Below is our detailed reply to review #3. It complements our generic reply to review #3 that was published HESSD 14 Sept 2010 [1].

Our complete replies to the reviews #1 and #2 have also been published on HESSD [2,3].

[1] www.hydrol-earth-syst-sci-discuss.net/7/C2306/2010/
[2] www.hydrol-earth-syst-sci-discuss.net/7/C1363/2010/
[3] www.hydrol-earth-syst-sci-discuss.net/7/C1365/2010/

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Abstract – The paper begins with an abstract that sets out to define the role of mountains as essential providers of water resources and identifies the goal of a workshop meeting in Switzerland. The abstract continues by giving an overview of the overall purpose of a special issue resulting from this workshop. In the last paragraph it lists a section-wise, numbered overview of the paper concerned. The goals of the paper are not revealed. The abstract does not provide any summary of the results or any conclusions of the paper.

1 Introduction – The paper begins with half a page of introduction but is devoid of any aims. The last paragraph of the abstract (lines 12-21) should be part of this introduction.

>> Re-written and re-designed, also to comply with the editor's comments (request to design a stand-alone introductory article to the Special Issue).

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p. 2831 Line 26. The list of functions of mountain water resources is incomplete.

>> We focus on the functions most important for water supply and argue that our list contains the most important functions (see e.g. overview by Bandyopadhyay et al., 1997).

- -

It is not clear which regions worldwide the paper is geared to, - is this Pakistan, or wet and dry regimes in general?

>> We attempt a comparison of case-study regions that represent different settings, and highlight common issues as well as issues that are characteristic for individual regions. We believe that this is sufficiently clear.

- -

How are water managers and politicians involved?

>> Our perspective is indeed research, as explained in our generic reply. Most of the authors, however, maintain active contacts to water managers and water management issues, four authors – B. S., G. K., K. S. and Y. H.– are actively involved in water management (see generic reply, our response to "No key experts in the water management and politics field in mountain regions"). We also made a survey among water managers in our regions that provided insight into the actual problems.

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2 Introduction of case-study regions – p. 2834 This section promises an introduction of the case study regions but the reader searches for this in vain. There are only one and half lines dedicated to the case-study regions which refer to a table and a world map. The table only provides the name of the mountain regions and river basins. There is no description of the case study region characteristics such as climate, area, proportion or altitude of mountains, hydrology, geology, groundwater, specific land-use, water use or problems etc.

>> In line with the rationale of our paper (see generic reply to review #3), we refrain from providing an in-depth characterisation of the case-study regions. In the way it is proposed, the description focuses on water stress, water management capacity and scientific capacity, which are indeed thouse issues with highest relevance for our paper. We have clarified that we wish to characterise our case-study regions with respect to the subject of our article and changed the Section heading accordingly. The predominant lowland climate was added since it is also decisive for a comparison of the regions in terms of mountain water resources (Viviroli et al., 2007).

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The boundaries of the case study areas on the map in Fig. 1 are not legible.

>> They look fine in the online pdf we have downloaded. To be on the safe side, we increased the line with of the boundaries.

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The table is confusing since it refers to 10 regions but omits the names of four of the ten river basins corresponding to the study regions, leaving only six rivers in focus.

>> A 'one size fits all' description is impracticable. Column 1 lists the mountain regions, and these regions are our main focus. Column 3 lists river basins where applicable, i.e. where one dominant major river basin (which is, in addition, familiar to the average reader) is present; this is, for example, not the case for the western side of the Tropical Andes. Clarified in text and table.

- -

Two of the regions are not even supported by a contribution in the special issue. Only five of the ten regions are actually defined by all criteria and it is indeed only these five rivers that are ultimately referred to, in more or less depth in the paper.

>> All regions are characterised according to our metrics, have been considered in our discussions and are thus represented in the findings of our article. This was clarified. It would indeed be nice to have special issue contributions for all rivers, but this is unreasonable to expect.

- -

All in all there are eight authors involved in the Special Issue. The contributions of Greenwood, Woods, Schwaiger and Schaedler are not apparent in the paper. No citations are made to their work.

>> The four co-authors mentioned have contributed substantial ideas and concepts to the paper and edited the manuscript.

- -

No reference is made to the Syr Darya or Tien Shan. For the Jordan river we learn in two dispersed sentences within the text that it has a transboundary groundwater aquifer and that there is a common platform of three nations working on it. We do not learn about the problems in the mountain areas and do not read any recommendations on water management in this area under present issues and future concerns of climate change. There is not a single citation on water management or mountain issues in the Jordan basin. Either this example should be omitted or totally revised.

>> We use the case-study regions to illustrate the issues we mention. A detailed and fully comprehensive assessment of the case-studies is hardly feasible. See also our generic reply. Note that the Middle East is also mentioned as an example for a region where population dynamics and economic development will significantly increase water demand.

- -

Concerning the second region, more reference is made to the Lower Indus River, with its plains and delta problems, than the Upper Indus and its mountainous parts. This example should be re-worked to enhance the relevant facts.

>> We disagree with this statement and would like to illustrate that there is a balance between reference to the Upper Indus as the predominant source of water resources and the Lower Indus: The first reference to the Indus (with respect to water stress, p. 2835, l. 13) gives the rationale for the reference to the Lower Indus where the effect of changes in water resource availability is predominantly felt. Further reference to the Upper Indus is on p. 2838, l. 18–22 with respect to snowmelt generated runoff, p. 2839, l. 8–12 with respect to glacier contribution and p. 2842, l. 20–22 with respect to glacier melt. Further references to the Lower Indus (effect of climate change and CO_2 on crop yields; groundwater recharge from river and canal leakage; abstraction information; downstream management of resources) are thus based on the dependence of downstream management on mountain-sourced upstream flows. The presentation follows our rationale of highlighting the issues we identified as being pressing with examples from our case-study regions.

- -

The focus on third example, the Changjiang River is on its lacking international scientific capacity to cope with climate change related water management. This is a quite surprising generalisation, since, against the background of the extremely strong growth in super computers and modelling capacity in China, it is to be anticipated that China could soon become world leader in climate change and hydrological modelling. Also, later in the text (under Recommendations) the excellent functioning of the Water Commissions is praised. Is this not a contradiction and a sign of lacking consultation amongst the authors?

>> This is not a contradiction. China's national scientific capacity is indeed higher than its international capacity (see Figure 2b and supplementary material). This is also explained in Chapter 2: "Upper Changjiang region (UCJ) presents an outlier from the aforementioned connection as it has relatively high national scientific capacity but rather poor international capacity. The emerging economic power of China has led to international scientific aid becoming less available as the country is increasingly expected to rely on its own scientific resources."

- -

The only more detailed example of a case-study region is that of the Columbia River, which opts for a regional description of successful interaction between researchers and water managers. Unfortunately, the reader is not informed about the issues in the basin (e.g. concerning the many dams or cooling water problems connected with nuclear power plants and conflicts with irrigation?) and how these are being dealt with (minimal flow, water temperatures?).

>> We select from different case studies for the purposes of discussion, but the reporting on case studies from each region is not intended to provide comprehensive coverage. Instead we leave this more detailed reporting to the regional companion papers. The issues associated with the Columbia are covered in more detail the special issue contribution by Hamlet (2010), but we added a brief reference to multi-purpose management objectives in the Columbia basin to Section 3.3 to help provide context for the subsequent discussion.

- -

The same is true for the Ebro River. It is introduced at a very late stage with respect to water diversion and towards the end the increased potential for conflict there at the regional scale is mentioned. Again, this example should be omitted or re-written.

>> The social opposition to dam building and the debate on water transfers from the Ebro River are used as illustrative examples of the complexity to match an environmental friendly water management strategy with the possibility to satisfy the water demand in regions where water scarcity is a frequent problem. They also reflect that sometimes water issues exceed the frame of researchers and water managers, turning into a political and social debate. Nonetheless, the example is mentioned in the manuscript as an illustrative example, since a full description of these problems is beyond the scope of the manuscript, and many pages would be required to present the specific information of the basin and the long history of water conflicts in the region.

- -

All in all it would have been more important to have focused on the essential integrated issues of two to three regions rather than skimming the problems in an ad hoc manner throughout the paper; Line 10 p. 2835. *".. we believe that our choice of case-studies forms a solid basis for identifying typical problems …"*. A justification or explanation for the choice is missing. According to which criteria and why were the case studies identified and chosen? To which "typical" problems are the authors referring? These should be listed and justified. How can the case studies be classified (catchment size, climate, altitude, problem)? What is a "solid base" - does this mean a representative number? The number, type and size of mountain regions chosen should depend on the type of problems that are being tackled. Are the five study regions that are finally integrated in the paper really a representative number?

>> Our discussions that lead to this article are based on all 11 case-study regions mentioned, as is clearly explained in Section 2. To clarify this further, we have removed the list of special issue contributions (it will be presented in the additional introductory article to the special issue). We do not believe that there are only two to three generic problems. We chose to highlight the main issues we identified and illustrate them with examples from our case-study regions. See also our generic reply.

- -

Line 23 How can a dynamic water stress index at a resolution of 0.5° by 0.5° help defining local and regional problems when it is well-known that mountains are very heterogeneous?

>> The dynamic water stress index serves, similarly to the capacity assessments, to place the case-study regions in a global context and enable a rough comparison between them.

- -

How is the inner-basin variability taken into account? Which mountain regions have 40 years of data? Where is the data from, what is it based on, how representative is it?

>> The 40 years of data are obtained from the well-known CRU climatology 1958–2001 by New et al. (1999). Since the paper by Wada et al. is not published yet, we have added the reference to New et al.

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How is water availability and demand defined for mountain regions if the authors state in section 3.2 that water demand is considered for the lowlands only? Is this not a contradiction? So the water stress index is not based on a mountain water balance with inputs and outputs? It should be clearly stated in the text and in the figure captions that the water stress component is only based on the lowlands and is not an indication of potential water stress in the upland catchments. // Lines 9, 14, 16 referring to the tropical Andes, Karakorum Himalaya and Pyrenees all put into question the water stress factor which seems to vary substantially over several orders of magnitude between highland and lowland. A clear separation between the two altitudinal units would seem essential.

>> Some regions consist almost exclusively of terrain that is classified mountainous as to Meybeck et al. (2001). A separation would leave only minor lowland areas in the ALC, ALE, PNW, PYR and SAL regions, and an analysis of these small lowland portions does not make sense. We believe that the range of water stress values in the entire region (already indicated) characterises the water stress situation in a useful manner.

- -

Line 5, p. 2834 Water management and water management capacity is probably one of the most important issues in this paper. But what are the criteria used, what are the questions?

What kind of data was obtained, where from and how? Transparency on these issues is totally missing.

>> We have added the complete set of questions and the corresponding scores as supplementary material (see also Reviewer#1, Question A1.1 and our reply).

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Line 13. How was the “national” and “international” scientific capacity defined? What are the questions? How are the “research centres” defined? According to the Shanghai list or according to their success in cooperating with practioners? How are the “competences in research” defined and are these compatible with practical requirements in water management? Does this depend on scientific profile, publications, Nobel prize, impact of scientific research on the scientific community, or rather, the impact of national scientific research on local stakeholders or the impact of international scientific research on local stakeholders? Is the criteria “international scientific capacity” for a country not a slightly colonialist and out-dated point of view? Should these not originate from experienced water management and development agencies? Would not capacity building at the national level be a more sustainable approach? How is the “water management capacity to adapt” to climate change defined? How can this capacity, especially in mountain regions, be generalised across several countries? How can precursor roles be identified? How can socio-economic aspects be integrated in this capacity? Why should climate change aspects override socio-economic issues? How can good practise examples of adaptation (for example at the sub-catchment scale) be generalised for a whole mountain range?

>> See supplementary material, which should also clarify ‘national’ and ‘international’. The scores are based upon the author’s subjective assessments (stated now in supplementary material). A separation of national and international scientific capacity was necessary according to our experience in order to achieve a useful comparison between the very diverse settings of the case-study regions. We have clarified that socio-economic aspects are also important.

- -

Line 26 How can recommendations be made for water management if this is based only on water stress?

*>> The goal of the corresponding section is to place the regions in the context of water stress and **the capacity to deal with water stress** and to provide a **framework for more detailed assessments and subsequent recommendations**. It is not suggested anywhere that our recommendations are based on water stress only.*

- -

Why should the scientific capacity to deal with climate change be less good at the national than at the international level? Why should this be a disadvantage for countries like China?

>> The lower scientific capacity at national level is explained by the fact that not each country has leading research institutions in the field of climate change and water resources. China’s scientific capacity is, for the reasons stated further above, better at the national level

than the international level. This means that China has only limited access to know-how from internationally leading research institutions, and needs to push research rather within the frame of its national capacity. In addition, it is very difficult to tackle international water issues under these circumstances (e.g. for the Himalayas).

- -

Line 2. Why should high physical water stress be found together with low adaptation capacity? Would not the inverse be expected? (strong tradition of adaptation by mountain people?).

>> We refer to regions with poor economic development where the technological measures for adaptation are not available for financial reasons. Clarified.

- -

How is the adaptation capacity defined? It was never mentioned anywhere in the text. How are non-technological solutions integrated in this index?

>> See supplementary material.

- -

Line 6, p. 2835. *"It should be noted that the value drawn for water stress refers to the mean of the entire case-study region, which may mask smaller areas with high water stress. This applies, for example, to Bolivia, Ecuador and Peru which were chosen to represent the Tropical Andes (ANT)."* In other words, the "real" problems, which are typically local scale or catchment scale considering the heterogeneity of mountain areas

>> Again, we attempt a comparison of the case-study regions at global scale for placing them in a context. Above quote explains what can be deduced from the MEAN value and what not. In the sentences following that quote, we explain that the grey (now coloured) range bars are shown exactly for the purpose of adding crucially important information to that mean by revealing the range: "The average water stress computed for this region is 0.15, while the arid parts of the region (the Andes themselves, including the Pacific slopes as well as the lowlands to the west) show values well above 0.4. Similar reservations apply to the average water stress value for the Karakoram Himalaya (0.29), especially because the Indus Plains – where the majority of the population lives – suffer from even more severe water stress (Archer et al., 2010), frequently with values well above 0.8. The average value for the Pyrenees (0.22) also hides that stress is much higher in the adjacent River Ebro Plain. It is therefore important to consider the value range indicated by the grey bars in Figure 2 and to bear in mind that the level of water stress is very diverse in some regions."

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The main diagram referring to this, Fig. 2, is illegible, in particular with reference to the "grey bars" largely confused by the white bars. Each of these diagrams should be presented over a full page accompanied by a table that explains the origin of the data and criteria used for each region with related citations.

>> There are no white bars. Maybe the reviewer refers to the white grid lines? We have increased the width of the range bars, coloured them and present the three diagrams in vertical rather than in horizontal order, which makes each diagram larger. The corresponding criteria and scores are provided as supplementary material (see above).

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Line 20. There is no citation for the statement on the management capacity and degree of water stress for the Central and Eastern Alps. How are these defined, what is the evidence, what are the examples, exiting work on these issues, why are regional differences that the water managers are faced with not taken into account?

>> See details of scoring in supplementary material.

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Line 26. The Pakistan case study region is classified as having a low national scientific capacity on climate change related issues. This does not correspond to the evidence given in the publication on “Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions” by Archer et al 2010 in HESS.

>> We disagree. The assessment of Pakistan in Section 2 of our summary article obviously refers to the capacity relative to the other regions, and we believe that it is correct in this context. The individual paper by Archer et al. 2010 in HESS provides, in turn, a region-specific and encouraging assessment with respect to recent improvements in research capacity rather than making a statement about overall capacity.

- -

3.1 Water supply (runoff from mountains) – This section is mainly focussed on discharge yet the authors do not justify why they have made this choice. Water resources in mountains comprise much more than only discharge (groundwater, lakes etc?). Why is this section (runoff from mountains) decoupled from the section 3.2 on Water demand (consumption in lowlands).

>> As explained in the reply to the generic manuscript comments, the knowledge available about groundwater is very limited. We state this now and mention the significance of groundwater. The impact of reservoirs is discussed in Section 3.1.5 further below, lakes are beyond scope. “Decoupling” of runoff from mountains from consumption in lowlands: See reply to comment on “3.3 Balancing demand and supply” below and our corresponding reply.

- -

3.1.1 Present state – This section describes snow and glacier-melt related runoff. Permafrost thaw is not considered.

>> Thawing permafrost may have an impact for water resources in selected local cases, but is negligible in mountain areas at global and regional scale (this is even true for the Arctic,

see McClelland et al., 2004). Although the subject is therefore is rather beyond scope, we have added a paragraph on permafrost to section 3.1.1 for clarification.

- -

Not a single reference is made to glacier-melt dependant hydropower: the issues, the problems and the future. Unfortunately, it is also missing in the section 3.2.2 on Hydropower despite the fact that glaciers play a major role in hydropower production in the regions studied (Peru, Bolivia, Ecuador, Pakistan, Switzerland, Austria, North America). It is not even mentioned that 50% of Swiss hydropower production depends on glacier melt. Is this type of runoff decreasing or increasing in the regions? What are the trends? What are the expected impacts on hydropower production?

>> Beyond scope. Also, we believe that the reviewer's notion that "50% of Swiss hydropower production depends on glacier melt" is unreasonable, and we are not aware of a corresponding figure in published literature. A quick 'reality check': Glaciers occupy, according to the Hydrological Atlas of Switzerland, a little more than 3% of the total area of Switzerland. Even if ice AND snow melt from glaciated areas would be considered, the figure seems to be far off reasonable limits.

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Line 20, p. 2838 Why is only one example cited world-wide for the high dependence on snowmelt run-off from Pakistan. How do all the other regions compare?

>> The example refers to the Western Himalaya and was chosen because the Himalaya-Hindu Kush region is mentioned by Barnett et al. (2005) as one of the most critical regions (although the authors highlight the importance of glaciers). The importance of snowmelt runoff in the Western Himalaya was corroborated by Immerzeel et al. (2010). We now mention additional regions identified by Barnett et al. (2005) as being highly dependent on snowmelt runoff.

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Line23. Why is the issue of summer discharge as related to glacier melt not elaborated? What is the percentage influence of glacier melt on flow, how many months per year, percentage influence during the months of July, August? Which streams and rivers could face serious problems in future? What is the seasonal dependence of hydropower on glacier flow?

>> Elaborating on these issues in detail is beyond scope. The corresponding Section gives, as the heading promises, an overview of the present state of runoff from mountains. In addition, comprehensive and reliable figures on glacier contribution to water resources are rare. We have incorporated some key findings of a recent article by Kaser et al. (2010) which was published after submission of the initial manuscript.

- -

Line 1, p.2839. The Himalayan Glacier controversy is cited in the wrong context. It was actually discussed in many scientific newsletters and the original paper was published in Science by Bagla 2009. It was put into perspective through an important, multi-authored response in the form of a letter to the editor by Cogley et al 2010 that states that the section in the IPCC report was inadequately scientifically reviewed. These two citations should be cited. The controversy is related to the date by which the Himalayan glaciers could disappear, depending on rates of glacier retreat and does not focus on the annual contribution of glacier melt to runoff.

>> We are perfectly aware what controversy is about – see p. 2841 / l. 26 to p. 2842 / l. 2: "This was recently shown by the controversy about the false IPCC statement that the Himalayan Glaciers could disappear by 2035 at present warming rates (see Bagla, 2009; IPCC, 2010; Schiermeier, 2010; see also section 3.1.1)". Our point in the paragraph mentioned by the reviewer is that the contribution of the Himalayan glaciers to water resources is very limited, in spite of what was implied by the relevant Section in IPCC AR4 (Crutz et al., 2007). Their disappearance may, therefore, not have such dire consequences for water resources. We clarified this. The reference to Bagla (2009) is already given at p. 2842, l. 2, we have added the reference to Cogley et al. (2010).

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Line 5 Why are no other examples cited?

>> We have added a reference to the recent study by Immerzeel et al. (2010) with a short critical discussion of its results. The studies by Singh et al. (e.g. Singh and Bengtsson, 2003; Singh and Jain, 2003; both already cited in our manuscript) apply to a limited area only. In addition, we now also refer to the freshly published article by Kaser et al. (2010).

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Line 6 For the seasonal proportions, elaborate for which months and where.

>> The paper by Armstrong et al. does not reveal these details.

- -

Line 8. ".. situated in a drier climatogical region..". This expression does not exist. Also, this is a monsoon regime, thus a wet and dry regime. This should be cited.

>> Clarified: We refer to the drier western part of the Himalayas (as compared to Nepal to which we refer in the preceding sentence).

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Line 16. The only citation concerning glacier retreat and runoff for the Alps refers to a paper published 20 years ago! An effort should be made to cite the most recent and most relevant literature on this. It would indeed have been easy to have read the paper by Cassasa.

>> The passage mentioned does not deal with glacier retreat and runoff in the Alps, but rather with the smoothing effect that ice melt runoff has on the coefficient of variation in summer runoff. Casassa et al.'s statement (that a minimum coefficient of variation in summer runoff is reached with a share in glaciated area of about 40%) is based on two references, one of which is the paper by Chen and Ohmura (1990). Section 3.1.4. refers to 11 recent

papers for the European Alps that focus on snow and glacier melt (further references were even added during revising that section).

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Line 17. The paper by Cassasa et al deals with changes in glacial run-off in nearly all the basins treated in the paper. None of the important conclusions drawn together are integrated within the paper, e.g. the decrease in run-off in south-central British Columbia, low elevations of the Swiss Alps and in the central Andes or the increase in run-off in other basins. Neither is any reference made to future predictions of water availability.

>> The section about glacier-related changes in runoff was revised, and the reference to Casassa et al. (2009) has been moved to the introduction where a mention along with its key findings is most suitable. A detailed discussion is beyond scope because, as we state further below, the glacier signal dilutes relatively quickly with basin size. Predictions of water availability are already discussed in Section 3.1.3 ("Climate change projections"), and we believe that the Section headings ("3.1.1 Present state"–"3.1.2 Past trends in mountain runoff"–"3.1.3 Climate change projections") are clear enough to guide the reader.

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Line 19- 20 This sentence is nebulous and does not contribute to an advance to existing knowledge.

>> We have clarified what we mean and are more specific, using the example of the European heatwave as analysed by Zappa and Kan (2007).

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Line 20 Why is nothing cited on the work by Haeberli on climate change and the world-wide retreat of glaciers and related to runoff?

>> The effect of retreating glaciers on runoff is already mentioned explicitly in the context of climate change (p. 2832, l. 18–20: "Glacier-related changes in runoff usually include increased runoff from enhanced ice melt, while water yield will decrease in the long term"); this statement was specified and says now that this decrease is expected to happen gradually over the next few decades as a consequence of the overall reduction in mass of glaciers due to global warming (Kundzewicz et al., 2007; Schneeberger et al., 2003). Also, we already refer to the work of Haeberli by highlighting the importance of the World Glacier Monitoring Service WGMS (Zemp et al., 2008) (p. 2859, l. 25–28).

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3.1.2 Past trends in mountain runoff – Lines 18-21, p. 2840; It would be important to cite more recent and more comprehensive literature related to snowmelt and introduce comparisons for the different case study regions as well as other examples world-wide. There is repetition in this paragraph, especially with relation to "earlier snow-melt regimes". The French Alps are not the only regions of the Alps experiencing earlier snowmelt! The western US is not the only region experiencing a transition from snow to rain, this is a phenomena recurring world-wide!

>> This section deals with past trends in timing of mountain runoff. Barnett et al. (2005) note the "very robust finding" that warming leads to changes in the seasonality of river flows where much winter precipitation currently falls as snow, but this statement applies to projections / hydrological impact studies (see discussion in our Section 3.1.3). Trends for the past are far less clear.
We chose to highlight the Alps (not only the French part indeed, see p. 2840, l. 9–18 right above with references to Birsan et al., 2005 and Barben et al., 2010) and the Western US because a) there is sound and peer-reviewed scientific evidence of earlier snowmelt runoff (not the case everywhere where this shift would be expected, and for the Alps, signals are still not completely unequivocal) and b) changes in these regions affect large populations and economies.
Stewart et al. (2009) also mention the Tibetan Plateau / Yellow and Yangtze Rivers with reference to Ye et al. (2005), but this paper does, in our opinion, not support the notion of earlier snowmelt, mainly because runoff at the station used is predominantly generated by rainfall and contribution from snow and glacier melt is very little, most likely below 1% (Yan Huang, personal communication, September 2010). In addition, the paper is in Chinese (with abstract in English), published in a journal that is not listed in ISI's expanded list of peer-reviewed journals (SCI-EXPANDED) and only available with subscription.
We have added a note about robust trends for earlier snowmelt and associated shifts in runoff that have been found for several basins in Siberia in the 20th century (Lena, Ob, and Yenisei Rivers).
A comparison of the case-study regions is not attainable due to lack of data.

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Line 22. "*As regards the associated changes in runoff…*" This is a vague sentence that does explain what kind of changes are being considered and therefore confuses the author as to its context. The author list is extreme repetitive and narrow e.g. Dettinger and Cayan 1995, Cayan, X, Dettiner, X 2001, Stewart, Cayan and Dettinger 2005. Surely this is not the only literature for the western US on the market!

>>These studies relate to hydrologic changes associated with loss of snowpack and related streamflow timing shifts, in some cases attributing these changes explicitly to greenhouse forcing. We added this introductory context.
With regard to the representative studies selected, there are a number of individual case studies that could provide more references, but we're not intending this to be a comprehensive listing. These authors have done a good job of reporting on the entire Western U.S. using consistent a consistent set of methods, which distinguishes these studies from most of the others. It's true that there is a relatively small group of researchers who have addressed these topics well in the last decade or so, but our selection is again not intended to imply that these are the only work being done.

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p. 2841, lines 4-7. "*In Mediterranean mountains such as the Pyrenees, for example, depopulation and subsequent land abandonment have led to vegetation growth which has been the main driver for reduced runoff generation and decreasing streamflow (Begueria et al., 2003; Lopez-Moreno et al., 2008*)." This sentence does not support the conclusions of the paper in prep by Lopez-Moreno et al, who state that the main drivers are dam regulation, decrease in snowpack, increase in evapotranspiration rates and increased water use for domestic, agricultural and industrial use.

>> The special issue contribution by Lopez-Moreno et al. (2010) does not contradict the outstanding influence of reforestation on the observed decline of water yield in the basin. Indeed, the authors stress that vegetation growth in large agricultural abandoned areas is the main driver of hydrological changes. Although they point out the other reasons mentioned by the reviewer as additional potential reasons of hydrological changes, their discussion clearly states that there is evidence about land cover being the main driver of hydrological change in the region. We have added the additional potential reasons to abovementioned paragraph in our manuscript for clarification and completeness.

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Section 3.1.3 Climate change projections – For the Andes, nothing is mentioned on the actual and future problems of water management and conflicts related to waterless rivers and low groundwater tables as a direct result of glacier retreat. In this context, the problem of water management as related to reliability of drinking water supply to large urban cities at high altitudes (e.g. in Ecuador, Bolivia) is missing.

>> This is now discussed now in the section mentioned, with additional references.

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Line 20, p. 2842. "…*snow melt systems such as the Indus River basin, the Ganges-Brahmaputra River basin and Northern China*." It is questionable whether the Indus is a snow-melt system. Where have all the glaciers gone?

>> The classification was proposed in the UN WWDR3 (WWAP, 2009, p. 113), and we cite this report for definition of vulnerable regions: "The UN WWDR3 (WWAP, 2009) mentions two mountain-related systems limited possibility of adaptation results in high vulnerability to projected impacts. The first are snow melt systems such as the Indus River basin…". The recent study by Immerzeel et al. suggests, indeed, that about 40% of meltwater comes from glaciers (and 60% from snow). We have added a clarification.

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Section 3.1.4 Representation of mountains in climate and hydrological models – "*Climatological and hydrological modelling are important tools for laying the foundations for successful and sustainable water management*". Yes, but how about the techniques for applying the model results and implementing water management? What tools are available for these?

>> Beyond scope.

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"*Insight into important processes of mountain areas is achieved through process-oriented hydrological modelling exercises with focus on snow and glacier melt.*" What happens to all the mountain chains without snow and ice? No citations?

>> Already the importance of snow melt for the world's population as presented by Barnett et al. (2005) justifies emphasis on snow and ice melt. See also our reply to the comment concerning emphasis on cryosphere. We believe that this specific statement does not need citations since it is followed by an abundance of examples (with citations). We wish to emphasise that there is a strong link to mountain chains without snow and ice throughout Chapter 4 ("Research and monitoring needs").

- -

This section is focused uniquely on the representation of mountains in the domain of natural sciences but lacks literature on the influence of socio-economic issues on mountain hydrology and climatology (e.g. influence of large dam reservoirs on local and regional climatology, influence of topographic aspects on water distribution and use, influence of irrigation, dams, drinking water and tourism, including alpine lake management on water availability).

>> The section deals, as the heading promises, with representation of mountains in climate and hydrological models. We agree that implementing further (e.g. socio-economic) issues is desirable but believe that the problems we highlight (spatial and temporal heterogeneity of conditions, lack of process understanding) are fare more pressing and fundamental and thus should be treated with emphasis at the scale we consider. We have added a note on the need for implementing socio-economic effects, but a more detailed discussion of these topics is beyond the scope of our article.

- -

The section does not sufficiently cover international literature and lacks many citations, narrowed down to few specific cases e.g. for the European Alps, and even here the literature is rather one-sided and scans eight Swiss and only one Austrian review, basically nothing from Germany, France or Italy. The citations for Scandinavia seem entirely restricted to Hock (no Scandinavians?), literature for the Rockies lacks important work and the Himalayas are restricted to the West (nothing on China etc).

>> We wish to focus on process-oriented hydrological modelling exercises that deal explicitly with snow and glacier melt; see also our reply to comment on literature for the western US / Rockies further above. European Alps: Added reference to Dadic et al. (2008), Michlmayer et al. (2008), Lambrecht and Mayer (2009) and Weber et al. (2009). Scandinavia: Added reference to Skaugen (2007) and Beldring et al. (2008). Note that Regine Hock, although no 'Scandinavian', was based in Kiruna and Stockholm 1998–2007. China: We are not aware of peer-reviewed scientific papers on the topic mentioned. We have completed the list with a reference to a study in Central Asia (Hagg et al., 2007).

- -

Section 3.1.5 The role of reservoirs – A description of current approaches on how to include dams and water storage in hydrological modelling is missing, despite the fact that many operational hydrological models are available that include dam reservoirs and flow regulation in their modelling routines (e.g. for the Alps, Rockies etc).

>> Including dams and water storages in hydrological modelling is challenging because it is very difficult to obtain the required data about dam operations. We now mention these difficulties at the beginning of Section 3.1.5. A detailed discussion is beyond scope.

- -

p. 2846, line 5. A sentence on the extreme problems of sedimentation (typical for high bedload transport rates in mountains) as related to the lifetime of a reservoir should be included in the list of problems and questions on p. 2845

>> We have shifted our statement regarding the sedimentation problem to the list of problems, slightly reworded it and added a reference to the textbook by Morris and Fan (1998).

- -

line 8 should read “water supply availability” or “the available water supply”

>> Changed to ‘the available water supply’.

- -

line 10 not only requires projections of 1) inflow, in particular seasonal changes in inflow but also 2) changes in patterns of evaporation and evaporation losses, particularly important in arid mountain regions and 3) controlled outflow according to the electricity or irrigation market demands and 4) minimal discharge requirements for ecology and the environment.

>> We agree that the points mentioned are important and have added them.

- -

How do mountain river ecosystems cope with the pronounced flow reduction or even prolonged drying up of river beds? How is this brought in line with regulations such as the European Water Framework Directive? Where is the Swiss literature concerning its precursor role in implementing environmental and green regulations for dams and green energy?

>> These problems are interesting and important, bur clearly beyond the scope of our paper.

- -

Line 18. It is stated that the Grande Dixence dam is the highest dam in the world. This statement is false. Already 25 years ago, the Rogun dam was built in Tajikistan and is 50 m higher!

>> The Rogun dam has not been completed to date (see Schmidt, 2007), but the Nurek dam, also in Tajikistan, indeed surpasses Grande Dixence in height by 15 m. Grand Dixence is, however, still the highest gravity dam to date. Corrected in the text.

- -

Nothing is mentioned on the long interbasin water transfer, the proportion of flow originating from glacier melt, the past and predicted future trends.

>> We have added a section on interbasin water transfers but think that it is not possible to quantify the proportion of reservoir inflow originating from glacier melt. Future trends are touched upon in Section 3.2.2.

- -

This section focuses solely on a description of reservoirs as related to power production and irrigation in mountains but it does not tackle water resources conflicts between hydropower and irrigation e.g. storing sufficient amounts of water as opposed to releasing sufficient amounts for irrigation, in particular as related to climate change e.g. drier summers. Most importantly, this section does not tackle the important role of alpine / mountain lake management and the control of lake levels through dam operation. Neither does it treat existing and future potential conflicts in lake level management for tourism as opposed to dam operation. Under climate change, the problems of reliability and prediction of lake inflow (related in particular to changes in snowmelt regimes or high altitude intermittent lakes typical for karst plateaux) and the provision of maximal lake volumes as influenced by seasonal floods or droughts should be considered, in particular in the transboundary context. Ample examples are available for this, e.g. for Switzerland/Italy, the problems of controlling the volume of Lake Lugano with respect to dam control for irrigation and the involuntary flooding of the city of Lugano (see missing references).

>> We have added a paragraph that describers the example of multipurpose reservoir operation in the Rhone River basin. Covering abovementioned topics in greater extent is beyond scope.

- -

In terms of climate change current water management problems such as the impact of droughts on electricity production are not mentioned. Important predictions related to climate change such as the amount of decrease in electric production due to decreasing discharge and increasing evaporation or cooling problems due to increase in river temperatures are not mentioned.

>> Projections for electricity production are extremely complex do not solely depend on changes in hydrology (which might even lead to a better use of installed capacities when winter flows increase and summer flows decrease) but also on power plant design and development of prices on the electricity market. These issues are beyond scope, as well as the increase in river temperatures which is not mountain-specific.

- -

Line 14, p.2845 "*…or intrusion of saltwater from the sea into aquifers (for example on the lower Indus, see Archer et al, 2010)*". It is questionable whether coastal processes such as intrusion of saltwater are relevant to mountain water resources. It would have been more interesting to have examined the relation between water abstraction in the Upper and Lower Indus and the impacts on minimal flow.

>> The quoted statement is made in Section 3.1.5 which deals with the role of reservoirs. In this context we agree that it is primarily the downstream abstractions and consumptive use which alter the amount of river flow, and not the dams. We have now omitted the statement because it is indeed misleading in the given context.

- -

Problems associated with increased irrigation water demand under climate change are not tackled.

>> Beyond scope.

- -

Section 3.2 Water demand (consumption in lowlands) – If this is a paper on mountain water resources, why does the section on water demand focus on water consumption in the lowlands? Where is the evidence and what publications exist on the differences between water consumption in mountains and lowlands?

>> Agriculture is responsible for the lion's share of water consumption (even more so in developing countries in the subtropical climate region), and agriculture is predominantly located in the lowlands.

- -

If a "detailed investigation of future demand is beyond the scope of this paper", how can you, at the same time give recommendations to water managers on future scenarios and projections, "bandwidths of probable futures" how can the uncertainties be "clearly addressed" and "communicated", e.g. Section 5.1. Is this not a major contradiction?

>> We do not believe that this is a contradiction. We stress the importance of uncertainties, and it is not necessary to provide a detailed investigation of future demand for this purpose.

- -

Water demand in the highlands is just as significant and very important for water managers, and since it is difficult to quantify, should be a future research field. How about large high altitude cities (S. America), tourism etc?

>> We have slightly extended the introduction to Section 3 to amend this.

- -

3.2.1 Agriculture – The whole section is focussed on lowland and pre-mountain agriculture. The section misses out completely on irrigation, including present and future water demand how this can change in mountain areas. The points tackled (population growth, changes in meat consumption and crop yield) are not related to the mountainous regions and are not analysed for mountain areas. This section should be re-written taking into account mountain-specific issues. The point on temperature and CO2 increase and changes in crop yield should be related to irrigation, water demand and relative humidity.

>> According to Huddleston et al. (2003), 78 percent of the world's mountain area is not or only marginally suitable for growing crops, and in developing and transition countries, only 7 percent of total mountain area is currently classified as cropland. We believe that this justifies or rationale of focusing on water demand (also that from agriculture) in lowlands at the scales we consider.

- -

3.2.2 Hydropower – This section barely scratches the surface of the actual and upcoming problems related to hydropower. The enormous increase in the number of dams is not critically reviewed. The section on air conditioning is only one of many other problems such as industry, infrastructure etc. What are the differences in air conditioning demand for tropical countries? What are the impacts of water temperatures on ecosystems? Power plant cooling is not discussed!

>> An extensive critical review is already found in Section 3.1.5, and we have extended Section 3.2.2 in this direction. The other aspects mentioned are clearly beyond the scope of our article.

- -

3.3 Balancing demand and supply – How can this section be assessed if demand and supply cannot actually be balanced due to an inadequate approach (water demand in lowlands, water supply in mountains?). This section cannot be limited to surface flow. What are the limits on groundwater, e.g. at the foot of the Rockies, groundwater-fed agricultural areas are highly stressed due to groundwater over-use and in China?

>> We now state at the beginning of Section 3 that the simplification is defendable in our attempt of providing a comparative overview. (Hasn't this reviewer stated that an upstream-downstream logic in hydrological issues and water management approaches is necessary?) A more detailed discussion of groundwater issues is, as explained in our generic reply, beyond reach. See also reply to "Water demand in the highlands is just as significant and very important for water managers…" further below.

- -

Line 4 Which mountain regions are experiencing water stress?

>> The examples refer to "extended regions that are experiencing water stress and, at the same time, depend at least to some degree on mountain water resources", not to mountain regions that are experiencing water stress. We have added the names of associated mountain ranges for clarification.

- -

Line 9 How can water supply be considered at the basin scale with the approach presented in this paper (see Figs 2-5?).

>> The 'approach' the reviewer refers to is most likely the global-scale overview which we use to place our case-study regions in a context, and for which we have already provided clarification above. Our statement ("This requires, above all, a paradigm shift to a water resources management that orients itself not by the water demand but by the limits of the supply and thereby considers all of the decisive factors across the entire river basin.") is not mentioned in the context of global-scale figures.

- -

Line 12 Is desalination a relevant and necessary technique for increasing water supply in mountain regions? This argument is somewhat out of context! Are you not confusing lowland and mountain issues here?

>> We deem desalination as relevant for increasing available water resources in the lowlands and thus reducing pressure upon water resources. Clarified.

- -

Line 17 How about the inverse problem, virtual water transport from dry, mountain-fed regions such as in the Mediterranean, South America and Asia to other regions?

>> This is indeed a relevant problem, and we have added a critical note about it.

- -

Line 22 "*much of the streamflow eventually becomes polluted*". This is a vague, undefined sentence for mountain chain 6000 km long! Please strengthen by arguments and facts. How about other regions world-wide?

>> Re-phrased. We limit our discussion to this example because water quality is not a focus of our article.

- -

Line 28 Reducing demand is not a new concept. Please cite relevant literature.

>> We now refer to the extensive overview by Molden (2007).

- -

Line 4, p. 2850 How can productivity in Pakistan be increased?

>> We believe that our statement that "… there is much scope for increasing productivity given the low crop yields (e.g., wheat yield per unit of water in Pakistan is 50% of that in the Colorado Basin)" is sufficient within the rationale of the paper. Further discussion is beyond scope.

- -

Line 6 How can water demand be reduced in mountain regions?

>> As we explain in Chapter 3.2, water demand is much larger outside of mountain regions. Reduction of water demand in mountain regions is, therefore, of low priority. In addition, technological and administrative measures for reducing demand may not even be feasible outside of industrial nations.

- -

4 Research and monitoring needs - Line 12. But how do you cope with droughts? Other variables of the hydrologic cycle concerning ecology, soils, meteorology etc?

>> We focus on issues that are most promising for improving runoff projections, and the priorities and their ranking are derived from our case-study regions and our discussions.

- -

Line 14 Which type of precipitation?

>> In our view, improvements are necessary and relevant for all types of precipitation (e.g., advective, convective, snow, rain, tropical, extreme). Added 'all types of…'.

- -

What can be done in case of data gaps?

>> This is not a mountain-specific issue but a common problem in hydrology, and therefore clearly beyond our scope.

- -

4.1.2 SWE – Line 5. A synthesis of snowpack representation in mountain hydrological models is missing.

>> We have extended the corresponding paragraph slightly and point to the generic types of snowmelt representation. A more detailed discussion of the innumerable possible permutations of methods involved (extrapolation of meteorological data to the snowpack, calculation of point melt rates, integration of melt over the snow-covered area, runoff routing – see e.g. Ferguson, 1999) is clearly beyond scope.

- -

Line 18, p. 2854 What are the problems of resolution and limits of interpretation in mountains?

>> Added a note on mountain-specific challenges in remote sensing with reference to Weiss and Walsh (2009).

- -

4.1.3. Soil information – This section heading is not scientific. Soil information is necessary, but how about geomorphology and geology? Infiltration? Near-surface flow?

>> Heading changed to 'soil parameters'. We now list relevant parameters and have extended the section as suggested by Reviewer #1. Geomorphology and geology are beyond scope.

- -

4.1.4 Evapotranspiration and sublimation – This section is poorly written. It does not contain a single citation on sublimation despite the fact that there is ample material available, especially from US studies. There are only two citations on evapotranspiration that stem from the same team of scientists and are not even related to evapotranspiration process in mountains or to the water resources management context [1]. They are limited to global climate models without any reference to the important role of evapotranspiration losses in the mountain water cycle. Surprisingly, no references are made to the author's own work e.g. by Schaedler whose recent publications state that evapotranspiration has increased in the Swiss Alps over the past century and who predicts that potential evaporation will further *increase* and that summer and autumn discharge is likely to *decrease* [2]! In the discussion there is confusion between the terms evapotranspiration and evaporation and between evapotranspiration and sublimation. No differentiation is made between evapotranspiration and potential evaporation, particularly for semi-arid mountains. [3]

>> (we have inserted numbers into above comment) [1] See our remarks regarding sublimation further below (comment "The magnitude of changes…"); [2] this is mainly due to a change in runoff regime and reduced precipitation, as explained in Section 3.1.2. ("Past trends in mountain runoff"). We feel that discussion is not due in the Section 4.1.4.; [3] clarified.

- -

Line 13 p. 2855. Concerning the citation of the Nature article *"The suppression of plant transpiration due to reduced stomatal aperture with increasing CO2 levels…. could, for example, counteract the general trend for higher evaporation at the global level*":

1) It is wrongly cited [1], since in the article by Gedney et al, increased runoff is attributed to reduced evaporation due to increased aerosol concentrations and decreased solar radiation. The original statement reads "*an increase in twentieth-century continental runoff is attributable to the suppression of plant transpiration by CO2-induced stomatal closure"* and does not refer to evaporation. [2]
2) The article is put seriously into question by Peel and Mahon and as stated by the authors themselves, it does not even apply to Europe, let alone the Alps! [3]
3) It is very questionable whether all mountain vegetation (grass, meadows, shrubs, trees) reacts in the same way to increased CO_2 as is the case for experimental greenhouse plants. It would have been important to have cited evapotranspiration studies such as the ones related to climate change experiments in Switzerland, which show striking differences between different species, even between deciduous and coniferous trees. [4]

>> Response (we have inserted numbers into above comment):

[1] The sentence mentioned is, as a whole, not a quote from Gedney et al., and we do not suggest that it is. Rather, the first part of the sentence ("The suppression of plant transpiration due to reduced stomatal aperture with increasing CO2 levels [see e.g. Gedney et al., 2006a; Betts et al., 2007]") correctly reproduces the sense of the Nature article by Gedney et al., as indicated by the reference.

[2] The reviewer's statement contradicts itself and is wrong. Careful reading of the Gedney et al. paper reveals that the reviewer's comment „[…] in the article by Gedney et al, increased runoff is attributed to reduced evaporation due to increased aerosol concentrations and decreased solar radiation.") is not correct because Gedney et al. quote a paper by Roderick and Farquhar on solar dimming and open pan evaporation. Also, the 'original statement' that the reviewer quotes afterwards is not from Gedney et al., but from the Peel and McMahon's comment.

[3] The reply of Gedney et al. says: "Third, we find that, over every continent except Europe, including the direct CO2 effect produces temporal behaviour that is closer to the observational data than when only the climate effect is included. This is also the case over Europe if we incorporate the net effect of human water consumption". Therefore, their findings are also applicable to Europe, and the Alps are not mentioned as an exception.

[4] The discussion was extended and completed.

We agree that the technical terms were not always used adequately and have amended this.

- -

Line 19 "*The magnitude of changes in ET and their impact on hydrology depend very much on the specific environment. In glaciated catchments in the Andes, for example, sublimation has a bigger impact on water resources than ET".* Sublimation is not an example of evapotranspiration. How does sublimation influence hydrology, the authors probably mean run-off? Does it increase or decrease? And, more importantly, what is the relation between sublimation, glacier melt, ET and river discharge? Where and when does sublimation take place? What are the expected interactions between sublimation and glacier albedo under climate change?

>> Sublimation is obviously not an example of evapotranspiration, and we agree that several aspects of sublimation should be discussed with more detail. We now elaborate, in an additional paragraph in Section 4.1.4, on the characteristics of sublimation, its regional relevance, its influence on river runoff and its relationship with glacier melt. However, we wish to emphasise that sublimation, while very important in subtropical high mountain regions, is of rather limited relevance on a global scale. It is therefore beyond the scope if our paper to treat all the issues raised by the reviewer in more detail. We have added additional references on sublimation where further information on sublimation processes can be found.

- -

The authors then go on to contradict their previous statement:
P; 2855 Line 23 "*In the Pyrenees, a significant* ***increase*** *in ET is expected due to the growth of vegetated area, caused by abandonment of agriculture and grazing and a rise of the tree line*." What is this assumption based on? Citations?

>> Obviously an increase of vegetation will lead to an increase in actual evapotranspiration which means a decrease in water yield. The very likely abandonment of much of the remnant agricultural and grazing activities cannot be supported by references as there are, to our knowledge, none for the Pyrenees. However, population in Pyrenean villages is very aged, and there is no replacement to continue with agricultural and grazing activities which are progressively disappearing in the area. A change in elevation of the tree-line as consequence of climate warming is widely accepted in ecology. We have slightly re-phrased the sentence and added a reference to López-Moreno et al. (2008).

- -

Sublimation is by-passed with half a sentence and not even contextualised with relation to climate change. No reference is made to improvement of measurement technology, e.g. snow lysimeters and how to integrate the potential changing proportions of sublimation in the water cycle. All recent advances on the topic in the Alps, Andes, Rockies and Eurasian mountains on the topic are omitted (see missing references). It should therefore either be eliminated from the title or re-written.

>> See our reply further above and the corresponding changes in the manuscript.

- -

In previous sections, no suggestions are made for improving field observations (lysimeters, Bowen Ratio, Eddy co-variance?) although the importance of these processes is likely to increase under climate change and have eminent effect on water management in economical sectors that are not directly related to discharge (agriculture, forestry etc). Interception and condensation is completely missing in this section.

>> These issues are clearly beyond scope and not mountain-specific – we do not wish to provide a comprehensive textbook of the water cycle.

- -

4.1.5 Groundwater – This section begins with the statement "*Although groundwater recharge is not a specific mountain process,….*" which sheds serious doubts on the scientific credibility of the work of the authors. The statement is a reflection of the lack of knowledge and missing literature review on the topic rather than the actual facts. Not even a partitioning of shallow and deep groundwater flow is attempted nor how it is impacted by the cryosphere. This is because literature is again limited to global-scale assessments with a total absence of literature related to the peculiarities of mountain groundwater and water management related problems, e.g. agriculture, tourism, groundwater recharge and springs, mountain karst, floods, etc. Which tools exist to cope with hydrological variability of groundwater in mountains?

>> Our statement is that groundwater recharge does not occur only in mountain regions (cf. Döll, 2009), but that it is "dominant in many basins in arid and semiarid climates". To clarify this, we rephrased the sentence. Regional examples from the Andes and from the Indus River basin are already mentioned. As explained in the first generic reply to the review, an in-depth coverage of groundwater issues is beyond scope.

- -

Line 6, p. 2856. It is not mentioned that the Central Andes, for example, are one of the regions where groundwater is most vulnerable to climate change (Doell 2009).

>> added further above to the example of the Atacama Desert.

- -

Line 13, p. 2856. Should it be groundwater dependence on water abstraction or the inverse?

>> We discuss the need "to improve process knowledge about ground-water flows or at least quantitative data about the extent and renewal rate of large aquifers.", and in this context, "dependence of groundwater on [natural vegetation, land management and] abstraction" is relevant. The inverse would be relevant for a discussion of water abstractions.

- -

Line 4 Wilson and Guan themselves give a list of interesting recommendations which are not considered, e.g. of shallow and deep flow paths and residence times, hydrogeologic characteristics, stream network geometry, relative streamflow contribution of surface runoff, shallow soil cover interflow and the discharges from shallow to deep subsurface, partitioning of rainfall and snowmelt (Yes, indeed a specific mountain process!) into vegetation-controlled evapotranspiration, surface runoff, and deep infiltration through bedrock, especially its fractures and faults.

>> We have incorporated the generic recommendations as proposed by Wilson and Guan, but a more detailed discussion as suggested is beyond scope. See also responses above.

- -

No reference is made to the impacts of climate change on groundwater quantity (through altered precipitation and snow- and glacier melt) or quality (e.g. observations on considerable increase in groundwater temperatures, in particular in spring time, in some sites with negative consequences on oxygen content in groundwater and possible effects on the quality of drinking water).

>> We mention now that assessment of climate and land use change impacts on groundwater must consider both quality and quantity, but an in-depth discussion is beyond scope.

- -

4.1.6 Enhanced warming and feedback mechanisms

The last paragraph in this section alludes to "a more detailed representation of energy budgets and feedback mechanisms in models". It would be important to know where and how these are to be determined. No discussion is offered on glaciers and surface energy balance and no differentiation is made between snow and glaciers. How can these research needs be linked to the section on sublimation? Nothing is mentioned on interactions between energy budgets and dynamic water bodies such as pro-glacial or supra-glacial lakes.

>> We have now included a short discussion on glacier energy balance and its relevance for sublimation in section 4.1.4 – see also our reply regarding sublimation further above. We wish to emphasize that a detailed discussion of all the topics raised by the reviewer are beyond the scope of this article as they would render it to the size of a textbook. This simply cannot be the intent of our overview. We have added 10 additional references to Section 4.1.4 where the interested reader will find further answers.

- -

4.2 Importance of environmental monitoring – Line 23, p. 2858 Please elaborate what you understand by "environmental modelling".

>> There is no mention of 'environmental modelling' in our manuscript. The heading and the line mentioned read 'environmental monitoring'. Lovett et al. (2005) (cited later on in our manuscript) defines environmental monitoring as "a time series of measurements of physical, chemical, and/or biological variables, designed to answer questions about environmental change." We do not think that it is necessary to explain the term.

- -

4.2.1 Variables of interest – This is a vague section heading and should be given a precise definition.

>> changed.

- -

Line 1 It would be important to add that fully equipped meteorological stations are the answer, since apart from precipitation, it is important to determine energy balance (was that not the point of section 4.1.6?)

>> We agree, although this is obviously a matter of cost. Added to the 5th paragraph of Section 4.2.1.

- -

Line 5, p. 2860. Measurement errors are mainly associated with wind.

>> Added. Additional references to Goodison et al., 1998, Nespor and Sevruk, 1999 and Yang, 1999.

- -

Line 7 Weather radar are already used reliably for nowcasting and hydrological modelling, e.g. in the Italian Alps and other regions of the world. An up to date literature review is required on this!

>> The paragraph mentioned deals with the lack of streamflow measurements, and nowcasting is not the subject of our article. We rather wish to stress that specific problems

still exist for use of weather radar in mountain areas and have added a corresponding statement further above in Section 4.2.1 where precipitation is discussed. It should also be borne in mind that use of weather radar data will, at least in the foreseeable future, most likely remain a hypothetical option for mountain regions of the developing world. For the Andes, for example, coverage is extremely low, and challenges are tremendous, not only because of the mountainous topography but also because of the extreme gradients of precipitation (space, intensity, time) in tropical mountain areas.

- -

Line 13. *"thanks to remote sensing"*. This is unscientific. Elaboration on this theme is urgently required. There are dozens of different methods, sensors and publications on remote sensing of snow in mountains world-wide. The Armstrong publications are not state-of-the art for remote sensing in mountains.

>> The section focuses on variables that have high priority in environmental monitoring, the paragraph mentioned focuses on snow. Elaboration of remote sensing is beyond scope, but we have updated the list of publications with further important contributions.

- -

How about problems with measurement of snow (lysimeters, pillows?)

>> A detailed discussion is beyond the scope of our article. We now refer to the comprehensive overview by Lundberg et al. (2010) in Section 4.1.2 where the importance of SWE is discussed.

- -

Line 16 Detailed field methods are available and running since a long time on SWE, in particular in the US. Elaboration and state-of-the-art literature is required on this.

>> See section 4.1.2 and reply to above comment.

- -

Line 20 Of all the phenomena studied in mountain regions, glaciers are probably the best investigated.

>> We disagree. The corresponding paragraph discusses data gaps in glacier mass balance, which is the variable with highest relevance for water resources and climate change as well as for model calibration. According to the WGMS Glacier Mass Balance Bulletin N°10 (WGMS, 2009), there are only 131 glaciers with mass balance observations world-wide, 19 of them without data after the year 2000, and only 16 with data before 1960. Almost half of the corresponding glaciers are located in Europe, and one fifth in North America. We believe that the corresponding paragraph expresses these facts already sufficiently.

- -

Line 1, p. 2860. Please refine the research needs here. More high altitude sites? More modified flow?

>> We wish to highlight the importance of high altitude sites. We clarified this and added a reference to Section 4.2.2 where this issue is discussed in detail.

- -

Line 12 Suggestions on how to improve ET and sublimation measurements are missing here and under the previous section. The increasing importance of ET in the hydrological cycle under climate change has not been mentioned.

>> Beyond scope.

- -

It is not so much groundwater level as partitioning of groundwater flow that is important.

>> Beyond scope, see also further above for our replies to questions regarding Section 4.1.5 that deals with groundwater.

- -

Line 13. ET should not be put into the same category as water quality and water consumption.

>> We merely summarise which variables were already discussed in the preceding sections: "While the importance of gauging further variables such as ET, groundwater level and water quality was already highlighted in the preceding section, water consumption needs better quantification". Slightly changed to set ET apart from water quality and water consumption.

- -

Water consumption is a highly important variable in mountains and their forelands. How can its measurements and quantification be improved? How can data be accessed? Costs, availability, rights?

>> Beyond scope.

- -

4.2.2. Representativeness for high altitudes – How can variables such as the density of precipitation and runoff stations at the continental scale (with values per continent only for all the different mountain ranges existing) be helpful for water management in a particular region within a particular mountain range and how can it be brought into accordance with existing or planned water management plans that are mostly at the communal or inter-communal level? Why are these relations not presented for the case study regions in question or for the related water management units? Would it not be more important to learn about the density of stations in the headwaters of key water-supplying rivers and within the boundaries of water management units? What are the solutions for water management in mountain regions that do not have data or measurements? What are the alternative approaches suggested? These variables are restricted to the spatial scale. Nothing is mentioned on the temporal variability of variables and no suggestions are given on optimal temporal measuring solutions in association with floods, droughts, seasonal or long-term forecasting.

>> Section 4.2.2 highlights the lack of high-altitude measurements for precipitation and runoff and proves, with the example of Switzerland, that the representativity for high altitudes is insufficient even for a mountain region with one of densest meteorological observing systems. Addressing the points mentioned by the reviewer is impossible at the local scale and not necessary to prove our point.

- -

Lines 21-22 Wording?

>> We believe that the sentence ("As indicated in the preceding section, variability and heterogeneity of processes in mountain areas are faced with a lack of instrumental records for high altitudes") is correct and gives a clear statement.

- -

Line 25 "Figure 3 characterises the global situation by showing…" what does the global situation mean? Of what?

>> It characterises the global runoff and precipitation observation network. Changed.

- -

Fig. 3 is misleading and difficult to interpret since it is not possible to differentiate the highest altitudes.

>> That's exactly what the large inset is here for (it is mentioned in the text). The inset shows a magnification for altitudes above 1500 m a.s.l. At altitudes above roughly 4500 m a.s.l., there's indeed nothing to be differentiated anymore. We have magnified the inset slightly and mention it now also in the figure caption.

- -

How can the Figures 3-4 help with understanding the research situation and research needs for mountain hydrology and help water managers in their respective catchments solve problems? None of these parameters provide any socio-economic data such as information on water abstraction and water availability. How can a resolution of 0.5° by 0.5° and a majority of stations below 300 m a.s.l. help in understanding and finding solutions for water management in mountains?

>> We explained the purpose of these Figures above. The reviewer's notion that the majority of stations is located below 300 m a.s.l. highlights the problem we discuss.

- -

A differentiation needs to be made between rainfall and snowfall measurements.

>> In line with WMO (1994), we refer to precipitation measurements as combination of the liquid and solid phase, and we chose to characterise the precipitation measurement network because we highlight its importance in the preceding Section 4.2.1. Snow water equivalent is treated in Section 4.1.2.

- -

Line 12 Here the authors refer to hydrometeorological stations, not precipitation stations? Why?

>> We refer to runoff and precipitation stations, as defined in the preceding section. Changed for clarification.

- -

Nothing is mentioned on the infrastructural, logistical, energy, economical and data transmission issues of meteorological stations.

>> In Section 4.2.3 ("The way forward"), we refer to the "high operating cost of measuring stations in remote mountain areas with their harsh environmental conditions." This covers the main idea of above comment, a more detailed discussion is beyond scope.

- -

Line 20 If the global and continental overview is a simplification and does not necessarily express regional or local characteristics why was not an alternative approach suggested? The authors fail to create the link between global and local scales.

>> First, we show that data available for high altitudes is insufficient at global and continental scale. Then, we show that monitoring of high altitudes is insufficient also at the local scale even for Switzerland where one of the highest network densities world-wide can be assumed (see below). We have clarified this link.

- -

Line 22 Why was the Swiss example chosen if no case study site was presented for a Swiss River?

>> Switzerland was chosen because it has one of the densest meteorological observing systems over complex topography world-wide (Schmidli et al., 2001; Weingartner and Pearson, 2001). We even say so in the text: "Therefore, a similar analysis was performed for Switzerland, representative of a region characterised by marked relief and at the same time possessing one of the world's densest runoff and rainfall observation networks." It should also be noted that the European Alps are represented by the contribution by Koboltschnig and Schöner (2010)."

- -

How are the runoff parameters related to availability of water quality data and data on water abstraction?

>> This is beyond scope and hardly possible to answer at the global scale.

- -

4.2.3. The way forward – Here it is suggested that more observational data is necessary from less developed regions of the world and that data on precipitation and river flow can be collected by local farmers. No suggestions are given on who should fund them, the locations of data measurements, how to overcome illiteracy in remote mountain regions and how to decide on the representativeness of data. No alternative approaches are suggested for ungauged water management units.

>> We have extended the respective paragraph (p. 2863, l. 25ff.) with notions about the need to improve scientific resources and the role of cheap and resilient sensor technologies and elaborate on the inclusion of local stakeholders in monitoring and modelling more extensively. It is also highlighted that the problem of data scarcity will remain an issue for the foreseeable future, and we mention the importance of developing regionalisation and uncertainty estimation methods for the specific conditions of data-scarce mountain environments.

- -

5.1 Recommendations for research – The recommendations for research are a top-down approach. It is based on the notion that modelling is the only answer to watershed management. The entire approach is fixed on water managers. A bottom-up approach is missing with suggestions how to integrate local actors and end-users and their existing knowledge and how scientists can learn and adapt their approach. A significant part of this section repeats itself due to the way in which the bibliography is cited one to one and rowed in consecutive order one after the other instead of structuring a meaningful discussion supported by references.

>> The Section was re-written.

- -

Line 16, p. 2864 Are models present for water managers in all basins? Do they work? Can the water managers operate them? What happens in remote and inaccessible basins? What else apart from models is necessary to establish safe management measurements (historical evidence, records?).

>> Re-written. The issues noted above are however mostly beyond scope.

- -

Line 21. How can uncertainties be addressed and communicated? Which methods? How and which scenario projections should be communicated and why?

>> The sentence mentioned reads: "Uncertainties and the reasons for their existence must thus be addressed clearly, and it is also necessary to clarify that scenario projections are not exact predictions but instead provide a plausible range of possible future system states (Kundzewicz et al., 2009). Moreover, model results should always be accompanied by a probability range (e.g. from using model ensembles), and interpretation of these ranges must be assisted." We believe that this is sufficiently clear, and that more detail is not warranted here.

- -

Line 1, p. 2865. *"Emphasis should also be put on future changes in the variability of water resources which, unlike variability itself, may pose serious problems if not addressed in management strategies."* This advice is very welcome, it may be novel for modelers but not for managers!

>> Our statement is of a neutral nature, and we feel that above comment, in an unjustified manner, distorts it to an accusation. The case-study by Hamlet (2010) indeed shows that changes in variability of water resources are a serious problem in management.

- -

Line 10 Roughly what level of detail is necessary, which parameters, what are "conceivable management options"? Please give some examples.

>> Beyond scope.

- -

Line 12, p. 2865. The section states that "*Impact of academic research on management practice could be improved further by publishing results in regional and national open-access water management journals*." Please give some examples? Since water management spans many different fields of land-use, it needs to address a wide spectrum of users that do not read only one type of journal. Impact can be made by many different methods apart from publications. Please re-write.

>> Re-written.

- -

Line 18 The recommendations are very naïve and should go beyond issues concerning language and expression, e.g. "*Regular discussion meetings can quickly clear up such misunderstandings"*. This depends on the type of problem, how the problem is understood by the scientists, how common the terms are and how often they are used, what language is being spoken (!!!!) and how trained and experienced the scientist is in communicating. How can, for example (with relation to the scientific capacity index for water management) a Chinese scientist convince farmers in Goeschenen and vice versa?

>> Re-written.

- -

Line 27 Please give examples at which levels the relationship between science and policy is difficult in times of heated debates and how it can be cooled off.

>> Our suggestions follow right below in the manuscript. We clarified that we refer to the public debate about climate change and its impacts. The sentence was slightly changed.

- -

Line 2, p. 2866. The citation of Storch 2009 is missing.

>> The author's name is 'von Storch', and he is already listed in the references list.

- -

Line 3 "*bandwidth of probable future*". This is a repetition of scenario options from above.

>> We removed this part of the sentence. The rest of the sentence, however, refers to "the implications of different decisions including their efficiency and costs, drawbacks and advantages" and was kept.

- -

Line 8 "*Communicate uncertainties*". This is a repetition of scenario options from above

>> Communicating of uncertainties is crucial, and the context for uncertainties here is not exactly the same as above. Kept.

- -

Line 13. "if *local decision-makers recognise the need for scientific support and are able to find appropriate expertise outside of the region at international level."* How is the language barrier overcome? Again, would local decision makers and mangers want to accept advice from the outside? How can scientists understand the local situation sufficiently well if the information is in a different language? What kind of structure would be necessary for this?

>> Beyond scope.

- -

Line 16 How can being member of a scientific body help in water management?

>> It facilitates interdisciplinarity in research (as we note in the preceding sentence).

- -

Line 25 Also, the need for observing and understanding climate change.

>> We agree, added.

- -

Line 28 How can data be exchanged if it is not available? What are the recommendations when historical data is not available for digitising? Alternatives for developing countries?

>> We highlight the need for data exchange because it would already be a major step forward if existing observations were shared more openly. We now mention the importance of regionalisation and uncertainty estimation methods for data-scarce mountain environments more explicitly in Section 4.2.3 ("Research priorities" > "Importance of environmental monitoring" > "The way forward"). Additions with regard to the value of limited field measurements have been added to Section 4.2.1 ("Variables with high priority").

- -

5.2 Recommendations for water resources management – This section remains purely theoretical and lists limitations and problems rather than providing any real recommendations or advance beyond what is already widely known. A methodology or framework of good practise, and the limitations of transferring it to other basins with completely different politics, culture, climatology and physical characteristics, is lacking.

>> Re-written. Providing a framework of good practice or alike is however beyond scope.

- -

"Since our background is mostly in research, we are aware that our limited insight into practical water resources management **forbids universally valid and definitive recommendations**". This statement itself contradicts the purpose and title of the paper.

>> The corresponding Section was re-written. Given the diversity of watersheds, it is unlikely that universally applicable recommendation can be made.

- -

line 9, p. 2867; The first recommendation is that "*there is urgent need to break away from present stationarity-based practices which assume that natural systems fluctuate within an unchanging envelope of variability*". It is questionable whether water managers and policy makers can: firstly, understand this statement and secondly, use it as a key for improving their current practices in water management. Even more so, it cannot be assumed that natural systems exist anymore.

>> The introduction to the corresponding paragraph was slightly re-written for clarification. We still believe that abandoning stationarity is crucial for successful water resources management. This is also shown by the special issue contributions by Hamlet (2010), Archer et al. (2010) and Huang et al. (2010).

- -

line 14. The second recommendation is that "*More flexible management and adaptation practices can reduce the risks of failure in supply very effectively*". This sentence does not advance beyond common knowledge and in fact, it is incomplete since it does not include demand management. In addition, adaptation is by nature “flexible” since it is a transformation process. It continues with “*the benefits are amplified if these practices are implemented into basin-wide water resources allocation and management*”. In the absence of a review on existing water management plans in mountain regions, the authors do not seem to be aware of the fact that water management can also be carried out independently of the basin-wide scale, particularly where very long distance interbasin water transfer schemes for large cities from highland catchments into the forelands exist (practically all large agglomerations at the foot of mountain chains world-wide). It would be more important to consider whether the basin plans are implemented, how they are controlled (by incentives or fines) and how progress is monitored.

>> We believe that the recommendation is of paramount importance. The level of detail suggested by the question is beyond scope.

- -

The third paragraph seems to have abandoned the notion of recommendations and remains a description of some potential problems.

>> Slightly re-phrased.

- -

Line 19, The phrase on “…*increasing potential for conflicts about water resources at the international level*” should be replaced by “….existing conflicts and increasing potential for conflicts…..”, since water conflicts are already a reality in these basins since a long time. It would be important to explain the origin of conflicts and propose solution strategies.

>> The phrase was changed, a detailed discussion is beyond scope.

- -

Line 24 “*Overall, basin-wide integrated water resources management is nowadays widely accepted and promoted by many international organisations*.” Which organisations, where are the citations, FAO etc? The fundamental question is whether the International Commission for the Protection of the Rhine or Danube carries out water management per say or whether, as the word “protection” indicates, they manage and monitor water quality rather than water quantity.

>> Organisations etc.: beyond scope, we believe that providing the examples of the ICPR, ICPDR and MRC is sufficient. Also, further discussion was added concerning the Yellow River Conservancy Commission (YRCC) and Changjiang Water Resources Commission (CWRC). ‘Protection’: the mission statement of the ICPR, for example, is broad and not restricted to water quality. A quick glance at the organisation’s webpage would reveal this. The ICPR also focuses on comprehensive flood prevention and protection (taking into account ecological requirements) and supports of the co-ordinated implementation of European regulations, such as the Water Framework Directive and the Floods directive.

- -

The problems and possible solutions that the Mekong River Commission has to deal with concerning dams, extreme flooding and the political situation i.e. water control for hydropower in the mountainous parts in China versus the problems of water availability for irrigation in the lower reaches in Thailand, Vietnam and Cambodia are not outlined. The same is true for the Chinese commissions, what kind of solution strategies and recommendations are being implemented against problems of interbasin transfer, recession in lake volume, downstream erosion, groundwater lowering etc.

>> Beyond scope.

- -

Line 4, p. 2868. Concerning the Chinese rivers, "….*they may take on an important role*"….but what are the issues, how can the mountain-derived water problems between northern and southern and eastern and western China be solved? How are the mountain regions integrated in these plans?

>> The description was slightly extended.

- -

Line 10. The sentence on "*Research institutions should however not be reluctant to point out the need for such joint efforts if they recognise problems on the horizon*" is rather general and colloquial and does not define what how and what kind of problems should be recognised.

>> Removed. We wish to stress, however, that we discuss these 'joint efforts' in the preceding sentences, and we have added another example from the Columbia River Basin for clarification.

- -

Line 19, p. 2869 " … *intermediate operation rules have turned out to be quite successful so far*." What does this mean? How have the extreme floods in the last decade been integrated?

>> We believe that the sentence is clear and that providing more detailed information is beyond scope for an overview article.

- -

The section lacks consideration of present day issues of water management concerning extremes, e.g. minimum and maximum discharge (droughts and flooding) caused both by climate and human change. Recommendations on how to avoid human mistakes in water management with relation to these extremes are not outlined. Aspects of water trading and associated cost benefit analyses are lacking.

>> Beyond scope.

- -

5.3 Recommendations for improving communication between research and management – The approach outlined is a typical, outdated, top-down approach that foresees scientists as "modellers" and water managers as the "model users" that are dependant on the scientists. The fact that water management comprises much more than only modelling and that scientists can contribute much more apart from modelling (evaluation of problems, technological advances, biological and agricultural developments, theoretical framework, integrative analysis, participatory processes etc) with direct and continual inputs of the water managers, is overlooked. Also, the fact that water management institutes exist in mountain areas (regional agencies, water institutes etc) that run their own, practical and user-oriented models is not mentioned. The possible interaction between consultancy firms, scientists and water management institutes is not outlined. The success story and recommendations from water management in mountain basins of the Western USA are not discussed.

>> 'Top-down': see comment further above. The remainder of this comment is beyond the scope of an overview paper.

- -

In many cases, it is unrealistic to expect that water management institutions will be able to *employ enough staff* to operate sophisticated hydrological models. It is not so much the number of staff as their qualifications and available infrastructure that counts.

>> Slightly changed and extended.

- -

Line 19, p. 2868. "*Workshops and continuing education seem to be an effective way…. "*. Where are the references, examples?

>> We have added the Canadian Water Network and the Swiss ProClim as examples. Further details are beyond scope.

- -

Line 25, p. 2868. The example presented on the British Columbia basin "…..evaluating anticipated climate change impacts on a management system" is interesting but it does not outline the water management system itself, nor how the inhabitants and water managers have to adapt and adjust their methods and approaches. Again it is an analysis of the problems rather than the step ahead in terms of recommendations. Powerful exercises have been carried out at the local and regional scale in the mountainous parts of the Columbia basin where scientists were funded by the local communities in order to develop water management plans, geared particularly in the direction of water conservation and implementation of new regulations.

>> It is a good point that many climate change assessments fail to move beyond the assessment of impacts towards recommendations and specific adaptation strategies. Stewart Cohen calls this the need to "Move beyond the damage report", and we have added some discussion of this concern in the recommendations sections. Experimentation bringing people together at different levels of governance has been one approach to identifying workable adaptation strategies. We now mention this as one approach. The regional reporting for the

PNW by Hamlet (2010) discusses the community based planning in BC mentioned above (with a reference to reporting by Cohen et al.), but examples of this kind are probably too numerous to cover in any detail this summary overview.

- -

Line 26. "A mix of *administrative* and scientific partners with emphasis on relevancy for practical applicability is also required in the EU Interreg…". The interreg programme does not require administrative partners but political, community, institutional, legal, economical and environmental partners. Can you elaborate on these programmes (also the Swiss ones), what are the methods, how do researchers and managers cooperate and what are the lessons learnt?

>> Interreg partners clarified. An elaboration is beyond scope.

- -

Why is the 7th framework project ACQWA not mentioned?

>> ACQWA is now mentioned in the conclusions where we refer to the 7th EU FP.

- -

How is the RISA programme applied for mountain water resource management, where are te examples?

>> We have added some more details to the presentation of the RISA programme in Section 5.3.

- -

Line 6, 2870. "An outstanding example for transdisciplinary, integrative and transboundary global change *research* is also the GLOWA programme…..". Again, this section focuses on the research aspects and does not explicitly indicate how researchers and water managers communicate in this programme and how other communities can learn from the example. How are the international programmes implemented in particular with respect to water sharing?

>> We have extended the presentation of the GLOWA programme accordingly.

- -

In addition, the Elbe River and Ouémé and Volta Rivers are not mountain rivers and should be excluded from the list.

>> Our list did refer to further GLOWA cluster projects in general. We agree that the Ouémé and Volta Rivers do not classify as mountain rivers and have deleted them from the list. We have, however, kept the Elbe River which has its source in the Karkonosze Mountains (subalpine characteristics).

- -

Existing benefits and draw backs of water management in European mountain catchments are not mentioned. Large projects such as water management of the Rhone are not mentioned.

>> Multipurpose reservoir operation in the Rhone River basin is now discussed as an example.

- -

5.4 Recommendations for policy – The title of this section should have been "Recommendations for politics" if it were to remain faithful to the title. However, it has been changed to policy. As for section 5.2, it goes astray in the second half and ends up discussing primarily research and research funding issues, rather than recommendations for policy and politics. The second half of this section should be integrated in the section on recommendations for research.

>> We now use policy throughout.

- -

This section should take into account existing good practise in governance and policy and recommend improvements. However already in the second sentences the authors state that they wish to "raise concerns" (which is not the same as a recommendation).

>> We have revised this section.

- -

Line 24. "Stronger governance systems are required…". There is no explanation of what kind of governance system, nor the legal aspects accompanying them. In general, a synthesis of the problems associated with legislation, institutional settings and water laws in mountain regions is lacking. Do they exist, how are they different from the lowlands, do they take into account mountain specific issues, are they implemented?

>> Beyond scope.

- -

Line 27 "…exchange of knowledge between research and management should be facilitated by…". This paragraph should appear into the previous section.

*>> We have now clarified that research managers should actively lobby to find ways to […] *facilitating collaboration and cooperation among different agencies as well as exchange of knowledge between research and management*.*

- -

Line 7 p. 2871 The example from Pakistan concerning the different authorities responsible for different data is not a specific one. The problem is common for Europe and many other countries too. It is a description of what is being done not, how and why. The author's interpretation of the issues override the actual background, the problems, future developments and solution strategies.

>> The corresponding paragraphs were slightly re-written to stress that the problem is not limited to the examples we note.

- -

Line 16, line 2871 to line 4, p. 2872 This paragraph should be moved to the section on recommendations for research.

>> The paragraph concerns research frameworks, and we feel that it fits well into Section 5.4.

- -

Line 5, p. 2872. The authors state that "We also believe that current assessment procedures and funding strategies for academic research tend to provide incentives that counteract practice-relevant science." This statement does not hold for European and US funding schemes, where proven stakeholder involvement and stakeholder participation as well as information dissemination plans form an integral part of project funding regulations. Nothing is mentioned on possibilities of direct funding by water managers or local communes, as is already the case in the basin of British Columbia.

>> We argue that the state, local, and water resources management agency supported funding the reviewer identifies does in fact exist in the U.S., but that the fundamental institutional problems identified further above remain an important factor. Researchers who engage primarily with practitioners on practical topics are sometimes accused of not engaging in 'real' science. If these activities do not result in publishable work, university departments often fail to recognize these activities as meaningful contributions (e.g. viewing them as 'consulting' as opposed to legitimate research). This was clarified at the instance mentioned by the reviewer and in Section 5.3 (notes concerning the RISA programme).

- -

Line 25. The statement "*In order to increase the autonomy and flexibility of local management institutions and provincial governments – which often have a higher awareness of regional problems –, it might also be a good idea to provide them with funds subject to use for seeking advice from researchers or initiating cooperation with them*." is superfluous since this is already being realised since decades in Europe (through e.g. Interreg programmes), and in the USA. The opposite should be more interesting, managers funding researchers to carry out applied research but this too is already quite common in certain fields.

>> We do indeed refer to local management institutions and provincial governments funding researches and agree that this is becoming more common. Still, we believe that the notion is valid as a recommendation – we now say that it IS a good idea to provide them [local management institutions and provincial governments] with funds.

- -

6. Conclusion – The conclusions state that knowledge on mountain runoff is still too general to move beyond “broad statements” on future changes and more regional studies are necessary for water managers. This conclusion stands in contradiction to the previous recommendations and is not valid for those mountain catchments already monitored world-wide, which is almost invariably at the regional scale. Surely there are a whole range of other aspects concerning water management that have to be considered. Starting with precipitation, it is not so much the lack of accurate downscaling of precipitation as the lack of high altitude measuring stations that is the problem.

>> We agree that the lack of high altitude measuring stations is indeed a fundamental problem, discuss this issue with considerable depth in the manuscript and note further down in the conclusions that observation networks are inadequate for capturing the heterogeneity and variability in important processes in many mountain areas and thus strongly hinder our understanding of high-altitude regions. A significant improvement is, however, not foreseeable and, for many mountain regions of the developing world, not even feasible for financial reasons. Therefore, we propose downscaling as more straightforward way for achieving improvements.

- -

p. 2873 Lines 2-5. It is somewhat unusual to find references in the conclusions. This sentence should be moved into the introduction.

>> Moved to Section 3.3 where the statement on increasing water demand by population growth and economic development seems appropriate.

- -

Line 7 *“….support adaptation processes in water resources management institutions by disseminating research results actively through practice-relevant conduits…”* This is nothing new. If adaptation has to be carried out in these types of institutions, what is their willingness and time scale to adapt, and how can scientists integrate existing information to develop adaptations strategies and how can they ensure that it their results are practise-oriented and understandable? Are scientists well-trained for this purpose, or are facilitators required?

>> It may not be new, but it is nevertheless crucial. An in-depth discussion is beyond scope.

- -

Line 8 “*….establish continuity in knowledge exchange…..through regular workshops and continuing education*”. Again, these recommendations are a top-down approach directed by scientists and are common, well-known methods. In the last 20 years many additional, successful, more diverse and tested methods have been developed apart from these two.

>> We recommend “knowledge exchange between managers and researchers”. This is neither top-down, nor does it imply that the process should be directed by scientists.

- -

The conclusion is reduced to problems such as the interactions between hydrology and climatology, basically the cryosphere and lists frequently cited peculiarities related to mountains such as their climate extremes. Nothing is mentioned on the remaining parameters of the hydrological cycle and groundwater resources which all impact water management. All other issues concerning crucial, present day problems, such as ecology, human impacts, interbasin water transfer etc are omitted from the discussion.

>> See scope of our paper.

- -

The funding schemes mentioned are only at the European level (what is the situation like for China, USA etc?) and as far as is known to the reviewer, none of these have produced a project on water resources management in mountains. What are future programmes and funding possibilities from the EU in this field?

>> In the relevant paragraph, we focus on funding schemes that address the concerns of water resources from mountain areas at national and international level; we mention two significant examples, which are indeed EU-funded. Further examples for funding (also China and USA) are discussed in Section 5.3. European projects related to water resources management in mountains: see e.g. the AlpWaterScarce programme (p. 2869, l. 28). Future programmes and funding possibilities from the EU: Beyond scope.

- -

This paper lacks cross-disciplinary analysis and overemphasises the cryosphere, whereas considerations of the atmosphere, hydrosphere, lithosphere, biosphere, and anthroposphere are missing. Impacts of human activities on the hydrological cycle in mountains and its implications on water availability, hazards and water management should be included.

>> Our emphasis on the cryosphere is justified by the vital importance of snow and ice for a significant part of the world's population, particularly in developing countries. The most important example is found in the Himalayas (a population of 1.4 billion – 20% of the global population – living in the five major river basins alone, see Immerzeel et al.), further examples are the Andes or the Rocky Mountains. An encyclopedic discussion is not the goal of our article. We do not call into question the cross-disciplinary aspects mentioned, but it is simply impossible (and beyond our scope) to cover these topics in reasonable depth within the frame of a journal article.

- -

Missing references – An important number of references essential to mountain water resources, concerning in particular watershed management and politics are missing, e.g. FAO, UNESCO, IHP-HELP, Alpine Convention such as Water and Water management issues, Report on the State of the Alps cited etc

>> We are grateful for the additional literature suggested for citation. We have added these and further references (far over 50 in total) as far as they seemed useful, relevant and necessary (see e.g. sublimation). It should be noted, however, that we provide an overview, as the manuscript title suggests. As explained further above, a comprehensive list of references

for any subject treated would be excessive. Instead, we highlight important papers without implying that this is the only work that has been done.

* *

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