1 Introduction

In Germany about 60% of the total energy consumption can be attributed to heating and cooling and the operation of buildings. There is great potential for using shallow geothermal energy systems to provide a large proportion of that energy demand. For example, around the year 2000, rising energy prices resulted in rapid developments in the use of shallow geothermal energy for heating buildings (increasingly cooling as well). The reason for the growing popularity of this technology is that up to 70–80% of heating requirements can be covered by geothermal energy, which means that only the rest has to be provided by conventional forms of energy. That results in potentially huge financial savings. Apart from that, geothermal systems save energy – in particular, they reduce the consumption of fossil fuels. The heat pumps needed for heating and the recirculating pumps needed for cooling can also be operated with electricity generated from renewable sources. In 2013, the proportion of renewable energy forms in the new-build sector in Germany was already 29% (22% heat pumps, 7% wood pellets + biogas), with a simultaneous decline in the proportion of oil heating systems down to <1% and gas heating systems down to <47% (BDEW, German Association of Energy & Water Industries, 2008). By 2008 some 64% of new heat pump installations were being used in conjunction with ground couplings. Only about 13% of heat pumps operated with geothermal energy sources are connected to well systems that enable the geothermal energy to be exploited directly. Most heat pumps in operation are based on indirect methods of extracting the geothermal energy through borehole heat exchangers (BHEs), ground heat exchangers and so on (BWP, German Heat Pump Association, 2009).

To some extent the state of the art is specified by guideline VDI 4640, the revised draft Part 1 of which has been available since 2010. One of the documents using this as a basis is the revised DVGW regulation W 120-2 (DVGW, 2013), which in future is intended to regulate quality control issues concerned with the provision of boreholes for heat exchangers. However, so far, training programmes for people in the industry to complement the technical documentation have been lacking. Therefore, when it comes to shallow geothermal energy, considerable responsibility is placed on the geoscientists and engineers who advise clients and design systems.

The provision of energy from below the earth's surface is mainly provided indirectly via borehole heat exchangers, which are also known as downhole heat exchangers (DHE); these can be as deep as 400 m. Most borehole heat exchangers are, however, typically between 70 and 200 m deep, although there is a trend towards deeper boreholes. Such boreholes use a closed

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system of pipes, usually made from high-density polyethylene (HDPE), in which a thermal transfer fluid (normally water-based) circulates. The operating temperatures are then made available through being coupled to a heat pump. Hundreds of thousands of boreholes that still have to be sunk will have to be assessed in terms of the quality of their design and execution in order to achieve optimum technical and economic efficiencies and, of course, to prevent damage on the one hand and latent risks to groundwater resources on the other.

The use of geothermal energy is constantly on the increase. According to the German Environment Ministry (BMUB, www.erneuerbare-energien.de, 2013), the proportion of heat in the final energy consumption rose from 4.9 to 7.1% between 2009 and 2012.

Figures for numbers of BHE systems in Germany vary – sometimes considerably – depending on the source consulted. According to the BMUB (2013), there are already about 350 000 heating (and cooling) systems in Germany using heat pumps to extract energy from below the ground. On average, a system consists of 2.5 BHEs. That means there could well be about 875 000 BHEs in Germany which also need to be inspected in the future, for example when valuing property prior to sale or for other reasons. However, in contrast to the BMUB, in 2009, the German Renewable Energies Agency (AEE) published a conservative figure of about 150 000 BHE systems as of 2008. Apparently, there were 27 000 new systems in 2007 and a further 35 000 in 2008. If we again assume 2.5 BHEs per system, we still arrive at a total number of about 375 000 BHEs in Germany.

Neither source includes BHE systems that have not been approved, for example in the form of an estimate of the numbers. We can therefore assume that, very roughly, half a million BHEs are already in operation in Germany. That is a very large number of significant changes to the ground, as it always involves a borehole up to several hundred metres deep. Despite a number of cases of damage that have become known in recent years, the number of installations will continue to increase significantly (Figure 1.0.1). The figure might well have doubled by 2015. At the moment, the frequency of damage cases related to BHEs can probably be regarded as low on the whole. More accurate figures are, however, not yet available and long-term damage has not been investigated yet.

In this context, the State Geological Surveys of Germany (SGD) organisation has looked at quality issues related to the known effects of geothermal projects and collated and evaluated these in a report (Geothermie, 2011). Concerns about the safety of technologies are understandable. However, it must be said

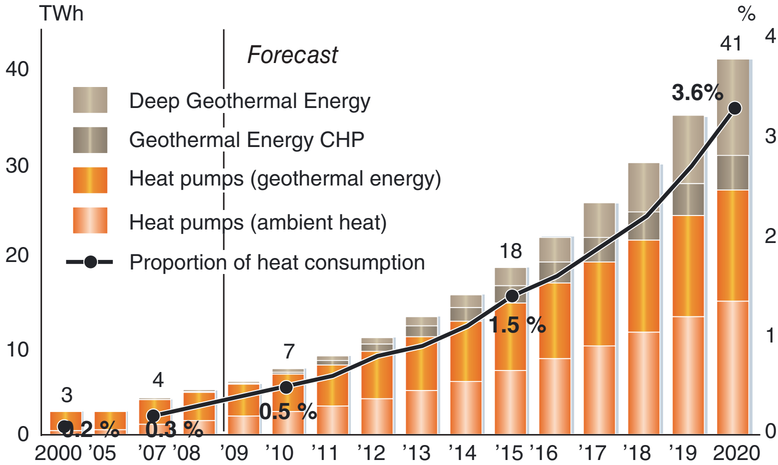

Fig. 1.0.1 Geothermal energy production forecast for Germany up to 2020; position as of October 2009. (Graphic: German Renewable Energies Agency, 2009.)

that so far the use of geothermal energy has not led to any injuries to persons. Not all energy sources can claim that.

Damage that can be caused by the sinking and operation of BHEs results from inadequate knowledge of the subsoil conditions and inappropriate drilling methods in particular. The following are some of the typical forms of damage:

- Leakage between aquifers (see Glossary for definition) in multi-layer groundwater systems
- Subsidence or heave affecting neighbouring infrastructure
- Transferring contaminants from higher to lower strata
- A rise in significantly mineralised groundwaters

Most boreholes for BHEs are sunk at least as deep as the uppermost aquifer of a multi-layer groundwater system. Boreholes as deep as this are definitely technically challenging alterations to the ground and, in principle, can impair or bypass the effects of confining beds.

If the pipes in the borehole heat exchanger are filled with a thermal transfer fluid that does not consist of just water, the fluid is classed as belonging to water hazard class 1 (WGK1 term of German Water Law). Therefore, in legal terms, BHEs are containers for WGK 1 substances, which require a double-wall construction when stored in the ground. This double-wall requirement is provided by, on the one hand, the closed system of pipes and, on the other, the backfilling to the borehole, which, being in most cases a cement-based bentonite slurry, constitutes a seal. Where public buildings and commercial geothermal energy systems are concerned, the technical specification given in the legislation on systems containing substances hazardous to water (*Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen* – AwSV, cl. 35, para. 2, 2014) permits the use of single-wall BHEs.

In addition, the drilling and construction activities themselves constitute a potential hazard for the groundwater. Consequently, in Germany, BHEs <100 m deep must be approved by the local water authority. One quality assurance problem that still remains is the fact that in Germany the mining authority is in charge of approving and supervising boreholes for BHEs >100 m deep. And in many of Germany's federal states, the water and mining authorities have different ideas about dealing with geothermal energy! This can lead to the situation that, for example, one project must comply with more stringent technical stipulations than a neighbouring project whose final depth is, for example, 30 m deeper, even though both fall under the remit of water legislation (<100 m deep). Nationwide implementation of the technical aspects of quality assurance addressed in the recommendations of this book is therefore hardly possible. The work on these recommendations has revealed that there is an urgent need to set up a logical, unified approval and monitoring system for the whole country. Therefore, the specialists from the Engineering Geology Sections of the German Geological Society (DGGV) and the German Geotechnical Society (DGGT) plus the Hydrology Section of the DGGV got together and pooled their practical knowledge for applications. This book is the result of that work. It represents the current state of knowledge and state of the art and is also intended to help avoid damage in conjunction with the use of shallow geothermal energy systems.