat extraction through a BHE leads to the formation of a heat sink along the BHE axis. The heat sink in the ground has cylindrical shape. The isotherms are, after a certain operational time, concentrated near the BHE. Figure 5 shows the measured temperature distribution around a 50 m long BHE, at the German test plant at Schöffengrund-Schwalbach near Frankfurt/Main (Rybach and Sanner 1999). Here a 50-m-BHE was surrounded by a total of 9 monitoring boreholes at 2.5, 5 and 10 m distance, also 50 m deep. Temperatures in each hole and at the BHE itself were measured with 24 sensors at 2 m vertical distance, resulting in a total of 240 observation locations in the underground. This layout allowed to map the temperature distribution in the vicinity of the BHE, as shown in Figure 5. The influence from the surface is visible in the uppermost ca. 10 m, as well as the temperature decrease around the BHE at the end of the heating season. The latter creates strong temperature gradients in the BHE vicinity, which in turn leads to heat inflow, directed radially towards the BHE, to replenish the deficit created by the heat extraction. This heat flow density attains, compared to the terrestrial heat flow (80 – 100 mW/m^2), rather high values (up to several W/m^2). A similar situation has been found at a site in Elgg/ZH, Switzerland (Rybach and Eugster 2002).

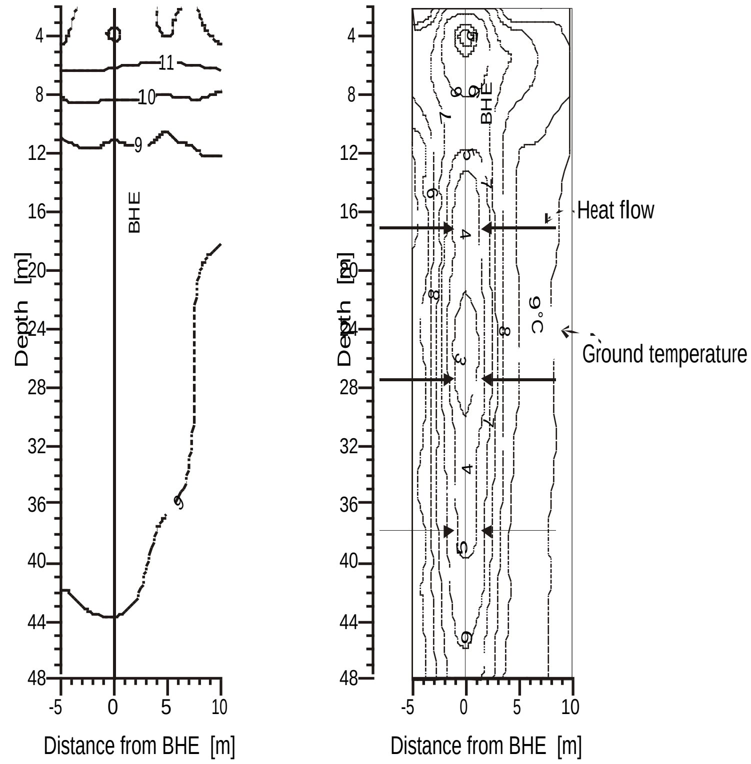

Figure 5. Measured temperature distribution in the ground at the beginning of the monitoring period (left, on 1.10.1986, after a total of ca. 2 hours of test operation) and at the end of the first heating season (right, on 1.5.1987), GHP at Schwalbach/Germany. The temperature deficit around the BHE leads to radial inflow of heat. From Rybach and Sanner (1999).

After the heating season the BHE heat extraction is shut down and regeneration of the ground begins during the summer, but the original temperatures are not met completely: during the production period of a single BHE, the draw-down of the temperature around the BHE is relatively strong during the first few years of operation. Later, the yearly deficit decreases asymptotically practically to zero. During the recovery period (after a virtual stop-of-operation) the ground temperature shows a similar behaviour: during the first years, the temperature increase is strong but tends with increasing recovery time asymptotically towards zero (see Figure 7). The time to reach near-complete recovery depends on how long the single BHE has been operational. Principally, the recovery period equals the operation period (Rybach and Eugster 2002).

A BHE array behaves in a similar manner: A practitioner's rule of thumb says that spacing should not be less than 8 m. Kälin and Hopkirk (1991) investigated the reciprocal influence for two neighbouring BHEs. They report that with a spacing of 15 m there is no noticeable influence. On the other hand, with a spacing < 5 m the influence is so strong that the system operation can break down (permafrost at the BHE!).

To get a more precise hold on the reciprocal effect of neighbouring BHEs, numerical modelling has been performed to investigate the effect of spacing (for details see Signorelli et al. 2004b). Hereby the spacing in a rectangular 6-BHE array with 150 long BHEs has been varied between 3 and 15 m and the results compared with the performance of a single BHE of the same length. Figure 6 compares the relative difference in minimum outlet temperature between the single BHE and the borehole fields over the first three years of operation. Analogous to the findings of Kälin and Hopkirk (1991), no significant effect results for BHE spacing of 15 m, but strong influences are visible for spacing shorter than 5 m (up to ~5 K difference). For the 7.5 m-spaced array the reciprocal influence is still clearly noticeable. It must be emphasized that production temperatures below -5 °C can cause mechanical damage of the BHE backfill and thus destroy the thermal contact between the heat exchanger pipes and the surrounding ground.

Comparison single BHE / BHE field

For the comparison, the sustainability of the single BHE and the 7.5 m-spaced BHE field has been addressed. Both BHE arrangements are simulated for an operation of 30 years, followed by 70 years of recovery. Thereby, the central BHE of the field with the highest reciprocal influence) is compared to a single BHE. Figure 7 shows the ground temperatures for both model runs. The temperature changes exhibit the same asymptotic behaviour as described in Rybach and Eugster (2002): The cooling is strong at the beginning and levels off at later times. The same behaviour results for the recovery period. Due to the mutual influence of BHEs in a field the ground cooling is significantly more pronounced than around a single BHE with no neighbours. And whereas for the single BHE, the deviation to the initial temperature field is <0.1 K already after 24 years, the recovery of the BHE field takes 70 years.

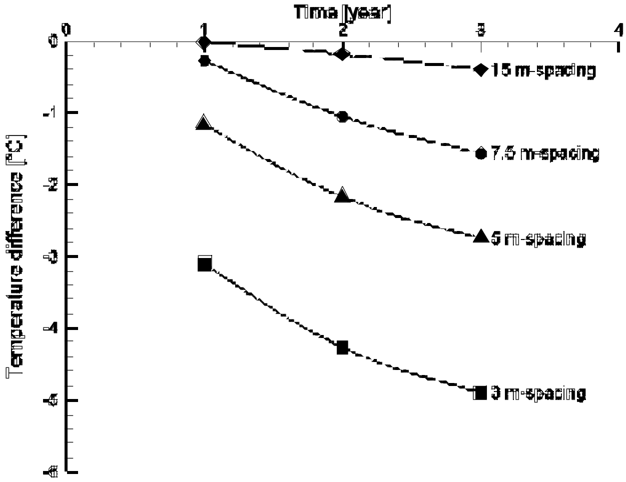

Figure 6. Temperature difference of the outlet fluid temperature of a BHE field relative to a single BHE. From Signorelli et al (2004b).

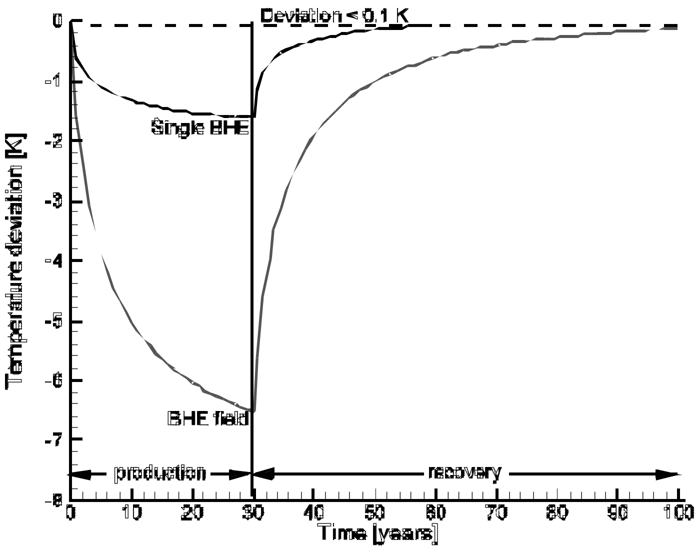

Figure 7. Ground temperature changes in 50 m depth at 0.12 m distance from the BHE(s), over a 30 year production and a 70 year recovery period. The temperatures are plotted at the end of August (i.e. before the start of the next heating season), for the single BHE and for the BHE field with 7.5 m spacing relative to the initial temperature of 12.7 °C. The curve for the BHE field represents the temperature evolution of the central BHE with the highest reciprocal influence. From Signorelli et al. (2004b).

Compensation through additional BHE lengths drilled

The thermal production power of the array with 6 BHEs is six times that of a single BHE, i.e. in our case 6 x 5 kW. But the reciprocal influence of the neighbouring BHEs leads to lower ground temperatures and correspondingly lower fluid outlet temperatures.

The lower temperatures can be compensated for the 7.5 m spacing by longer BHEs (=additional drilling meters). Figure 8 shows the deviation of the minimum fluid temperature for various additional BHE lengths up to 50 m, relative to the single BHE, during the first 10 years of operation. Drilling the BHE field deeper by ~30 % yields the same fluid temperature than the single BHE after 10 years of operation. We recognize from Figure 8 that the temperature decrease slows down with time and the difference in fluid outlet temperature between year 9 and 10 is less than 0.1 K. Therefore, no significant changes must be expected during further operation.

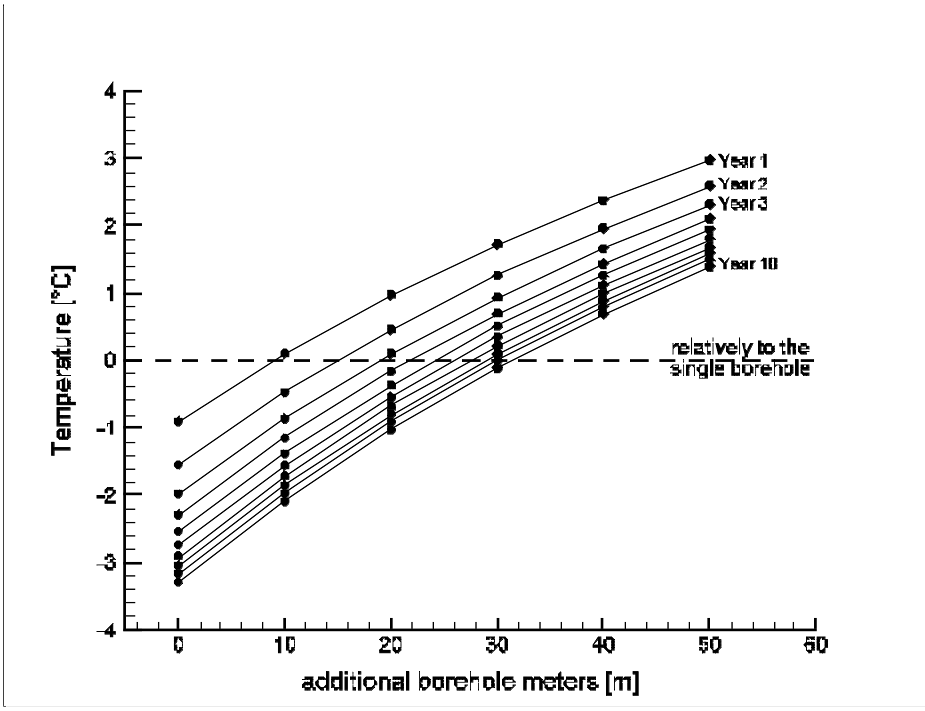

Figure 8. Difference between single BHE and BHE field fluid production temperatures during the first 10 years of operation, in function of additional drilling meters. To achieve the same fluid temperature as the single BHE, additional drilling meters of > 30 % are needed for a field with 6 BHEs. From Signorelli et al (2004b).

Conclusions, outlook

- The installation of GHP systems in Switzerland proceeds, since their introduction in the late 1970ties, at high speed; the number of newly installed systems increase with an annual rate > 10 %. With over 1 GHP units every 2 km^2 their areal density is the highest worldwide. Four system types are in use: i) GHP with borehole heat exchangers, ii) GHP with shallow horizontal pipes, iii) groundwater heat pumps, iv) geostructures like foundation (“energy”) piles. They all use the shallow geothermal resource.
- The shallow geothermal resource –the heat content of the ground right below our feet– represents an immense and ubiquitous energy source. Nevertheless its tapping and use must be done in a controlled and –ideally– in a regulated manner. The main aspect to be considered for new GHP installations is groundwater protection. Groundwater in Switzerland is not a private property; cantonal authorities are responsible for regulation, including groundwater protection. Switzerland consists of 23 cantons; several cantonal water protection authorities have established maps for delimiting various zones. By these zones the limitations for establishing GHP installations are set. The cantonal authorities also provide the application forms for installation permits.
- Besides water protection aspects also the possible reciprocal influence of neighboring installations must be considered. In particular this concerns the spacing of BHEs. The spacing in a BHE field is a critical factor: the reciprocal influence of neighbouring BHEs –when charged with the same thermal load– leads to lower ground temperatures and fluid production temperatures than a single BHE. The minimum spacing shall not fall short of 7 –8 m even in ground with high thermal conductivity (>3 W $m^{-1}K^{-1}$) to provide sustainable production. Additional drilling meters provide feasible help: drilling a BHE 7.5 m-spaced array deeper by ~30 % yields the same fluid temperature than the single BHE.
- Heat extraction from BHEs increasingly cools the surrounding ground with the operation progressing. During heat extraction stop, the

ground recovers to heat inflow due to strong temperature gradients created by the BHE heat sink. The ground around the BHE cools and recovers in an asymptotic manner: the cooling is highest at the beginning and slows asymptotically down later; also the recovery is strong in the beginning and with time it levels off. The recovery duration roughly equals that of operation: For a single BHE, after 30 years of operation, the thermal recovery of the ground needs ~30 years; for BHE fields the recovery needs longer (~70 years).

- In the future, regulation could be needed for minimum distances between installations on neighbouring ground (property rights). Special design like recharge in the summer could also be envisaged.

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