Natural Variability in Annual Maximum Water Level and Outflow of Yellowstone Lake

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Abstract

The water level in Yellowstone Lake varies each year in response to differences in the winter's snowpack accumulation, spring precipitation, and air temperatures. Restriction at the outlet of Yellowstone Lake retards the outflow, and water backs up in the lake during periods of high inflows. The U.S. Geological Survey started publishing Yellowstone Lake elevations in 1922 and outflows in 1926. The gage for observing the lake's elevation was originally located at the Lake Hotel dock. It was moved 1,500 feet southwest to the National Park Service dock on 17 June 1940. On 1 October 1966, the gage was moved to Bridge Bay marina, where it is currently located. The U.S. Geological Survey stopped publishing gage heights of Yellowstone Lake in 1986, but the Bridge Bay ranger staff and boating concessionaire employees have continued to make periodic water level observations. Since the early 1950s, the dates of Yellowstone Lake's freeze-up and melt-out have been obtained from ranger, resource, and marina caretaker staff. Since 1926, the highest water level recorded was 7.72 ft on the Bridge Bay staff gage in 1997. The lowest annual maximum was 2.40 ft in 1934. The 1971–2000 average annual maximum water surface elevation on the staff gage is 5.46 ft. During winter months, readings are limited, but water levels that have been recorded are usually near or below zero on the staff gage. A summary of annual maximum gage readings and outflow and dates observed from 1926 through 2001 is presented. Freeze-up and melt-out dates are available for most years since 1951. Impacts of the 1988 fires on Yellowstone Lake water surface elevations are discussed, as are methods of forecasting upcoming elevations from snow survey and precipitation data. Recommendations for future observations are presented.

Introduction

The water level in Yellowstone Lake varies in response to the winter's accumulation of snowpack within the drainage, amount of spring precipitation, and temperatures during snowmelt. The restricted outlet causes water to back up in the lake during periods of high inflow. Water surface elevations and outflow have been observed since 1922 by various entities. Observers have recorded freeze-up and melt-out dates for most years since 1951. The water level in Yellowstone Lake affects water temperatures in the Yellowstone River, spawning dates of cutthroat trout, success of spawning runs, the fishing success of bears, boating through the Bridge Bay channel, nesting success of white pelicans on Molly Islands, streamflow over the Upper and Lower Falls, downstream flows in the

Yellowstone River, shoreline erosion, and many other resources in the area. The fires of 1988 had some influence on Yellowstone Lake elevations and outflows.

Study Area

Yellowstone Lake is located in the southeastern part of Yellowstone National Park and covers an area about 136 mi^2 (352 km^2) depending on the level of water in the lake. There is no artificial regulation of lake levels. The 1,006-mi^2 (2,606-km^2) drainage area is the headwaters of the Yellowstone River, a tributary of the Missouri River. The highest point in the watershed is 12,156 ft (3,705 m) at Younts Peak in the southernmost part of the Yellowstone River headwaters. The U.S. Geological Survey (USGS) established a stream gage at the outlet of Yellowstone Lake in 1922, but only gage heights were recorded through the 1925 water-year. Outflow was measured starting in the 1926 water-year, and these data continue to be recorded and published by USGS. Elevation at the stream gage location about 450 ft (137 m) downstream from Fishing Bridge is approximately 7,730 ft (2,356 m). A separate gage for lake level observations was established at the Lake Hotel boat dock on 7 October 1921. On 17 June 1940, the lake elevation gage was moved 1,500 ft (457 m) southwest to the National Park Service (NPS) boat dock. On 1 October 1966, the gage was moved approximately 2 mi (3.2 km) southwest to the Bridge Bay marina docks. This location is about 3.7 mi (6 km) from the outlet. The datum of these gages was 7,729.51 feet from 1926–1932 and has been 7,729.45 feet since. In 1986, USGS stopped publishing the records. Gage readings have been observed since then by staff from the Bridge Bay ranger station, Yellowstone National Park resource division, and Bridge Bay marina boating concessionaire. Restriction near the outlet causes the water level in Yellowstone Lake to rise when the inflow exceeds the outflow during spring runoff. The 1961–1990 average annual precipitation for the drainage was 38.2 in (971 mm) (Farnes et al., in press) that produced an average 1961-1990 annual water-year outflow of 966,000 acre-ft (1,192 $m^3 \times 10^6$). Since 1926, this annual outflow has varied from 494,000 acre-ft (609 $m^3 \times 10^6$) in 1934 to 1,631,000 acre-ft (2,012 $m^3 \times 10^6$) in 1997. About 59% of the annual outflow occurred during the period of April through July. During the Yellowstone fires of 1988, 21% of the watershed had canopy burn. Increase in annual outflow as result of the fires was estimated to be about 3.2% (Farnes et al., in press).

Methods

Data have been obtained from USGS Water Supply Papers, the Natural Resources and Conservation Service (NRCS) database in Portland, Oregon, Yellowstone National Park archives, and from the park's resource management, ranger, and concessionaire staff. Missing records in 1983 (outflow), 1987 and 1988 (both elevation and outflow), and 1989 (elevation) have been estimated using the relationship between outflow and Yellowstone Lake elevations, outflow and downstream flows at the Corwin Springs gage, and outflow and snowpack and precipitation. In some years, the maximum outflow or staff gage readings extends for more than one day. Dates shown in Table 1 are for the latest day.

Levels from a known benchmark to the staff gage at Bridge Bay marina have probably not been run since the USGS discontinued observations in 1986. The

Table 1. Dates of freeze-up, ice-off (melt-out), maximum daily outflow, and maximum lake elevation for Yellowstone Lake, 1926–2001. Volume of maximum daily outflow is given in cubic feet per second (cfs). Annual maximum elevation given in feet, as measured on Bridge Bay staff gage.

Water-year	Date of freeze-up	Date of ice-off	Maximum daily outflow, cfs (date)	Maximum lake elevation, ft (date)
1926			3,200 (Jun 14)	3.67 (Jun 15)
1927			7,420 (Jul 01)	6.12 (Jun 30)
1928			5,680 (Jun 10)	5.25 (May 31)
1929			3,700 (Jul 05)	4.00 (Jul 02)
1930			3,780 (Jun 26)	3.95 (Jun 25)
1931			2,480 (Jun 19)	3.20 (Jun 19)
1932			5,570 (Jul 05)	5.00 (Jul 05)
1933			4,520 (Jun 30)	4.42 (Jun 30)
1934			1,740 (Jun 22)	2.40 (Jun 16)
1935			4,360 (Jul 09)	4.40 (Jul 06)
1936			4,690 (Jun 19)	4.53 (Jun 19)
1937			3,590 (Jul 01)	3.84 (Jun 28)
1938			5,950 (Jul 02)	5.32 (Jul 03)
1939			3,230 (Jul 09)	3.68 (Jul 09)
1940			3,590 (Jun 23)	4.04 (Jun 21)
1941			2,750 (Jun 28)	3.48 (Jun 27)
1942			3,890 (Jul 13)	4.41 (Jul 09)
1943			6,900 (Jul 10)	6.26 (Jul 10)
1944			3,450 (Jul 10)	4.03 (Jul 10)
1945			3,940 (Jul 17)	4.48 (Jul 20)
1946			3,700 (Jun 24)	4.20 (Jun 19)
1947			4,490 (Jul 11)	4.78 (Jul 14)
1948			5,580 (Jun 19)	5.45 (Jun 20)
1949			5,260 (Jun 23)	5.15 (Jun 23)
1950			6,120 (Jul 11)	5.76 (Jul 12)
1951		May 18	5,090 (Jul 10)	5.18 (Jul 11)
1952	Dec 26	May 16	5,340 (Jun 15)	5.25 (Jun 16)
1953	Dec 25	May 20	4,240 (Jul 06)	4.58 (Jul 07)
1954	Jan 11	May 18	5,580 (Jul 05)	5.52 (Jul 02)
1955		May 27	4,090 (Jun 30)	4.66 (Jul 01)
1956	Dec 14	May 25	7,570 (Jun 21)	6.54 (Jun 18)
1957	Dec 23	May 29	5,270 (Jul 04)	5.32 (Jul 04)
1958	Dec 31	May 21	3,500 (Jun 13)	4.24 (Jun 24)
1959		May 27	5,590 (Jun 28)	5.47 (Jun 30)
1960	Dec 18	May 22	3,210 (Jun 21)	4.05 (Jun 22)
1961	Dec 11	May 27	3,690 (Jun 20)	4.43 (Jun 22)
1962	Dec 10	May 21	5,780 (Jul 02)	5.73 (Jul 01)
1963	Jan 12	May 30	5,230 (Jun 25)	5.50 (Jun 26)
1964	Jan 08	May 29	6,420 (Jul 09)	6.06 (Jul 09)

continued

Table 1 (continued)

Water-year	Date of freeze-up	Date of ice-off	Maximum daily outflow, cfs (date)	Maximum lake elevation, ft (date)
1965		May 28	6,820 (Jul 11)	6.47 (Jul 11)
1966	Jan 16	May 21	3,570 (Jun 24)	4.64 (Jun 25)
1967		May 31	6,590 (Jul 09)	6.28 (Jul 06)
1968	Dec 15	Jun 02	4,600 (Jun 30)	5.28 (Jun 30)
1969	Dec 21	May 17	4,500 (Jun 08)	5.24 (Jun 29)
1970	Dec 28	Jun 04	6,460 (Jun 30)	6.33 (Jun 30)
1971	Dec 14	May 31	8,140 (Jun 29)	7.06 (Jun 30)
1972	Dec 28	Jun 02	6,880 (Jun 24)	6.38 (Jun 24)
1973	Dec 10	May 27	3,460 (Jul 01)	4.37 (Jul 01)
1974	Dec 24	May 27	9,120 (Jun 30)	7.34 (Jun 30)
1975	Jan 01	Jun 07	6,360 (Jul 14)	6.06 (Jul 15)
1976		May 21	5,380 (Jul 12)	5.68 (Jul 07)
1977		May 13	2,130 (Jun 20)	3.45 (Jun 22)
1978	Dec 21	May 17	5,400 (Jul 12)	5.74 (Jul 12)
1979	Dec 28	May 27	3,710 (Jul 02)	4.78 (Jul 02)
1980	Dec 29	May 10	3,770 (Jul 06)	4.78 (Jul 09)
1981	Jan 12	May 19	4,250 (Jun 28)	5.09 (Jun 29)
1982	Jan 07	May 26	7,670 (Jul 12)	7.00 (Jul 09)
1983	Dec 15	May 30	4,700 (Jul 11)	5.40 (Jul 11)
1984	Dec 22	May 31	5,080 (Jul 08)	5.74 (Jul 10)
1985	Dec 06	May 21	3,470 (Jun 19)	4.66 (Jun 25)
1986	Dec 11	Jun 04	7,360 (Jun 20)	7.01 (Jun 19)
1987	Dec 16	May 08	2,000 (Jun 16)	3.55 (Jun 16)
1988	Dec 24	May 19	2,150 (Jun 21)	3.70 (Jun 21)
1989	Dec 18	May 18	4,470 (Jun 22)	5.20 (Jun 22)
1990	Dec 30	May 20	4,290 (Jul 03)	4.95 (Jul 05)
1991	Dec 21	Jun 01	5,670 (Jun 22)	5.74 (Jun 22)
1992	Dec 17	May 08	2,780 (Jun 30)	3.94 (Jul 01)
1993	Jan 04	May 28	4,700 (Jun 23)	5.04 (Jun 24)
1994	Dec 27	May 16	3,000 (Jun 10)	3.92 (Jun 12)
1995	Dec 25	Jun 03	5,730 (Jul 13)	5.70 (Jul 13)
1996	Dec 01	Jun 03	8,730 (Jun 28)	7.08 (Jun 24)
1997	Dec 19	May 20	9,930 (Jun 19)	7.72 (Jun 22)
1998	Dec 26	May 15	4,750 (Jul 08)	5.20 (Jul 11)
1999	Jan 26	May 29	6,720 (Jun 27)	6.44 (Jun 29)
2000	Dec 28	May 06	4,250 (Jun 14)	4.94 (Jun 08)
2001	Dec 27	May 15	2,520 (Jun 14)	3.56 (Jun 16)
average, 1971-2000	Dec 24	May 23	5,200 (Jun 29)	5.46 (Jun 29)

staff gage was replaced at the same elevation and location on 25 September 1998 because ice had destroyed some numbers on the lower portion of the gage. Double-mass analysis was used to compare annual maximum outflow with the highest water levels of Yellowstone Lake and the maximum annual outflow with the annual weighted snow and precipitation values for period of record.

Results

Data for Yellowstone Lake freeze-up, melt-out, maximum annual outflow, and maximum water level are shown in Table 1 for water-years 1926 through 2001. The water-year starts on October 1 and goes through September 30. Some data were estimated, as noted above. Double-mass analysis comparisons between maximum daily outflow and staff gage readings of water surface do not show any significant breaks for the period of record. However, there are some differences associated with each individual staff gage location. Analysis using double-mass regression suggests that the annual maximum lake level since the 1988 fires may have been reduced slightly even though the total inflow volume increased. This was due to increased melt rates in the fire-generated openings in the forest canopy, which spreads the snow melt over a longer period due to the increase in percentage of open stands (McCaughey and Farnes 2001). Freeze-up and melt-out dates are functions of air temperatures and early-winter water levels in Yellowstone Lake. However, no detailed analysis has been performed to develop a relationship. Assuming low-water levels near zero on the staff gage around the time of ice-off, the spring rise in the lake water level over the past 75 years has varied from about 2.5 ft (0.7 m) to 7.75 ft (2.4 m), with an average annual rise of about 5.5 ft (1.7 m). The maximum elevations of the water surface in Yellowstone Lake and the maximum outflow from Yellowstone Lake are well correlated (R^2 = 0.927) for the entire period of record (1926–2001) for the staff gage at three locations. Separating the correlations for period of record at each gage location improves the R^2 to 0.989, 0.971, and 0.970 for the three locations.

Summary

Both the outflow and maximum water surface elevation of Yellowstone Lake for each year are functions of the winter's snow accumulation and spring precipitation inputs, and vary significantly from year to year. Yellowstone Lake's water levels and outflows have a direct effect on many of the resources in the vicinity of the lake or downstream. Water temperatures are suppressed in heavier-snowpack years as meltwater draining out of the snowpack is near 32°F (0°C). These suppressed stream and lake temperatures delay emergence of salmon flies and spawning of cutthroat trout. Success of spawning runs has been related to runoff and can influence recruitment of cutthroat trout (Farnes and Buckley 1964). Streamflows during spawning runs affect success of bears feeding on migrating and spawning cutthroat trout (Dan Reinhart, personal communication). High and low lake levels affect tour boating and boat rental operations by the Bridge Bay concessionaire (Hal Minugh, personal communication). Nesting success of white pelicans has been greatly diminished during years with high water levels because the Molly Islands are almost completely covered with water then (Terry McEneaney, personal communication). Shoreline erosion can be accelerated in high-runoff years particularly if accompanied by wind during times of the highest water levels. Downstream water users have been affected by low-water years (e.g., by shortages of in-stream flows and irrigation water supplies).

Recommendations

Since the elevations of the water surface in Yellowstone Lake affects many resources, it would be desirable to have the Montana office of the USGS Water Resources Division resume responsibilities for Yellowstone Lake level observations at the Bridge Bay gage and make these data available to the public in a manner similar to that of the outflow observations. This would provide a level of accuracy comparable with that of earlier records.

Have the Montana office of NRCS develop procedures to forecast upcoming elevations of Yellowstone Lake at the Bridge Bay gage using snow–water equivalent, soil moisture under the snowpack, and spring precipitation and make this information available on their Web page in a format similar to that of other water supply forecasts. This would provide warning of low or high water levels that could affect resources associated with lake elevation. It would also permit researchers advance time to arrange for collection of any related data that might be pertinent to their study.

Suggest that researchers consider the impacts of natural variability in inflow, lake levels, and outflow when researching phenomena associated with Yellowstone Lake.

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