Review of the article

Spatial assessment of probable recharge areas - Investigating the hydrogeological controls of an active deep-seated gravitational slope deformation

J. Pfeiffer et al.

The subject is of major interest in mountainous context where it is often difficult to make a water balance in this kind of environment. There are many reasons for this: difficulties in estimating the recharge area, difficulties in estimating the outflows, because they are frequently masked by quaternary formations or rivers. To make a water balance of an aquifer allows to better manage the water resource, which in mountainous environment is fundamental because these are often the only water resource of small communities.

This paper proposes a methodology for estimating recharge areas in particular environments that are gravity instabilities. In these environments, estimating the search area is a real issue, because it is recognized that water is an aggravating factor in the displacement of these slopes. Any identification of water inflow is therefore essential to be able to set up remediation systems (example of drainage cited by the authors).

The method developed in this study is original and seems to give promising results. Unfortunately, there are many inaccuracies in both form and substance that taint these results.

On the form:

The figures are not all good quality and need to be revised

F**igure 1**

the DSGSD's right of way should be better marked

Are all the sources represented perennial? What guided the choice to follow certain sources rather than others?

On the location of the site, it would have been nice to indicate a known city (for those who do not know the Austrian Alps)

Figure 2

The identification of the sampling points is not intuitive for someone who is not familiar with the area. Moreover, it is written relatively small. This identification appears on figures 4, 5, 7 and 10 and really weighs down these figures, which does not facilitate reading. Maybe we should think about another simplified annotation.

What is the difference between "housed spring" and "natural spring"? Is the water from the "housed spring" captured subsurface water? Can you clarify? Is it necessary to differentiate between the two types of springs?

Does Figure 2c also include the rain sampler and snow sampler photos? Same for figure 2d? It probably does, but you can improve the readability of the figure by putting frames around the "photos that make up Figure 2C and the 4 photos in Figure 2d.

Figure 4

This figure could be improved by changing the names of the sampling points. It is not possible to differentiate the physico-chemical parameters of the water taken from the boreholes at different depths. There are two boreholes and three different symbols (red square, black square, and grey square). Is it a way to identify the samples taken at different hydrological periods in these wells? This is not intuitive and yet it is important information in terms of identifying water masses.

Could you specify the date of sampling and indicate the hydrological season (low water level, high water level)

Figure 5

This temporal figure is not very readable for some curves. The choice of colours for some curves should be reviewed. As there is not much variation for the electrical conductivity for temperature, you could add a table with statistical data would have been enough to describe the behaviour of this parameter (min, max values, standard deviation).

Concerning the O18 isotopes, why not have represented the δ H2 as a function of the δ O18 using the meteoric line even if there is no local meteoric line. This representation gives information on the origin of the water and makes it possible to differentiate infiltration water according to the seasons. This would have been a plus in your demonstration.

Figure 7

It can also be improved in the choice of colours for the flows.

Why not correlate these data with the precipitation data?

Figure 10

What colour code did you use to identify the points?

Is it to discriminate them from the colour code chosen for the ITTP? If so, why are there dark dots that do not appear in the ITTP scale?

Did you represent all the points? And if not, can you explain why?

Could you specify the date of sampling and indicate the hydrological season (low water level, high water level)?

Calling figures in the text: it is a bit anarchic

In paragraph 2 describing the Vögelsberg landslide, only figure 1a is called. It is not until paragraph 4.1 Hydrogeological characterization that figures 1 b, c and d are mentioned. This is very surprising. Paragraph 2 states the knowledge of the slide so if these measurements represented on figures 1b to d are new they must be integrated in another figure.

Figure 2b called before figure 2, figure 2c called before figure 2a. It seems to me that there must be an order to respect in the calling of the figures which is not the case on almost all the figures in this article.

Figure 3b is called before 3a and I stop my inventory there. I leave it to the editor to let you know if the order of calling the figures is important in the articles of this journal.

Paragraph 2

I am surprised to see no hydrogeological analysis in this paragraph. There are however things that exist since you have the inventory of springs. Has this hydrogeological description never been done? It is surprising because working directly on the recharge without having an idea of the hydrological context.

Paragraph 3.1

The whole sampling protocol is rather confusing and should be rewritten for a better understanding.

For example, I did not understand the measurements made in the drillings. Could you specify at what depth the measurements were made? This is important at least for borehole KB2 because you have an electrical conductivity that varies significantly over 18m which is not the case for borehole KB1 which raises questions about the origin of the water masses in these boreholes.

Paragraph 3.2

No need to quote again Tetzlaff et all (2009) on line144 because already quoted in the same paragraph on line 142

Paragraph 4.2

Why not compare the responses of springs in terms of flow variation with precipitation? This is usually done in classical hydrological studies. This gives indications on the response time of the aquifer but also on the transit times.

On the content

The introduction poses the problem well except that the authors remain too much in a context of hydrogeological investigations in unstable massifs.

Concerning the use of isotopes for hydrogeological studies, there are many publications that are not necessarily related to a gravity context, which describe very well the interest of oxygen isotopes in the characterization of the origin of water masses, the seasonal effect of infiltration and on the infiltration altitudes.

there are references more accessible to the community at large than Moser and Rauert, if you want to leave this ref add one more accessible

page 45: missing are geophysical methods that are increasingly used to characterize variations in groundwater flow and storage in gravity contexts. These are non-invasive methods that are being used successfully. I think we need to add more references on this topic.

Results

The authors describe the fractured medium as an equivalent porous place, which is consistent with their value of transit time of a little more than 3.5 years. A brief theoretical calculation confirms this assumption with a theoretical hydraulic conductivity of the order of 10-4 m/s (displacement of a 50m)

The coupled analysis of conductivity, temperature and ITTs allows to propose a conceptual model of the flows in DSGSD. Here, conductivity is used as a tracer of transit times. Using only electrical conductivity as a transit time can lead to misunderstanding. The authors explain the increase in electrical conductivity because of increased upstream-downstream mineralization due to longer water-rock interaction time due to longer upstream-downstream transit times.

The conductivity of the water varies from 80µS/cm to about 600µS/cm. This corresponds approximately to waters with a TDS (total dissolved solids) between 52mg/l and 450 mg/l.

In this part, we are missing some important information to understand these variations of electrical conductivity. The electrical conductivity reflects the mineralization of the water. If we are dealing only with silicate minerals, the water coming from this environment is not very mineralized, whatever the time of water-rock interaction. This is because the kinetics of silicate minerals are very weak under surface conditions. Therefore, 450mg/l of TDS cannot be explained solely by the dissolution of these minerals.

There are two possibilities

- Either the waters flow only on silicates (less mineralized waters), or the waters have a carbonate signature (due to the influence of marbles? Or other minerals more soluble ?).

A final explanation may be a mixture of water between these two poles (silicate and carbonate). One thing is sure, electrical conductivity is a tracer of mineralization and not of transit time.

This is what Hilbert (2016) writes . « The groundwater quality depends on the aquifer lithology, and is therefore very variable with mostly alkaline pH-values and higher mineralisation in carbonate units, while slightly acidic groundwater and low mineralisation are typical in the fractured parts of the mountain range (Austrian Geological Survey 2004)

The authors describe the geology as part of the Quartzphylite complex, whose minerals are mostly silicate with marble intercalations. This description is not sufficient to understand the true electrical conductivity

Peter TROPPER* & Andreas PIBER (2012) Geothermobarometry of quartzphyllites, orthogneisses and greenschists of the Austroalpine basement nappes in the northern Zillertal (Innsbruck Quartzphyllite Complex, Kellerjochgneiss, Wildschönau Schists; Tyrol, Eastern Alps) describe the mineralogy more precisely. This article could help the authors in their geological characterization.

In the absence of a chemical characterization of the water bodies, I am not convinced by their argument that the further downstream the source is, the longer the distance travelled, the longer the transit time. If this is the overall trend, how can we explain the points 093_001 (high altitude, inferred distance of about 1000 and conductivity about 100µS/cm? 103-001 high altitude, inferred distance of approximately 500 and conductivity approximately 200µS/cm? and points 047-001 and 048_001 which are at the same altitude with an inferred distance of double and a electrical conductivity around 300µS/cm.

Sources with high EC values but low flow path lengths (e.g. 064-001, 062-001 and 018-001) are influenced by longer residence times (e.g. low ITTP) resulting in comparatively slower flow as is the case for sources with lower EC values at the same altitude (Figure 10b): this may simply be a mineralogical effect.

I think there is a bias in the interpretation

While there is indeed a correlation between infiltration distance and transit time, there is no correlation between transit time and mineralization, especially in these complex environments where all it takes is one soluble mineral to significantly mark the mineralization of the water

The arguments of Kilberg (2016) on electrical conductivity should be considered again

“Specific electrical conductivity (EC) is a key parameter for quantifying total water mineralization (the physical background is given for example by Matsubayashi et al. 1993). EC is primarily controlled by dissolution processes within the aquifer; therefore, the parameter can be used as an indicator for various aquifer lithologies. Due to the variable solubility of the mineral phases, carbonate and even more evaporite aquifers are characterized by highly mineralized groundwater, whereas silicate lithologies contain groundwater with comparatively lower EC values (Kilchmann et al. 2004)”.

Have you tried to analyze the low and high-water level representative points separately? In low water level, the conductivity signal represents the water/rock interaction signal, whereas in high water level , it is rather the infiltration signal. This may shed new light on your interpretation.

One last comment:

I disagree with your argument about temperature increasing with decreasing elevation as a marker of transit time. It would be necessary to specify the dates of sampling on figure 4, it seems to me that this is not indicated and can be seen with the precipitation. When we analyse the temperature time series, we can see the seasonal variations. The minima seem to be around 5°C except perhaps for the lowest sources. Obviously, the peaks are shifted in time, the graph is not of very good quality. It is worth reanalysing these data.

In conclusion,

This is an interesting article that develops a methodology for estimating recharge as a function of water infiltration altitude using O18 isotopes and a numerical field model that allows us to constrain these recharge areas.

I think that the flow part still lacks data, especially on the different water masses. The only measurement of the electrical conductivity is not sufficient to constrain these flows and cannot in any case be used as a tracer of transit time in complex geological environments.

A suggestion for your next study

I would start by mapping the water outlets (temperature, pH (the pH would allow to isolate the flows on the silicates) and electrical conductivity) that I would place on a geological support (look at where these marble banks are in relation to the outlets).

Then I would select springs which are differentiated by these parameters and make high frequency measurements of electrical conductivity, water height (or flow) on a transect.

I would also equip the boreholes with this type of probe (does the bottom of the boreholes reach the fracture surface? If so, it's good because these surfaces are major drains of flows.

Nevertheless, I find your approach to determine the recharge zones really very good, your hydro study a little less so