Montezuma Well: A Dynamic Hydrologic System

Charles C. Avery

School of Forestry
Northern Arizona University
Flagstaff, Arizona 86011

Martin Helmke[1]

Prescott College
Prescott, Arizona 86301

Abstract. We investigated the hydrology of Montezuma Well, Arizona, to determine if the system was homeostatic (as previously implied) or dynamic. The discharge records for the past 6 water years show variation in outflow and a dynamic system. A seasonal trend was evident where values are slightly greater in winter and spring months and slightly lower in late summer and fall months. The water level fluctuations have a coefficient of variation of 32.5%, and the measured discharge fluctuates both on an annual and a daily scale. While seasonal variation might contribute to the erratic nature of the observed discharge at the Montezuma Well gage, we were unable to document a causative mechanism without intensive study.

Key words: Arizona, hydrologic system, hydrology, Montezuma Well, water balance.

Montezuma Well in Arizona has been implied to be a homeostatic (or constant flow regime) hydrologic system. Several reports have mentioned, in support of this assumption, that the water level within the well remains almost constant throughout the year (Cole and Barry 1973; Blinn and Wagner 1987; Blinn et al. 1988; G. A. Cole, National Park Service, unpublished report). The recharge to the system is also assumed to be constant (i.e., an informational sign installed by the National Park Service at the well's rim states that the recharge exceeds "a million-and-a-half gallons per day [2.35 $feet^3/s^{-1}$], *an amount unvarying* [italics author's], apparently, since prehistoric times"), thus requiring that the outputs from the system be constant.

According to Brazel and Barnett (1975), the well system possesses some unique features that reduce its coupling to the immediate atmospheric environment so that the lake's evaporation rate is suppressed. G. A. Cole (unpublished report) notes that some persons believe that only barometric pressure changes have an effect on the water flow.

This commentary poses the question, Do any significant variations occur within the Montezuma Well hydrologic system? We examined historical records and made some on-site measurements; testing the question will require a more intensive effort.

[1]Present address: Route 1, Box 211, Mt. Jackson, Va. 22842.

Setting

The continuous water supply afforded by the well encouraged nearby prehistoric settlement that was not unlike that at Montezuma Castle. There can be little doubt, however, that the tranquil setting of the well had a special significance in those times, as it does today for certain people. The land irrigated with water from the well provided a staple source of foodstuffs for the nearby early settlements. An archaeological interpretation of the site is beyond our scope here; the uniqueness of the locale speaks for itself.

Study Site

Montezuma Well is located in the Upper Sonoran Grassland near Rimrock, Arizona (34°39' N, 111°45' W). It is currently thought of as a collapsed travertine spring mound (Nations et al. 1981)—not a collapsed limestone (karst) feature or the remnant of a dissolved salt lens—and is thought to be fed by warm artesian waters (24°C) from bottom vents. According to G. A. Cole (National Park Service, unpublished report), the well has a mean water depth of 6.7 m and a maximum depth greater than 17 m. (A 1991 expedition by the U.S. Geological Survey [USGS] Water Resources Division undertook a detailed analysis of the lake, and the division will shortly release updated values.) Water leaves the well through a small cave located at the southeast margin, although there may be other exits as well. Due to high levels of dissolved CO_2 (>600 mg/L^{-1}), fish are not present, and some unique interpredatory relations have evolved among the well's organisms (Blinn and Wagner 1987).

Methods

A simplified water balance was constructed for the well to demonstrate the relative importance of the several components. The form of this simplified equation

$$\text{Well inflow} = \text{lake evaporation} + \text{outflow} - \text{precipitation}$$

assumes no significant losses to seepage and that storage changes are zero. It does, however, require homogeneity of the measurement units for its application and necessitates a precise determination of the well's surface area. We have determined a value, 0.73 ha, from our surveys in 1990 and 1991 using electronic total station equipment. We are not yet able to construct a reliable stage–volume–area relation for the top meter of the lake, which would show the change in surface area (or volume) as a function of change in stage. Moreover, an assumption of significance is that the gauging station record (from the USGS gage) realistically represents the well's outflow. No effort was made to validate this assumption.

The historical discharge data we obtained from the published records for USGS stream-gauging station 09505260, located slightly downstream of the well's outlet (Fig. 1). Daily values are available from these records for 1979–90. To obtain hourly records, the discharge of the well was measured close to the well's outlet for the 26-h period from 1100 h on 24 March 1990 to 1200 h on 25 March 1990. A staff gage read at irregular intervals between May 1990 and May 1991 provided data on the water level within the well.

Climatic records were obtained for the Beaver Creek Ranger Station, located 8 km northeast of Montezuma Well. These records included daily maximum and minimum temperature values and daily precipitation amounts from 1958 to 1988. Because of the simplicity of the available data set, Thornthwaite's formula for calculating potential evapotranspiration was used as a first approximation for lake evaporation. The values so calculated were then transformed into probable lake values using the work of McGuinness and Bordine (1972) and Yitayew (1990). It seems that Thornthwaite's temperature-driven, empirically derived formula shows a good approximation in yearly trends to lake evaporation recorded at Coshocton, Ohio (McGuinness and Bordine 1972). We concluded from Yitayew's recent work that an annual correction factor of 1.3 for this location was appropriate. Together, both works underscore that the rate of potential evaporation greatly exceeds that of actual precipitation in this arid region!

Results

The USGS discharge records for the past 6 water years (1985–90) show considerable variation in outflow. The lowest of these daily values is 0.9 cfs (0.58 million gallons/day) and the greatest is 3.1 cfs (2 million gallons/day). Although this amounts to an almost 250% variation, there seems to be a seasonal trend—reported values are slightly greater in the winter and spring months and slightly lower in late summer and fall.

The hourly discharge measured over the 26-h period in March 1990 also shows variability. While some fluctuations might result from measurement error, the 5-h moving mean seems to show a slight drop in discharge during early morning hours (Fig. 2).

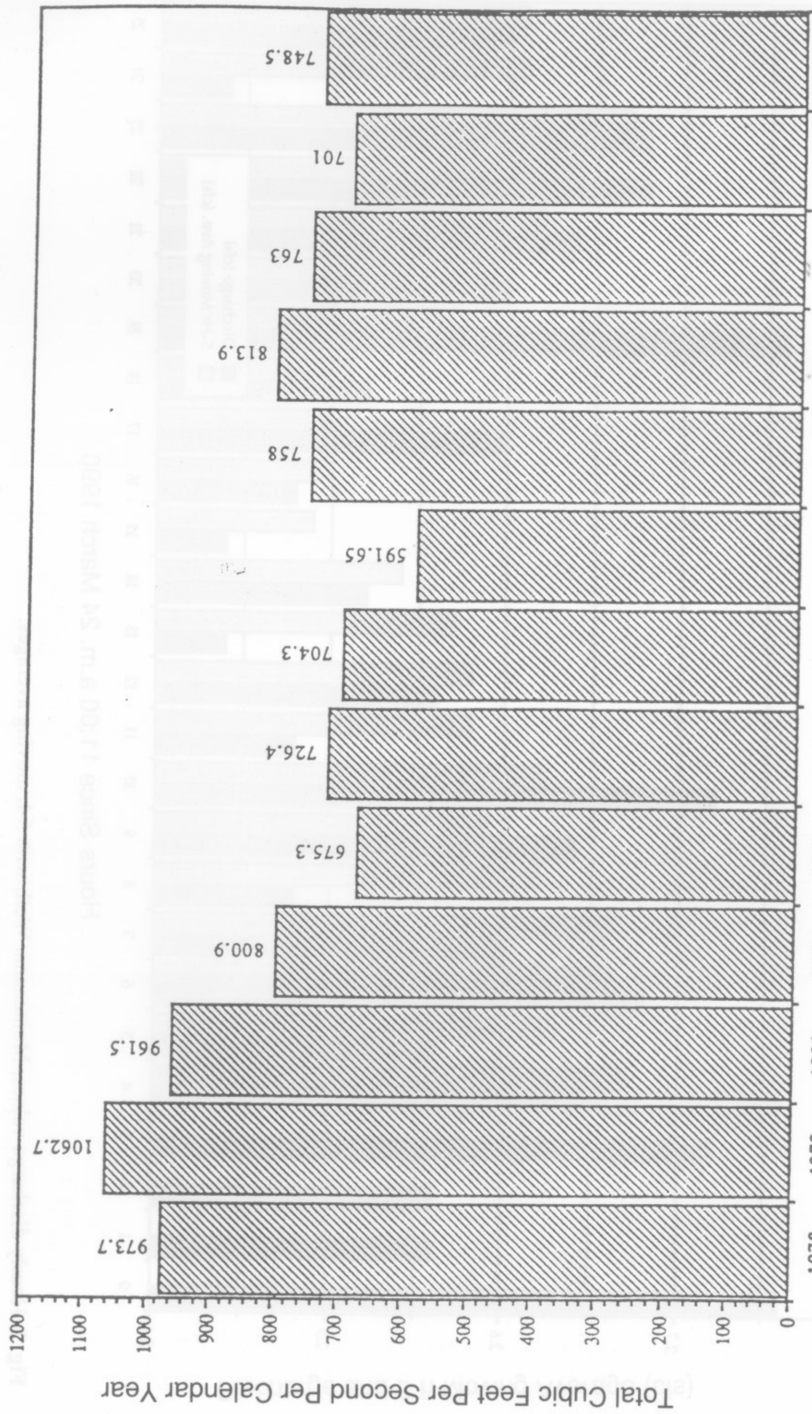

Fig. 1. Annual discharge at the Montezuma Well gauging station, 1978–90.

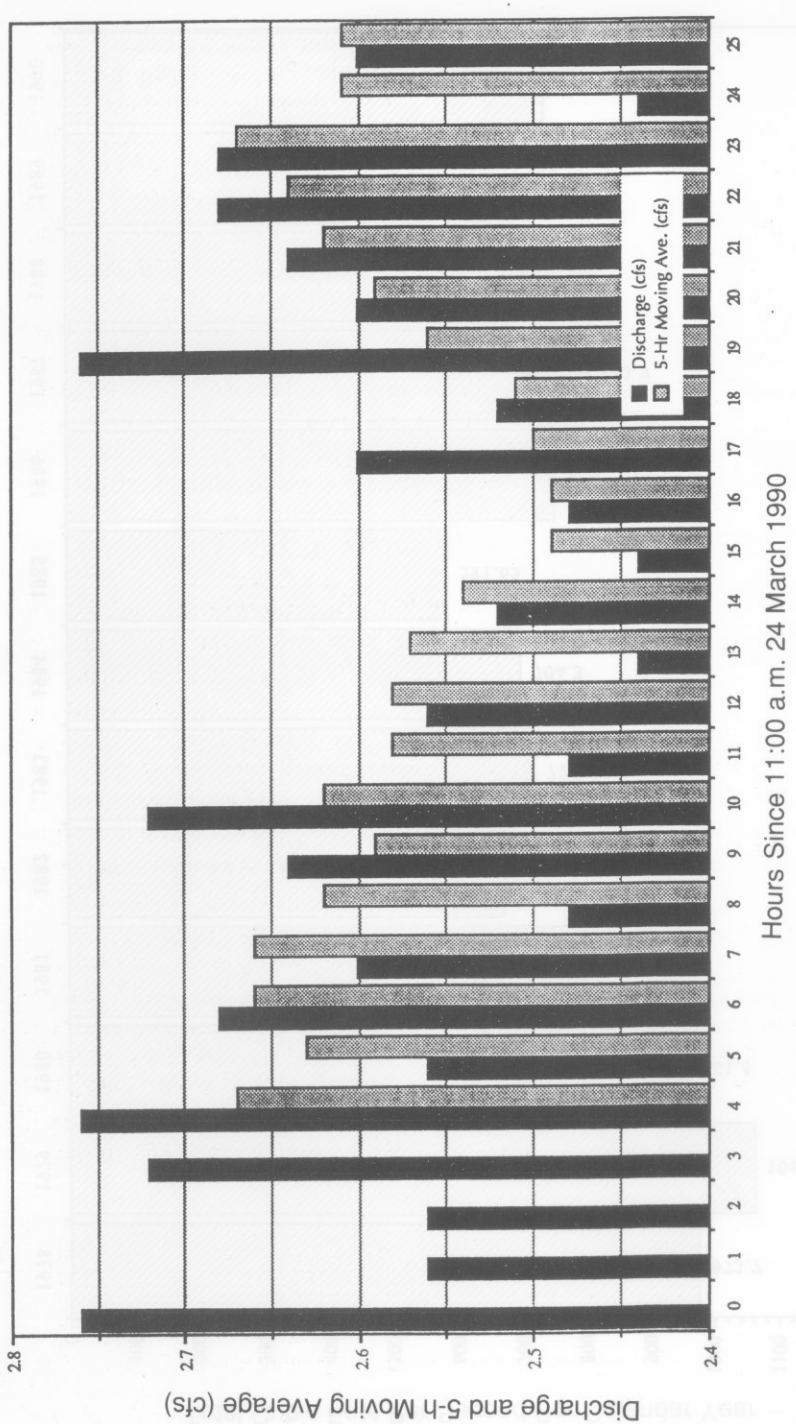

Fig. 2. Hourly discharge values, Montezuma Well, with 5-h moving averages.

The records of the water level within Montezuma Well clearly show slight increases and decreases in stored volume (Fig. 3). During the 1 year that these observations were made, there was a maximum variation of 0.14 m. We could not determine whether or not it is seasonal (repetitive) in nature because of the inconsistent time step and brief duration of the record (Fig. 4).

The precipitation records for the past 30 years seem to reflect the usual and customary seasonal variations for Arizona. While seasonal variations might contribute to the erratic nature of the observed discharge at the Montezuma Well gage, there is no way to document a causative mechanism to explain this observation. We emphasize that the conservative values derived from the calculation of precipitation minus evaporation for the well are so insignificant (e.g., 5.14% for 1979–89 relative to the measured outflow) that any long-term fluctuations in well volumes seem to be groundwater-dependent.

Conclusion

The data indicate that Montezuma Well is a dynamic hydrologic system rather than a homeostatic one: the water level within the well fluctuates slightly; the value of annual precipitation on the well surface minus the probable lake evaporation has a coefficient of variation of 32.5%; and the measured discharge fluctuates both on an annual and a daily scale. Moreover, the computed well inflow reflects a variation of 34% for 1979–86.

There is much research remaining to be undertaken for thorough understanding of this dynamic system. We have shown that the hydrologic setting of the well may be more complicated than suspected in the past. We hope that scientists who continue to study this unique system will gather data sufficient to explain the system and the means to maintain its functioning.

Additional instrumentation to monitor the well's hydrologic performance should include a water-level recorder on the well's surface and an evaporation pan near the well. A 10-year program of intensive monitoring is needed to determine the significance of leakage and seepage paths related to the well. A scientific advisory committee should evaluate existing data and recommend management actions to ensure the continuity of the well's regimen in light of rapid regional real estate development. The underlying question regarding the well's source remains unanswered.

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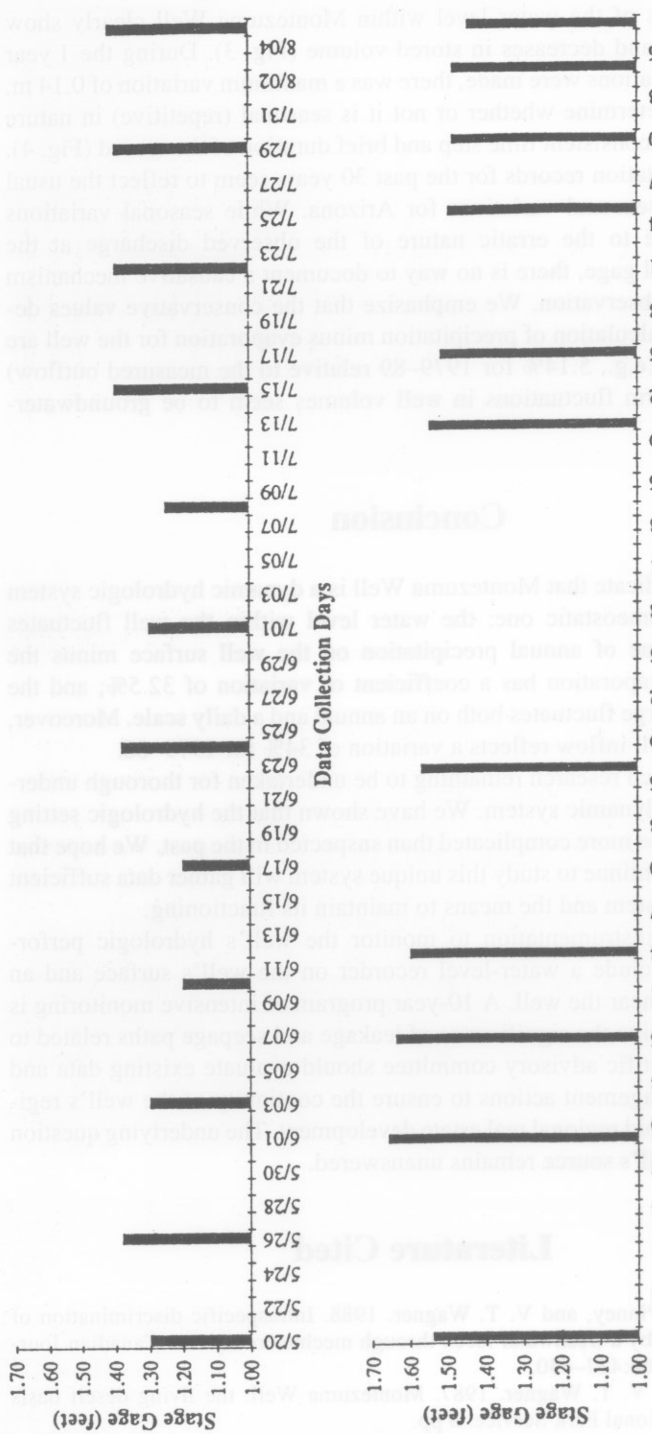

Fig. 3. Water level readings on gage within Montezuma Well, 1990–91.

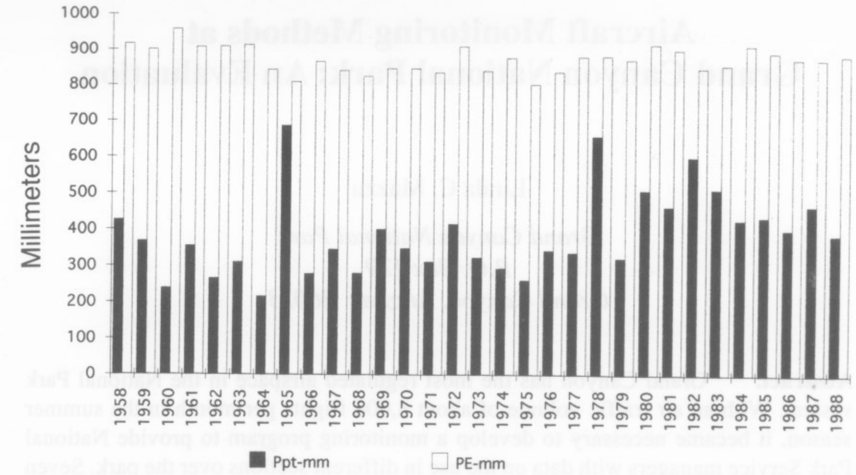

Fig. 4. Precipitation and potential evaporation near Beaver Creek.

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