Hydrol. Earth Syst. Sci. Discuss., 10, C2249–C2276, 2013
www.hydrol-earth-syst-sci-discuss.net/10/C2249/2013/

Hydrology and Earth System Sciences Discussions
Open Access

Interactive comment on "Identification of glacial melt water runoff in a karstic environment and its implication for present and future water availability" *by* D. Finger et al.

D. Finger et al.

fingerd@gmx.net

Received and published: 5 June 2013

Dear Dr. Schaefli (Editor), dear Prof. Dr. Leibundgut (Reviewer #1), dear Dr. Bakolowicz (Reviewer #2) and dear Reviewers #3 and #4.

(please see supplement pdf file for nicer layout)

We(1) would like to thank you for your valuable comments and for the positive evaluation of our manuscript entitled "Identification of glacial melt water runoff in a karstic environment and its implication for present and future water availability. In the following we will comment on each evaluation separately, replying to every comment raised

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

by the editor and the four reviewers. We are confident that after the requested minor revisions you will find our manuscript suitable for publication in HESS.

1 B. Schaefli (Editor)

Received and published: 1 May 2013

All reviewers judge de significance, the scientific and presentation quality of this paper as being good to excellent. They raise an important number of detailed comments and critics, but overall, they recommend publication of this paper with minor revisions rather than a substantial re-writing or expansion of the manuscript. Before preparing the revised manuscript, I would like to invite the authors to give a detailed response to each of the reviews. Hereafter, I give a short overview of the main comments:

- Reviewer 2 and 3 highlighted that the literature review seems incomplete.

- Reviewer 2 would also like to see a better presentation of the functioning of subglacial karst hydrology.

- Reviewer 3 suggest to improve the terminology and to better discuss the limitations and transferability of the results.

- Reviewer 4 made critical comments on the over-ambitious scope of the paper and recommends reducing the scope and setting a more modest aim of establishing the hydrogeology of a glacierised karst depression. A better definition of the scope of the manuscript might also be required in view of the comments of M. Bakalowicz and the ensuing discussion.

- Besides many other detailed comments, reviewer 4 also asks for a better integration of all obtained results and avoiding conclusions that cannot be directly drawn from the analyses of this paper.

- Finally, several reviewers find the manuscript not yet very well structured and mention repetitions. And reviewer 1 would like to have more precise indications about the original contributions of this paper.

Response:

We thank the editor for the positive evaluation and the concise summary of the four reviews. The objective of our study is to identify current and future water availability in the Plaine Morte region by combining meteo-hydrological observations, tracer experiments, isotopic investigations, karst modeling and projections of glacier melt runoff. This interdisciplinary approach represents a novel and heuristic approach of how numerous datasets from different disciplines can be interpreted. While the results are surely only valid for the Plaine Morte Region, the interdisciplinary approach can be applied to any similar mountainous study site and certainly is a valuable asset for water resources research. During the revision process we will do in particular the following:

- Incorporate suggested and relevant peer-reviewed literature

- Revise the description of the subglacial karst hydrology

- Revise the terminology and the discussion in order to clarify the limitations and transferability of our findings

- Revise the wording of the scope of the paper. It is our firm belief, that science lives from innovative approaches and that there should also be space for reasonable and well-founded hypothesis to assess future water availability. We will revise the manuscript to demonstrate that our approach allows us to make assumptions about current and future flow paths and assess water availability in the Plaine Morte region. All climate change projections are just hypothesis based on founded assumptions.

2 C. Leibundgut

Received and published: 8 April 2013

Overall assessment

Scientific Significance: excellent

The manuscript represents a substantial contribution to scientific progress within the scope of Hydrology and Earth System Sciences by its holistic approach dealing from hydrology up to the complex regional water ressouces systems.

Scientific Quality: excellent

The scientific approach and applied methods are valid. Also the results are discussed in an appropriate and balanced way.

Presentation Quality: excellent

The scientific results and conclusions are presented in a clear, concise, and wellstructured way. The number and quality of figures/tables is appropriate. I am not competent to perform an English language check.

Further aspects:

The paper address relevant scientific questions within the scope of HESS by presenting novel concepts (holistic), ideas, tools (combination of methods and techniques and a lot of new data. There are substantial conclusions reached as well scinetificly (i.e. karst model) and regionally (i.e. glacier runoff). The scientific methods and assumptions are valid and clearly outlined. In particular the validation occurs with independent data (i.e. tracer data) which is a modern concept but not always used. Without doubt the results are suitable and sufficient to support the given interpretations and conclusions. The description of experiments and calculations is clear, supported by the tables and figures, is complete and precise to allow their reproduction by fellow scientists. The authors give proper credit to related work. The reference “Tracer experiments in temperate alpine glaciers” in Leibundgut Ch., P. Malozewski, Ch.Külls: Tracers in Hydrology. Wiley-Blackwell, 2009: 310-321 would address directly the issue on page 2746. It would be an improvement if they clearly indicate their own new/original contribution more explicitly. The title reflects clearly the contents of the paper. The abstract provide a concise and complete summary. The overall presentation is well structured and clear with a small restriction: there are some redundancies probably due to the single contributions provided by the single author groups. All mathematical formulae, symbols, abbreviations, and units are correctly defined and used. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? : no, except the mentioned reduncances. The number and quality of references are appropriate. I made a proposal for a supplement above. The amount and quality of supplementary material is appropriate.

Response:

We would like to thank Prof. Dr. Leibundgut for his positive evaluation of our manuscript. It honors us that the significance, the quality and the topic presentation of our manuscript were evaluated as being "excellent". This evaluation is even more honoring as we are aware of the immense knowledge on karst hydrology of Prof. Dr. Leibundgut.

Certainly, we will include the peer-reviewed reference Leibundgut (2009) and will incorporate its content into the manuscript. We will also outline and emphasis on the new/original contributions to the field of tracer hydrology by emphasizing the importance of interdisciplinary research.

3 M. Bakalowicz

We also would like to thank Dr. Bakalowicz for his valuable comments. As Dr. Bakalowicz has raised several concerns regarding our manuscript we will comment on each of his comments specifically below:

General comments: This is a really interesting, but complicated issue, seldom considered, for two reasons: (i) combining glacial and karst hydrology looks to be a difficult challenge; and (ii) generally there is no practical interest what does not push scientists to work on. So the bibliography is relatively scarce. All the more reason to try to make a review as comprehensive as possible! I regret to tell that the authors seem to ignore a large part of the literature about karst and glacial hydrology. I think that they could give to their work a broader scope than in its present state. Glacial hydrology presents characteristics very close to karst hydrology to such an extent that the best synthesis on glacial hydrology was written by two karst specialists, A. Eraso and M. Pulina.

- Eraso A. and Pulina M. 2011. Cuevas en hielo y rios bajo los glaciares. McGraw Hill, 2nd ed., 280 p. (and GLACKMA, 3rd ed., 300 p.). See http://www.glackma.es/

- Works of the International Committee "Glacier caves and karst in Polar Regions" (GLACKIPR) created in 1989 in Budapest, during the 10th International Congress of Speleology. They were published in symposium proceedings, the first one in 1990 in Madrid, Spain, and the 8th in 2007 in Katowice, Poland.

Response:

We agree with Dr. Bakalowicz. During the revision of the ms we will perform an extensive literature research including the work by A. Eraso and M. Pulina. Nevertheless, in accordance with the comment of reviewer #3 and the HESS guidelines, we will primarily reference peer reviewed articles, and only refer to conference proceedings if specific aspects of our case study (area of Glacier de la Plaine Morte) make it necessary.

C.C. Smart is probably the pioneer of subglacial karst hydrology. I agree that his PhD was unpublished, but he published some interesting papers which could have helped the authors in a better presentation of the relations between the glacier and the underneath karst and in a more generalized approach. - Smart C.C. 1983. Hydrology of glacierised alpine karst. PhD, McMaster University, 343 p. - Smart C.C. 1983. The hydrology of the Castelguard Karst, Columbia Icefields, Alberta, Canada. Arctic and Alpine Research, 15 (4): 471-486. - Smart C.C. 1997. Hydrogeology of glacial and subglacial karst aquifers: Small River, British Columbia, Canada. Proc. 6th Conference on Limestone Hydrology and Fissured Media, La Chaux-de-Fonds, Switzerland, p. 315-318. I also suggest to read the following references: - Ford D.C. and Williams P.W. 2007. Karst hydrogeology and geomorphology. Wiley, 562 p. See especially 10.3.

The cold extreme: karst development in glaciated terrains, p. 410-421. - Lauritzen S.E. 1984. Evidence of subglacial karstification in Glomdal, Svartisen. Norsk Geografisk Tidesskrift, 38 (3-4): 169-170. - Lauritzen S.E. 1986. Kvithola at Fauske, northern Norway: an example of ice-contact speleogenesis. Norsk Geografisk Tidesskrift, 66: 153-161. These references could help the authors in presenting in a better way the functioning of subglacial karst hydrology, and particularly the hydraulic connection through glacier "moulins" between the seasonal flows at the surface of the glacier and the karst sinkholes below it. This is clear from figure 11, but unclear at all in the 1st paragraph of 2.3 Hydrology, characteristic (i). This is a particularly important point which needs to be detailed, because some tracing tests combine glacial and karst flows and the contribution of glacial water looks important during summer melting.

Response:

In accordance with the comment from reviewer #3 we will search the scientific databases for the work by Smart C.C and incorporate peer reviewed literature relevant to our study. Nevertheless, in accordance to the comment posted by Prof. Dr. Leibundgut and in accordance with the scope of our study we cannot focus on subglacial karst hydrology only, as this is only one aspect of our scope. We recall that the scope of our study is to assess present and future water availability in the Plaine Morte region – not to investigate specific subglacial karst processes.

Furthermore the manuscript is sometimes confusing, difficult to follow. I make some suggestions in order to help the authors in improving their manuscript. First, this Chapter 2.3 Hydrology should give as an introduction the different flow types described in karst and glacial hydrology, from the literature. Then the paragraph could be re-written for instance in that way: "Discharge from snow and ice melt, as well as rainfall runoff is characterized by different mechanisms depending on field characteristics in the Plaine Morte area: (i) water storage in the glacier and the snow fields, (ii) rapid subsurface flow under gravel covered soil, (iii) low flow in fertile agricultural soil, (iv) retention in natural swamps, (v) storage in natural and artificial lakes, (vi) seasonal streams running on the glacier, partly swallowed in “moulins” and crevices connected to sinkholes underneath the glacier, and (vii) a well-developed karst system which drains melt water to karstic springs at lower elevations.”

Response:

We will edit the manuscript as follows:

“Discharge from snow and ice melt, as well as rainfall runoff is characterized by different mechanisms depending on field characteristics in the Plaine Morte area: (i) water storage in the glacier and the snow fields, (ii) rapid subsurface flow under gravel-covered soil, (iii) low flow in fertile agricultural soil, (iv) retention in natural swamps, (v) storage in natural and artificial lakes, (vi) seasonal streams running on the glacier, primarily swallowed in “moulins” and crevasses partly connected to sinkholes underneath the glacier, and (vii) a well-developed karst system which drains melt water to karstic springs at lower elevations.”

In this aim, Chapter 2.2 Geologic setting should be re-named Geology and hydrogeology settings.

Response: We will edit the title as suggested.

Chapter 3 “Methods and data” is quite surprising. What is named “Karst model” (Sub-chapter 3.1), and defined as one of the tools used for studying the hydrology, is in fact a 3-D representation of the geology in which the flow paths inferred from tracing tests are indicated. This hydrogeological model (see fig. 3, which is not really easy to read) is an interpretation, synthetizing geological, hydrogeological and tracing data. It can’t be presented before tracing results. I think that it should be considered in Chapter 5 “Discussion” with sub-chapter 4.3 “Karst model results” all included in sub-chapter 5.1 “Hydrogeological model”, and not in “Methods and data”, because it is an interpretation of all hydrogeological data.

Response:

HESSD
10, C2249–C2276, 2013

The two pathways presented in blue and coming from the injection points on the glacier are not a result of the tracer experiments, but rather a hypothesis for the possible pathways based on 3D geology and previous tracing tests. The karst model was used as a tool to identify the best locations on the glacier for tracer injections. In Figure 7 we present the modified pathways according to results of the tracer experiments on the glacier. Results of the tracer experiments reveal that the first guess of flow paths presented in Figure 3 are only partially correct. We will improve Figure 3 and 7, edit the ms and change the caption of Figure 3 as follows:

“3-D view towards the East of the Urgonian limestone basis (top of Valanginian Marls). Red and transparent planes are faults. Tracing experiments previously carried out are represented in green, including the expected underground flow paths. The Plaine Morte is visible in the middle (dark blue). Blue spheres are karstic springs. The blue surfaces with some transparency are karstic nappes. The two flow path (light blue) coming from potential injection points on the glacier are inferred from the 3D geology. This interpretation was used to design the strategy of the tracing experiment."

Sub-chapter 3.2 regards all climatic (not meteorological, which is related to weather forecast) and hydrological data.

Response:

In our understanding, meteorological data are short term (seasonal) data of few months or a couple of seasons, while climate is described by long term observations of several decades. Accordingly, we think meteorological data is more suitable.

In Chapter 4, may tracing test data help in interpreting the observed differences in isotopic compositions of the springs, as a result of different contribution from ice melting?

Response:

To some extent yes but only one tracer was found at the source of Loquesse (Duasyne), while no tracers were detected at the other sites used for isotopic monitoring. The

HESSD

10, C2249–C2276, 2013

isotopic composition for the site at Loquesse at the time of the tracer breakthrough indicated that karst water is dominated by glacier melt water during late summer. This is clearly also the case for the other spring (Ertènse), where glacier melt water dominates over the summer months. In contrast, the Tièche (small river) is likely to be dominated by surface runoff during the summer months. We will clarify this point by editing the ms as follows:

The temporal evolution of the isotopic composition in the two karst springs of Loquesse and Ertènse as well as the river sampling site of Tièche are all dominated by snow melt water in spring and early summer. In contrast, once the snow has completely melted, the water in the two sources is dominated by glacial melt water and only the river gets dominated by surface run-off with isotopic compositions approaching those of the summer to autumn precipitation. For Loquesse the tracer breakthrough only about 17 to 24 hours after injection is also clearly transported by glacial melt water, as supported by the isotopic composition measured in August. As there was no rainfall directly before and during the tracer injection, both sources remain close to the isotopic compositions for the glacier and only the river sampling site of Tièche is dominated by the 18O-enriched August/September rain water.

In addition, the following sentence will be added to page 20 of the discussion:

Glacial melt water as the dominant transporting agent for the tracers to the karst springs is also clearly indicated by the isotopic compositions of the water sampled at Loquesse (and Ertènse) in 2011.

Did you try to compare the results of the glacier melt modelling to the observed flows? I think that they could help in testing some of the assumptions of the models (hydrogeological functioning and glacier melting).

Response:

The modeled glacier runoff only refers to the surface of the actual glacier as catchment and not to the entire drainage basin. It would be beyond the scope of this paper to incorporate all the poorly understood processes (hydrogeology etc.) into a complete model at the basin scale which would allow direct comparison against runoff measurements. Our results on glacier melt runoff were, however, validated against direct measurements on the glacier such as long-term ice volume change, and ablation measurements (Huss et al., submitted, Geographica Helvetica). This will be clarified in the revised ms. Furthermore, detailed hydrological models are being tested for the southern slopes of the Plaine Morte area within the PhD-thesis of M. Kauzlaric.

In Chapter 6 “Conclusions” point 1 is interesting, because this is not really said in the text. In fact the interpretation of tracing test data (sub-chapter 4.2) should have explained that the tests show that the flows are typical of karst conduits, from the surface of the glacier to the springs.

Response:

We will edit the manuscript and make sure that the discussion states clearly how we come to conclusion 1!

Despite I am not a native English speaker, I think that the English writing should be revised, although the paper is understandable as it is.

Response:

In accordance with reviewer #4 we will look for possibilities to let the manuscript be read by a native speaker.

4 Anonymous Referee #3 Received and published: 19 April 2013

Summary and general recommendation: Finger et al. have studied a glacier-karst system in the Swiss Alps and have used different methods to estimate the possible impact of climate-change induced glacier retreat on karst groundwater resources. This is an interesting and relevant study. The paper is suitable for publication following moderate changes, mainly concerning the use of terminology (sometimes incorrect) and missing information on some figures (that look good but are not really comprehensible). Also some scientific aspects need to be improved, e.g. concerning the limitations and transferability of the results.

Specific and general comments: line 6: The term “souterrain” is inappropriate. Do you mean underlying or underground? Anyway, the word can be deleted without losing any information. In fact, the entire sentence is not logical. Yes, glacier retreat is an important issue for water resources. Yes, karst aquifers are relevant. However, it is not clear why glacier-karst systems require particular attention. Either delete this statement or find a better justification why your test site / study are relevant. In fact, most Swiss / alpine glaciers are not located on karst but on crystalline rock. Maybe you could indicate somewhere the proportion of glacier on karst and on other rock types?

Response: We deleted the term “souterrain” and replaced it by "underlying".

24-25: I would also mention drinking water (small quantity, but very important) and irrigation (= irrigated agriculture). Not sure if snow production makes much sense here.

Response:

We added drinking water and will edit the ms accordingly.

2746: You cite 2 papers by Vivian Gremaud et al. who have studied the directly adjacent and very similar glacier-karst system of Tsanfleuron. You should refer again to these papers in your discussion or conclusions and compare your results with their results. Not all results are presented in the published 2 papers. There is more in Vivian’s PhD thesis, including an estimation of future water availability under conditions of glacier retreat. A third paper by Zeng, Gremaud et al. (2012) quantifies the efficiency of this glacier-karst system as a CO_2 sink under global warming. Another reviewer has also observed that the literature review is incomplete and has agreed some relevant references. I agree, particularly concerning the pioneer work done by Chris Smart in the Canadian Rockies. However, I would not cite too much gray literature (old conference proceedings) but focus on papers in international journals and books – there is enough!

Response:

As suggested we will integrate relevant peer-reviewed literature.

2748, line 3: Completely snow-free: Very important observation! This means that there is NO accumulation, i.e. the glacier is not only retreating but disappearing. Say this! Similar situation at Tsanfleuron, reported by Gremaud et al.

Response:

We will emphasize on our result that the glacier will disappear within the current century in the revised ms. This is also illustrated in Figure 10.

Line 8: 1-1,5 %: Are you sure? I don't have better numbers, but it seems to me that many Swiss glaciers are much, much larger, so I would suppose a smaller number. Please check!

Response:

The total ice volume in the Swiss Alps is currently (2013) between 50 and 65 km3. This number is confirmed by several recent studies (Farinotti et al., 2009; Linsbauer et al., 2012, Huss and Farinotti, 2012). With a volume of 0.8 km3 Plaine Morte thus accounts for about 1.5% of the total ice volume. A reference is given in the manuscript.

2749, line 5: Urgonian = Schrattenkalk (mention the name of this very famous limestone formation that hosts the two largest caves in the Alps)

Response:

As suggested, we will include the names of the limestone formation.

14: The term "land use" is inappropriate here, because much of the area is not used!

Response:

HESSD
10, C2249–C2276, 2013

We agree and will replace the term “land use” with “land types” or similar.

2751, line 20-22: Correct in principle, but not as simple in this case, because folds and faults can create reservoir structures and phreatic conditions above the level of the springs.

Response:

We will edit the manuscript pointing out that folds and faults can create reservoir structures and phreatic conditions above the level of the springs.

2753, line 16: The injection quantities are crazily huge – Gremaud et al. used about 10-100 times smaller quantities in the Tsanfleuron area.

Response:

Indeed, this was one of our first findings: we expected most of the tracer to infiltrate into the karst and assumed that it would dilute a lot more. Accordingly, we drastically reduced tracer amounts during the 2nd and 3rd injection. Please also note that the discharge rates of springs from the Tsanfleuron area are about 10 times lower than those of the Plaine Morte area. The discharge rate of the Loquesse spring can reach up to 15 m3/s. The rate of the Siebenbrunnen spring can be at least 6.5 m3/s. The total amount of water flowing at the bottom of the glacier was unknown before the first tracing experiment. Quantities for the first test (three injections in 2011) were too high but this was adjusted in 2012 with smaller quantities. We will edit the ms to clarify this point.

2757, line 23: The maximum concentration are enormous! Uranin concentrations are 20 times above the limit of visibility. At some place, you should mention that your injection quantities were extremely overdosed, otherwise you give a bad example for future tracer tests. I prefer μg/L over mg/m3, but that’s a question of taste.

Response:

HESSD

10, C2249–C2276, 2013

We agree (see also reply above). Nevertheless the particular setting of the Plaine Morte requires tracer amounts that are also detectable at karst sources as well as in the surface runoff. We will edit the ms to clarify this issue.

2758, line 7: “amount of tracer passing” => use the term (tracer) recovery (%)

Response: We will edit the ms as suggested.

Discussion: Bette compare your findings with results from the literature, e.g. concerning flow velocities of subglacial, englacial and supraglacial melt waters. In fact, these important glaciological terms are not used in the entire paper. You should really read and cite more glacier (and karst) literature and use the relevant terms and concepts in your paper.

Response:

We will incorporate relevant peer reviewed literature. If reviewer #3 has some specific suggestions we would be very pleased to consider them.

Table 3: Amount of tracer => recovery (%)! See comment above.

Response:

We will edit the ms as suggested.

Table 4: Table heading makes no or little sense. Do you mean: Comparison of tracer recoveries and flow velocities obtained from the three tracer tests?

Response:

We will edit the headings and change “Amount of tracer” to “recovery rate (%)”.

Figure 1: A scale bar in figure b would be useful.

Response:

We will add a scale bar in panel b.

HESSD

10, C2249–C2276, 2013

Figure 2: There should be a legend explaining the stratigraphy!

Response:

We will add a description of the stratigraphy to Fig 2.

Figure 3: The figure looks amazing, but in fact, it is incomprehensible: No vertical scale, no horizontal scale, no orientation, the relation between geology and topography is unclear: does the figure shows surface geology (outcrops) or the internal geological structure or a bit of both? Inacceptable in the present form (although it looks good). Must be improved.

Response:

We will revise Fig 3 and add a scale bar and orientation. We cannot show geology and topography because it's superimposed. However, we will rework it thoroughly making it easier to read.

Figure 5 and 6: Such graphs are called (tracer) breakthrough curves! In general, you should use the correct terms from the glacier, karst and tracer literature.

Response:

We will edit the ms as suggested.

Figure 7: Similar problem as figure 3: What is the relation between the colorful parts of this figure and the non-colored part in the upper left corner?

Response:

The objective Figure 3 is to demonstrate the possible flow pathways in the rocks. Standard hydrogeological maps would assume that flow paths follow the thalweg, ignoring the geologic underground. As stated above, we intend to illustrate in Figure 3 flow pathways based on the currently know geologic setting of the underground. In the revised ms we will revise the figure thoroughly.

HESSD

10, C2249–C2276, 2013

Interactive Comment

General comment: The limitations of your study should be addressed more clearly! Your results are (hopefully) true for your test site and for the neighboring test site studied by Gremaud et al.

Response:

Tracer concentrations have been measured by our tracer experts Dr. Fischer and Dr. Wernli. The method proved to be very reliable in past studies. Of course they cannot be transmitted to a neighboring study site, but their interpretations and the system understanding can help to understand processes in other, similar settings.

However, the transferability to other areas is very limited, even within the Alps: There are very few glacierised karst systems in the Alps, and very different general trends can be expected for non-glacierised areas and for areas including large glaciers (that will not disappear so quickly).

Response:

Indeed, the results cannot be directly transferred to other study sites, as nature is very heterogeneous and each study site has its own characteristics. Nevertheless, the interdisciplinary approach and the process understanding can be transferred to any other case study. We will clarify this issue in the revised ms.

5 Anonymous Referee #4

Received and published: 30 April 2013

“Identification of glacial melt water runoff in a karstic environment and its implication for present and future water availability” by D. Finger et al. The problem of glacier-karst hydrogeology has largely been piecemeal studies, largely by the empirical investigation of field sites. Despite use of quantitative measurement and analytical tools, our understanding remains essentially qualitative. This paper therefore has an ambitious objective in attempting to further our understanding at a generalisable quantitative level, by incorporating field observations and predictive models for underground flow routing and future mass balance scenarios. Unfortunately, these ambitious aims are only met superficially. The models used are poorly developed and are not integrated into the overall study. The field work components also appear to have little overall integration. The study therefore is a useful, but essentially parochial (local) investigation of glacierkarst hydrogeology.

Response:

We agree with the reviewer and are aware that our objective to assess current and future water availability in the Plaine Morte region is very ambitious. But shouldn't every scientific project have the ambition to explore innovative techniques in order to establish new theories? We are convinced that our study presents valuable new insights into the understanding of processes influencing water availability in the region. While this is a valuable asset for local residents depending on the water resources, the presented holistic approach presents a new innovative approach in karst hydrology. As stated above, certainly our results are only valid for our study site. Actually, this applies to all case studies. Nevertheless, our innovative approach of combining different investigation techniques is applicable to any study site in the world.

The Glacier de la Plaine Morte is perhaps the definitive example of a glacier-karst system as the glacier largely occupies a massive closed depression. However, it is far from typical and the ice is largely stagnant. (This probably means it hosts a more stable internal drainage system than more dynamic glaciers.) I suggest that extrapolating from this unusual site (and the limited data set) to global scale is over ambitious. The generalisation that loss of alpine glacier ice will reduce late summer flow is widely recognised, and poorly supported by the analyses presented here.

Response:

We agree and are aware that our results are only valid for our study site. However, as stated above, our approach can be applied to any case study in the world. We will clarify this issue in the revised ms.

The “karst model” utilised in designing the tracer experiments appears to be an excellent tool, particularly valuable in the complex tectonics of the Swiss Alps. It does appear to have some limitations, however. First, the relationship between lithology, structure and hydrogeology has to be explicit. (Here it is not apparent which units and discontinuities (faults) are considered susceptible to karst permeability.) Similarly, there is no obvious inclusion of glacier ice (or talus), so the predictions are tenuous (and indeed appear to have been misleading in missing recharge from the major outlet stream). Finally, the tool’s effectiveness relies on parallax-based three dimensional rendering and fails when printed on a page. It would have been much more effective to provide a clear map showing the inferred flow routes. Overall, the flow visualisation model seems a bit disappointing. The “predictions” (in text as figure 3 is unreadable) seemed to indicate various underground drainage routes. In contrast, the results seemed to show (again figure 4 is not readable) that the subglacial karst has surprisingly limited and conditional permeability (which we already know) and the tracer delivery more or less travels to the nearest spring. The dominant results of surface routing and subsequent capture on the Bernese side were not explictly predicted by the model (as far as I can see. Although the likely capture of the surface stream to springs is fairly evident using Google Earth; to which I would add the possibility of a talus aquifer linking the Reitzliberg and Siebenbrunnen Springs). The routing model might be more effective if were used to make specific, well-illustrated and tested hypotheses.

Response:

The karst model is continuously being developed by the Swiss Institute for Speleology and Karst Studies (ISSKA). The presented application represents a first application which will be improved in the future. As stated above, we will improve the two figures and the ms will be edited to clarify the raised concerns.

The hydroclimatic data are quite substantial, but their discussion does not seem to relate to the main purpose of the paper. They are only used explicitly in attempting to characterise glacier melt, though presumably used in various ways in analysis and

HESSD
10, C2249–C2276, 2013

modelling.

Response:

We performed tracer injections during three periods of distinct melting: i) just after the snow on the glacier disappeared, ii) during intense melting and iii) after the first snowfall in autumn. The objective of these three injections was to see tracer evolution during the three distinct meteorological conditions. Accordingly, the date relates directly to the results. We will emphasize on this topic in the revised ms.

The artificial tracing work is interesting, must have taken considerable work and is worth publishing. However, I would recommend some revision to reach a reasonable professional standard. The description and analysis lack the substance I would expect in a work of this scale. The tracers and traces are not well described. I could not find data on the Duasyne, but as one of the "optical brightener" tracers, it will show quite different optical and tracer performance to the other two closely related compounds (eosine and uranine). Unfortunately, the use of a synchronous scanning strategy implied in the terse section on analysis is likely to fail quite badly on typical optical brightener tracers. "Blue" (and to some extent "green) tracers are also expected to have a high natural background which is not apparent from the figures.

Response:

The tracer analysis was carried out in our in house laboratory by our tracer experts Dr. Wernli and Dr. Fischer. We will revise the ms adding descriptions on all tracers used and revising the description of the laboratory procedures.

The masses of tracer injected are exceptionally large and could result in prosecution in some jurisdictions.

Response:

As stated in the response to reviewer #3 there are two reasons for the high amount of tracer injection: i) tracer has to be also detected in karstic sources, where dilution is about 100 times higher than in the surface runoff and ii) during the first injection we did not expect the tracer to drain through the surface runoff. Tracer amounts were drastically reduced during 2nd and 3rd injections. But we still wanted to be able to detect tracer concentration in karst sources, where concentration is expected to be more than 100 times lower.

The injection descriptions imply random release on the ice surface. Tracer injection usually requires prior dissolution (typically to ppt level) and instantaneous injection without perturbation of steady flow. This is virtually impossible with the masses used, even if a suitably large supraglacial stream were present. (I could see none larger than perhaps 1m3/s in Google Earth.) Did the stream then sink into a moulin, or run over the surface? I was also confused by the descriptions of the 2012 injection sites; were they close to or near the 2012 I2 site?

Response:

Tracer mass was diluted on site with melt water from the glacier. Runoff of the supraglacial meltwater streams was about 0.2-0.5 m3/s during the injection. The injection was performed in safe distance of 10-20m from moulins that drained the water quickly to a depth of >50m within the glacier ice. Swiss national television reported live from the injection (see link below).

Link of TV report:

http://www.videoportal.sf.tv/video?id=8b441b32-ce13-4496-975b-1a204dc20bd7

We will edit the manuscript to clarify this issue.

Why was the glacier outflow not monitored? It is surely the most critical monitoring point!

Response:

The immediate outflow at the glacier terminus is not well accessible and does not allow

HESSD

10, C2249–C2276, 2013

Interactive Comment

the installation of sampling devices. However, Trübbach is the site which represents the glacier outflow well. Unless there is heavy precipitation almost all the water in Trübbach comes directly from the glacier. We will edit the ms to make this clearer.

The tracer analysis remains fairly rudimentary (which is appropriate in a novel setting), but some clarification is required. To compensate for contrasts in fluorescence intensity, the tracer concentration can be readily normalised to concentration per mass (typically 100g for some reason).

Response:

By giving the actual concentrations, we can discuss the efficiency of the karst system. This is an important asset in order to justify our conclusions about water availability. We do not see an added value in normalizing the concentrations and how this could contribute to our objective.

Tracer velocities require a characteristic travel time (first arrival, mean or peak?) and path length (straight line, sinuous or true path?). It is not clear what is being used here. Tracer recoveries are useful in general, but not meaningful when the breakthrough curve is poorly defined as it is for the main river traces in 2011.

Response:

We agree with the reviewer and will clarify how travel time was computed. Nevertheless, this will not have any impact on our main conclusions on present and future water availability.

The conditions of melt and routing through the glacier are fundamental to the design of the tracer tests, the analysis of results and the future modelling. It is therefore surprising that the glacier hydrology in the paper is fairly superficial. It is implied that peak melt develops with full ice cover. This is not normally the case, peak local runoff occurs in the late stage of snowpack loss. It is not clear what route the melt water was taking. Was it supraglacial, marginal or through a perennial or seasonal conduit

HESSD

10, C2249–C2276, 2013

system?

Response:

We do not fully agree with the reviewer here: For catchments without glaciers the peak runoff occurs at the late stages of the snowpack loss. Due to the albedo contrast of snow and ice, melting is however much stronger after the disappearance of the snow cover. This effect is directly captured by the glacio-hydrological model applied which has been tested and validated in numerous studies on alpine glaciers. Furthermore, the objective of our study is to investigate current and future water availability in the Plaine Morte area – not to describe specific processes of glacier hydrology. Nevertheless, glacier hydrology is one important aspect of our investigation. Accordingly we treated it only to an extent that is necessary for our objective. We will edit the manuscript to give more emphasis on glacier hydrology.

What was the likely state of this system at the time of tracing? How is the routing likely to change through the year and how will this influence recharge?

Response:

In order to answer these questions we performed three injections during different hydrometeorological conditions (this is why we need these observations, as stated in reply to the concerns raised above). We will emphasis on this issue in the revised manuscript.

Is the absence of recharge really due to “silt” and “loess” at the bed, or is the melt water routed away from recharge windows? I have never seen basal silts beneath a glacier and loess (a wind-blown silt) seems improbable. Most deglacierised karst surfaces exhibit extensive solutional permeability and sediments are generally coarse (permable) and dominantly very late or post glacial in timing. So either some substantive evidence has to be advanced, or the absence of recharge maybe attributed to routing of melt through the ice. The concluding diagram (Figure 11) proposes a dual porosity model for the glacier. This might seem a reasonable proposition for testing, but seems poorly

HESSD

10, C2249–C2276, 2013

supported by the work.

Response:

The results of our study clearly indicate that during the low flow season water penetrated primarily into the karst while during the melt season melt water is evacuated through the glacier to the north. This is a fact we could demonstrate with our tracer experiments and which is relevant for our objective to determine current and future water resources in the area. A detailed description of the recharge of the karst is certainly interesting, but is not the primary objective of our study. Nevertheless, our understanding of recharge to the karst is sufficient to draw conclusions regarding current and future water availability. We will clarify this issue in the revised ms.

A potentiometric surface is often postulated in glacier hydrology despite lack of empirical evidence. Such a model is very difficult to sustain for impermeable glacier ice. Instead, a seasonally and spatially variable sheet-cavity-conduit is more widely supported. It is most unlikely that a coherent water table exists in a glacier such as Plaine Morte. Some direct or indirect observations are needed to construct an appropriate glacier hydrology in a setting like this. In the light of the results provided, the only substantial evidence appear to be the high season tracer results (five traces in all) reported cessation of surface outflow (no data are given). No tracing has been undertaken under non-overflow conditions, so the Bernese subglacial routing remains hypothetical. The lesson learned from the substantial body of work on glacier tracing is that results vary dramatically with injection conditions, location, season and runoff (diurnal and storm driven). Glacier karst tracing is expected to be even more idiosyncratic because of the likely variation in recharge opportunity at the bed. So the only relevant tracer test of the key focus of this research is those injections (three in all) observed at Loquesse spring.

Response:

The five tracer injections had two main purposes: i) the three simultaneous injections at three different locations on the glacier had the objective to determine flow paths from three representative parts of the glacier and ii) the three injection at location I2 during three different seasons (just after snow disappearance, during melt season and after the first snow in fall) had the objective to assess flow paths during different seasons.

The stable isotopic data are too sparse to provide much insight. Two sites have not been proven connected to glacier. The key heavy signal at Tieche is presumably a transient rain event captured at that site. I would omit this section.

Response:

Indeed, the stable isotope data is sparse but they nonetheless give a valuable insight to the connections between the glacier and the karst sources in the southern part of the Plaine Morte area. The August and September measurements for both karst sources are clearly compatible with melt water dominating in these sources at this time as there was no precipitation just prior to the injection of the tracer that was detected in Loquesse in August 2011. In addition, all snow-melt was already drained. In contrast, the Tièche river is surface-water and hence precipitation dominated during the late summer and autumn, but this is NOT the case for the southern karst sources. As in this region no artificial tracer was observed after tracer injection in the Ertènse source, it must be assumed that snow and glacier melt from other regions of the glacier than the injection points must infiltrate into the karst and drain to the karst sources. The isotopic observations confirm this; accordingly, they present a valuable asset to the objective of assessing water availability in the region. Both in chapter 4.4 and in the discussion, the text was rephrased in order to bring these points out more clearly (see above).

A glacier melt model is used to predict the future geometry of the glacier. It is not clear how a daily model is calibrated using two digital elevation models fifty years apart and validated using three years of limited accumulation and ablation data. Although it provides a crude linear trend, extrapolating this trend into the untested geometry of a closed basin seems very risky, especially when rather dire implications are drawn. It is not clear that the hydrology has been fully implemented. If the leaky closed depression model (figure 11) is used, then it seems that an increasingly large fraction of the melt would be retained in the depression and subsequently recharged. The data in this paper would seem to suggest that relatively little melt would travel north (Bern) and a greater fraction would be routed south (Valais).

Response:

We are aware that model projections are highly uncertain. Besides the limited calibration data available this is also due to the uncertainties in future climate projections, and model assumptions as mentioned in the HESSD paper. In the revised ms we will clarify that the modeling approach used does not include the karst hydrology, but only provides the total quantities of glacier melt input into the system. Accordingly, the model results themselves do not allow an assessment of future water flow paths. Calibration of a glacio-hydrological model in karstic environment is very difficult. Observed snow accumulation and ice melt data allow constraining the most important components of the water balance at time scales comparable to the projection period. We are aware of the uncertainties and clearly mention them in the paper. However, we are confident in the general results provided by this model that has proven to be well suited in modeling alpine runoff regime changes (see e.g. Farinotti et al., 2012).

Overall, there are substantial weaknesses in all the components of the paper and in their integration. It is not clear that the conclusions are based on substantive analysis. This is unfortunate as the various components of the research are interesting and challenging, but lack adequate treatment in attempting to compose an integrated report. The results provided suggest that a test of underground flow predictions using dye tracing would be worth reporting. Similarly, the forward modelling looks promising. It is not clear that the results allow much advance in our understanding of glacier karst recharge. Therefore, the primary purpose of the paper is not adequately addressed.

HESSD
10, C2249–C2276, 2013

Response:

We can convincingly demonstrate current water flow paths: Our results show that i) glacier melt water from the eastern and northern injection points is evacuated rapidly through the glacier to the northern surface runoff (no tracer was found in the southern karst sources) ii) during melt season glacier water from the southern injection point is drained to approx. equal masses through the glacier to the northern runoff and to the Loquesse source. iii) at the beginning of the melt season glacier water from injection point I2 is drained also to the northern surface runoff as well as to the Loquesse source, however, travel velocities are almost halved to due lower melt production iv) at the start of the winter season (after the first snow) glacier water from injection point I2 is drained only to the Loquesse source, as no tracer was observed on the northern side. v) Although numerous small karst sources did not reveal any tracer concentrations, isotopic signatures indicate that water composition is dominated by glacial water during melt season. The findings are based on the five tracer injections, hydro-meteorological data, isotopic investigations and satellite snow cover data. Based on these insights and climate change projections of the glacier melting, we make assumptions about future water availability. We are convinced that after revisions of the ms our conclusions will be fortified. We will edit the conclusions in order to clearly differentiate between facts and interpretation of facts.

A final comment on the language: the English is good, but in places the technical usage is incorrect and possibly misleading. A editorial proof reading is advisable.

Response:

We will revise the English and incorporate technical terms as suggested also by the other reviewers. An editorial proof reading would be welcomed.

(1) Side note to the author contribution:

Finger: writing of the ms, planning, coordination, supervision of project and first author

Hugentobler: wrote a MSc thesis about the tracer experiments

Huss: glacier modeling and contribution to text editing

Voinesco: wrote a MSc thesis about ice thickness and mass balance of Plaine Morte

Fischer: lab analysis of tracer concentrations

Weber: karst modeling and contribution to text editing

Jeannin: karst modeling and contribution to text editing

Kauzlaric: hydro-meteorological data and sampling after two injections in the south

Wirz: wrote a MSc thesis about the isotope investigations

Vennemann: isotope investigations and contribution to text editing

Hüsler: processing of MODIS satellite data

Schädler and Weingartner: project initiators, coordinators and PI of the MontanAqua project

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/10/C2249/2013/hessd-10-C2249-2013-supplement.pdf

---

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 2743, 2013.