Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-368-AC1, 2016

Hydrology and Earth System Sciences
Open Access
Discussions

Interactive comment on "Rainfall and streamflow sensor network design: a review of applications, classification, and a proposed framework" *by* Juan Carlos Chacon-Hurtado et al.

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Received and published: 7 December 2016

» The authors present an overall picture on hydrometric network design methods and approaches to increase or reduce sensor density using different methods e.g. expert opinions and hydrologic models. They also classify these methods and present an optimal network design using complementary rainfall-runoff model performance. The use of hydrologic model makes sense as the products of the sensors are usually used by the hydrologic models. This review paper addresses an interesting topic. However, the presentation of the cases needs some more details on country scale applications as listed below. What are the practices in very densely monitored countries (e.g. Germany) and data scarce ones (e.g. Poland, Spain and Turkey). Also what is the optimum

level of network density.

Overall, major revision is recommended for the the manuscript. »

REPLY. We thank the reviewer for the valuable contributions. This helped us with improving its quality, and also to address some points that could have been clearer or that were not considered with the adequate level of detail.

We agree with the reviewer that practitioners may be interested in country-wise practices of hydrometric network expansion or modification. As the essence of the manuscript is to review the available mathematical methods to make such network expansions/modifications optimal, the connection to practical applications appeared weak.

In order to address the reviewer's comment we have included references to country-scale network density, where the reader can find more detailed information (page 1, 31-34). We have also added statements to clarify that the optimal density of the network is case-specific (p3, 91-99), pointing out that practices in optimal monitoring network design would be, per-se, another in-depth study. We have framed these ideas in the new version of the paper without jeopardizing its main focus. Also, main considerations about the selection of the appropriate number of gauges in the measurement-based methods are highlighted. In the new version of manuscript we added the following text:

-> Design of rainfall and streamflow sensor networks depends to a large extent on the scale of the processes to be monitored, and the objectives to address (TNO 1986, Loucks et al. 2005). Therefore, the temporal and spatial resolution of the measurements are driven by the measurement objectives. For example, information for long-term planning does not require the same level of temporal resolution as for operational hydrology WMO (2009). On the global and country scale, sensor networks are commonly used for climate studies and trend detection (Cihlar et al. 2000, Grabs and Thomas 2002, WMO 2009, Environment Canada 2010, Marsh 2010, Whitfield et al. 2012). This is also supported by the National Climate Reference Networks (WMO

2009). On a regional or catchment-scale, applications require careful selection of monitoring stations, since water resources planning and management decisions, such as operational hydrology and water allocation, require different temporal and spatial resolution data.

-> The sensor network design can also be seen from an economic perspective (Loucks et al. 2005). In most cases, the main limitation in the deployment of sensor networks is related to cost, being the main driver for the reduction scenarios. The valuation between the costs of the sensor networks and the cost of the lack of information is not usually considered, because the assessment of the consequences of decisions is made a-posteriori (Alfonso et al. 2016). In most studies, it is seen that the improvement of information content metrics (e.g., entropy, uncertainty reduction, among others) is marginal as the number of extra sensors increases (Pardo-Iguzquiza 1998, Dong et al. 2006, Ridolfi et al. 2011), and thus the selection of the correct density can be based on a threshold in the increase in accuracy. However, in many practical applications the number of available stations may be defined by budget limitations. Therefore, the optimal density of a sensor network is strictly case-specific (WMO 2008).

» Specific Comments: 1. Title: Rainfall and streamflow sensor network design: a review of applications, classification, and a proposed framework Recommended title: Review of precipitation and streamflow sensor network design methods from hydrologic modeling perspective. »

REPLY. It is interesting that we suggested a similar title when we submitted this paper for the first time. During the first round of reviews, we found that the concept of hydrological modelling implied the inclusion of groundwater processes which are not included in our review. Therefore, we decided to avoid the term hydrological modelling, and try to manage readers' expectations in the title including only rainfall-runoff processes. We hope that the reviewer finds this decision adequate.

» 2. Section/subsection titles should be reorganized in a clear way. For example sub-

section 3.3.2 Methods based on expert judgement and 3.3 Methods based on expert recommendations are similar and confusing. »

REPLY. We totally agree. We have renamed the methods in section 3.3.2 as 'Practical case-specific considerations', as we believe this better reflects the content. Additionally, section 5 (opportunities) has been removed and merged into the section Conclusions and Recommendations.

» 3. In most of the European countries (e.g. Denmark and Germany) or even in USGS, the number of rainfall/streamflow sensors/stations is decreasing due to maintenance costs and use of radar data. I would expect to read some more insight on specific examples about sensor density and the country based approaches. Compare, for example, Spain/Poland and Germany from network density aspect to indicate an optimum approach. Now the content is very technical and dry for the reader. »

REPLY. Indeed, we agree that the practices within countries are different, and that there is a clear progress in monitoring technologies, such as radars and remote sensors. Although we believe that making the comparisons suggested by the reviewer would expand the current objective of our manuscript, we think that reviewing the current practices and monitoring plans of different authorities will beat the focus of our discussion. For this reason we have added a paragraph in this regard, in which the following useful references for the interested readers are included.

Cihlar, J., W. Grabs, J. Landwehr. Establishment of a hydrological obsevation network for climate. Report of the GCOS/GTOS/HWRP expert meeting. Report GTOS 26. Geisenheim, Germany. WMO. 2000.

EC. EU Water Framework Directive. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. European Commission. 2000.

Grabs, W. and A. R. Thomas. Report of the GCOS/GTOS/HWRP expert meeting on the implementation of a global terrestrial network – hydrology (GTN-H). Report GCOS 71, GTOS 29. Koblenz, Germany. WMO. 2001.

WMO. Guide to hydrological practices. Volume II: Management of water resources and application of hydrological practices. WMO 168, 6th ed. 2009.

Environment Canada. Audit of the national hydrometric program. 2010.

Marsh, T. The UK Benchmark network – Designation, evolution and application. 10th symposium on sthocastic hydraulics and 5th international conference on water resources and environment research. Quebec, Canada. 2010.

Dent, J. E. Climate and meteorological information requirements for water management: A review of issues. WMO 1094. 2012.

Withfield, P. H., D. H. Burn, J. Hannaford, H. Higgins, G. A. Hodgkins, T. Marsh and U. Looser. Reference hydrologic networks I. The status and potential future dierctions of national reference hydrologic networks for detecting trends. Hydrological Sciences Journal 57 (8), 1562 - 1579. doi:10.1080/02626667.2012.728706. 2012.

» 4. I couldn't find an answer on network density regulations at European scale. The reader can be curious if the number of monitoring sensors are arranged by some directives/regulations in EU e.g. Water Framework Directive etc. These aspects could make the content more fruitful then the current very technical classifications. »

REPLY. Indeed, it is a relevant point to address. Most of the regulations consider monitoring necessities to meet a given observation objective, instead of defining (or suggesting) particular network densities. For example, the EU Water Framework Directive Article 8, states that "Member States shall ensure the establishment of programmes for the monitoring of water status in order to establish a coherent and comprehensive overview of water status within each river basin district", and only stipulates that technical specifications should be in accordance with a regulatory committee.

Other entities such as the USGS and Environment Canada do not outline regulations,

but monitoring plans. These are re-evaluated, in function of the monitoring objectives and budget limitations. Only WMO provides minimum density recommendations, as presented in the paper. We have extended the text pointing this out:

"Consequently, regulations regarding monitoring activities are not often strict in terms of station density, but in the suitability of data to provide information about the status of the water system (EC 2000, EPA 2002)."

EC. EU Water Framework Directive. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. European Commission. 2000.

EPA. Guidance on choosing a sampling design for environmental data collection, EPA. US Environmental Protection Agency. 2002.

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