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Potential Mapping of Geothermal Heat Pumps with GIS in Southern Germany

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ABSTRACT

Although the amount of sold heat pumps in Germany as well as the interest in using shallow geothermal energy grew enormous within the last years, a better knowledge of the factors influencing the efficiency could lead to a more effective and widespread application of the shallow geothermal energy source.

Potential estimations of a special site are based on geological, hydrogeological and lithological studies of the area. With the resulting informations a 3-dimensional model of the underground can be constructed with the software GIS, dividing the model into several layers with similar thermal properties. Depending on the depth of analysis, parameters like heat conductivity or specific heat extraction can be assigned to the relevant thickness of the layer. The resulting maps show the distribution of the weighted mean values.

Such potential maps were created for the region called Donau-Iller in southern Germany, which includes parts of the Swabian Mountains and the Molasse Basin.

The resulting maps are based on three different parameters: thermal conductivity, specific heat extraction and cold extraction, which are projected for the analysis depths of 100 m, 150 m and 200 m. The choice of the assigned thermal conductivity values is mainly influenced by lithological and hydrogeological aspects.

If the heat demand of a building is known, the map shows the potential specific heat extraction which can be used to estimate the needed length of a borehole heat exchanger. The third and last map of the cold extraction potential shall point out, that borehole heat exchangers present a simple and cost-effective possibility for cooling of buildings without an additional heat pump (Geo-Cooling).

The constructed potential maps shall show the difference of geothermal heating and cooling potentials in dependency on local changing geological conditions with respect to different considered depths.

1. INTRODUCTION

1.1 Source of Geothermal Energy

One third of todays Geothermal Energy has its origin in the time of the earth's genesis. It consists of heat, which was produced by the heat and gravitation energy that existed already prior the genesis. The remaining two-thirds are created by radioactive decay within the earth's crust and the upper Mantel of the earth (Sanner 2004, Kaltschmitt et al. 1999). In approximately one kilometer depth temperatures between 35°C and 40°C can be found. The average temperature increase within the earth amounts to 3°C per 100 m depth.

1.2 Geothermal Exploitability and Borehole Heat Exchangers

The shallow temperatures can be used in combination with a heat pump system for heating and/or warm water generation purposes. The heat source can be exploited by horizontal ground heat exchangers, ground water heat pumps, spiral-type ground heat exchangers, energy piles (foundation piles) as well as borehole heat exchangers (BHE). Because BHE's are the most commonly used technique, the potential maps were created for this purpose. For this reason only this technology will be described below.

In the beginning of 2009 12,548 BHE's existed in the German state Baden-Württemberg (LGRB). Most BHE's consist of plastic tubes, filled with a circulating heat transfer medium, like water in combination with an antifreezing compound. They are installed vertically (Figure 1) or inclined into the underground. In Germany BHE's are generally installed into up to 100 m depth, due to the permission of mining law, which is inevitable for greater depths.

To ensure the functional efficiency, the borehole must be backfilled with a swellable, stable and caulking suspension that features a high thermal conductivity.

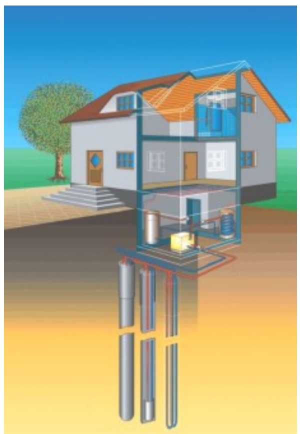

Figure 1: Borehole heat exchanger (Source: www. systherma.de).

To heat up a single-family house one or two heat exchangers suffice, whereas for the supply of housing developments or office and commercial buildings multi-borehole systems are needed. It is very important to keep a minimum distance between the heat exchangers to avoid mutual interferences. According to Hopkirk & Kälin (1991) simulations resulted in a minimum distance of 5 m. Depending on the depth of the borehole heat exchanger, minimum distances of 5 or rather 6 m are recommended by the VDI 4640 and the Bundesverband Wärmepumpe (2003). The Umweltministerium (2005) even mentions in its guideline for BHE's in Baden-Württemberg a minimum distances of 10 m to avoid the mutual interaction.

1.3 Cooling with Geothermal Energy

Compared to usual air conditioners, geothermal cooling affords a much more energy-saving and cheaper solution. The low temperatures of the shallow underground can be used directly for the cooling of the buildings. Except the circulation pump, the heat pump can stay switched-off, so that the power consumption is reduced dramatically. Depending on the geological and hydrogeological conditions, the underground can be used for an all-season climatization of buildings. In the summer, waste heat can be induced and stored in the subsurface. In winter time the stored heat can be used for heating purpose again. A combination of heating and cooling benefits the temperature regeneration of the underground and results in lower drilling depths. The described technique is not only used for climatization of buildings, but also for temperature control and deicing of streets and bridges.

1.4 Factors Influencing the Specific Heat Extraction

The thermal properties of the subsurface are mainly depending on the chemical and physical rock composition (lithology) and the presence of groundwater. With increasing groundwater flow velocity the thermal properties of the underground are positively influenced, due to the heat that is transported together with the mass flow of the water, to the BHE.

The lithology and the groundwater flow are controlling in particular the thermal conductivity and the thermal capacity of the underground. Among these two parameters the annual mean temperature of the ground, the sunshine duration (also depending on the topography) and the rainfall have an impact on the extraction of a BHE.

Furthermore the value is affected by the duration of the specific heat extraction (operating hours per year), the mutual interferences of the BHE's, the diameter of the borehole, the grout material and the position of the pipe within the borehole.

Failures in dimensioning can result in under- or oversized systems. While oversized systems lead to the purchase of to big and expensive plants, undersized dimensioning results in a heat extraction that is much too high for the planned system. The underground would cool down until the subsurface begins to freeze. Hereby the efficiency would decrease and the layers that were cooled down can't regenerate during the summer months (Reuss 2004).

2. STUDY AREA

2.1 Geographical Position

The so called region "Donau-Iller" is situated in southern Germany and belongs to the German states Baden-Württemberg and Bavaria. It consists of 7 rural districts and has an area of 5,464 km^2. The extent of the investigation area is shown in Figure 2.

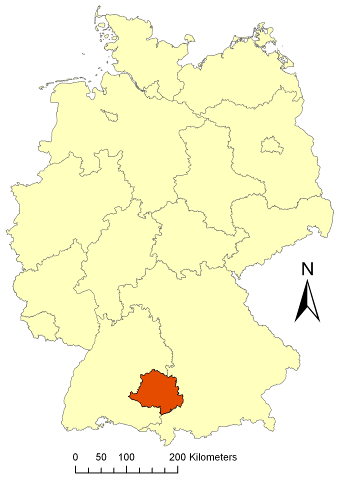

Figure 2: Geographical Position of the investigation area Donau-Iller (orange).

2.2 Geology

The development of the Alps during the Cretaceous period lead during its last stadium to the formation of the so called Molasse basin (Geyer & Gwinner, 1991). The subsidence at the margin of the Alps was enormous. More than 5,000 m of sedimental layers were deposited. The sedimentation occured so fast, that the surface of the sedimentation layers was mainly located above the sea level and compensated the subsidence of the basin. In this way layers of the "Süßwassermolasse" and "Meeresmolasse" were deposited on the top of the Upper Jurassic in the southwestern part of the german Molasse basin. The cross section from the Upper Rhine Graben to the Molasse basin in southwest Germany is shown in Figure 3. It points out the increasing thickness of the Molasse sediments into southeastern direction, whereas the layers strike out on the Jurassic rocks at the Swabian Mountains in the northwest.

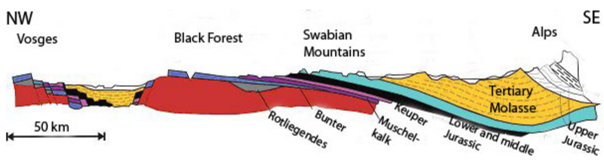

Figure 3: Cross section from the Vosges to the Alps with high vertical exaggeration (Geyer & Gwinner 1991).

During the Ice Ages of the Pleistocene and the following postglacial period, quarternary unconsolidated sediments were deposited on the top of the tertiary sediments and the OSM in particular. These deposits are responsible for today's appearance of the region with its glacial, glaciofluvial and glaciolimnic accumulation and erosion forms. But also younger sediments were deposited, like sediments within the valley, high moor, fens or loess.

3. METHODOLOGY - THREE-DIMENSIONAL MODEL OF THE SUBSURFACE

3.1 Base Data

In the following, the base data that was used in GIS for the construction of the three-dimensional underground model will be described:

Digital Height Model (DHM)

A DHM with a resolution of 50 m x 50 m was used for the assignment of the height of geological outcrops.

Geological Maps

Because each german state distributes its own geographical material, digital data often doesn't fit together at the border area. The only map that largely fulfills this condition is the geological map sold by the "Bundesanstalt für Geowissenschaften und Rohstoffe" (BGR) on a scale of 1: 200,000. It was generated by several maps with different scales, varying from 1: 25,000 to 1: 100,000. The investigation area lies within the map sheets 7918 Stuttgart, 7926 Augsburg, 8718 Konstanz and 8726 Kempten.

The mentioned maps were used to outline geological deposits and furthermore to obtain informations on the outcrops of geological units.

Drilling Data

An additional base data used for the construction of the model are stratigraphically subdivided drilling profiles, showing the depth of the stratum boundaries. For the investigation area a total amount of 540 profiles were analyzed and included in the interpolation of the layers.

Maps of Stratification and Thickness

This kind of base data represents one of the most important input parameters for the modelling, due to its area-wide informations. The depth of different layer surfaces and informations on the thickness were taken out of the following sources: "Geologisches Landesmodell" of the Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg (2008), the "Bayerischer Geothermieatlas" Landesamt für Umwelt (2004), Bertleff & Watzel (2002), Doppler (1989) and Geyer & Gwinner (1991).

Hydrogeological Data

For the estimation of the quarternary, unconsolidated sediment's heat conductivity, the saturated thickness plays a decisive role. As a basis for the following estimations, shapefiles including informations on the groundwater altitude were kindly provided by the Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW).

3.2 Construction of the Model

General

The basic principle of the present Potential Mapping, created with ArcGIS 9.3 from ESRI, is based on the construction of a model with a resolution of 100 m x 100 m. The model is subdivided into several units, according to their thermal properties. Different attributes, like thermal conductivity and heat extraction were assigned to the finished model to create the potential maps within different depths.

Interfaces

The underground model was built of different interfaces that subdivide layers with different thermal properties. The interface construction is based on point data (respectively line data that must be converted into point data), which contains space-oriented informations into x-, y- and z-direction.

The thermal properties of the underground are as aforementioned depending mainly on the lithology and the presence of groundwater. Therefore, during the subdivision of the model, all geological units that differ from lithology and groundwater presence shall be bordered of each other. Such a subdivision within the tertiary layers as well as the Upper Jurassic and the quarternary, unconsolidated sediments was not possible, due to the unsteady developed rock composition and -thickness as well as the lack of informations concerning the layers. For this reason, the natural stratum boundaries are taken as interfaces and mean values must be used for construction of the potential maps. Figure 4 pictures the schematic profile and interfaces that were used to build up the three-dimensional model, with OSM = "Obere Süßwassermolasse", OMM = "Obere Meeresmolasse", SBM = "Süßbrackwassermolasse", USM = "Untere Süßwassermolasse". Quarternary layers are missing.

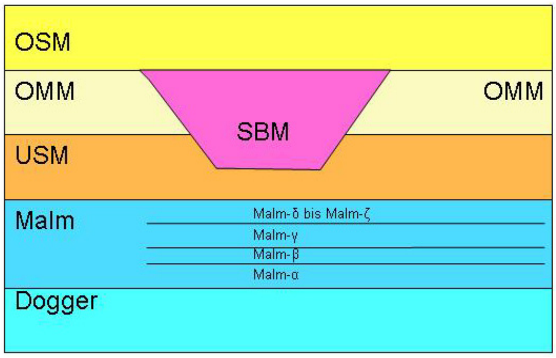

Figure 4: Schematic profile of the underground model, excluding quarternary layers.

As a result of the enormous complexity of the quarternary deposits, several units had to be summarized while others were neglected, due to the lack of informations (no drilling data, no stratigraphically subdivision in the Quarternary within the drilling profiles, units were overlayed by younger sediments and therefore invisible on the geological map, etc.). Therefore four different groups were classified. The oldest Deckenschotter of the Donau-, Biber- and Günz-Ice Age, the younger Deckenschotter that consist of deposits from Haslach- and Mindel- Ice Age, moraines that are mainly composed of deposits of the two youngest Ice Ages (Riß and Würm) and the deposits within the valley that were summarized with the high moor and fen deposits. Although the loess can reach considerable thicknesses, it had to be neglected, due to the missing spatial informations.

Interpolation

With the interpolation method "Inverse Distance Weighted" (IDW) raster datasets with area-wide informations on the top of the layers were made out of the composed point data, considering geological faults as barriers. This method permits the best possible modelling of the natural geological settings. Figure 5 shows as an example the input data that was used for the interpolation of the top of the Malm (Upper Jurassic). On the left side of the figure the input data before its conversion into points is pictured, consisting of outcrop data and informations from several existing stratification maps. The smaller figure represents the faults appearing in this depth, which were used as barriers.

For the conversion of the pictured line data into points, ArcGIS has no tool within its standard Toolbox. Therefore an additional program was downloaded called "Hawth's Tools" available for free from http://www.spatialecology .com.

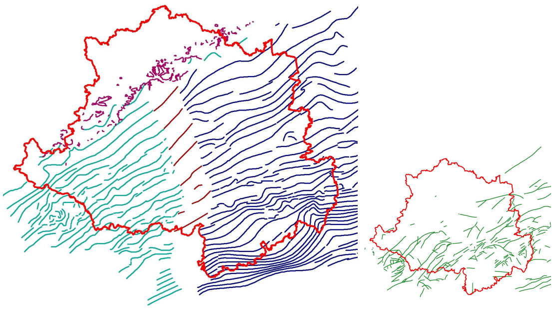

Figure 5: Top Malm – Left: Input line data from outcrops and existing maps of stratification, Right: faults within this depth.

Most of the interfaces were created in this way. Exceptions were made for the layers dividing the Malm and a part of the quarternary layers, due to their existing informations based upon the layer's thickness. For this reason the interfaces of Malm-α to Malm-γ were constructed by adding their cumulative thickness to the top of the Dogger layer.

For the majority of the quarternary sediments, informations concerning the layer's thickness are only available from drilling data. One exception is the so called "Decken-schotter", which was deposited mainly planar on the ancient top of the OSM. For this reason, the construction of the depth can be done by geological outcrops, as explained before.

For all other quarternary layers, informations from drilling data were used. With the Interpolation method IDW the relevant thickness was constructed immediately.

Raster Templates

The output of the interpolation consists of a raster that contains informations on the whole region. Because most of the geological units appear only in a part of the region, raster templates must be created to tailor the geological units to their real distribution.

With the command "Reclassify" the templates are sub-divided into two different parts. The part where the geological unit exists obtains the attribute value 1, the second part beyond the deposit is allotted to 0.

The real deposit of the unit can be calculated during the calculation of the relevant thickness (see following subchapter), by multiplying the interpolated raster with the template.

Transformation of the Layer's Top Raster to the Layer's Basis Raster

Due to the available base data, the top of the geological units were interpolated. For the calculation of the relevant thickness however (see the following subchapter), the basis of the layers are needed. Therefore most of the constructed layers were transformed directly (see Figure 4, where e.g. top Dogger accords Basis Malm-α). Two exceptions are the layers of the OSM and SBM, whose basis consists of several layer tops and must therefore be calculated.

Relevant Thickness

For the query of the potential (heat extraction, thermal conductivity, etc.) it is necessary to know the thickness of each geological unit. For this reason, the term "relevant thickness" and its calculation procedure will be described below.

The relevant thickness is understood to be the thickness of a single layer that lies within the top ground surface and the considered depth (here 100 m, 150 m and 200 m respectively). The DHM represents the ground level and can therefore be used as the upper boundary of the relevant part. The lower boundary results from the substraction: DHM minus considered depth. Figure 6 shows the boundaries for an analysis depth of 100 m.

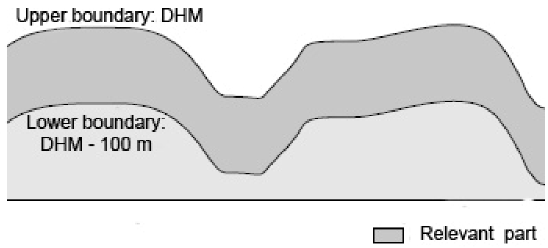

Figure 6: Boundaries of the relevant part for an analysis depth of 100 m; Upper boundary: DHM, Lower boundary: DHM – considered depth (Ondreka 2004).

Where the geological unit lies below the lower boundary, the relevant thickness is smaller than the real thickness of the unit. The input data for the calculation of the relevant thickness consists of the upper and the lower boundary as well as the layer's basis.

For the calculation the three following scenarios were considered:

1. Layer's basis lies above the top ground surface: the height of the top ground surface is substracted from the top ground surface. Thus, the relevant thickness amounts zero meters.

2. Layer's basis lies within the upper and lower boundary: the value of the layer's basis is substracted from the top ground level. Therefore the relevant thickness lies between zero and 100 m (150 , 200 m respectively).

3. Layer's basis lies below the lower boundary: Substraction of the considered depth from the top ground level. Therefore the relevant thickness amounts 100 m.

The calculation starts for the topmost layer. By multi-plication with the raster templates, the deposit must be directly fitted to its real distribution. For the topmost layers an additional correction is necessary (see subchapter "Correction of the calculated relevant thickness"). Afterwards, the calculation of the following layers can go on. For the lower layers it is important that the already calculated relevant thickness of the overlying layers is substracted from the results.

The interpolated rasters of the quarternary deposits, showing the thickness of the quarternary layers (except for the Deckenschotter) can be used immediately as relevant thickness, due to their maximum depth, which is smaller than the considered depth (<100 m). Therefore they can be substracted directly in the calculations of the lower layers.

Correction of the Calculated Relevant Thickness

Due to the complex, quarternary sediment discharge, a correction during the calculation of the relevant thickness is necessary for the topmost layers. Caused by the substraction of the overlying, younger layers, negative values of the relevant thickness can appear. One possible reason is shown in Figure 7.

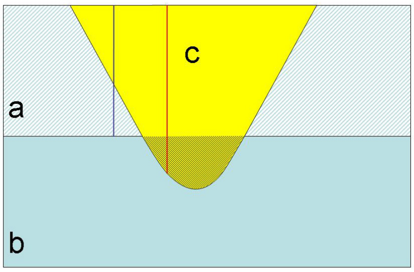

Figure 7: Schematic diagram for better comprehension of the negative value's origin.

During the interpolation of the interfaces, the eroded and newly sedimentated areas were neglected. The calculated thickness of layer (a) is therefore consistent with the height of rectangle (a). In the calculation of the relevant thickness, the thickness of layer (c) is substracted from layer (a). In the range of the left, grey line, the resulting relevant thickness will be correct and runs from basis (a) to basis (c). If the thickness of layer c is substracted at the right, red line, the substracted thickness is higher than the maximum thickness of layer (a). This results in negative values, although the real thickness of layer (a) should be zero in this place. These negative values must be set to zero. This is done by a condition with the Raster Calculator, where all values smaller than zero are reset to zero.

Once the calculations of the relevant thickness for each geological unit and the corrections are finished, the construction of the three-dimensional underground model is completed. Now, the evaluation of the potential is just a query function that can be varied in any order.

4. RESULTS

4.1 Thermal Conductivity

To illustrate the geothermal potential, the average heat conductivity of the considered depth intervall can be used. Therefore typical values are allotted to the finished lithological underground model. The applied values for the Jurassic layers as well as the USM and OSM derive from Clauser & Koch (2006). The determination of the missing values is based on the guideline VDI 4640, considering the lithological rock composition of the units that is known from several references.

For the final calculation of the potential map based on thermal conductivity a query in the raster calculator was done. In this calculation, the thermal conductivity is weighted with the relevant thicknesses, by multiplying the values with the belonging relevant thicknesses for every single unit. The results are summarized and divided by the considered depth.

Although the created map shows the thermal conductivity in the unit [W/(m*K)], the value can not be used to convert the values to any depth. The pictured values are only reliable for the considered depth that was used during the calculation (100 m, 150 m or 200 m).

The following figures (Figure 8 – 10) show the potential maps based on the thermal conductivity for 100 m, 150 m and 200 m depth. Additionally the water protection areas, existing borehole heat exchangers in Baden-Württemberg, cities and rivers are pictured in the maps.

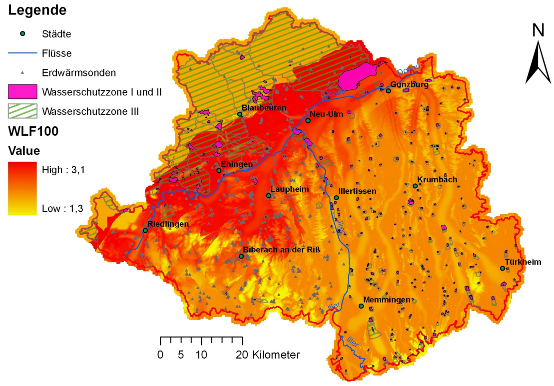

Figure 8: Potential Map based on thermal conductivity in W/(m*K), for the depth of 0-100 m.

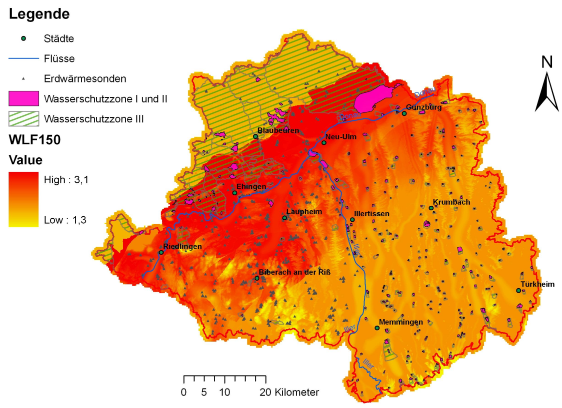

Figure 9: Potential Map based on thermal conductivity in W/(m*K), for the depth of 0-150 m.

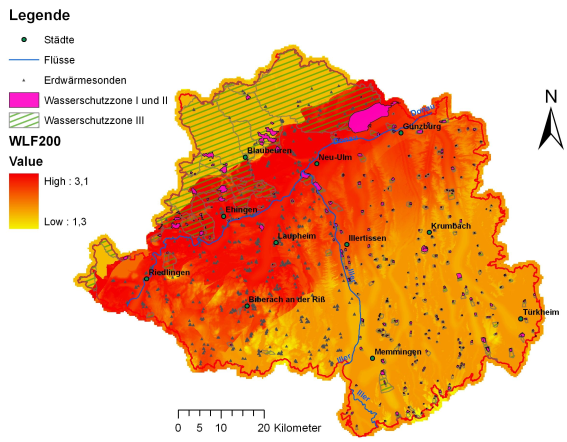

Figure 10: Potential Map based on thermal conductivity in W/(m*K), for the depth of 0-200 m.

At first sight, the three potential maps look quite similar. The range of values varies always between 1.3 W/(m*K) and 3.1 W/(m*K). This derives from the geological structure, where the layers dip in south-east direction and therefore occur completely within the first 100 meters. With increasing depth, the zone of maximal thermal conductivity that consists in particular of OMM and USM layers as well as the uppermost layers of the Jurassic, extends in south-east direction.

The thermal conductivity of the quarternary layers was chosen conservatively, due to missing informations concerning the groundwater level. The influence of the Quarternary layers is most conspicious in the potential map of the first 100 meters. With increasing depth the influence of the quartenary layers decreases, due to the considered thickness.

The abrupt step within the thermal conductivity in NE-SW direction near Blaubeuren results from the lithological boundary within the Jurassic, where the thermal conductivity increases from 2.36 to 3.1 W/(m*K).

4.2 Specific Heat Extraction

The specific heat extraction in [W/m] specifies the power that can be extracted from the underground without effecting its progressive cooling down. According to Sanner (1999) the heat extraction depends on the following factors:

- Heat transport capability (heat conduction, convection)
- Duration of the heat extraction (annual operating hours)
- mutual influence of borehole heat exchangers
- borehole diameter, grout material, position of the tube within the borehole

For borehole heat exchanger systems of up to 30 kW, the guideline VDI 4640 gives values for the specific heat extraction, which are based on empirical values. These depend on the absolute heat flow volume that is extracted within one year, the geological formation and the thermal conductivity respectively. The given empirical values however, can differ from the real values on-site, due to factors like cleavage, schistosity or weathering.

Other limitation factors for the validity of the values given in the guideline are:

- Only valid for heat extraction (heating and hot water)
- Maximum length of the borehole heat exchangers between 40 m and 100 m
- Distance between two heat exchangers at least 5 m for lenghts of 40-50 m and 6 m for lengths of > 50-100 m
- Diameter of the pipes: DN20, DN25 or DN32
- Not applicable for greater amounts of smaller systems within a defined area

In spite of the limitation concerning the maximum depth of the borehole heat exchanger, the values given in the guideline were also used for the depth intervals 0-150 m and 0-200 m. For deeper drillings larger diameters and therefore more grout material are necessary. For this reason the borehole thermal resistance increases and as a consequence the specific heat extraction decreases. With rising depth, however, the temperature increases, what benefits the specific heat extraction again. This influence caused by the geothermal gradient is negelcted in the values of the guideline. On this account, the potential maps can only be used for a general comparision of the potential within the region Donau-Iller. The real on-site values can differ more or less from the calculated data and can only be determined exactly by on-site explorations.

For the calculation of the potential maps based on the specific heat extraction the relevant thickness is multiplied with the belonging heat extraction value and summarized in the end. The resulting maps show the specific heat extraction in the region Donau-Iller in kW per BHE. This unit was chosen to avoid a further calculation for arbitrary depths, because the pictured heat extraction is only valid for the considered dephts (0-100 m, 0-150 m and 0-200 m).

The specific heat extraction varies with the geological structure and therefore with the depth. According to the thermal properties of the underground the heat extraction can be varied by using one or more borehole heat exchangers with the same total length. If, e.g., the thermal properties of the shallow layers are much higher, multiple borehole heat exchangers would lead to a more efficient result than just one deep BHE. In general however, the temperature increase with the depth benefits the length of a BHE. Therefore, according to Sauer (2008), one deep BHE is more efficient than two shorter BHE’s, lying in the same lithological unit. For this reason the potential maps based on the specific heat extraction were calculated for three different depths (100 m, 150 m and 200 m). Figure 11-16 show the calculated maps for the two different operating hours 1800 h and 2400 h.

The result of the potential maps based on the specific heat extraction looks similar to the maps based on thermal conductivity. With increasing depth the zone with maximal values expands in south-east direction. In general with annual operating hours of 1800 h higher heat extraction values can be reached. These vary between 2.5 W/m and 16.8 W/m. For 2400 h the heat extraction values are lower and range from 2 W/BHE to 14 W/BHE.

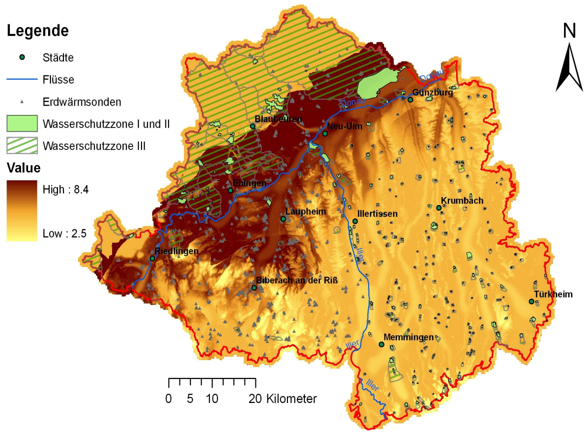

Figure 11: Specific heat extraction for the depth interval of 0-100 m and an annual operating hour of 1800 h in [W / BHE].

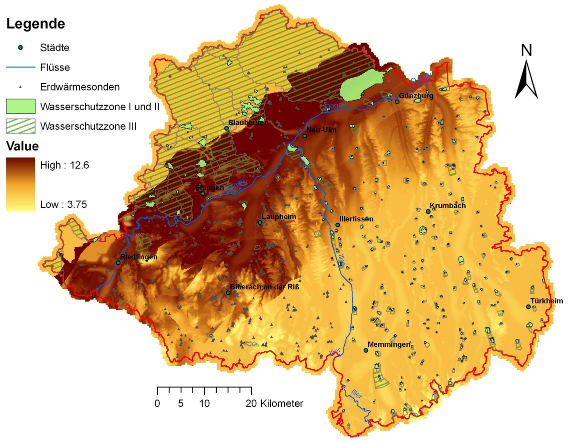

Figure 12: Specific heat extraction for the depth interval of 0-150 m and an annual operating hour of 1800 h in [W / BHE].

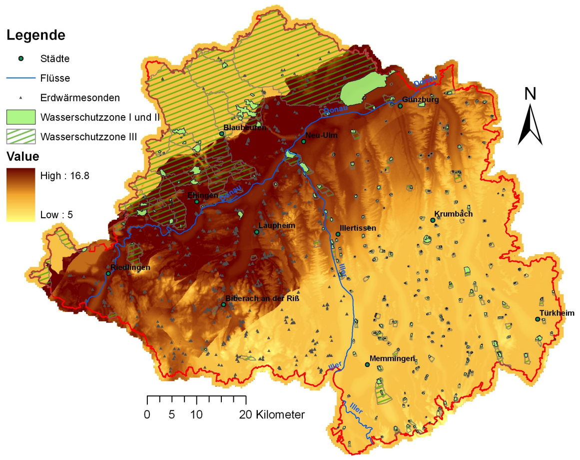

Figure 13: Specific heat extraction for the depth interval of 0-200 m and an annual operating hour of 1800 h in [W / BHE].

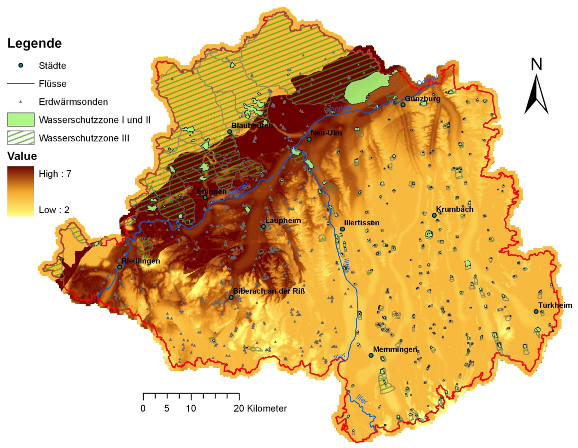

Figure 14: Specific heat extraction for the depth interval of 0-100 m and an annual operating hour of 2400 h in [W / BHE].

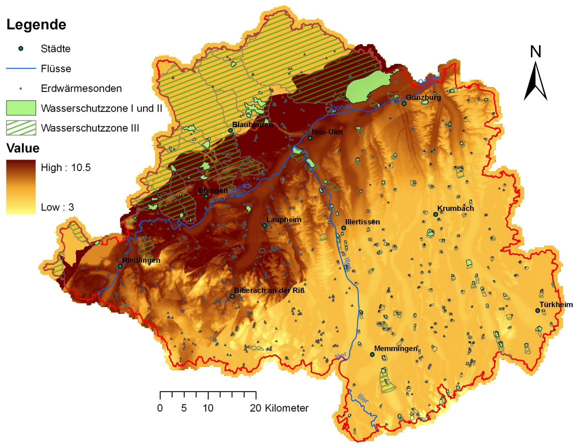

Figure 15: Specific heat extraction for the depth interval of 0-150 m and an annual operating hour of 2400 h in [W / BHE].

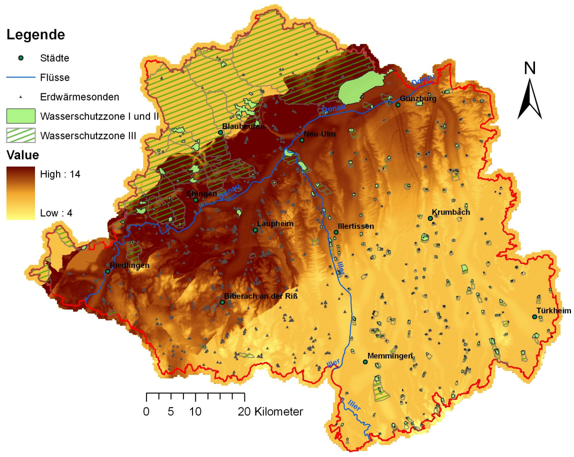

Figure 16: Specific heat extraction for the depth interval of 0-200 m and an annual operating hour of 2400 h in [W / BHE].

5. VALIDITY OF THE POTENTIAL MAPS

The generated potential maps shall give a survey of the spatial distribution and the relative size of the expected potential (thermal conductivity and heat extraction). The maps are therefore suitable for a general and spacious illustration of the underground's applicability concerning geothermal usage. Due to different sources of errors as well as the resutling inaccuracies in the model, the maps can not be used for detailed and site-specific conclusions. The rock formation for instance, has an essential influence on the real, natural potential but due to the region's scale and the availability of informations it was not possible to take these factors into account. Thus the cleavage, schistosity, void ratios and weathering of the rocks were neglected during the choice of the used values. Like already mentioned before, the groundwater flow has an important influence on the real potential as well. Caused by the groundwater flow, a great amount of heat flows to the borehole heat exchangers and leads to a faster temperature generation within the underground. Also without the influence of flowing groundwater, saturated rocks show higher thermal conductivities than dry rocks. This can be traced back to the fact that the thermal conductivity of water is much higher compared to air. For these reasons the real, local potential can vary enormously from the values that were used for the potential calculations.

If the needed heat demand and its temporal division are known, the length of a borehole heat exchanger can be estimated. For an accurate calculation however, a simulation for the dimensioning of the borehole heat exchanger is inevitable.

6. CONCLUSION

The calculation of the different potential maps is based on the construction of a three-dimensional underground model. This model must be subdivided into several layers that vary in their lithological composition. Furthermore the ground-water presence must be included. For the constructed model the geological layer boundaries were used, due to the irregular developed layers and the available base data. Before the final calculation of the potential can start, the relevant thickness of the layers must be determined.

The creation of the potential maps in the following is just a query function. Parameters like heat conductivity and the specific heat extraction were assigned to the calculated relevant thicknesses and summarized in the end. These potential maps were created for three different depths (100 m, 150 m and 200 m) to point out its change with increasing depth. The maps show an area in the middle part of the region with higher potential compared to the surrounding area. This is caused by the geological structure, where OMM, UMM and layers of the top Malm are deposited near to the surface. With increasing depth the zone of maximal potentials is dislocated in south-east direction, where the layers subduct under the layers of the OSM.

In the near future, potential maps based upon the cold extraction shall be created, to point out that a combination of heating and cooling with BHE's benefits the thermal regeneration of the underground and results in less drilled meters.

Furthermore a fourth potential map is planned. This shall show the specific annual extraction work that plays an important role regarding the long runtime of the systems.

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