ANALYZING THE EFFECTS OF THE SALUDA DAM ON THE SURFACE-WATER HYDROLOGY OF THE CONGAREE NATIONAL PARK FLOODPLAIN, SOUTH CAROLINA

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Abstract. The Congaree National Park includes extensive swamps of old growth bottomland hardwood forest. Since 1930, the Congaree River (created by the confluence of the Saluda and Broad Rivers) has been influenced by regulation of the Saluda Dam on the Saluda River. Many ecologists and water-resource managers have hypothesized that the regulated flows on the Saluda River have substantially decreased the magnitude and frequency of flooding of the riparian wetlands in the Park.

To evaluate the effect of the dam on the flow and water levels of the Congaree River, the U.S. Geological Survey, in cooperation with the National Park Service, analyzed the historical data of the Saluda, Broad, and Congaree Basins. Results from the study show that the Saluda Dam had much more of an effect on low and medium water levels than high water levels. The dam increased monthly minimum river stages by up to 23.1 percent and decreased monthly maximum river stage by up to 7.9 percent. Analyses of annual peak flows indicated that changes in the magnitude and frequency of floods on the Congaree River for pre- and post-regulation periods may be more related to climatic variations rather than changes in regulation of the Saluda River basin.

INTRODUCTION

The Congaree National Park (CNP) is located along the north bank of the Congaree River, 25 miles downstream from the confluence of the Saluda and Broad Rivers. The CNP includes extensive swamps of old growth bottomland hardwood forest. Since 1930, the Congaree River has been regulated by the Saluda Dam on the Saluda River, which impounds Lake Murray, and to a lesser extent, by small dams on the Broad River.

Many ecologists and water-resource managers have hypothesized that the regulated flows on the Saluda River have substantially decreased the magnitude and frequency of flooding of the riparian wetlands in the CNP. A previous investigation compared the magnitude and frequency of floods for two different periods at U.S.

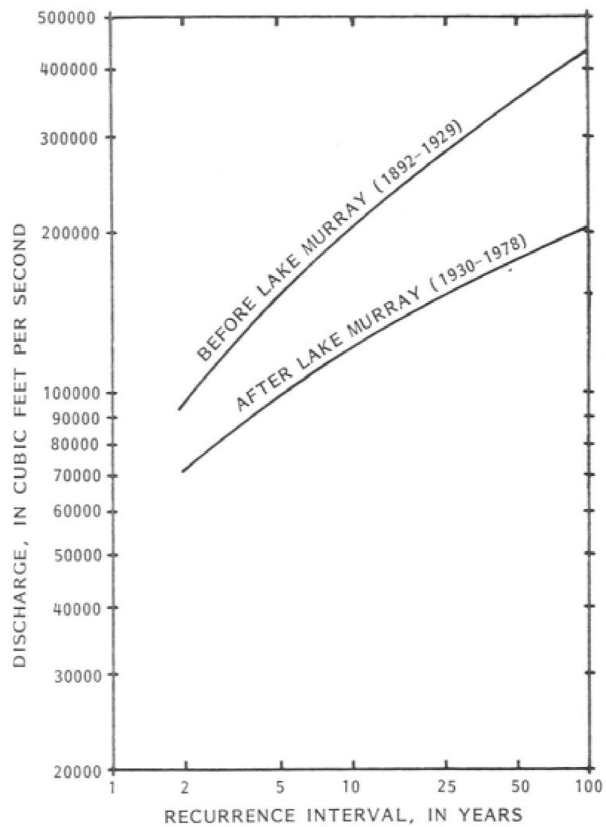

Figure 1. Flood frequency for Congaree River at Columbia, S.C. (from Whetstone, 1982).

Geological Survey (USGS) stream-flow gaging station 02169500, Congaree River at Columbia, S.C. (Whetstone, 1982; Patterson and others, 1985). The two periods analyzed were: 1) 1892-1929, representing the period before the construction of Lake Murray (pre-regulation); and 2) 1930-1978, representing the period after construction of Lake Murray (post-regulation) (fig. 1).

Patterson and others (1985) presented figure 1 with information suggesting that the operation of the Saluda Dam had significantly affected the magnitude and frequency of floods at stream-flow gaging station 02169500. As an example, the report stated that the 2-year recurrence-interval flow for the pre-regulation period was equivalent to a 4.5-year recurrence-interval flow for the post-regulation period. It also stated that a 5-year recurrence-interval flow for the pre-regulation period equated to a 25-year recurrence-interval flow for the post-regulation period. Following that same line of reasoning and examining figure 1, it would appear that the 10-year recurrence-interval flow for the pre-regulation period would equate to something beyond the 100-year recurrence-interval flow for the post-regulation period. Thus, without being explicitly stated, the implication was that construction of the Saluda Dam had significantly altered flooding in the Congaree River, and subsequently in the CNP. However, current statistical analysis of the data along with comparisons of other long-term USGS streamflow gaging stations indicates otherwise.

APPROACH

Data mining is an emerging field that addresses the issue of converting large databases into knowledge (Weiss and Indurkhya, 1998). Data-mining methods come from different technical fields such as signal processing, statistics, and machine learning from the science of artificial intelligence. The artificial neural network (ANN) models used in this study are a form of machine learning. This knowledge encompasses both understanding of cause-effect relations and predicting the consequences of alternative actions.

There is a long-term USGS hydrologic database for the Saluda, Broad, and Congaree Rivers. The database is a valuable resource for analyzing flow conditions before and after the construction of the Saluda Dam. Additionally gaging station 02191300, Broad River above Carlton, Ga. (Broad River-GA), an unregulated stream in the Piedmont physiographic province in Georgia was used for comparative purposes.

ANALYSIS OF PEAK FLOWS

For comparison purposes, peak-flow records from Congaree Columbia were compared with Broad River-GA, an unregulated stream with similar length of record. Peak-flow data from Congaree Columbia and Broad River-GA, show a similar period of high flows in the beginning of the 1900s.The largest peaks at Congaree Columbia occurred in water years 1908, 1912, 1916, 1928, 1930, and 1936. Because the Saluda Dam was completed in 1930, one could assume that the reason only one major flood (1936) has occurred at Congaree Columbia since that time is because of regulation on the Saluda River.

The Broad River-GA gage has a drainage-basin size of 760 square miles (mi^2), is completely located in the Piedmont region of Georgia, and is located approximately due west of Columbia, S.C. The largest floods occurred in 1902, 1908, and 1912. Through water year 2005, there are 107 years in which peaks were measured at both gaging stations. Of those 107 years, there were 47 years in which the peaks were concurrent within plus or minus 8 days. Another 16 peaks were concurrent within one month suggesting similar climatic characteristics between the two basins and giving additional validity for comparing the two stations. The similarities between the peak-flow data at these two stations indicate that the differences in the pre- and post-Saluda Dam recurrence-interval flows on the Congaree River may have more to do with varying climatic conditions than regulation of the Saluda River.

Regression Analysis Using Historical Peak-Flow Data

In an effort to quantify how regulation on the Saluda River has affected peak flows on the Congaree River, MOVE.2 regression techniques (Hirsch, 1982) were used to develop pre-regulation relations between the peak flows at Congaree Columbia and Broad River-SC. For the period from 1897 to 1928, there were 13 years for which peak flows were measured at both the Congaree Columbia and Broad River (SC). The correlation coefficient between the peaks was 0.99. Because the regression was done using the period from 1897 to 1928, it defines the relation between the peak flows on the Congaree and Broad Rivers as they were prior to regulation on the Saluda River.

The regression was used to synthesize peaks for Congaree Columbia as they would have existed at Congaree Columbia for unregulated conditions on the Saluda River. A log-Pearson Type III analysis was then made using the synthesized peaks for the Congaree River

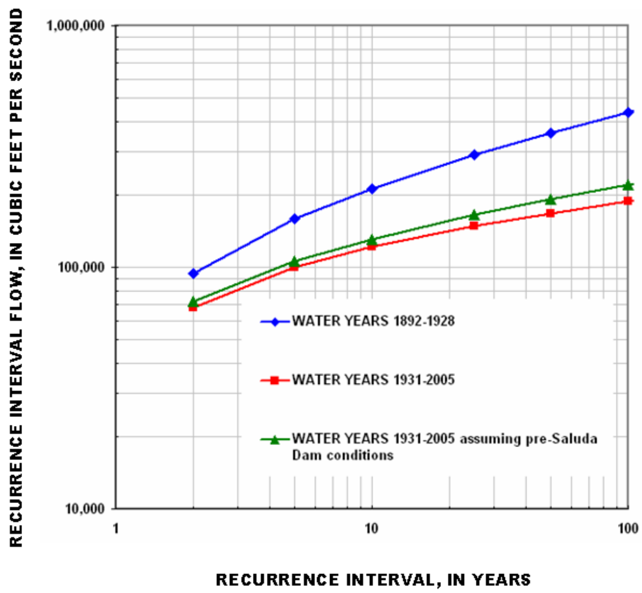

Figure 2. Comparison of recurrence-interval flows at Congaree Columbia computed using measured peak-flow data for water years 1892-1930 (blue line and symbols) and 1931-2005 (red line and symbols) and using synthesized peak-flow data for water years 1931-2005 (green line and symbols).

gage and was compared with results from the similar analysis using the measured peaks (fig. 2).

Figure 2 shows that the magnitude and frequency of floods have been affected by regulation of the Saluda River but not to the extent that previous publications had suggested. The 2-year to 100-year recurrence-interval flows computed from the measured and synthesized data and the percent differences ranged from 6.1 to 17.6 percent. Thus, this analysis indicates that the significant difference in the magnitude and frequency of floods when computed using measured data at Congaree Columbia for the periods before and after the construction of the Saluda Dam are primarily the result of the major floods that occurred in the early 1900's. Floods of these magnitudes have not been experienced in the Congaree River basin in the last seven to eight decades.

ANALYSIS OF DAILY GAGE HEIGHTS

To integrate the pre-dam flow data with the contemporary gage data at Congaree CNP, artificial neural network (ANN) models were developed to generate a 75-year synthetic flow hydrograph for the Saluda Columbia gage without the dam and 75-year synthetic gage height hydrograph for the Congaree CNP gaging station with and without the effects of the dam. The type of ANN used for this investigation was the multi-layered perceptron described by Jensen (1994), which is a multivariate, non-linear regression method based on machine learning.

The simulation of 75-year "dam" and "no-dam" conditions were developed using a series of two cascading models where the output of the first model is used as input to the second model. The first model, the pre-dam model, simulated the Saluda Columbia flows using the pre-dam dataset from October 1926 to August 1929. Two variables were used as input to the ANN model – the 2-day moving window average of flow and the 3-day change in flow at Saluda Chappells. The dataset was divided into training and testing datasets with 26 vectors in the training dataset and 1,063 vectors used to evaluate the model. The coefficient of determination (R^2), the mean error (ME), root mean square error (RMSE), and percent model error (PME) for the testing datasets are 0.88, -134 cubic feet per second (ft^3/s), 2,137 ft^3/s, and 3.8 percent(%), respectively. The PME was computed by dividing the RMSE by the range of the measured data.

The second model simulates the gage height for the Congaree CNP gage using flow inputs from the Saluda Columbia and Broad River-SC gages. To develop a representative empirical model, the optimal time delays (lags) of input variables, or explanatory variables, on a response variable were determined. For the flow inputs from the Saluda and Broad Rivers, it was determined that a 1-day delay (or lag) and a 3-day moving window average was the optimum signal transformation for the highest correlation for both flow inputs to the Congaree CNP gage height. For the input to the Congaree CNP gage-height model, a 1-day lag and 3-day moving window average was applied to the Saluda Columbia and Broad River-SC flow data, and the resulting time series were summed for input to the model.

The dataset for the Congaree CNP gage height model was randomly divided into training and testing datasets. Approximately 25 % of the data (1,456 vectors) was used to train the ANN model and 75 % of the data (4,502 vectors) was used to test the model. The Congaree CNP gage height model captures the overall trend of measured data, but is unable to simulate the extremes of the range of gage heights, especially the low gage height. Overall, the testing dataset for the Congaree CNP gage height model has a percent model error of 4.2 % and the R^2, ME, RMSE were the testing dataset for 0.95, -0.3 feet (ft), and 0.86 ft, respectively.

Application of the Models and Results

The models were used to evaluate the effect of the operation of the Saluda Dam on the gage heights at Congaree CNP. Two 75-year simulation gage-height hydrographs were generated using the measured Saluda Columbia flow data and a simulated hydrograph of the Saluda Columbia flow data using the “Without dam” model scenario. The simulated hydrographs were compared for changes in the magnitude, timing, and duration of gage heights at the Congaree CNP gage. It should be noted that the simulated “Without dam” hydrograph is not completely unregulated because of the regulated flows at the Saluda River Chappells gaging station from the upstream operations of the Lake Greenwood dam.

The frequency distribution curves of the two 75-year hydrographs show that the overall effect of the dam is to increase the occurrences of low to medium gage heights and to decrease the occurrence of medium to high gage heights (fig. 3). The two frequency curves cross at a gage height of 8.5 ft. Figure 3 shows that for the “With dam” scenario, more daily mean gage heights occur at or below 8.5 ft (the lower gage heights increase) and fewer occur above 8.5 ft (the higher gage heights decrease). For example, for the “Without dam” simulation, 79.2% of the daily mean gage heights are less than or equal to 12 ft (20.8% are greater than 12 ft). For the “With dam” data, 83.2% of the daily mean gage heights are less than or equal to 12 ft (16.8% are greater than 12 ft). Therefore, for the “With dam” dataset as compared to the “Without dam” dataset, there are fewer daily mean gage heights that are less than or equal to 4.0 ft (the lower gage heights increased). Conversely, for the “Without dam” simulation, 20% of the daily mean gage heights are less than or equal to 4.0 ft; whereas, for the “With dam” data, only 13.6% of the daily mean gage heights are less than or equal to 4.0 ft.

Hydroecological Indices. Differences in gage height

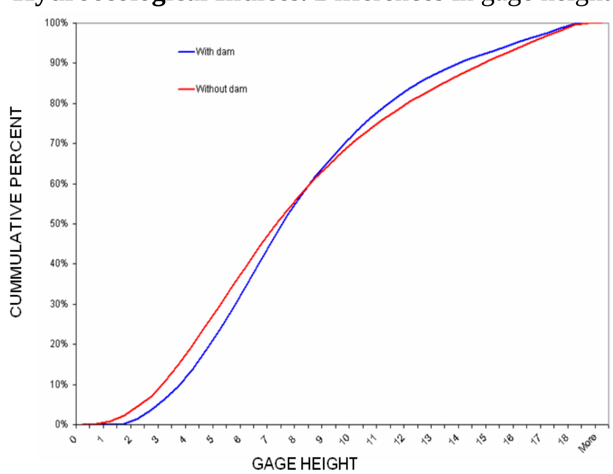

Figure 3. Frequency distribution curves for daily simulated gages heights for the Congaree River CNP gage for the period October 1929 to September 2005.

Table 1. Monthly change in percent from a "Without dam" condition for minimum, mean, and maximum gage heights.

Month	Minimum (percent)	Mean (percent)	Maximum (percent)
January	-12.7	-7.4	-3.8
February	-11.1	-7.2	-3.6
March	-11.1	-9.2	-3.1
April	-14.3	-10.0	-6.0
May	-6.2	-7.2	-7.9
June	4.4	3.8	-1.1
July	15.6	12.6	5.1
August	22.2	15.8	5.5
September	23.1	18.5	6.7
October	19.7	13.6	6.3
November	10.9	8.3	3.1
December	-0.8	-1.5	-4.3

characteristics also can be analyzed by determining hydroecological indices of the “With dam” and “Without dam” hydrographs. Substantial research has been done over the last decade on the ecological importance of streamflow characteristics and the ecological integrity of natural flow conditions (Richter and others, 1996; Poff and others, 1997). Typically, hydroecological indices characterizing the magnitude, frequency, duration, timing, and rate of change of flows of pre-impoundment and post-impoundment streamflow records are computed and compared. The 75-year synthetic gage height record at Congaree CNP was used to compute hydroecological indices using the National Hydroelological Integrity Assessment Software (Henriksen and others, 2006). Of the 171 indices computed by the software, 56 were selected to quantify the percent change in the temporal magnitude, frequency magnitude, duration, and timing of the two synthetic gage-height hydrographs.

The monthly minimums, means, and maximum gage heights were determined for the 75-year hydrographs and the percent change from the “Without dam” were computed to evaluate the change in temporal magnitude (table 1). The monthly mean values show that the dam decreased mean gage height between December and May by as much as 10 percent whereas the monthly mean gage heights with the dam have increased by as much as 18.5 percent between the months of June and November. Readers interested in the results on the duration and timing of the two synthetic gage-height hydrographs are referred to Conrads and others (2007).

SUMMARY AND DISCUSSION

A common perception of the effect of the Saluda Dam on the Congaree National Park was that the dam had significantly reduced the frequency and magnitude of peak flows (and gage heights) and the ecological benefits of periodic inundation of the CNP floodplain. Although not explicitly expressed in Patterson and others (1985), the two flood-frequency curves in the report for pre- and post-impoundment floods implied a large decrease in the frequency and magnitude in flood flows, affecting the understanding of many hydrologists and ecologists on the impact of the Saluda Dam.

Analysis of peak flows in this study indicated the reduction in peak flows after the construction of Lake Murray and the Saluda Dam was more a result of climate variability and the absence of large floods after 1930 than the operation of the dam. The analysis for this study showed that the recurrence interval of the 2-year to 100-year peak flows were reduced 6.1 to 17.6 percent, respectively. Analysis of the daily gage height of the Congaree River showed that the dam has had the effect of lowering high gage heights in the first half of the year (December to May) and raising low gage heights in the second half of the year (June to November).

REFERENCES

Conrads, P.A., Feaster, T.D. and Roehl, E.A., Jr., 2007, Separating anthropogenic influences on hydrology using data mining techniques – A case study of the Congaree National Park, South Carolina, Water Environment Federation Technical Exhibition Conference 2007, San Diego, California, October 2007

Henriksen, J. A., Heasley, J. Kennen, J.G., and Niewsand, S., 2006, Users' manual for the Hydroecological integrity assessment process software (including the New Jersey Assessment Tools): U.S. Geological Survey, Biological Resources Discipline, Open File Report 2006-1093, 71 p.

Hirsch, R.M., 1982, A Comparison of Four Streamflow Record Extension Techniques: Water Resources Research, Vol. 18, No. 4, pages 1081-1088.

Jensen, B.A., 1994, Expert systems - neural networks, Instrument Engineers' Handbook, Third Edition, Chilton, Radnor PA.

Patterson, G.G., Speiran, G.K., and Whetstone, B.H., 1985, Hydrology and its effects on distribution of vegetation in Congaree Swamp National Monument, South Carolina: U.S. Geological Survey Water-Resources Investigations Report 85-4256, 31 p.

Poff, N.L, Allan, J.D., Bain, M.B., Karr, J.R., Presetegaard, K. L, Richter, B.D., Sparks, R.E., Stromberg, J.C., 1997, The natural flow regime, Bioscience, vol. 47, p. 769-784.

Richter, B.D., Baumgartner, J.V., Powell, J., and Braun D.P., 1996, A method for assessing hydrologic alteration within ecosystems, Conservation Biology, vol. 10: P 1163-1174.

Whetstone, B.H., 1982, Techniques for estimating magnitude and frequency of floods in South Carolina: U.S. Geological Survey Water-Resources Investigations Report 82-1, 78 p.

Weiss, S.M. and Indurkhya, Nitin, 1998, Predictive data mining-a practical guide, Morgan Kaufmann Publishers, Inc., San Francisco, 228 p.