Have We Been Here Before?: Hindcasting Lake Levels for Minimum Flows and Levels Evaluations Using a Rainfall Decay Model

Fatih Gordu, Brett Goodman, Tony Cunningham, and Adam B. Munson

Figure 1. Lake Brooklyn

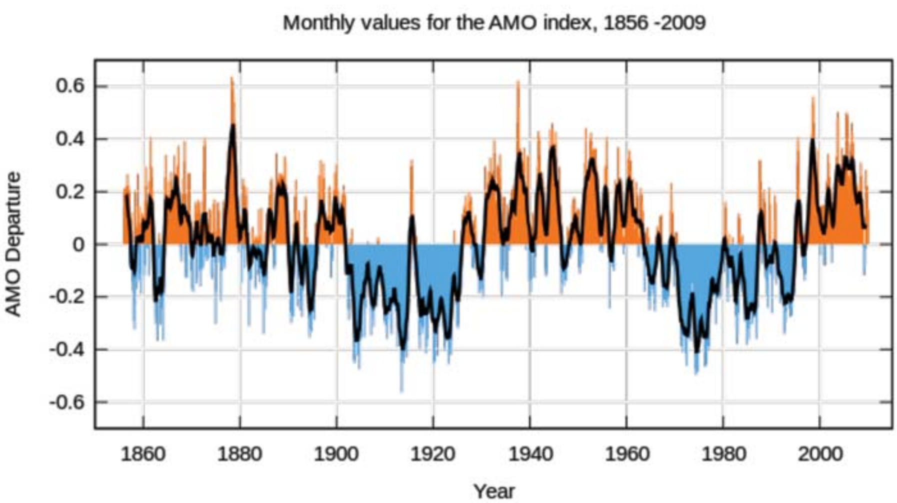

Figure 2. Atlantic Multidecadal Oscillation Index Departure (NOAA, 2008)

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Over the past 30 to 40 years, significant downward trends in the Keystone Heights-area lakes have raised public concerns about declining property values and economic hardships in the nearby communities. Lakes have been stressed significantly in north Florida due primarily to severe rainfall deficits. The population of north Florida has also grown dramatically over the same period, causing increased groundwater use and raising concerns about declining lake levels. Figure 1 is an aerial photograph of Lake Brooklyn in 2012. The water management districts in Florida set minimum flows and levels (MFLs) to protect the lakes from significant harm caused by consumptive uses.

One of the great challenges in establishing MFLs and measuring their compliance is the availability of sufficient data to evaluate an appropriate range of conditions and to suitably characterize the frequency of specific hydrologic events in the history of a particular waterbody. Establishing the natural long-term variations in lake levels is extremely difficult when lakes exhibit wide fluctuations in levels and the period of record does not capture several high- and low-level cycles. While a 50-year record can be sufficient for making observations about annual cycles, it may be insufficient for discussing events with infrequent return intervals. The difficulty arises if the expectations for high flow or stage conditions established during the late 1950s and early 1960s are viewed as events that are likely to occur with a frequency of once every 50 years, when they actually represent less frequent events or more extreme events. If this is the case, the expected return frequency of a minimum flow and level could be overstated.

The study presented is an attempt to understand the influence of climate on lake levels in the Keystone Height area, which can be useful in establishing the return frequency and levels used in establishing MFLs. The goal was to use readily accessible data to establish relationships between climate and recorded lake levels from 1957 to the present to "hindcast" lake levels from 1874 to 1957.

In central Florida, the period from about 1930 to 1965 is considered a period of high precipitation and the period from 1965 to 1995 is considered to have been generally dry. This effect has been tentatively linked to the Atlantic Multidecadal Oscillation (AMO) by Kelly (2004) (Figure 2). According to Enfield (2001), Florida rainfall and lake levels have strong correlations with warm and cool phases of the AMO. The National Oceanic and Atmosphere Administration (NOAA) indicates that rainfall in central and south Florida becomes more plentiful when the At-

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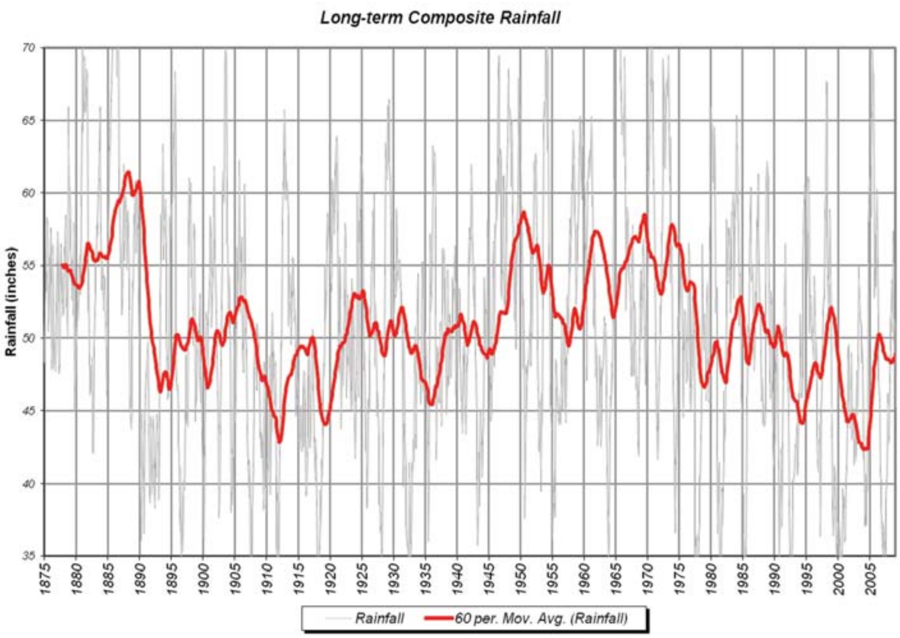

Figure 3. Composite Annual Rainfall from 1874 to 2010 with 60-Month Moving Average for the Sandhill Lakes Region

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lantic Ocean is in its warm phase, and droughts are more frequent in the cool phase. For establishing MFLs, a lake record without a full AMO cycle could bias the determination of the frequency of extreme events and result in erroneous thresholds.

The Rainbow River is an example of how the period of record can influence the interpretation of trends and extreme events. From 1965 onward, the Rainbow River shows a 25 to 30 percent decline in flow. These significant declines are based on U.S. Geological Survey (USGS) measurements that began in 1965. However, if the physical flow measurements collected by USGS since 1917 are included in the period of record, the flow decline is considerably less alarming. The Southwest Florida Water Management District concluded that the reduction to the mean annual springflow caused by groundwater withdrawals is about 1 percent (Basso, 2009). This is consistent with the composite rainfall record developed for this study (Figure 3), which shows that in the 1910s and 1920s rainfall was similar to that of recent years. The composite record is made from the following gauges: several Gainesville NOAA gauges from 1874 to 1989; Lake Brooklyn gauges from 1989 to 1991; Lake Geneva gauges, with some additions from Lake Brooklyn, from 1991 to 2001; Lake Lily gauges in 2002; and Goldhead State Park gauges from 2002 to 2010.

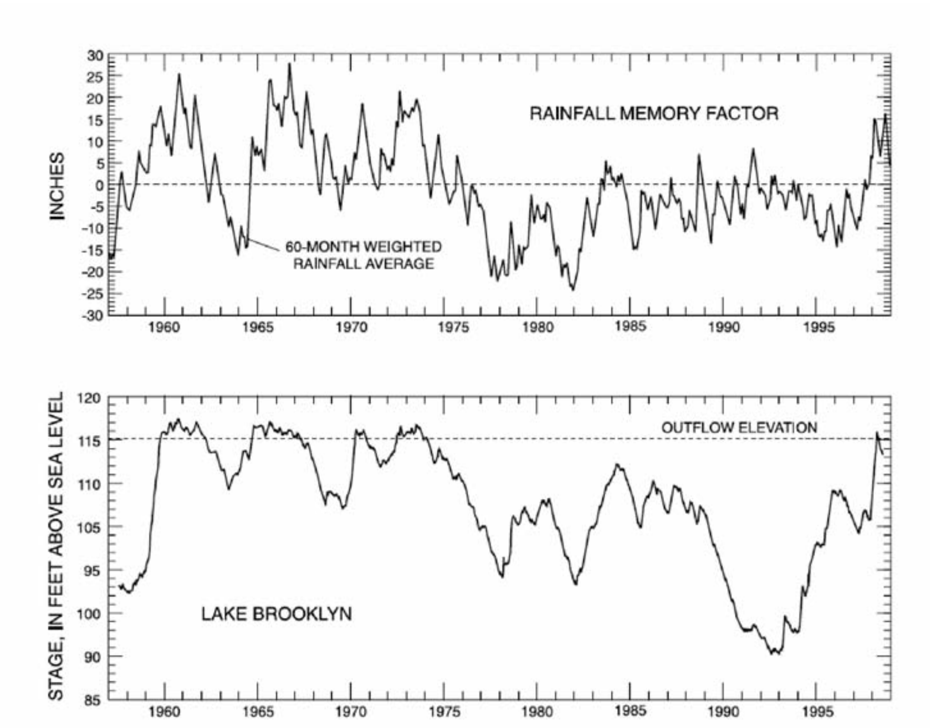

Figure 4. Lake Brooklyn Level and Rainfall Memory Factor (Merritt, 2001)

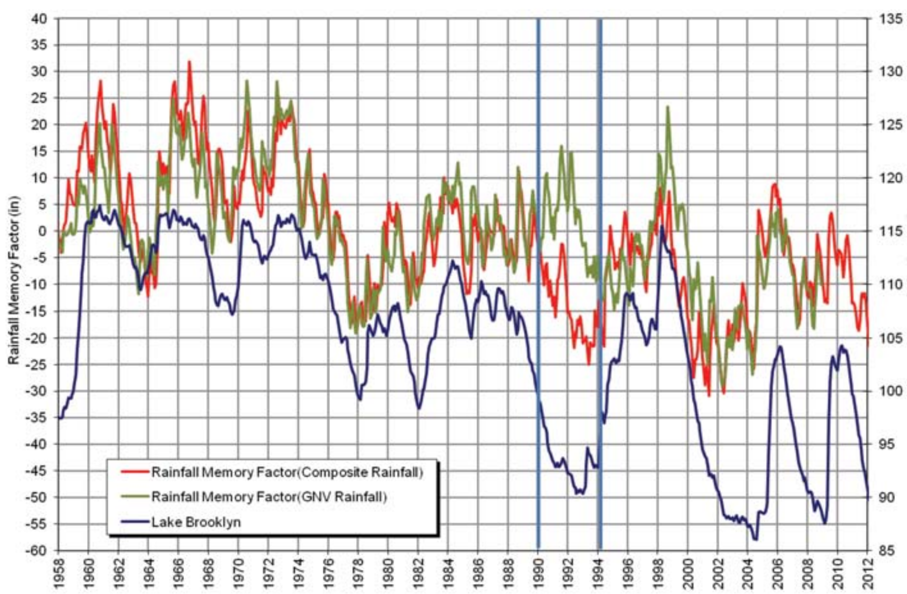

Figure 5. Comparison of Rainfall Memory Factors Using Gainesville and Composite Rainfall

Understanding the declines in lake levels without sufficiently addressing the climate's influence on the Sandhill Lake system would be difficult. Many concerns result from limited observed lake levels in periods of known rainfall deficits. As a result, Jones Edmunds focused on overcoming limitations in the period of the lake-level records and assessed the possibility of using long-term rainfall to extend the lake-level records back to 1900, or earlier.

Since Lake Geneva has not been receiving water from Lake Brooklyn since the 1970s, developing a correlation between Lake Geneva and rainfall for the recent period and using it to predict the water levels before 1957 would be difficult. Fortunately, sources of Lake Brooklyn inflows have not been changed since 1957. Therefore, Lake Brooklyn was chosen for extending the lake level records to before the 1950s. Fortunately, numerous studies of this area (Clark et al., 1963; Motz and Heaney, 1991; Robison, 1992; and Merritt, 2001) provide a foundation of information that supports the understanding of the influence of climate on these lake systems.

Rainfall Decay Model Development

Merritt (2001) established a relationship between the rainfall data obtained from the Gainesville weather station and Lake Brooklyn levels, which was called the Rainfall Memory Factor (RMF). The basic equation of this factor is:

$$Rmf = \sum_{i=1}^{n} R_i[1-(i-1)/n] - \overline{Rmf},$$

Where

Rmf is rainfall memory factor

Ri is the rainfall total for month i

n is the number of months in system "memory"

The concept of rainfall decay is that observed lake levels serve as the system's memory to past rainfall events. Rainfall occurring closer to the observation is given more weight in predicting lake levels. As Figure 4 shows, a clear correlation between the rainfall memory factor and lake levels was established by USGS; a notable exception to the strong correlation is between 1989 and 1996.

Using Merritt (2001) as a basis, a rainfall decay model (RDM) was developed to simulate lake levels of Lake Brooklyn back to the 1870s. The RMF was modified using 12-month moving average data and a composite rainfall dataset that is more representative of the Keystone Heights area. The rainfall dataset indicated a cumulative difference of 68 in. in rainfall from 1989 to 2008 between Gainesville and local rainfall, which explains the lack of correlation between the RMF and Lake Brooklyn levels from 1989 to 1996 (Figure 5). Once the local rainfall dataset was used and a better match was obtained between the 1989 and 1996 data, the RDM was refined through correlation and verification.

Model Correlation

The period from 1980 to 2009 was used as the correlation period for the model. After a series of trials, the best correlation between the modified RMF and Lake Brooklyn level that can be achieved is with a 60-month (five-year) memory span (Figures 6 and 7). The correlation period (1980 to 2009) could include anthropogenic influences on lake levels; however, the latest double-mass curve analysis from the St. Johns River Water Management (SJRWMD) indicated that the water level decline in the Upper Floridan Aquifer (UFA) well (C-120) adjacent to Lake Brooklyn due to pumpage is no more than 2 ft from 1960 to present (Robison, 2012 draft). There-

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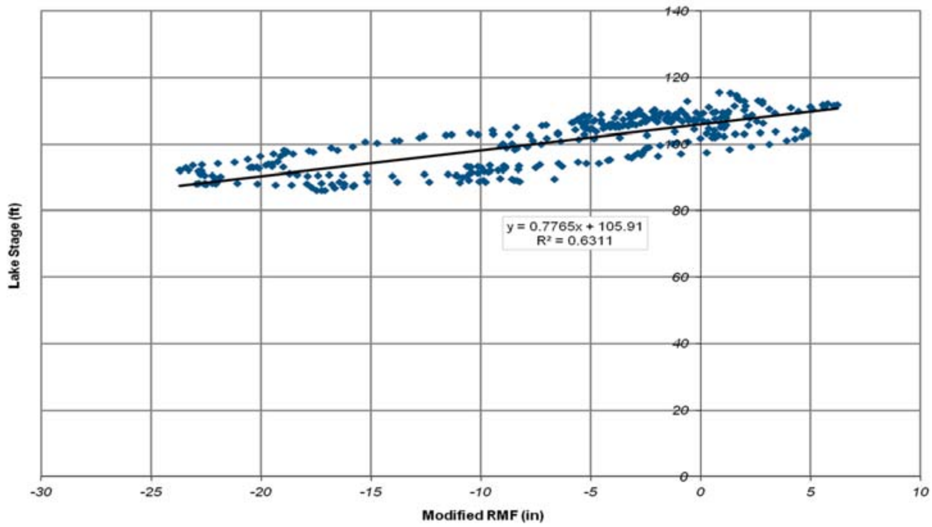

Figure 6. Correlation Between Lake Brooklyn Level and Modified Rainfall Memory Factors

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fore, possible anthropogenic influences on lake levels during the correlation period are not significant compared to the long-term fluctuation of lake levels.

Model Validation

The 1957-to-1980 period was used to test the model's predictive capability. Figure 8 shows the predicted water levels for the entire period and that the observed lake levels are available.

As Figure 8 shows, the RDM predicted the lake levels reasonably well. The following reasons could explain the significant differences between the simulated and observed levels at some periods:

- Lack of local rainfall.
- The lake is broken into multiple lobes; therefore, stage-area relationship changes dramatically when the lake stage is very low.
- Lake-bottom seepage is not uniform due to the existence of sinkholes.
- Possible sinkhole activities at lake-bottom or within the drainage area over time.

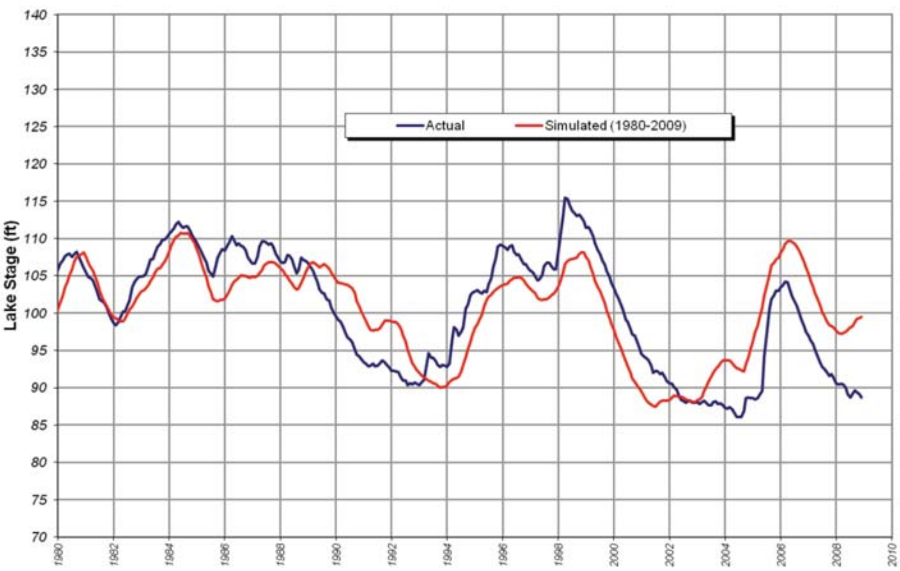

Figure 7. Simulated and Observed Lake Levels (Correlation Period)

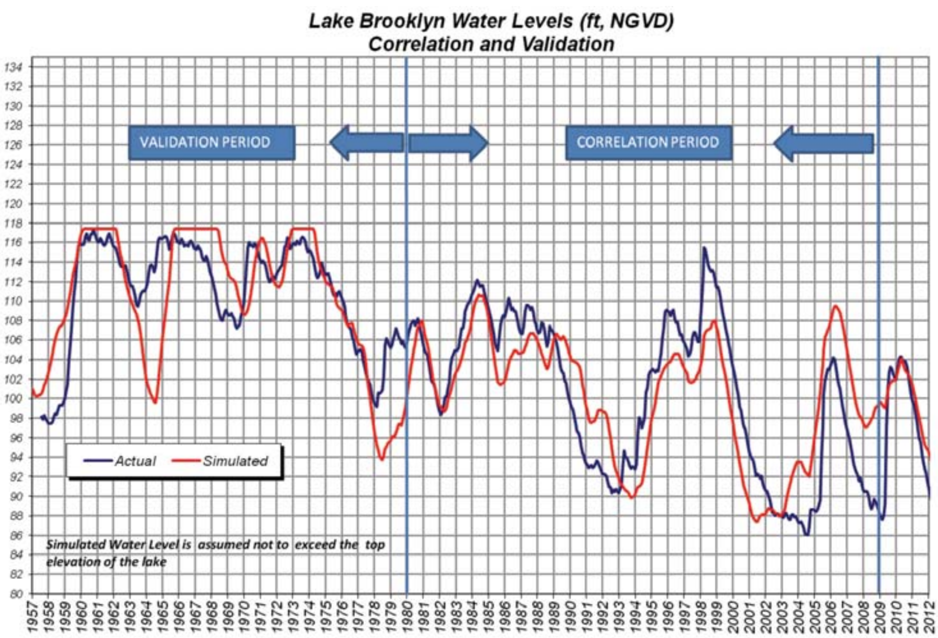

Figure 8. Simulated and Observed Lake Levels (Correlation and Validation Periods)

Predicted Historical Lake Levels

After correlation and validation, the model was used to predict the lake levels from 1874 to 1957 in Lake Brooklyn. Figure 9 shows the results of the modeling analysis. The simulated water levels were kept at the top elevation of the lake when water levels are higher.

The model-predictive water levels were compared with some historical information provided by SJRWMD, with court records showing high levels in February and April 1954, and lake levels in the area increasing from 1942 to 1949 when Lake Geneva was estimated to reach a high water level of 109.1 ft. In addition, a drop of 20 ft was recorded in Lake Brooklyn levels in 1957, whereas the rainfall decay model predicted an 18-ft drop (Figure 9).

Summary and Conclusions

The evaluation of the predicted long-term lake levels indicates that lake levels are highly correlated with long-term climatic cycles and that the current conditions likely represent conditions experienced during the droughts from 1910 to 1920 (Figure 10). The analysis also reveals that the oscillating wet-dry periods are consistent with the AMO climate cycle presented by Enfield et al. (2001), and lake levels are unlikely to return to the levels recorded in the early 1970s over the next 15 to 20 years, even in the absence of anthropogenic influences. Hindcasting historical lake levels results in a better understanding of long-term water level fluctuations. Recognizing correlations between long-term climate cycles and lake levels can help water management districts improve their methodologies for establishing return intervals for MFLs.

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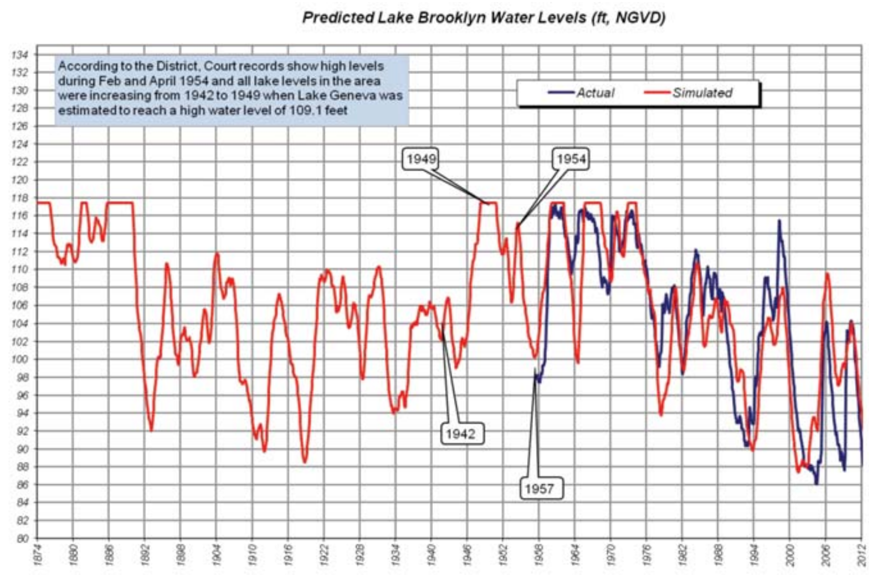

Figure 9. Modified Rainfall Memory Factors Model Results

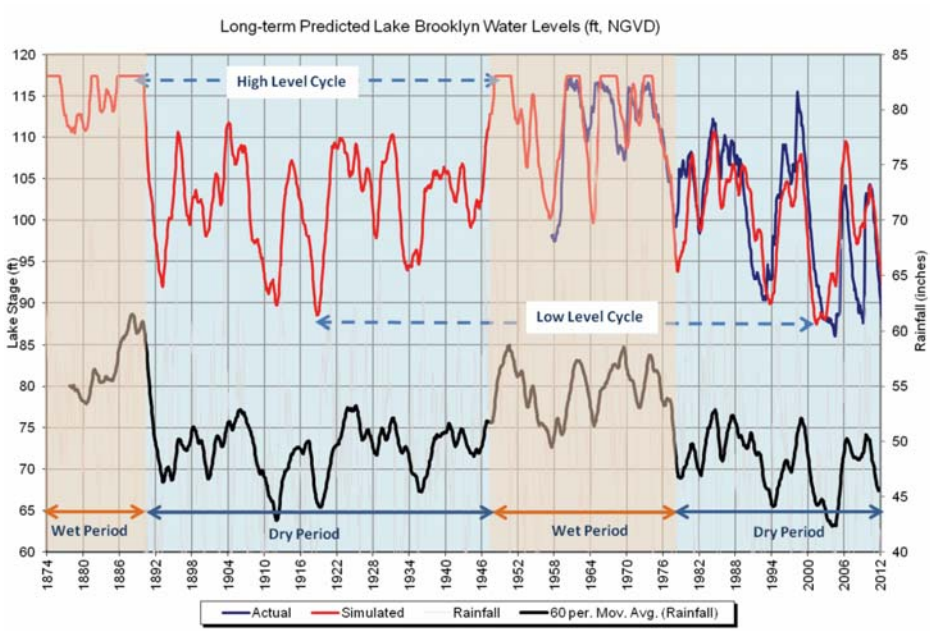

Figure 10. Long-Term Observed and Predicted Water Levels and 60-Month Moving Average Rainfall