Comparison of Reservoir Evaporation Rates from the Collison Floating Evaporation Pan to Atmospheric Evaporation Techniques and the Importance of Wind Speed and Direction

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Extended Abstract

Accurate tracking of open-water evaporative losses, one of the largest consumptive uses of water in the Southwestern United States, will become increasingly important in the future with anticipated climate shifts toward warmer temperatures and longer, more severe droughts. The current methods for estimating reservoir evaporation have uncertainties ranging from ±20 to 70 percent. Reduction of these uncertainties through improved evaporation monitoring tools could provide water-resource managers with a better understanding of current and future water supplies, and allow for improved real-time water management.

With funding from the US Bureau of Reclamation and the US Army Corps of Engineers, the University of New Mexico is testing a new tool for improved real-time monitoring of reservoir evaporation rates, the Collison Floating Evaporation Pan (CFEP, Figure 1, U.S. Patent 10,082,415, Collison [2018]). In 2017, testing of this device was initiated on a 50,000-acre-foot flood-control reservoir, Cochiti Lake, located in central New Mexico. Since then, additional CFEPs have been planned or installed on Lake Powell in Utah, and Elephant Butte Reservoir in southern New Mexico. Through innovative design and extensive field measurements, this study aims to develop a more accurate, robust, automated, and real-time technique for measuring near-actual reservoir evaporation rates, leading to effective long-term monitoring and management of the nation's water resources.

The CFEP is semi-submerged to minimize the difference in water temperature between the CFEP and the reservoir. Additionally, the CFEP's design has minimal influence on the atmospheric boundary layer (imagine a dome of cooler, wetter air overlying the body of water) overlying the pan relative to the reservoir. The CFEP's accuracy was verified through the use of a hemispherical evaporation chamber designed to measure near-actual evaporation rates adjacent to the CFEP. In addition to measuring evaporation, the CFEP has a full micrometeorological weather station attached to it, allowing for other evaporation models to be calculated and compared to the CFEP. Results from the Cochiti Lake CFEP were compared to other evaporation models, including Hamon (Hamon, 1961), Hargreaves's (Hargreaves, 1975), and U.S. Weather Bureau equation (Kohler and others, 1955) and to the on-site Class A Evaporation Pan managed by the U.S. Army Corps of Engineers, see Figure 2 below.

Figure 1. Collison Floating Evaporation Pan (CFEP) on Cochiti Lake, New Mexico (8-foot diameter evaporation pan and 16-foot diameter outer wave guard).

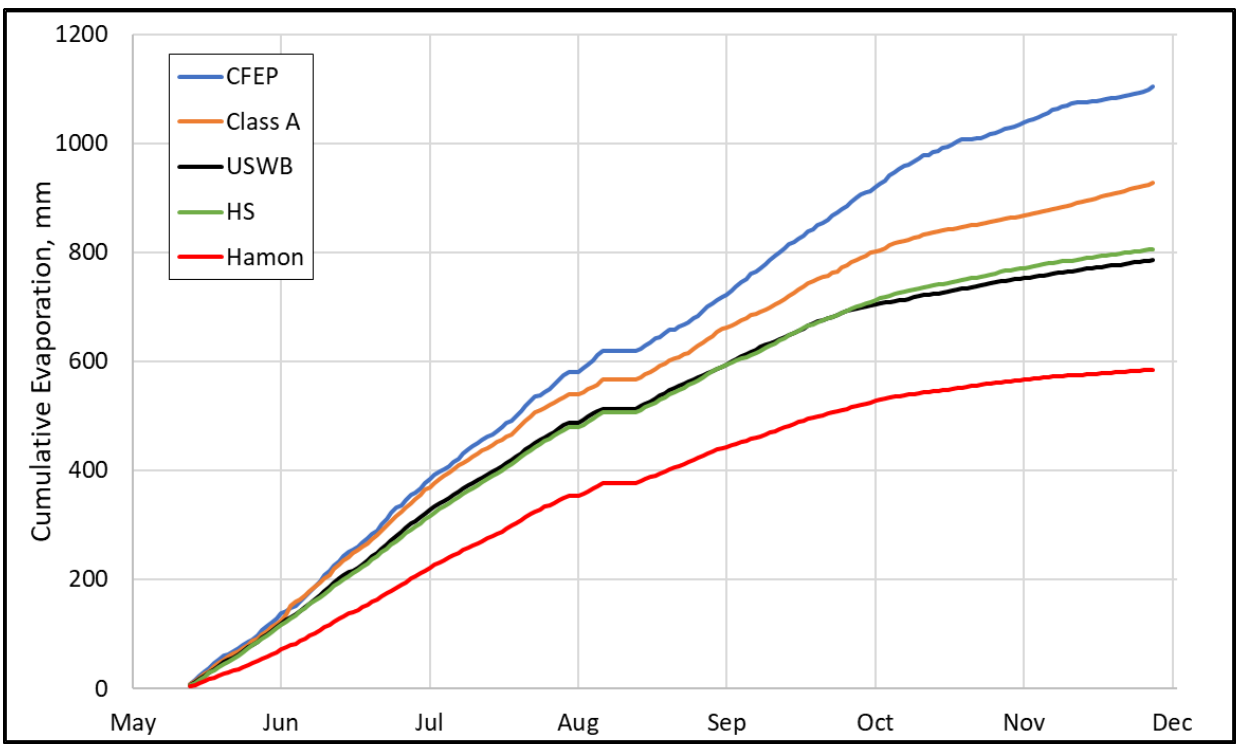

Figure 2: Cumulative evaporation for the CFEP (Collison Floating Evaporation Pan), Class A Pan, USWB equation (U.S. Weather Bureau), HS equation (Hargreaves-Samani), and Hamon equation.

The agreement between the CFEP and Class A Pan was the closest of all evaporation estimation techniques calculated, especially in May and June, but this agreement begins to decrease in late summer through fall. The difference in evaporation estimated by the CFEP and the other four techniques is most apparent in the fall, due to the energy stored in the reservoir during the spring and summer being released through increased evaporation rates in the fall. This increase in evaporation in the fall is captured by the CFEP due to its being placed within the atmospheric boundary conditions of the reservoir whereas the other four techniques do not account for this.

Figure 3 below represents one week of evaporation (blue line), vapor pressure deficit (red line), and wind speed (green line) data collected by the Cochiti Lake CFEP, where vapor pressure deficit (VPD) is determined as the difference between the maximum potential vapor pressure in the air at the current air temperature (function of air temperature) and the current ambient vapor pressure. The high correlation between evaporation rate and wind speed is clearly evident, but so is the correlation between evaporation rate and high VPD values. Wind at this location predominately came from the south during the course of the study, except between 5 a.m. and 8 a.m., when it came from the north. The Cochiti Lake CFEP has roughly 110 meters of open water to the south and 2,000+ meters of open water to the north. Thus, when wind comes from the south, it is traveling off the hot and dry desert. This hot and dry air has a high VPD, and, when coupled with an increase in wind speed, causes a spike in evaporation rates at the CFEP location. Increases in wind speed during the mornings of July 10th and 14th are not associated with a large spike in evaporation because these winds are coming from the north and have traveled across 2,000+ meters of open water. This effect of windward (shore-to-lake) and leeward (lake-to-shore) winds on evaporation rates is apparent in Figure 3, where higher evaporation rates are associated with windward, southerly, wind directions.

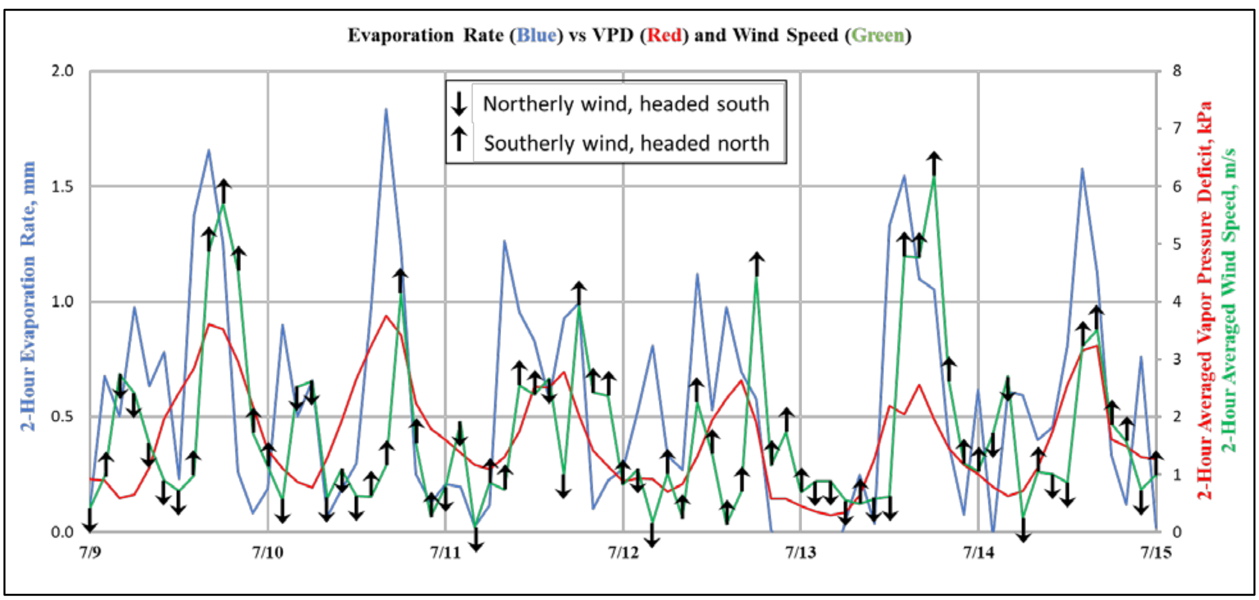

Figure 3. Evaporation Rate measured by the Collison Floating Evaporation Pan vs Vapor Pressure Deficit (VPD) and Wind Speed and Associated Wind Direction.

The large spikes in evaporation during southerly wind events and smaller spikes in evaporation during northerly wind events occur year-round at this site. It is reasonable to assume that similar evaporation spikes occur at other reservoirs and lakes in arid and semi-arid environments, and occur more strongly when winds arrive at a given location from dry land without flowing over a significant area of open water. These spikes represent a considerable amount of the daily evaporative losses at the CFEP measurement location on Cochiti Lake, where evaporation during southerly winds accounted for 62% of the evaporation during this study. These southerly, hot, dry winds, especially during high wind events, destabilize the normally wet, cool atmospheric boundary conditions over Cochiti Lake, increasing the evaporation rate significantly and illustrating the destabilization of atmospheric boundary conditions present over large bodies of water. Atmospheric boundary conditions over reservoirs impede evaporation, as seen by the magnitude of evaporation and VPD values based solely on wind direction at Cochiti Lake.

The analyses presented here demonstrate that techniques describing evaporation rates from large water bodies must include stored energy, wind speed, and wind direction in order to accurately estimate evaporation losses. Additionally, this study was able to quantify the importance of wind direction on evaporation rates, specifically shore-to-water and water-to-shore, where shore-to-water winds accounted for 62% of the evaporation estimated. In the Western and Southwestern U.S., reservoirs are often built within canyons that are long and narrow; based on this study, winds which travel along the minor axis of these reservoirs will have a considerably larger evaporation rate than winds traveling along the major axis. Understanding and accounting for spatially varying evaporation rates will greatly enhance the accuracy of evaporation estimates instead of just applying a single evaporation rate to the whole body of water.

At the Cochiti Lake CFEP study site, data from the CFEP have demonstrated that wind conditions are the major driving force for reservoir evaporation. Furthermore, the CFEP data have demonstrated the importance of wind direction, as an indicator of the amount of open water over which air has passed before reaching the measurement location, in the measured evaporation rate. Additional monitoring and research are needed to determine the impacts of these differences in wind direction and local evaporation rates on the overall evaporative losses from the reservoir.

References

Collison, J.W., 2018, “Floating evaporation pan with adjustable freeboard and surrounding wave-guard,” U.S. 10,082,415 September 25, 2018.

Hamon, W.R, 1961, “Estimating potential evapotranspiration,” Journal of the Hydraulics Division, ASCE. 87(HY3):107-120.

Hargreaves, G.H., 1975, “Moisture availability and crop production,” Trans. Am. Soc. Agric. Eng. 18(5):980-984.

Kohler, M.A., Nordenson, T.J., and Fox, W.E., 1955, “Evaporation from pans and lakes,” U.S. Weather Bureau Research Paper 38, 82 p.