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Hydrology and Earth System Sciences
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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.

Juan Carlos Chacon-Hurtado et al.

j.chaconhurtado@unesco-ihe.org

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» This article presents a review of methodologies to address the design of sensor networks in hydrology and water management. The topic of the review is timely and certainly of interest to hydrologists and practitioners. However, the Authors should consider the following comments to improve on the overall clarity of the manuscript. »

REPLY. We appreciate the thoughtful comments of the reviewer, and its constructive approach to improving the clarity and reach of this paper. The particular comments are addressed below.

» 1) The manuscript language should be considerably improved. Please avoid typos

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and reword extensively to better clarify concepts. »

REPLY. We agree. The paper had a complete re-revision to improve language and clarity.

» 2) Section 3 should be improved through a clear and simple explanation of underlying mathematical concepts and by adding representative case studies. Also, rather than listing applications, the Authors should provide comments on pros and cons for each approach, thus guiding the reader toward the selection of a suitable technique. Sometimes I found it difficult to follow the text as concepts were not properly connected. Few comments are devoted to Table 2 and to the Conclusions and recommendations. »

REPLY. This comment has triggered several changes in the manuscript, as Section 3 is one of the core sections of the paper. Indeed, Table 2 was extended to consider some relevant cases where the methods described in Section 3 are applied, thus guiding the reader into selected in-depth material. Additionally, and we thank the reviewer for the idea, a new table (Table 3) has been added to highlight advantages and disadvantages of the different methods. The new tables 2 and 3 are provided as an attachment to this reply.

» 3) Section 6 is poorly related to the others and its title is not sufficiently informative. I suggest Sections 5 and 6 are merged into a more comprehensive Discussion. »

REPLY. We totally agree. We have merged Section 5 and 6.

» 4) What is the relevance of the topic? I am sure of the importance of the subject but the Authors could better emphasize through key cases why the design of sensor networks is crucial and what major issues engineers/researchers may face in their definition. »

REPLY. We agree with the reviewer on highlighting the importance of sensor network design may help the paper reach a wider audience. However, we are concerned about doing it through case studies, as the context would necessarily change the focus of the paper towards case-specific design practices or regulations. We therefore suggest the following compromise: we clarify the scope of the paper, and add a paragraph with references to literature (mostly reports) where the interested reader can find more information.

“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, Dent 2012). 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), and denoted as 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 high temporal and spatial resolution data (Dent 2012).”

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.

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Table 2 Classification of sensor network design criteria including recommended reading

Classes		Approaches: Measurement-based, Model-free	Approaches: Measurement-based, Model-based	Approaches: Measurement-Free
Statistics-based				
	Interpolation variance	Pardo-Iguzquiza (1998) Bardossy and Li (2008) Nowak et al. (2010)		
	Cross-correlation	Maddock (1974) Moss and Karlinger (1974)	Vivekanandan and Jagatp (2012)	
	Model error		Tarboton et al. (1987) Dong et al. (2005)	
Information Theory				
	Entropy	Krstanovic and Singh (1992) Alfonso et al. (2014)	Pham and Tsai (2016)	
	Mutual information	Husain (1987) Alfonso (2010)	Coulibaly and Samuel (2014)	
Expert recommendations				
	Physiographic components	Samuel et al. (2013)	Moss and Karlinger (1974) Moss et al. (1982)	Lazie (2004)
	Practical case-specific considerations			Wahl and Crippen (1984) Nemec and Askew (1986) Karaseff (1986)
	User survey			Sieber (1970) Singh et al. (1986)
Other methods				
	Value of information	Alfonso and Price (2012)	Black et al. (1999) Alfonso et al. (2016)	
	Fractal characterisation			Lovejoy and Mandelbrot (1985) Capecchi et al. (2012)
	Network theory	Sivakumar and Woldemeskel (2014) Halverson and Fleming (2015)		

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Fig. 1.

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Table 3 Advantages and disadvantages of sensor network design methods

	Advantages	Disadvantages
Statistics-based		
Interpolation variance	Useful to assess data scarce areas No event-driven Minimise uncertainty in spatial distribution of measured variable	Heavily rely on the characterisation of the covariance structure No relationship with final measurement objective
Cross-correlation	Useful for detecting redundant stations Computationally inexpensive	Augmentation not possible without additional assumptions Limited to linear dependency between stations
Model error	Has direct relationship with the measurement objectives	Biased towards current measurement objectives Biased towards model and error metrics
Information Theory		
Entropy	Assess non-linear relationship between variables Unbiased estimation of network performance	Formal form is computationally intensive Quantising (binning) of continuous variables lead to different results Optimal networks are usually sparse Difficult to benchmark Data intensive
Mutual information	Idem	Idem
Expert recommendations		
Physiographic components	Well understood Functional for heterogeneous catchments with few available measurements Useful at country/continental level	Not useful for homogeneous catchments No quantitative measure of network accuracy
Practical case-specific considerations	No previous measurements are required Useful to observe specific variables	Biased towards expert Collected data does not influence selection Biased towards current data requirements
User survey	Pragmatic Cost-efficient	Extensive user identification Biased towards current data requirements
Other methods		
Value of information	Provides a full economical assessment	Hard to quantify Usually decisions are made with available information Biased towards a rational decision model
Fractal characterisation	Efficient for large networks Does not require data collection	Not suitable for small networks or catchments Does not consider topographic or orographic influence
Network theory	Provides insight in interconnected networks	Not useful for augmentation purposes Data intensive

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Fig. 2.

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