CLIMATOLOGY

Global loss of lake water storage

Drying trends are prevalent worldwide

By **Sarah W. Cooley**

Lakes sustain a wide variety of ecosystems and provide vital water for agriculture, hydropower, and direct human consumption. Often characterized as "sentinels of climate change" (*1*), lakes integrate multiple basin-scale climatic processes including precipitation, runoff, and evapotranspiration. The amount of water stored in lakes therefore reflects both short- and long-term climate fluctuations. However, attributing changes in lake water storage to climate is complex, because direct human activities such as reservoir management, water withdrawals, and land-use change also affect lake water storage. On page 743 of this issue, Yao *et al.* (*2*) present a dataset of decadal-scale trends in lake water storage from 1992 to 2020 and attribute them to human activities and climatic patterns.

Lake water storage fluctuations are primarily driven by the balance between precipitation and evapotranspiration in a lake's watershed (*3*). As the climate warms, evapotranspiration is broadly increasing owing to increasing air temperatures and changing surface energy balance (*4*). The effect of climate warming on precipitation is less globally consistent, but in some regions (e.g., the Arctic, the Upper Mississippi), precipitation increases are expected (*5*). As a result, climate change can lead to both net water gain and net water loss in lakes. The "dry gets drier, wet gets wetter" paradigm is often used to summarize these patterns, though this can break down locally, and local characteristics can complicate the interpretation of global-scale trends. For example, changes in other forms of water storage can also influence long-term patterns, such as on the Tibetan Plateau, where increasing glacier melt has led to net gains in water volume (*6*).

This complexity in understanding long-term, climatic drivers of lake water storage is further magnified by direct human activities, which can affect lake water storage in both natural lakes and human-managed reservoirs. Human diversion of water for irrigation, for example, can lead to declining water inputs to lakes, thus causing substantial water loss (*7*). In human-managed reservoirs, an additional threat to water storage is sedimentation, whereby the presence and operation of a dam traps sediment that would otherwise travel downstream. Over time, this sediment can accumulate and reduce a reservoir's storage capacity (*8*). Conversely, construction of new dams and reservoirs can increase lake water storage. Although dam construction has declined in North America and Europe, in many river basins in Asia, Africa, and South America, extensive dam construction has altered lake water storage patterns (*9*).

By building a water storage variability dataset for 1980 of the world's largest lakes, Yao *et al.* identified a widespread net decline in lake water storage (21.72 ± 2.11 Gt year^{-1}), finding that drying trends are prevalent worldwide. The authors attribute most of this trend in natural lakes to increasing air temperature and evaporative demand, and to direct human activities. These trends are global but tend to be stronger in arid climates. Roughly one-third of the global drying trend in natural lakes is offset by lake water storage increases, predominantly caused by increases in precipitation and runoff. The analysis also reveals a declining trend in reservoir water storage in both arid and humid regions owing to sedimentation, though the recent boom in reservoir construction, primarily in humid regions, has led to a net increase in reservoir water storage.

"...nearly one-quarter of the world's population lives in a basin with a large, drying lake."

These insights into lake water storage trends are enabled by advances in cloud computing, satellite altimeters (*10*), and reservoir datasets (*11*). Yao *et al.* produced their dataset by fusing time-varying water areas mapped using Landsat satellite imagery with water surface elevation measurements from satellite altimeters to produce a 30-year dataset of lake volume variability. Previous work either focused on seasonal variability (*12*) or was limited by gaps in the satellite data record (*13*). Improvements in satellite technologies and data availability may better elucidate global patterns in storage variability. For example, NASA's Surface Water Ocean Topography mission will soon provide regular water level observations for millions of lakes globally (*14*), potentially enabling expansion of this analysis to include many more water bodies, including small lakes.

The global-scale decline in lake water storage in arid regions falls within the "dry gets drier" framework of climate impacts on the water cycle, but the drying trends in humid regions complicate the "wet gets wetter" part. Although this result counters previous work on long-term lake storage trends (*13*), it agrees with climate-modeling analyses challenging the global applicability of the "dry gets drier, wet gets wetter" framework (*15*). This lack of storage increases in natural lakes in humid regions, which is attributed to increasing evapotranspiration, emphasizes that we should not expect greater water availability in humid basins to offset water losses in arid basins.

Yao *et al.* estimated that nearly one-quarter of the world's population lives in a basin with a large, drying lake. Considering the importance of these lakes for ecosystem services, water supply, irrigation, and/or hydropower, the potential consequences of lake drying are both locally and globally important. Future work may combine observed drying trends with climate modeling to better constrain these changes at local to global scales. ■

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