Focus on water storage for managing climate extremes and change

2016 Environ. Res. Lett. 11 120208

(http://iopscience.iop.org/1748-9326/11/12/120208)

Environmental Research Letters

OPEN ACCESS

PUBLISHED
21 December 2016

EDITORIAL

Focus on water storage for managing climate extremes and change

Bridget R Scanlon[1] and Vladimir Smakhtin[2]

[1] Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, Texas, USA
[2] United Nations University- Institute for Water, Environment and Health, Ontario, Canada

The articles in this focus issue evaluate various aspects of water storage to manage water supply variability related to climate extremes and change within the context of reduced natural storage associated with wetlands, groundwater floodplains, glaciers and snow. Most of the papers in the focus issue address topics related to surface water reservoirs, including estimating storage-reliability-yield relationships, storage requirements for water supply variability, economic issues related to coordinated reservoir management, storage operations under climate change, impacts of regulation and fragmentation on river flows, and economic aspects of management. In addition to surface reservoirs, storage from rainwater harvesting and in aquifers are also examined. Studies vary from global to basin scale. This focus issue provides valuable insights for use of storage to buffer climate extremes and change considering human and ecosystem demands for current and projected future climate conditions.

Understanding storage issues is critical for managing water resources. The following simple equation highlights important factors to consider related to storage change:

$$\text{Input(water supply)} - \text{output(water demand)} = \text{change in storage} \qquad (1)$$

There is increasing concern about global declines in water storage; however, it is important to understand whether storage declines are related to reducing supplies, increasing demands, or both. Increasing climate and water resource variability (including extremes such as droughts and floods), continuous population growth, controversy surrounding development of traditional surface reservoir storage, recognition of ecosystem water demands, and general understanding of the need to find ways for buffering variability in the future for water supply and food security reasons underscore the issues of water storage for both developing and developed countries. Projected increases in magnitude and frequency of water-related extremes with climate change and reduced natural storage associated with wetlands, aquifers, glaciers and snow amplify these problems. Water storage, in its various forms, provides a mechanism for dealing with water resources variability. If planned and managed correctly, storage could increase water and energy security, and overall adaptive capacity of nations. Water storage can help to resolve the temporal disconnect between water supplies and demands from wet to dry periods.

Articles in this issue focus primarily on surface reservoir storage at varying scales from global to regional. Valuable insights are provided on storage-reliability-yield of reservoirs, emphasizing the fact that water supply yields do not depend on the storage capacity or reliability of the reservoir system, but rather the length of the reservoir inflow records and statistical attributes of the inflow time series (Kuria and Vogel 2014). This global analysis underscores the importance of long time series for developing more reliable data on reservoir yields; however, future climate change may alter the characteristics of these flow systems. A global water balance model was used to assess the value of storage capacity for enhancing water security in the world's ~400 largest river basins by storing water from wet months for use during dry months (Gaupp *et al* 2015). This analysis identified water shortage risks in India, N China, Spain, W US, Australia, and many parts of Africa. This study also considered environmental water requirements, showing that water demand for humans results in overextraction of water that is critical for ecosystems in many regions. The results of the modeling indicate that more storage is required to address water supply variability to meet human and ecosystem needs; however, the authors emphasize that a variety of storage options should be considered to meet these needs, not simply surface reservoirs. Many studies emphasize the negative issues related to surface dams and reservoirs. Development and application of an index based framework for evaluating river fragmentation and flow regulation indicated that, 'on a global basis, 48% of river volume is moderately to severely impacted by either flow regulation, fragmentation, or both' (Grill *et al* 2015). If the projected or planned ~3400 dams are completed, the river flow volume impacted would increase to ~93%, attributed primarily to major dam construction in the Amazon. The authors emphasize the importance of developing a baseline of natural fragmentation by evaluating small to medium sized dams and waterfalls.

Many of the studies address reservoir issues in different regions. Geressu and Harou (2015) applied a screening analysis to consider trade-offs to inform investment decisions using the Blue Nile as a case study. Results of this study indicate that the proposed capacities of the reservoirs may be too large depending on the amount of energy considered sufficient. The approach described in this analysis provides data to determine optimal reservoir type and storage to increase benefits to Sudan, which is downstream. Giuliani *et al* (2016) considered reservoir operations in the Red River (China, Laos, and Vietnam) within the context of climate change. Results show that flood damages could increase by 35%–520% and water supply deficits could increase by 15%–160% depending on the climate scenario and time period evaluated. Adaptation strategies were examined to partially mitigate some of the negative impacts. The costs associated with lack of coordination of multireservoir systems were quantified by Jeuland *et al* (2014) using data from the Mekong system as a case study. Results show that coordination enhances net benefits from irrigation and hydropower by ~3%–12%, corresponding to US \$12–53 million yr^{-1} based on assumptions of moderate levels of flood control, with coordination benefits increasing with the water availability and inflow variability. Remote sensing approaches (radar altimetry and optical imagery) for monitoring reservoir attributes, including water height, areal extent, and storage variations, are advancing as described for the Syr Darya system in Cretaux *et al* (2015). Significant improvements are expected with new missions, such as surface water and ocean topography with global coverage for reservoirs with minimal areal extents of 250×250 m ($\pm$20 cm accuracy).

While most of the articles focused on traditional surface reservoir storage, Hanson and Vogel (2014) evaluated storage-reliability-yield relationships for sizing rainwater harvesting systems across the United States. The analysis should provide valuable data for determining the optimal storage tank size considering yield and reliability, collection area, and rainfall statistics. Aquifers provide a valuable reservoir alternative to traditional surface water reservoirs because of reduced evaporation losses. Lopez *et al* (2014) examined the coordinated management of Wadi Al Murwani in Western Saudi Arabia with a downstream (45 km) aquifer storage and recovery system that could be gravity fed, reducing energy costs. The authors indicate that combining dams with ASR would enhance water management under extreme drought and climate change. Aquifers have been widely used for storing water in the southwestern US where conjunctive use of surface water and groundwater and managed aquifer recharge have been practiced for decades (Scanlon *et al* 2016). Large scale infrastructure, including 1000 s of km of canals and aqueducts, import water from humid to arid regions in California and Arizona to support conjunctive use and managed aquifer recharge. These projects have stabilized groundwater storage in many of these regions and resulted in groundwater level recovery in some areas. Use of aquifers for storage is projected to expand in the future with policies toward more sustainable groundwater management in California.

The 10 articles compiled in this focus issue have collective downloads of ~22 000 and provide an excellent resource on many aspects of water storage to buffer water supply variability related to droughts and floods.

The papers on water storage in this focus issue complement many recent studies on water storage at regional to global scales. Advances in remote sensing is greatly enhancing our ability to monitor reservoir storage changes using satellites (Cretaux *et al* 2016, Gao *et al* 2012, Zhang *et al* 2014). Global analysis of surface reservoir storage is of interest for assessing their contribution to global land surface water storage changes (Zhou *et al* 2016). The negative impacts of surface reservoir storage are increasingly being recognized, with topics such as balancing hydropower and biodiversity in large basins, such as the Amazon, Congo, and Mekong (Winemiller *et al* 2016) and policy debates in China about dam removal relative to further construction (Miao *et al* 2015). There seems to be increasing recognition of the value of subsurface storage with recent special issues in different journals on managed aquifer recharge (Sheng and Zhao 2015, Megdal and Dillon 2015). All of these studies, along with those in this special issue, underscore the importance of water storage for managing water supply variability related to climate extremes.

References

Cretaux J F, Abarca-del-Rio R, Berge-Nguyen M, Arsen A, Drolon V, Clos G and Maisongrande P 2016 Lake volume monitoring from space *Surv. Geophys.* **37** 269–305

Cretaux J F, Biancamaria S, Arsen A, Berge-Nguyen M and Becker M 2015 Global surveys of reservoirs and lakes from satellites and regional application to the Syrdarya river basin *Environ. Res. Lett.* **10** 015002

Gao H, Birkett C and Lettenmaier D P 2012 Global monitoring of large reservoir storage from satellite remote sensing *Water Resour. Res.* **48** W09504

Gaupp F, Hall J and Dadson S 2015 The role of storage capacity in coping with intra- and inter-annual water variability in large river basins *Environ. Res. Lett.* **10** 125001

Geressu R T and Harou J J 2015 Screening reservoir systems by considering the efficient trade-offs-informing infrastructure investment decisions on the Blue Nile *Environ. Res. Lett.* **10** 125008

Giuliani M, Anghileri D, Castelletti A, Vu P N and Soncini-Sessa R 2016 Large storage operations under climate change: expanding uncertainties and evolving tradeoffs *Environ. Res. Lett.* **11** 035009

Grill G, Lehner B, Lumsdon A E, MacDonald G K, Zarfl C and Liermann C R 2015 An index-based framework for assessing patterns and trends in river fragmentation and flow regulation by global dams at multiple scales *Environ. Res. Lett.* **10** 015001

Hanson L S and Vogel R M 2014 Generalized storage-reliability-yield relationships for rainwater harvesting systems *Environ. Res. Lett.* **9** 075007

Jeuland M, Baker J, Bartlett R and Lacombe G 2014 The costs of uncoordinated infrastructure management in multi-reservoir river basins *Environ. Res. Lett.* **9** 105006

Kuria F W and Vogel R M 2014 A global water supply reservoir yield model with uncertainty analysis *Environ. Res. Lett.* **9** 095006

Lopez O, Stenchikov G and Missimer T M 2014 Water management during climate change using aquifer storage and recovery of stormwater in a dunefield in western Saudi Arabia *Environ. Res. Lett.* **9** 075008

Megdal S B and Dillon P 2015 Policy and economics of managed aquifer recharge and water banking *Water* **7** 592–8

Miao C Y, Borthwick A G L, Liu H H and Liu J G 2015 China's policy on dams at the crossroads: removal or further construction? *Water* **7** 2349–57

Scanlon B R, Reedy R C, Faunt C C, Pool D and Uhlman K 2016 Enhancing drought resilience with conjunctive use and managed aquifer recharge in California and Arizona *Environ. Res. Lett.* **11** 035013

Sheng Z P and Zhao X 2015 Special issue on managed aquifer recharge: powerful management tool for meeting water resources challenges *J. Hydrol. Eng.* **20**

Winemiller K O *et al* 2016 Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong *Science* **351** 128–9

Zhang S, Gao H L and Naz B S 2014 Monitoring reservoir storage in South Asia from multisatellite remote sensing *Water Resour. Res.* **50** 8927–43

Zhou T, Nijssen B, Gao H L and Lettenmaier D P 2016 The contribution of reservoirs to global land surface water storage variations *J. Hydrometeorol.* **17** 309–25