doi.org/10.22498/pages.horiz.3.44

GLOSSARY

Hydrological extremes

Water moves continuously in all its phases (ice, liquid and vapor) above and below Earth's surface, including the atmosphere, oceans, glaciers, rivers, vegetation, soils, and groundwater. The study of the distribution and movement of Earth's water is **hydrology**. Energy, measured in temperature, drives the movement of water through its many pathways. The hydrologic cycle always changes, but sometimes, water abundance in a single location can intensely change in a short time, referred to as **hydrological extremes**. For example, heavy rainfall during storms can quickly overwhelm a soil's capacity to store water. This causes water to flow over the ground as runoff and rapidly fills local lakes or stream channels, leading to flooding. Hydrological extremes cause floods and drought hazards that impact society and ecosystems worldwide. Warming temperatures in our atmosphere and oceans intensify the rate and magnitude of water movement in the hydrologic cycle, leading to more hydrological extremes.

Paleohydrology proxies

We can't measure pre-instrumental precipitation or river flow directly, as we do today. Instead, we use indirect indicators of past environmental changes called **paleoproxies** to determine how hydrology varied in the past (so called "paleohydrology"). Changes in hydrology affect our natural environment in measurable ways. By comparing direct hydrologic measurements to the environmental responses that we see today, we can understand and reconstruct past hydrologic conditions based on indicators found in the natural landscape. Below, we briefly discuss three commonly used paleohydrology proxies in this magazine, and the broader scientific community.

Speleothems: Water dissolves and transports minerals from soil and rocks in solution. When groundwater carrying calcium carbonate ($CaCO_3$) enters a cave with low carbon dioxide (CO_2) concentrations in the air, the calcium carbonate will fall out of its water solution in a chemical process called precipitation (not to be confused with rainfall). Carbonate cave rocks (**speleothems**) form as water drips in low CO_2 concentration cave air, leaving behind the precipitated calcium carbonate minerals. Water drops, leaving behind minerals that repeatedly "grow" the speleothem rocks. Generally, rapid speleothem growth means more moisture, and little or no growth means drought. Scientists also look at the oxygen isotopes from the oxygen portion of the $CaCO_3$ mineral. The relative proportions of the "light" oxygen (^{16}O) and less abundant "heavy" oxygen (^{18}O) gives us insight into the intensity of rainfall generating the groundwater, or the source of the moisture. These ratios vary by cave, so dripping water monitoring is needed for accurate interpretation of the proxy records.

Tree rings: Trees grow annual rings that tell us how old the tree is and the environmental conditions the tree experiences year to year. Trees respond to various environmental variables, including temperature, rainfall, soil moisture and physical damage from fires and boulders. Additionally, trees grow in two distinct phases during the year after their dormant period: earlywood is a lighter, spongier ring that forms in the cool season, and latewood is the darker, denser ring that forms in the warm season. Therefore, tree rings provide highly detailed paleoproxies at the seasonal scale for thousands of years in some regions. By selecting tree species and locations highly sensitive to hydrological changes, we can use ring width and isotope measurements calibrated to modern records to reconstruct seasonal precipitation, soil moisture and streamflow. In some studies, damage to trees or tree rings can even provide flood stages or coastal storm surges.

Sediments: Sediment is organic or inorganic loose material that can be described by size, mineral composition and transportation process. The depositional record in landforms preserves sediment transported to a given location from other locations in response to various mechanisms (e.g. water, wind or ice). Sediment records from lakes, rivers and coastal landforms contain numerous and unique paleoproxies of wet or dry periods. We core these landforms to pull out intact sediment samples from a site. These sediment "cores" may represent hundreds to thousands of years of periodic deposition. Some sediment deposits are indicative of hydrological extremes as they are only transportable at high water levels, such as flood deposits in high-elevation rock shelters, or coarse sand in floodplains.

Hydrological risk

Paleohydrology studies are often conducted to improve our understanding of drought or flood risk. **Risk** is the exposure to an undesirable hazard. Often city planners and water-resource managers reduce risk with strategies such as damming rivers to reduce flood heights in very wet years, and retain water in very dry years. Understanding the full range of a natural hazard in a particular region is essential to quantifying risk. Paleohydrology studies are well suited to answer this important question.

A key measurement of risk is the **probability**, or likelihood, of a hazard in any given year. Probabilities (between 0 and 1) are estimated using a frequency distribution of real-life measurements. In hydrology, these measurements may be precipitation or streamflow. Generally, the higher the probability of an event (closer to 1), the more frequently this event occurs in nature. Low probability events (0.01 or smaller) are rare but would expose the largest amount of people to severe impacts and can, therefore, still be high risk. The availability of hydrological measurements can impact the accuracy of these probability estimates. If we have measured streamflow for 100 years, then the number of observations of the low probability events is likely one observed extreme flood, which is a very poor sample size. Also, it's not likely that these 100 years creating our sample of events have the same distribution as events occurring under warmer climates. This is where paleohydrologists come in! By adding thousands of years into the known event record, we obtain a greater sample size of extreme events, especially those occurring during warmer climates than those of last the 100 years. A large sample size means more certainty in probability estimates, and reduced uncertainty when evaluating risk.

ACKNOWLEDGMENTS

The editors extend their sincere gratitude to Nikita Kaushal, Laura Endres, Borja Antolín, Ana Moreno, Catherine Martin-Jones, Encarni Montoya, Francis Micheal Ludlow and Jaime Madrigal González for lending their expertise in reviewing the articles in this issue.

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PRINTED ON RECYCLED PAPER BY
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PARENT PROGRAM
PAGES is a Global Research Project of Future Earth.

SUPPORTERS
The PAGES International Project Office and its publications are supported by the Swiss Academy of Sciences (SCNAT), the Chinese Academy of Sciences (CAS), and the University of Bern, Switzerland.

doi.org/10.22498/pages.horiz.3