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Geothermal use of an Alpine aquifer—Davos pilot study

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Abstract

Topographically induced Alpine regional groundwater flow systems below the unconsolidated valley fillings constitute a substantial unused geothermal resource. Within the framework of the INTERREG VB project GRETA (shallow geothermal energy in the Alpine region), we developed a method to quantify the groundwater flux of complex alpine aquifers. The basis of the study is a regional-scale hydraulic groundwater model, which is based on a 3D tectonic model of the Davos region in Switzerland. Based on data from a large pumping test, we were able to calibrate the hydraulic model and to calculate basics for various usage scenarios of energetic exploitation for the Arosa Dolomite aquifer. Favourable conditions for an energetic exploitation are related to large-scale topography differences between groundwater recharge and potential exfiltration areas in the valleys, thanks to the 3D geometry of the large-area tectonic nappe units with their root zone located within river valleys. In general, the proposed concept could be applied to manifold similar geological and hydrogeological settings of the Alpine belt.

Keywords SGE (Shallow Geothermal Energy) · Regional Groundwater Circulation · Alpine Hydrogeology · 3D Geologic Model

Geothermische Nutzung eines alpinen Aquifers – Pilot Studie Davos

Zusammenfassung

Regionale durch die Topografphie induzierte alpine Grundwassersysteme unterhalb von Lockergesteins-Talfüllungen stellen eine größtenteils ungenutzte geothermische Ressource dar. Im Rahmen des INTERREG VB-Projektes GRETA (shallow geothermal energy in the Alpine region) haben wir ein Konzept entwickelt, welches erlaubt, Bilanzen komplexer alpiner Aquifere zu quantifizieren. Mit Daten eines Großpumpversuches konnten wir das für die Region Davos aufgebaute Grundwassermodell kalibrieren und Grundlagen für verschiedene energetische Nutzungsszenarien für den Arosa-Dolomit-Aquifer berechnen. Aufgrund der 3D-Geometrie der großflächigen tektonischen Deckeneinheiten und deren Wurzelzone im Bereich der Flusstäler, sind die Voraussetzungen für großräumige Topographieunterschiede zwischen Grundwasseranreicherungs- und potenziellen Exfiltrationsgebieten in den Tälern gegeben. Grundsätzlich könnte das hier vorgeschlagene Konzept in verschiedenen Gebieten des Alpengürtels mit ähnlichen geologischen und hydrogeologischen Randbedingungen angewendet werden.

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Introduction

Various national and European projects aim to reduce consumption of non-renewable fossil energy in the Alpine area. A popular way of meeting this goal is to use heat from the shallow subsurface. Until recently, the construction of borehole heat exchangers (BHE) was very common. But due to several limiting factors, such as increasing BHE density, many of the systems (up to 30%) already show excessive cooling after only 15 years of operation (Kriesi 2017). Other factors include hazards due to BHE in particular geological formations or groundwater protection requirements (Butscher et al. 2011). As a consequence, BHE are supplemented by geothermal systems (groundwater pumping). For economic reasons, stakeholders generally prefer to have larger installations, which is why larger tourism complexes are particularly suitable for such installations in Alpine regions.

In Alpine valleys, the uppermost sequence of the subsurface often consists of a sequence of fluvial gravel and glacial sediments, underlain by lake sediments. When drilling in geological formations below the lake deposits, one often encounters confined or artesian groundwater. The regional groundwater circulation is significantly influenced by the height differences between groundwater recharge areas and the valley floors (Toth 2009). In such cases, these areas represent regional aquifers with groundwater recharge in topographically elevated areas. To prevent uncontrolled connections of groundwater from different aquifers, the use of BHE in artificially confined aquifers is often prohibited. Therefore, in the community of Davos (canton of Grisons, Switzerland), the idea consequently is to explore artesian aquifers at medium depths as a potential energy source. In combination with other energy sources, this new energy source could contribute to the reduction of fossil fuel consumption. A major advantage of SGE, as opposed to other renewable energy sources like solar or wind energy, is that it is suitable for baseload.

After an initial drilling phase four hundred meters deep in Davos, it was clear at a depth of 270 m that there was artesian groundwater present with a temperature of 11 °C. But then questions arose about the sustainable productivity of the aquifer and the origin of the groundwater (e.g. groundwater recharge areas). The artesian groundwater conditions that were observed suggested that the Arosa Dolomite is part of a regional topography-driven circulation system.

As part of the INTERREG VB project called GRETA (shallow geothermal energy in the Alpine region), the potential of SGE from the Arosa Dolomite in the Davos area was determined. This work was conducted by the Applied and Environmental Geology (AUG) from the University of Basel, together with five project partners: the community of Davos, Geotest AG Davos, the Office of Nature and Environment Chur (ANU), and the Federal Offices for Spatial Development (ARE) and for Energy (SFOE). To determine the relationship between the source of water and the yield of this complex groundwater system, the AUG set itself the task, within the framework of the INTERREG project, of developing a tool to determine the dynamics of this Alpine groundwater system.

In this paper, we describe the individual steps taken in developing the methodology to evaluate the groundwater dynamics of the Arosa Dolomite. The main task included developing a tool to evaluate the groundwater dynamics in a complex Alpine nappe system. Since the available hydrogeological information was limited to the area of the valley, we decided to create an expandable regional hydraulic model based on a 3D tectonic model of the Davos area. The calibration of this expandable model was based on a large pumping test in which the groundwater abstraction was increased to 1628 l/min in five steps over a period of 24 days. Finally, the results and questions about the methodology's potential for application to other areas are also discussed in this paper.

Study site and geology

The area of the city of Davos is the focus of the investigation. This is where geothermal energy from the Arosa Dolomite aquifer is to be used. In order to be able to determine the spatial position and distribution of the hydraulically relevant aquifers and aquicludes, the geometries were derived from a 3D geological model of the Davos region (Fig. 1a). The focus of the aquifer research is the Arosa Dolomite, a predominantly Dolomite tectonic unit which was the target of the geothermal exploration well drilled in Davos in 2012 (Regli et al. 2014). The Arosa Dolomite nappe is superimposed by the Silvretta Crystalline nappe, located near the town of Davos on the western flank of the valley. That nappe can be traced along the Landwasser chain SSW into the Lenzer Horn area (Fig. 1b). The geological 3D modelling was performed based on the knowledge of regional and local nappe structures. Since no 3D regional studies had been performed before, there were open questions regarding the location and orientation of the main thrusts. Thus, the 3D model results were presented to four experts[1] for review. In a second step, the complex 3D tectonic model was slightly simplified before the model was discretized for the hydraulic model. In addition, surface and subsurface catchment areas were derived from the 3D tectonic model, and the dynamics of discharge and recharge zones could also be derived from hydrogeological modelling.

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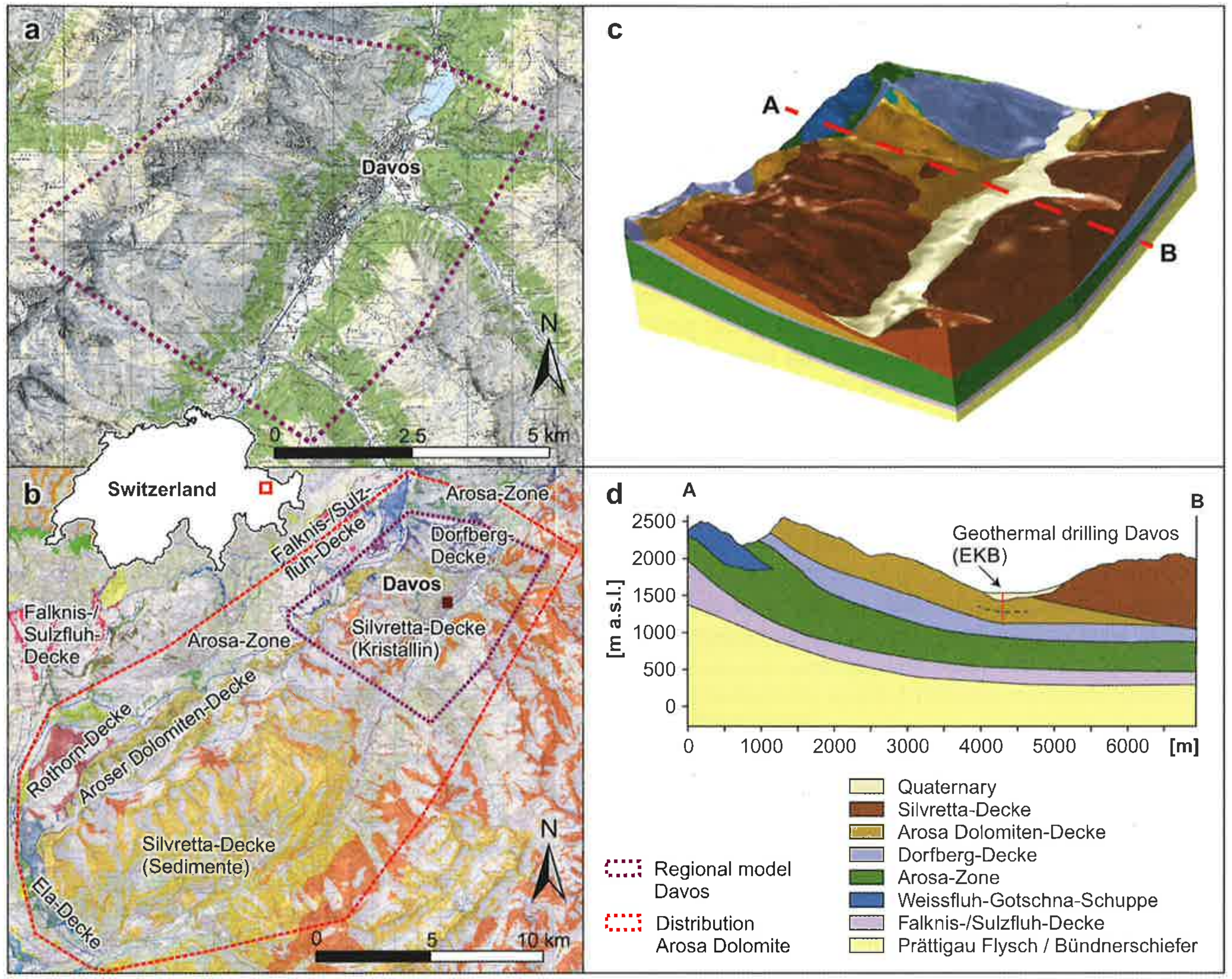

Fig. 1 Model perimeters for the geological and hydraulic models: **a** regional perimeter for the hydraulic model, **b** perimeter for the tectonic model, **c** hydrogeological model with volumes according to the geological 3D model, **d** Cross section from WNW to ESE through the EKB geothermal well

Abb. 1 Modellperimeter für die geologischen und hydraulischen Modelle: **a** regionaler Perimeter für das hydraulische Modell; **b** Perimeter für das tektonische Modell; **c** hydrogeologisches Modell; **d** Querschnitt von WNW nach ESE durch die Erkundungsbohrung (EKB)

Approach

The objectives of the pilot study were to develop a geological and hydrogeological model of the Davos area. With the help of these two models, we aimed to understand the complex groundwater situation of the area, and to determine the Arosa Dolomite aquifer's use potential and SGE productivity. The main ideas of the underlaying conceptual model are that topography is a motor of the groundwater flow and that the groundwater table is a replica of the topography (Ingebritsen et al. 2006). The bulk hydraulic properties of the geologic units represent estimates from which the conductance between the main structural hydrogeological units are derived. Other factors which determine the groundwater flow regime on a regional scale are the interplay between topography and the 3D geological structures, particularly the sequence of aquifers and aquitards.

Most existing hydrological data is from an exploratory well which was drilled in 2012, known as the "Erkundungsbohrung" or EKB well (Regli et al. 2013). Today, it supplies energy to the ice rink and the congress hall, most famously used each January for the World Economic Forum (WEF). As part of this exploration well, a comprehensive measurement programme was carried out. Step-by-step, new measurements of a measuring program (GEOTEST 2017) were integrated. With the hydraulic parameters around the exploration, more knowledge could be obtained about the system of the regional groundwater flow.

Regarding the hydraulic constraints of the aquifer boundaries, the main challenge of the project was to create a new regional groundwater model based on limited data. The basis of our new model consists of a framework of the 3D geological data (GOCAD ©). These data were then transferred into a numerical groundwater flow model (COMSOL ©). The result was our new model (Fig. 1c). Integrating a geological model into a hydrogeological model requires making some simplifications with respect to the complex geometry of some edges of the nappe boundaries. Importing geological structures into numerical groundwater flow models requires, among other things, a layer-independent integration of geologic structures. Our approach makes it possible to understand regional ground water circulation (Scheidler et al. 2019), what effect structures like tunnels have (Butscher et al. 2017), the dynamic character of pumping wells' capture zones, as well as to test how different boundary conditions and hydraulic property distribution influence calculated flow regimes.

Geological 3D model—hydrological model

The groundwater model is based on the 3D geological model. The creation of the geological model includes the integration of balanced 2D cross-sections (Suppe 1983) into a consistent 3D geological model (Groshong 1999; Zanchi et al. 2009). The most important tectonic unit in this new groundwater model is the Arosa Dolomite, a regional aquifer. The Arosa Dolomite is a predominantly Dolomite tectonic unit that was the target of the geothermal exploration well, the EKB well, in Davos in 2012 (Regli et al. 2013). As the information from drilling the EKB well shows, the Arosa Dolomite is subdivided hydraulically into two different volumes (Fig. 1d). The upper unit of the first 100m of the Dolomite acts as an aquifer, while the lower one, where almost no water flows into the borehole, is considered to be a low permeable unit. The Arosa dolomite is partially overlaid by the Silvretta Crystalline, which acts as an aquiclude. The core of the hydrological model contains the spatial location and distribution of the hydraulically relevant aquifers and aquicludes from the nappe system. The integration of the geological structures into 3D numerical groundwater flow models is by no means a straightforward operation (Ross et al. 2005). To make the hydrological model, the geometries of the relevant hydraulic units created by the 3D geological model were imported as surfaces into the hydraulic model.

Parameterization, Boundary Conditions and Model Setup

Data from previous work (Regli et al. 2010) provide the basis for the hydraulic parameters in the hydrologic model. The hydraulic permeabilities are listed in Table 1. Groundwater recharge (precipitation minus evaporation) is based on the hydrological atlas of Switzerland (BAFU 2015). The amount of water infiltrating through the surface depends on the permeabilities of the outcropping geology. A distinction in recharge was made between the different outcropping geological units with corresponding hydraulic permeabilities (Table 1). We thus integrated a higher recharge above potential aquifers and a lower recharge above aquitards. The groundwater table in the quaternary sediments represents a head boundary condition with a semipermeable interface to the Arosa Dolomite. The hydraulic permeability of this semipermeable interface was determined by inverse model calibration. All other model boundaries were assigned in a first approach as no flow boundaries. Together with the hydraulic parameters of the sequence of geological units, it is possible to calculate the large-scale groundwater circulation and different scenarios with regard to changes in uses, boundary conditions or sensitivity of the different geological units even without extensive measured values, which in most cases are not available.

Calibration

In the present case, only hydraulic data from the exploratory well (EKB) and three monitoring wells for monitoring the hydraulic conditions of the Arosa Dolomites were available for the calibration of our model. With the model, we could simulate how the existing monitoring boreholes hydraulically reacted to the multi-stage pumping test. Data

Table 1 Hydraulic permeabilities used in this study. The anisotropy factor of the hydraulic permeabilities (kf_z/kf_x) is 0.5
Tab. 1 Verwendete hydraulische Durchlässigkeiten. Der Anisotropiefaktor der hydraulischen Permeabilitäten (kf_z/kf_x) beträgt 0,5

	Hydraulic Conductivity (k_f-value) [m/s]
Quaternary	1E–4
Arosa Dolomite (upper part)	2E–6
Arosa Dolomite (lower part)	1E–8
Silvretta Decke	1E–9
Weissfluh-Gotschna-Schuppe	1E–6
Arosa-Zone	1E–8
Schafläger-Decke	1E–7
Rothorn-Schuppe	1E–9
Davoser Dorfberg-Decke	1E–9
Falknis-/Sulzfluh-Decke	1E–7
Prättigau-Flysch	1E–8

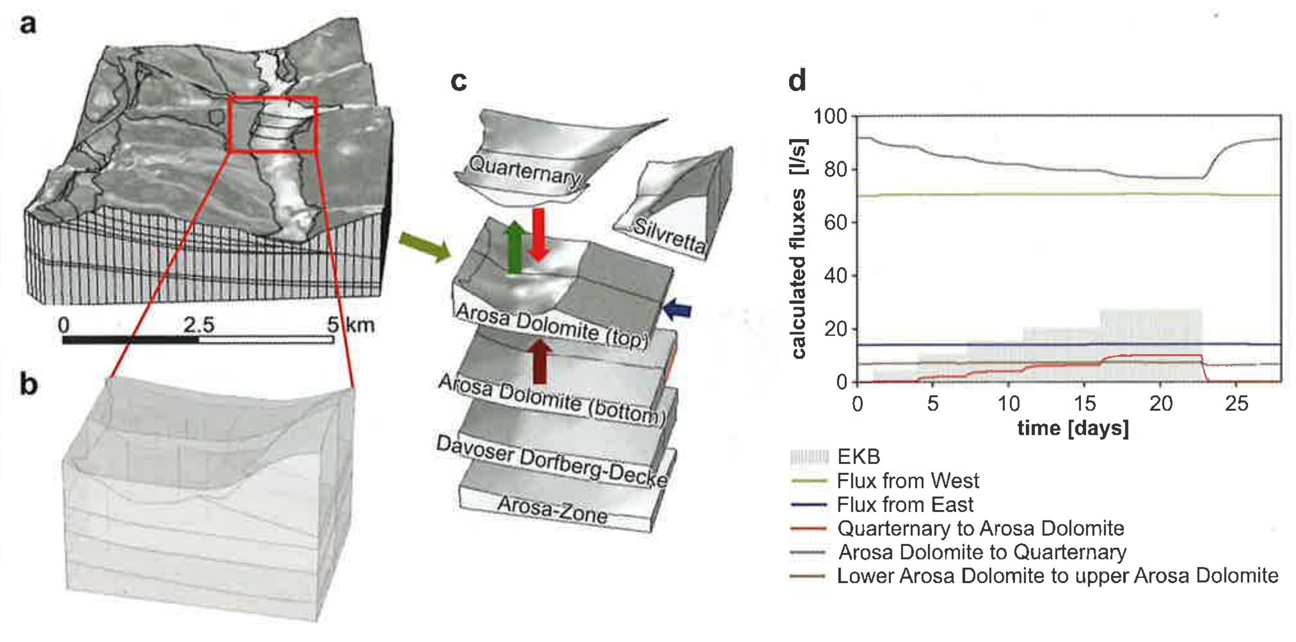

Fig. 2 Hydraulic model with the budget box for the calculation of water fluxes: **a** hydraulic model, **b** budget box, **c** separated volumes of the budget box with the main groundwater fluxes, **d** calculated fluxes as a result of the pumping test
Abb. 2 Hydraulisches Modell mit Bilanzbox zur Berechnung der Wasserflüsse: **a** Hydraulisches Modell; **b** Bilanzbox; **c** getrennte Volumina der Bilanzbox mit den Hauptgrundwasserflüssen; **d** berechnete Bilanzen während des Pumpversuchs

from both the real and the simulated hydraulic head shows the response to pumping is quick, and the reaction of the pumping test could be well simulated. On the other hand, the lowering of the groundwater in the observations or in the EKB could only be simulated to some extent. The decline of the water table of the different observation wells is underestimated, while the decline in the EKB is overestimated. These results indicate that the assumptions the model makes with respect to the hydraulic behaviour at the transition from the Arosa Dolomites to the Quaternary would need to be adjusted based on new groundwater observation wells. The groundwater tables in the monitoring wells are portrayed qualitatively by the calculated head distribution during the pumping test. However, the deviation of the head values in the observation wells indicates a more complex hydraulic data distribution in the Quaternary deposits, as well as a more complex conductance between the Arosa Dolomite and the overlain geologic units. Although there is a lack of observational data, we use the model results for the scenario calculations and the main trends of the flow regime in selected subdomains.

Results

In a first step, results are presented for groundwater budgets and groundwater circulation on a regional scale. Furthermore, we discuss specific questions concerning a new geothermal well and the future licensing practice.

Groundwater Budgets

An important result of groundwater modelling is the groundwater budget and its temporal change. They were calculated for the different hydrogeological units (Fig. 2), and the exchange between these units was calculated as well. With the existing model, it is possible to determine the groundwater fluxes over different cross-sections. In a first step, therefore, a sub-model (Fig. 2b) was set-up around the exploration well in the form of a balance box. Fig. 2a shows the location and the individual compartments of this balance box. This allows us to evaluate the flow direction between the Quaternary and the Arosa Dolomites, and how it changes with increased groundwater extraction at the EKB. The calculation of the water budget in this case was also based on the pumping test carried out as part of the GNAMA project ("Grundlagen der geothermalen Nutzung alpiner mitteltiefer Aquifere" (GEOTEST 2017)). The largest share of the groundwater balance is due to the influx from Arosa Dolomite into the Quaternary (Fig. 2c). Although the semi-permeable layer between Arosa Dolomite and Quaternary reduces the groundwater flow, it simultaneously builds up the hydrostatic pressure, which is responsible for the artesian conditions on most piezometers and at the exploration well. The graph in

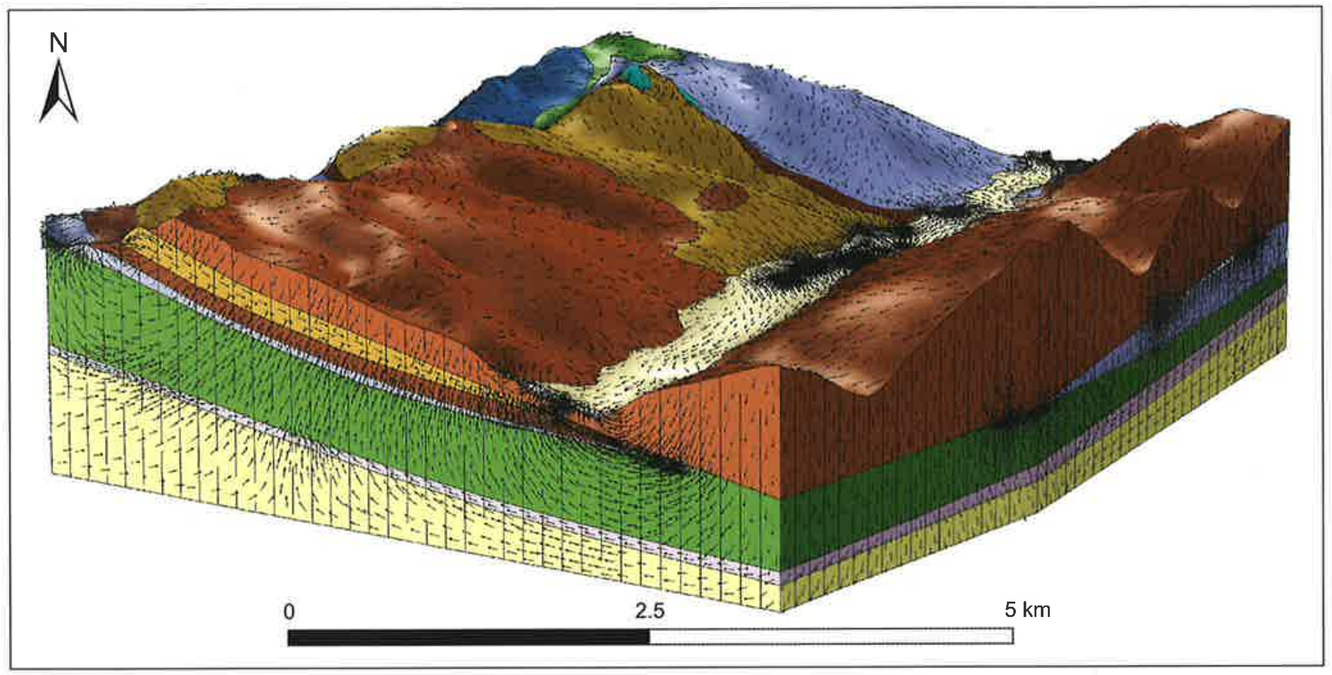

Fig. 3 Result of regional scale groundwater modelling: the *arrows* represent the flow direction. The density of the *arrows* is based on a Gaussian distribution and is not to be equated with a volume or a velocity

Abb. 3 Ergebnis der Grundwassermodellierung auf regionaler Ebene: Die *Pfeile* geben die Fließrichtung an. Die Dichte der *Pfeile* basiert auf einer Gaußschen Verteilung und ist nicht mit einem Volumen oder einer Geschwindigkeit gleichzusetzen

Fig. 2d shows how different fluxes respond to increasing groundwater extraction. With increasing extraction during the pumping test, the rising groundwater quantity is reduced. The inflow from the west (within the Arosa Dolomite) remains constant, at about 70 l/s, regardless of whether groundwater is extracted or not. This also applies to the inflow from the east (about 16 l/s) and to the inflow from the lower Arosa Dolomite (about 7 l/s). These latter two fluxes, however, are significantly lower than the influx from the west. Before starting the pumping test, there was no groundwater flow from the Quaternary to the Arosa Dolomite. But when the pumping test begins, the changes amount to a value of approximately 9 l/s, with a maximum groundwater extraction of approximately 27 l/s.

Regional Flow System

The regional groundwater flow regime provides information on how the sequence of aquifers and aquicludes affects groundwater circulation. The calculation of regional flows is done more in the interest of seeing what impact changing boundary conditions has, but it is less important for detail clarifications on a local scale. With the visualization of the flow lines, individual geological units of the groundwater model can also be investigated. With the regional representation of the groundwater flow system (Fig. 3), it is possible to localize areas of groundwater flowing up and down. It is also possible in particular to visualize changes in different boundary conditions, or changes in the use of the rock aquifer. If further groundwater measuring systems are to be built, then meaningful locations can be recommended with the knowledge of the regional flow system. With the calculation of flow lines, single geologic units and capture zones of new extraction wells can be analysed.

Mutual Influence of Different Geothermal Wells

The model could be used as a tool in case the electric power company "Elektrizitätswerk Davos AG" (EWD) would like to use water from the Arosa Dolomite. This illustrates future applications the tool may have. For example, the model could also be used in connection with approval procedures for the use of heat from the underground. The EWD operates a small heat network with heating oil in the Schulstrasse area in Davos Platz. This could be expanded and supplemented with the use of water heated from the Arosa Dolomite. To do that, we need to extract a quantity of around 1000 l/min of groundwater. For this purpose, the expected effects on the groundwater flow regime in the aquifer of the Arosa Dolomite and the existing heat utilization (uses in the Arosa Dolomite) were calculated. Fig. 4 shows the extent of the drawdown due to the additional groundwater use and the existing use of the EKB. The two drawdown radii merge into each other, which suggests they mutually influence each other (Fig. 4a). But if the drawdown of the surrounding observation wells is considered to

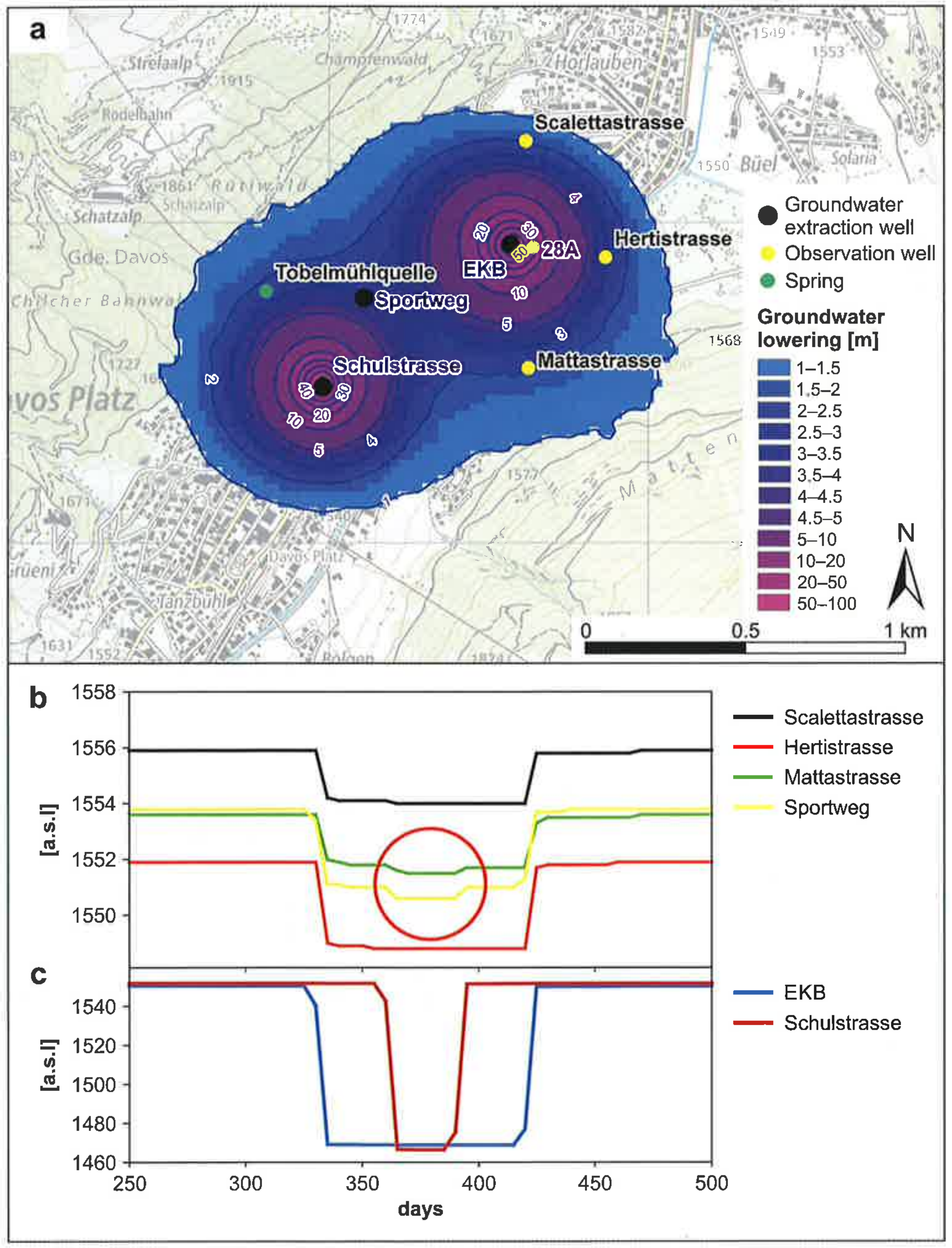

Fig. 4 Mutual influence of two extraction wells: **a** the two depression cones of the extraction wells, **b** measured hydraulics at the observertion wells near the EKB well; the *red circle* highlights the infuence of the Schulstrasse well, **c** measured hydraulics at the EKB (*blue*) and Schulstrasse (*red*) extraction wells

Abb. 4 Gegenseitige Beeinflussung von zwei Entnahmebrunnen: **a** die beiden Absenktrichter der Entnahmebrunnen; **b** gemessene Ganglinien an den Beobachtungsbrunnen in der Umgebung der EKB; der *rote Kreis* hebt den Einfluss der Entnahme „Schulstraße" hervor; **c** gemessene Ganglinien an den Entnahmebrunnen EKB (*blau*) und Schulstraße (*rot*)

be only slightly higher, then a lowering of the groundwater level can be observed (Fig. 4b, red circle). From the present calculations, it can be concluded that the Arosa Dolomite is productive enough thanks to groundwater yield, and that no major impact on the EKB is to be expected.

Groundwater Potential Maps

To approve BHEs, the corresponding Office of Nature and Environment Chur (ANU) requires a map to be used which shows the confined artesian areas. Therefore, the model was used to define different zones with respect to hydraulic potential. The groundwater potential is calculated for the top of the Arosa Dolomite, and afterwards intersected with the high-resolution digital elevation model (Fig. 5). The confined artesian area is illustrated only for the area of the valley floor. For the creation of these maps different boundary conditions like groundwater recharge or new extraction wells were considered. In the south, and also to the east of the valley floor, the groundwater potential is very high. The reason for this is the thrust of the Silvretta nappe over the Arosa Dolomite. That means the groundwater in these parts cannot flow away, thus suggesting a strong increase in hydraulic pressure.

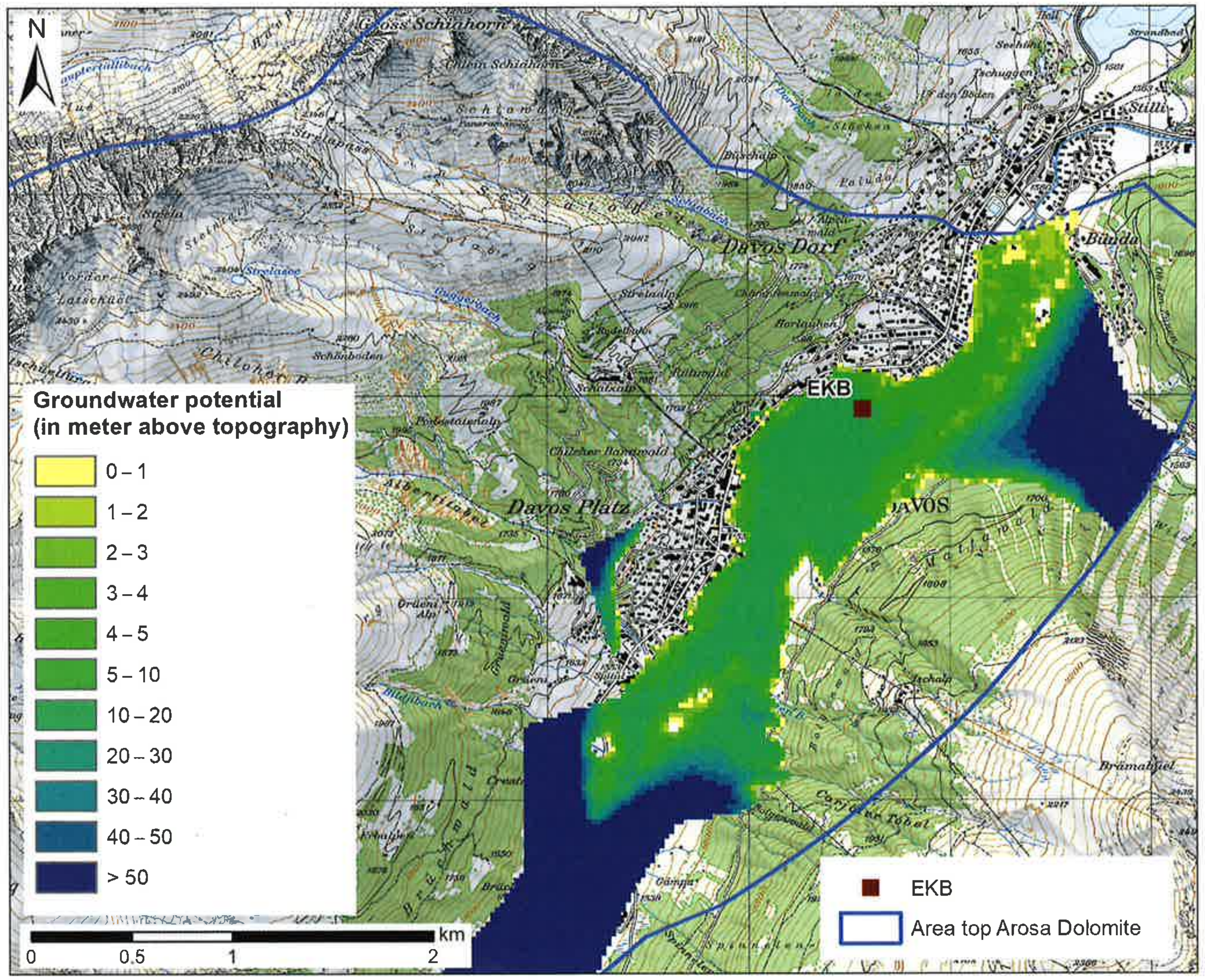

Fig. 5 Calculated groundwater potential. The *color marks* show areas with confined artesian groundwater. The groundwater potential was calculated for the top of the Arosa Dolomites (*blue border*) and shown only for the bottom of the unconsolidated rock deposits

Abb. 5 Berechnetes Grundwasserpotential. Die *Farbmarkierung* zeigt Gebiete mit artesischem Grundwasser. Das Grundwasserpotential wurde für den Top Aroser Dolomit (*blaue Linie*) berechnet und nur für den Bereich des Talbodens dargestellt

Discussion

In most tourism centres located in Alpine valleys, there are hydrogeological data related to the planning and construction of tourist infrastructure such as water supplies, transport routes, cable cars, hotels, and sports facilities. However, these data are insufficient in many cases when it comes to understanding the groundwater dynamics in the unconsolidated rocks of the valley fills. This is mainly because it is difficult to define hydraulic boundary conditions without a suitable monitoring system. It has been shown that it takes a great deal of persuasion to construct measuring systems for groundwater and heat transport models at sites suitable for the definition of boundary conditions. In the case of large-scale bedrock aquifers, suitable measuring systems are almost completely absent. In this context, Davos is actually an exception with its geothermal borehole.

In Davos, an existing measuring network could be accessed in the shallow aquifer. Existing exploration wells drilled to explore for heat potential from groundwater in bedrock aquifers at medium depth also provided us with an important additional hydrogeological data source. However, even with these data, the groundwater flow regime and interactions between the different aquifers can only be roughly understood from geochemical data. Thus, these data are insufficient when it comes to estimating the geothermal potential and estimating the possibility of geothermal energy use of several larger plants.

Due to the lack of knowledge about the system, the choice of making a conceptual model for regional groundwater circulation systems is an elegant way of roughly assessing the hydrogeological conditions in an early exploration phase. This allows for the planning of specific monitoring systems where the greatest possible improvement in hydrogeological knowledge can be achieved through new data. In the case of Davos, a large pumping test was used to calibrate the hydraulic model. On the one hand, with the current model it has been shown that the lowering of the groundwater table during the pumping test can be recorded well. On the other hand, the model also shows that the exchange processes between the Arosa Dolomite groundwater and the unconsolidated rock groundwater are poorly understood. This means that our understanding of the interaction between the two aquifers could be improved with a suitable monitoring system. This is important because, according to our hydrogeological model, by increasing the water production from the Arosa Dolomite, more water will flow from the unconsolidated to the Arosa Dolomite aquifer.

An important obstacle to using artesian groundwater as an energy source in the Alpine area is that many of the potential aquifers are heavily mineralized. A re-infiltration back into the artesian aquifer proves often to be difficult. The possibility of reintroducing the mineralized water into surface waters has to be evaluated carefully based on the requirements of the regulations (temperature changes and the quality requirements). With the help of the tools developed here, a basis can be created for decision makers when dealing with sustainable heat use in Alpine areas. From the point of view of groundwater protection and the required investigation effort, target users would not be individual smaller users, but rather larger units such as hotels, sports facilities, or conference buildings. Finally, applying our model in different Alpine regions as part of other pilot projects could provide more information on the exploitation of the energy potential of water resources in urban Alpine areas.

Conclusions

In this paper, we proposed a new groundwater flow model for the Davos area with information from Alpine nappe structures (3D geologic model). In addition, the model we presented is based on the concept of topography driven groundwater flow (Toth 2009). In this concept, the groundwater table in the mountainous area is a replica of the topography. In our case, the groundwater table in the elevated topographic area is assumed to be 30 m below terrain surface.

It is still a challenge to technically integrate 3D geological models with numerical groundwater flow models there is still no possibility of directly combining a complex geological model with a hydraulic model. In the present case, it was already necessary to prepare the individual areas in the geological model for use in our hydraulic model. After inserting the geological data into the hydraulic model, a large number of Boolean operations had to be carried out in order to ultimately obtain the desired volumes.

Although there have been extensive studies done thanks to the EKB geothermal exploration well, hydraulic data are limited for creating a groundwater model of the Arosa Dolomite aquifer. However, the regional approach was used in order to be able to develop a tool which may clarify changes in the groundwater flow regime and make specific calculations for the mutual influence additional groundwater extraction wells have, or to make groundwater potential maps. By obtaining the sequence of aquifers and aquicludes and with the topography as driving force, it was possible to get a usable tool despite having limited data for boundary conditions. With the pumping test used for calibration, the response of the pumping test in the monitoring wells could be qualitatively understood. Both the real and the simulated hydraulic head show there is a quick response to pumping, and the reaction of the pumping test could be simulated well. On the other hand, the lowering of the groundwater in the observation wells or in the EKB could only be simulated to some extent. Thanks to new data, however, it is possible to improve the model's meaningfulness step-by-step.

An important result of groundwater modelling is to develop an understanding on groundwater budget and its temporal change. Those can be calculated for individual hydrogeological units, as well as for the exchange between the units. In addition, it was already possible with this version of our model to provide specific statements to decision-makers regarding the opening up of additional extraction wells or the approval procedures for BHEs. Nevertheless, a major obstacle to using groundwater as an energy source in the Alpine area is that many of the potential aquifers are confined, or even artesian. These uses are thus problematic for reasons of water protection. However, the confined artesian groundwater deposits in the Alpine region still represent a potential source of energy. Before they are used, it is necessary to make preliminary hydrogeological investigations and take water conservation concerns into consideration.

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TECHN. MITTEILUNG UND/ODER FALLBEISPIEL

Altersbestimmung an thermalen Tiefenwässern im Oberjura des Molassebeckens mittels Krypton-Isotopen

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Zusammenfassung

^{81}Kr ($T_{1/2}$ 229.000 a) ist ein idealer Datierungstracer für alte Tiefengrundwässer. Die Oberjura-Formation im tiefen Teil des Molassebeckens stellt ein herausragendes Georeservoir für thermale Tiefenwässer (bis 140 °C) dar. Über die genutzten Thermalwässer mit zumeist kaltzeitlicher Bildungscharakteristik (Na-HCO_3-Cl-Typ) ist jedoch im Hinblick auf die Neubildungsprozesse, Herkunftsgebiete und Fließdynamik wenig bekannt. Für die Interpretation der Genese und Entwicklung (Ionen- und Isotopenaustausch, Gasflüsse, etc.) fehlen bislang verlässliche Altersinformationen.

Erstmals wurden nun neun thermale Tiefenwässer erfolgreich durch ^{81}Kr/^{85}Kr-ATTA-Untersuchungen datiert. Die abgeleiteten Altersinformationen zeigen im westlichen und zentralen Molassebecken vorherrschend eine Bildung während der letzten Kaltzeit (Würm-Glazial), die sehr gut zur subglazialen Bildungshypothese über alpennahe, sehr mächtige Deckschichten hinweg passt. Im Ostteil des Molassebeckens weisen die Tiefenwässer hingegen einheitlich deutlich höhere Alterscharakteristiken (Günz/Mindel Interglazial) bzw. ein langsameres Strömungssystem auf, das allenfalls durch geringe Neubildungsanteile aus den jüngeren alpinen Vergletscherungen beeinflusst ist.

^{81}Kr/^{85}Kr-Dating of thermal groundwaters in the Upper Jurassic (Molasse Basin)

Abstract

^{81}Kr (half-life 229,000 years) is an ideal tracer for old groundwater. The Upper Jurassic rock in the deep Molasse Basin is an outstanding geothermal groundwater reservoir (with temperatures up to 140 °C). However, due to the complex groundwater evolution (ion and isotope exchange, gas flux, etc.), comprehensive hydrogeological studies completed to date, including ^{14}C-DIC and He isotopes, could not resolve the recharge dynamics and residence times. Nine geothermal wells were therefore sampled for ^{81}Kr/^{85}Kr employing the laser-based atom trap tracer analysis technique (ATTA). In the western and central basin, the results reveal predominant groundwater recharge during the last glacial period with one sample influenced by infiltration during the earlier glacial period. Recharge signatures and ^{81}Kr-model-ages fit very well to subglacial recharge with cross-formational flow through the sedimentary cover (600 to >3000 m deep). In the eastern basin, the results point to the Cromerian complex, indicating a slower flow system with less influence from recharge during glacial periods.

Keywords Molasse basin · Old groundwater · Krypton · Isotope · Dating · Recharge · Cross-formational flow · ATTA · ^{81}Kr · ^{85}Kr

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