Modeling the Effects of Climate Change on the Thermal Structure of Yellowstone Lake

By Steve Hostetler with Introduction by John Varley

In 1868, explorer Legh Freeman called Yellowstone Lake "... the largest and strangest mountain lake in the world." Indeed, current scientific research concentrates on many of the lake's more complex and subtle enigmas. The lake is cold yet it straddles a geological hot stove. The outlet of the lake is continuously being raised and lowered by geothermal activities. The great depths of the lake are still being surveyed by robot camera; and, over the past year, a diatom unique to the lake was described, and the first underwater geyser was found in the lake. Today Yellowstone Lake supports an abundant population of Yellowstone cutthroat trout that are a primary food source for wildlife (pelicans, osprey, eagles, bears) and are the basis of an important sport fishery. The many facets of Yellowstone Lake make it a priceless natural treasure.

Modeling Study

The annual cycle of water temperature plays a key role in the water balance and productivity of Yellowstone Lake. The surface water temperature and the water balance of the lake are linked through evaporation. Productivity is influenced by characteristics of the temperature structure such as duration and thickness of ice cover, onset of stratification in spring, the strength and duration of stratification through summer, and turnover in autumn. An investigation of the temperature structure of Yellowstone Lake has been underway for the past 15 months together with investigations of the water budget and productivity of the lake. The findings of these studies will be used to reconstruct the climate of the basin over the historical record and for the Holocene. These investigations are cooperative studies that involve personnel from the National Park Service, USFWS, USGS, the University of Minnesota, the University of Oregon, Oregon State University, and the Philadelphia Academy of Sciences.

The goal of the lake modeling study is to apply a previously developed thermal model (Hostetler and Benson, 1990; Hostetler, 1991). The model is one-dimensional and is used to simulate thermal structure, evaporation, and ice cover in response to meteorological conditions (solar radiation, atmospheric radiation, air temperature, humidity, and wind speed). Over the past 15 months the meteorological data has been collected hourly at a site on the northern shore of the lake; data collection will continue for another 1 or 2 years. Profiles of water temperature and data on the duration of ice cover, ice thickness, and depth of snow on the ice also are being collected to provide information to compare with results of model simulations.

Results from a 449-day (June 28, 1991 to Sept. 9, 1992) simulation indicate that the model is able to predict the thermal characteristics of the lake, including lake surface temperature (Fig. 1) and ice cover for the winter of 1991-92 (Fig. 2). Preliminary comparisons of simulated and observed data (USFWS, unpublished data, E. Theriot, Philadelphia Academy of Natural Science, personal communication) indicate that the model closely simulates the actual surface temperature of the lake for the period. The simulated date of fall turnover in 1991 was Oct. 12, a date within the estimated period of actual turnover. The onset of total ice cover over the lake was simulated to be December 18, a date within a few days of the observed onset (Dec. 13; J. Lounsberry, A. Siebecker, NPS, personal communication). The winter of 1991-92 was the warmest on record in Yellowstone Park. As a result, the maximum ice thickness of 0.85 m was less than normal (> 1 m) and simulated values agree well with a mid-winter measurement (C. Whitlock, University of Oregon, personal communication). Another result of the warm, relatively dry winter was that break-up of the ice occurred earlier than normal. The date of break-up simulated by the model (May 4) is within a few days of the observed break-up (May 7). Following break-up, cool, windy conditions prevailed and the lake was observed to mix for a period of more than 2 weeks. This period of mixing is captured by the model and is indicated by the slow rise of water temperature that was simulated until about the first of June, 1992.

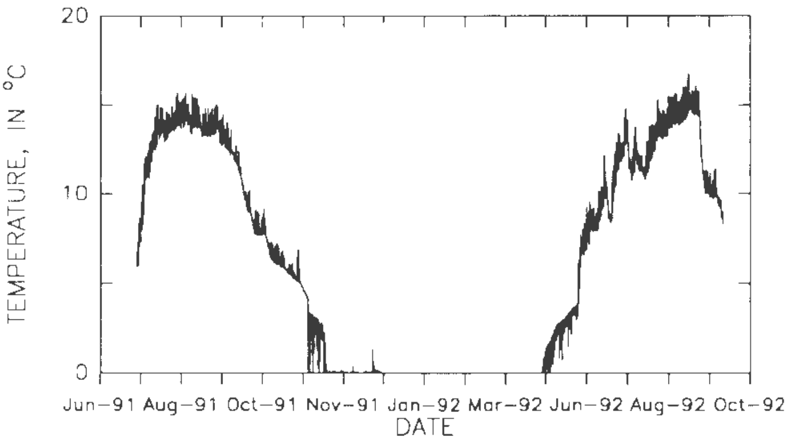

Figure 1. Simulated hourly values of the surface temperature of Yellowstone Lake.

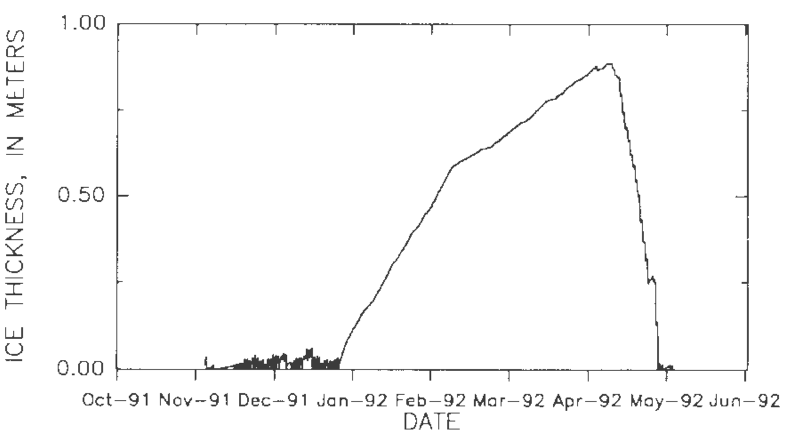

Figure 2. Simulated hourly values of the thickness of ice on Yellowstone Lake.

Because the lake model simulates evaporation in response to climatic conditions, it also will be used to evaluate the present and past water balances of Yellowstone Lake. Knowledge of the water balance is important to making estimates of lake level. A field project is currently in progress at the lake to evaluate the water balance.

The thermal model will be used to investigate the effects of climate on the productivity of Yellowstone Lake in several ways. For example, the onset and level of spring productivity under ice depends on the intensity of light (solar radiation) penetrating the ice, and the associated convective mixing that is initiated by heat from the penetrating radiation. The model can be used in sensitivity tests to link climatic-determined conditions of the ice (e.g., presence or absence of late spring snow) with productivity. For Holocene climate reconstructions of the lake, the model and data set will be used to reproduce thermal characteristics (e.g., spring mixing, onset and strength of stratification) that are favorable to diatom assemblages identified in sediment cores obtained from the lake.

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References

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