Pluvial Lakes of the Great Basin

Elaine J. Hanford

Left: Present-day Tooele City, Utah, looking south toward the Oquirrh Mountains with Interstate 80 and the Great Salt Lake in the foreground. Right: This reconstruction shows Lake Bonneville between 19,000 and 15,000 years ago, at a highstand of 5,090 feet elevation, submerging the Tooele Valley. Source: Used with the permission of the *Tooele Transcript Bulletin*.

ANYONE WHO HAS LIVED IN THE GREAT BASIN OF THE Western United States has vivid memories of the impacts of the Pineapple Express (a.k.a., atmospheric rivers). Torrential rains that spawned mudslides and debris flows or epic snowstorms that enhanced the snowpack by tens of feet and supported skiers well into the summer months are memorable because they bring vast amounts of precipitation to a currently water-stressed region. More recent headlines have bemoaned the impacts of drought on the Great Salt Lake in Utah and the demise of Lake Abert in south-central Oregon.

The vagaries of weather can vary from season to season, year to year, or even decade to decade. But geology and hydrology remind us that we must view such conditions in the longer term, by understanding the history of pluvial lakes in the Great Basin as climate has fluctuated. Scientific understanding of the changes over geologic time can help minimize unintended consequences of human activities and support more sustainable interactions with our environment.

The Echoes of Past Lakes

The Great Basin lies between the Sierra Nevada and Cascade Mountains to the west and the Wasatch Mountains to the east. The pluvial lakes in the Great Basin date to the Pleistocene Epoch, which lasted from roughly 2.5 million years ago until about 11,700 years ago. The Pleistocene was characterized by a series of Ice Ages interrupted by short warming periods known as interglacials, when pluvial lakes periodically occupied portions of the Great Basin. These pluvial lakes—in contrast to, say, the Great Lakes or the ancient Lake Agassiz—were not formed directly by glacial ice. Rather, they were created by excessive rain (*pluvia* is Latin for rain) that collected in closed basins with no drainage outlet under temperature regimes that supported low rates of evaporation. Successive pluvial lake formation during interglacials tended to mask surficial evidence of prior episodes.

The Great Basin is hydrographically closed and encompasses smaller internally drained basins. In other words, what precipitates in the Great Basin stays in the Great Basin. In total, as many as 120 pluvial lakes inundated more than 103,600 square kilometers (sq km), which means more than 20% of the Great Basin was flooded. It has been estimated that more than 80% of nearly 200 drainage basins within the Great Basin contain remnants of extensive pluvial lakes that existed during the late Pleistocene Epoch.

The last Ice Age in North America, called the Wisconsinan, lasted from about 75,000 to about 11,000 years ago. It featured several vast ice sheets, including the Cordilleran Ice Sheet, covering what is today western Canada, and the Laurentide Ice Sheet, stretching across

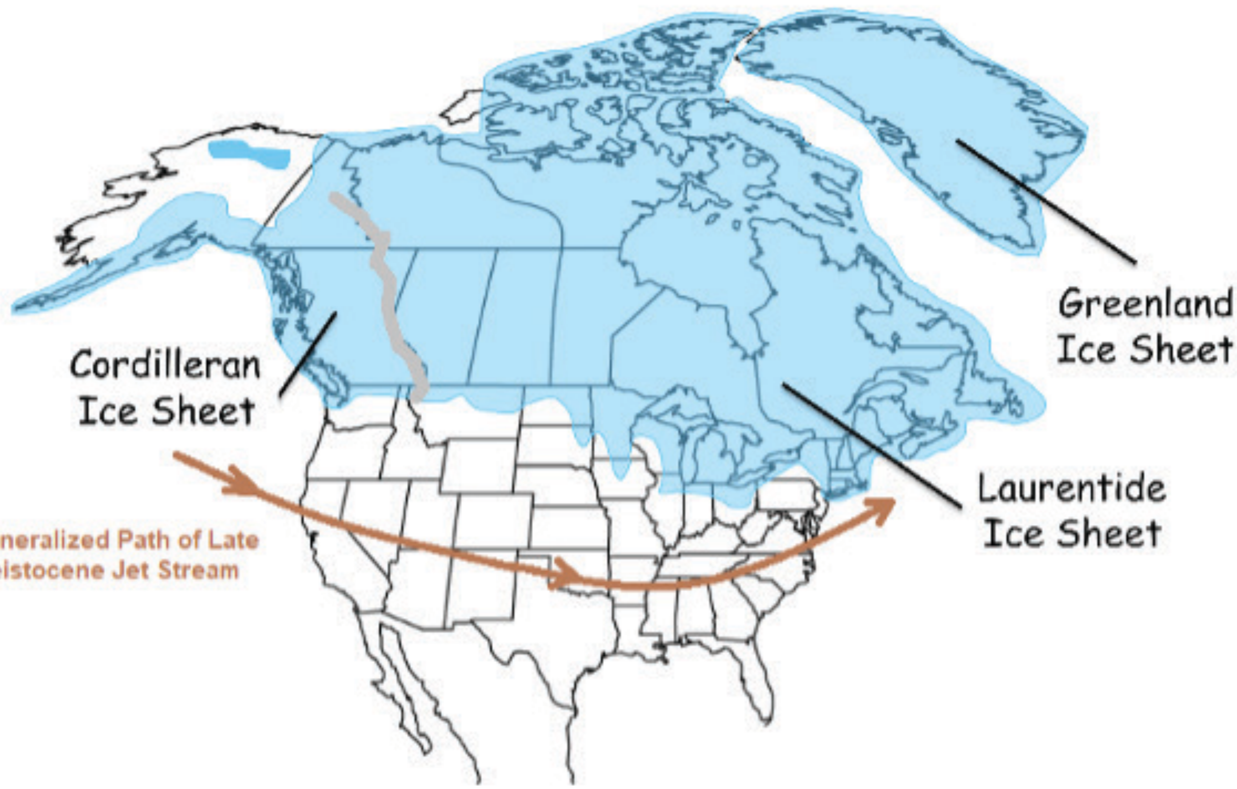

Figure 1. Generalized extent of the Cordilleran and Laurentide Ice Sheets across North America during the Last Glacial Maximum. Adapted from **Quora**.

today's central and eastern Canada and the Great Lakes region (Figure 1).

The continental ice sheets caused changes in the prevailing global wind patterns, influencing local and regional climates. Across North America, the jet stream crossed what is now the Western United States and continued across the southern tier toward the Atlantic Ocean, bringing precipitation to rates that were likely 1.5 to 2.4 times greater than under modern conditions. Furthermore, about 25,000–23,000 years ago, when the Last Glacial Maximum occurred, roughly 30% of Earth's landmass was covered by snow and ice, whose reflectivity helped cool the planet. These cooler temperatures in turn significantly reduced rates of evapotranspiration.

In the Great Basin, the increase in precipitation and decrease in evapotranspiration resulted in the formation of pluvial lakes that reached their maximum extents—their highstands—between about 18,000 and 14,000 years ago, following the Last Glacial Maximum. Lake Bonneville and Lake Lahontan were the two largest of these pluvial lakes.

As the continental ice sheets waned following the Last Glacial Maximum, the position of the polar jet stream shifted northward, resulting in rising and fluctuating water levels in the pluvial lakes. The lakes across the Great Basin did not achieve highstands all at once. Local and regional factors—including hydrogeologic setting, El Niño–Southern Oscillation, and convergence of moisture-laden air masses—would have also influenced lake levels.

To write the history of the three main pluvial lakes in the Great Basin—Bonneville, Lahontan, and Chewaucan (Figure 2)—geologists can draw on a range of tools. Evidence is derived from outcrops, geomorphology, core samples, pollen, and isotopic studies. Direct evidence of lake levels, changes in lake margins, and geologic events such as catastrophic floods, drainage-basin changes, and isostatic rebound—that is, the rise in landmass after the weight of ice sheets or water is removed—is combined with proxies for changes in lake level, water temperature and chemistry, and ecological conditions.

The resulting history provides a glimpse of the dramatic changes that have taken place across the Great Basin in the past 20,000 years.

What precipitates in the Great Basin stays in the Great Basin.

Lake Bonneville

At its maximum extent, Lake Bonneville occupied multiple basins in central and northwestern Utah,

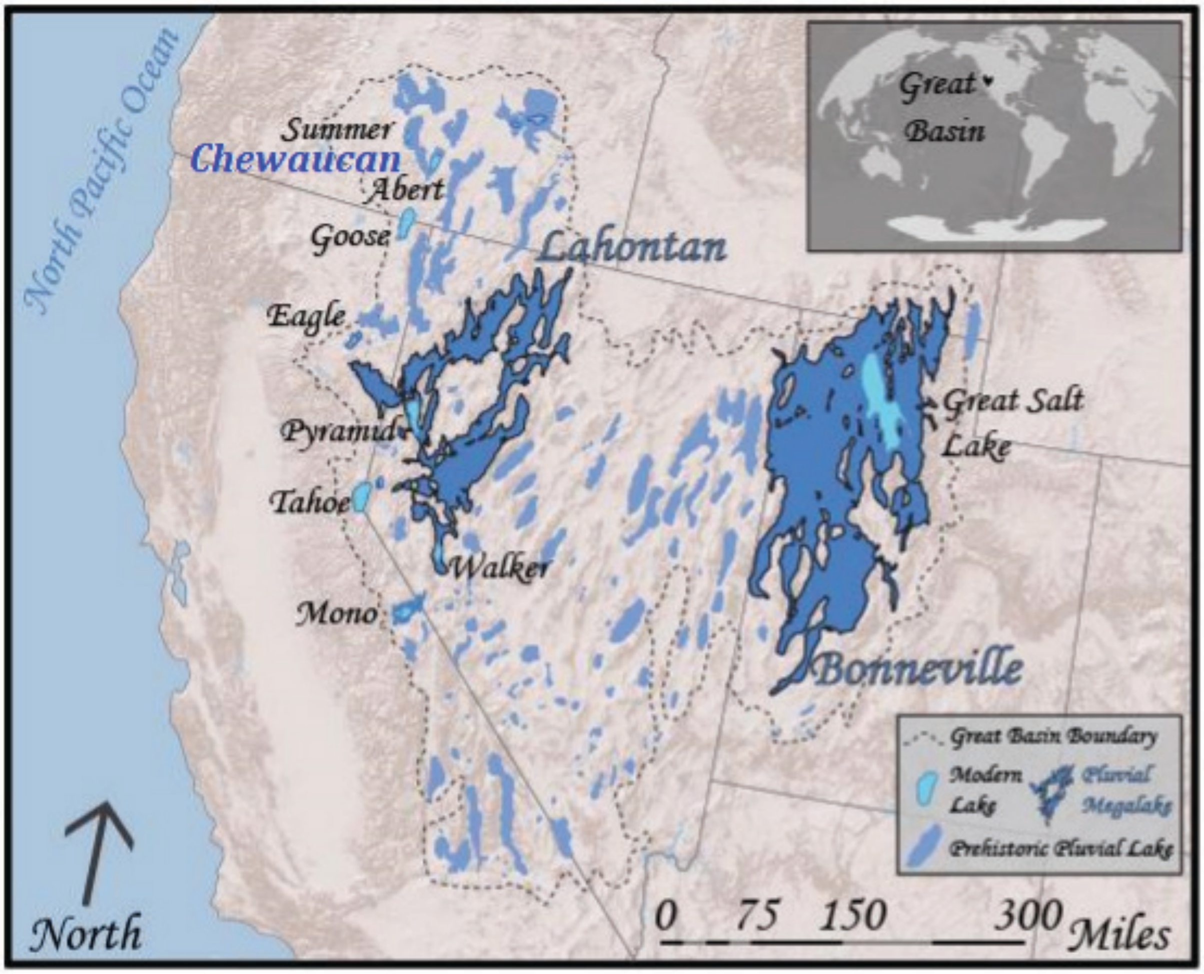

Figure 2. Pluvial lakes of the Great Basin. Adapted from **Lakeshore**.

northeastern Nevada, and southern Idaho, including the Bonneville Basin and the Sevier Basin. It encompassed more than 51,000 sq km and was more than 300 meters deep at its deepest. The lake's initial rise was quite rapid, potentially because the basin was capturing river water. Given its large size, Lake Bonneville may have influenced precipitation within its watershed and become partially self-sustaining.

Three distinct shorelines reflecting the expansion and receding of the lake over time can be traced throughout the basin. The lake did not occupy a completely closed basin; at times, its water overflowed into adjoining basins.

The lake was at its highest level between 19,000 and 15,000 years ago. Catastrophic flooding of an estimated 5,000 cubic kilometers of water into the Snake River Basin occurred prior to 18,000 years ago. About 15,000 years ago overflow ceased, and with continued regression, Lake Bonneville split into Lake Gunnison in the Sevier Basin and the Gilbert-episode lake that encompassed the modern Great Salt Lake. Isostatic adjustment and recovery—the sinking and lifting of the landmass—continue to influence the elevation of Lake Bonneville's shorelines, with maximum elevation of the highest shoreline in the central part of the basin more than 64 meters higher than the south and north ends.

Lake Lahontan

At its largest, Lake Lahontan covered more than 22,000 sq km in western Nevada and northeastern California, with a maximum depth of about 270 meters at present-day Pyramid Lake. The lake reached a brief highstand about 15,700 years ago and had a consistent shoreline at 1,256 meters elevation. By about 13,250 years ago, the lake had fallen to 1,206 meters, and as the lake shrank its waters were limited primarily to the Pyramid and Winnemucca Subbasins. Modern remnants include Walker Lake, Pyramid Lake, and the Carson and Humboldt Sinks. Winnemucca Lake has been dry since the 1930s, and Honey Lake periodically dries out. The decline of Pyramid Lake was exacerbated by diversions of irrigation water from the Truckee River starting in the early 1900s. A similar fate has afflicted Walker Lake because of irrigation diversions from the Walker River.

It has been estimated that more than 80% of nearly 200 drainage basins within the Great Basin contain remnants of extensive pluvial lakes that existed during the late Pleistocene Epoch.

Lake Chewaucan

Lake Chewaucan occupied four subbasins in southern Oregon: Summer Lake, Upper Chewaucan Marsh, Lower Chewaucan Marsh, and Lake Abert. At its maximum, the lake covered roughly 1,240 sq km with a maximum depth of 115 meters. Sometimes the subbasin lakes were connected, depending on the level of the lake. After an episode of desiccation around 17,000 years ago, the lake's highstand occurred between 14,000 and 13,000 years ago at an elevation of 1,356 meters. Then the lake began to shrink. Lake Abert and Summer Lake are modern remnants that dry up during mid- to late summer each year. Lake Abert has become a true saline lake whose desiccation is related to a number of factors, including overuse and restriction of inflow by human activities.

Beginning of the End or a Short Intermission?

The warming trend and northward migration of the jet stream began in the late Pleistocene about 21,000 years ago, followed by an abrupt change about 18,000 years ago to warmer conditions that generally persisted until a return to cold conditions during the Younger Dryas from 12,800 to 11,700 years ago. Since then, warmer conditions have persisted throughout most of the Holocene Epoch, with increased temperatures and decreased precipitation causing pluvial lakes to become playa lakes that appear seasonally. Human activities in the 20th century have exacerbated this transition. Will pluvial lakes once again return to the Great Basin with the onset of the next Ice Age? ■

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