WRP Technical Note HY-IA-2.2
May 1994

Time Scale Analysis Can Assess Hydrologic Cumulative Impacts

PURPOSE: This note describes an aid for assessing cumulative impacts on wetlands. Certain analysis techniques are employed to reveal time-frames when disruption to basic flow patterns may have occurred. This information is significant when attempting to perform cumulative impact analysis (CIA).

BACKGROUND: Water-level patterns largely determine the nature of wetlands. Therefore, studies of historic water trends associated with wetlands should explain causes-and-effects operating on wetlands and the resulting landscape/ biotic composition. Keys to characterizing historic water-level trends are called "hydrologic indices."

SIMPLE INDICES SAMPLE: Hydrologic indices may be categorized as either simple or complex. Simple indices are easy to compute and include parameters such as mean, median, and range of flows. However, these indices often fail to describe adequately periodicity, seasonal behavior, or evolution of stream character resulting from land-use changes and channelization.

Despite obvious limitations, such simple indices can reveal important features of streamflow and how they compare with those of other streams in the same basin. These simple indices can also give clues regarding the timing of historic, momentous events, such as the abrupt decrease of the monthly maximum flow in the Little Red River record (1961) shown in Figure 1 with records of other selected streams in the White River Basin (Arkansas/Missouri).

The effects of more subtle but perhaps no less profound impacts may be better detected and quantified using indices that are somewhat more complicated to derive but which may yield more insight into cumulative impact analysis. One such index, time-scale analysis, is given here. Another index, harmonic analysis, is treated in WRP Technical Note HY-IA-2.1.

TIME-SCALE ANALYSIS INDEX: Time-scale analysis compares relative "short-term" vs. "long-term" fluctuation in stage/levels of flow. This index relies on the theory of fractals (Peitgen and Richter 1986, Turcotte 1992), specifically that seemingly complex physical patterns such as daily stream flow vary in much the same way in a short period (few days) as in a longer period (many days)--the same shape is found at another place in another size. (The respective time periods are "self-similar").

An important fractal property, the fractal dimension, is commonly obtained using a "method of rulers." In this approach, progressively larger rulers are used to measure the perimeter of physical feature. A straight-line relationship between the common logarithm of both ruler length and perimeter is indicative of strong fractal properties. The slope of this line is termed the "fractal dimension." This relationship implies that a single underlying pattern is being repeated, but at different scales, within the feature.

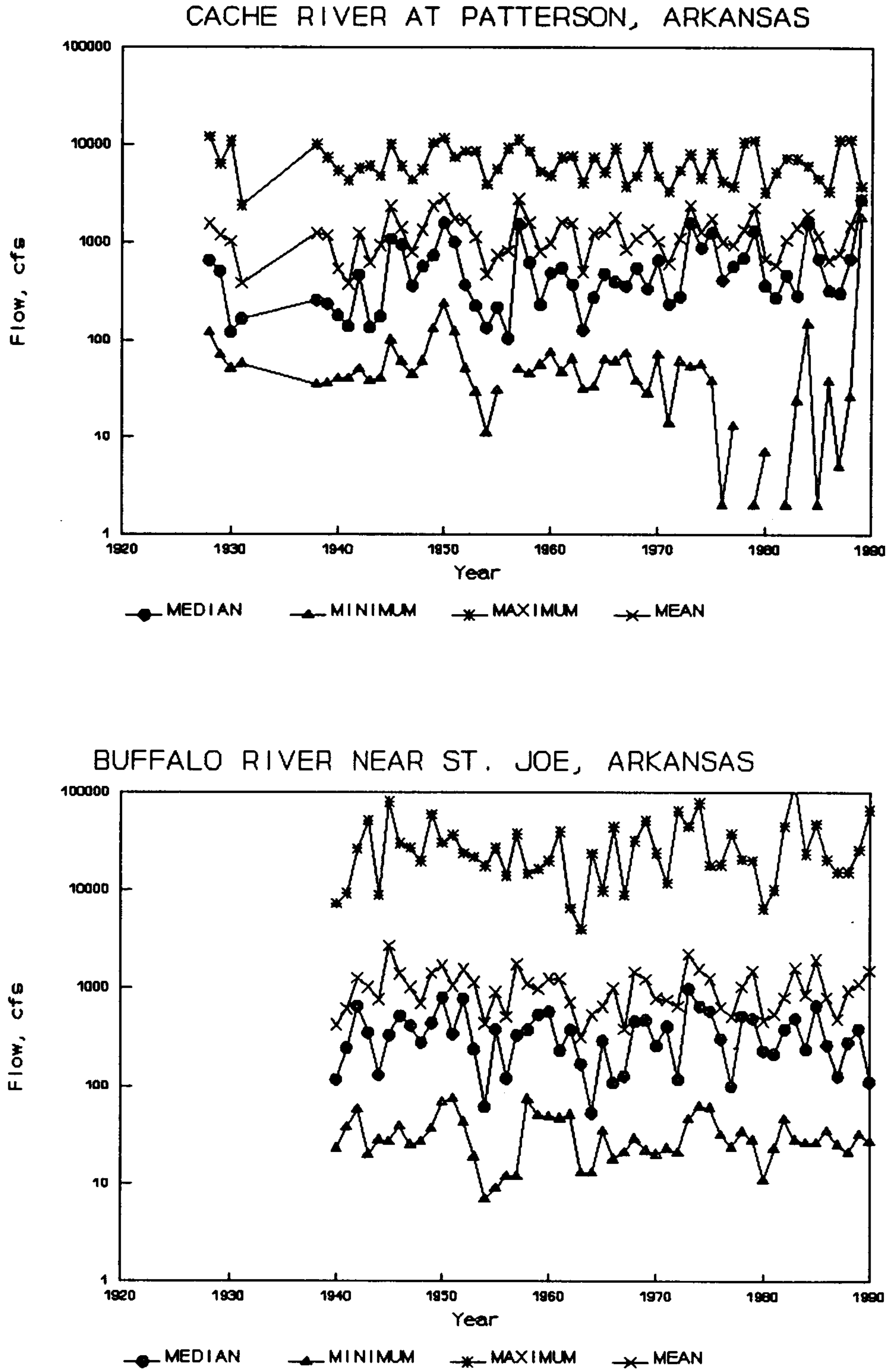
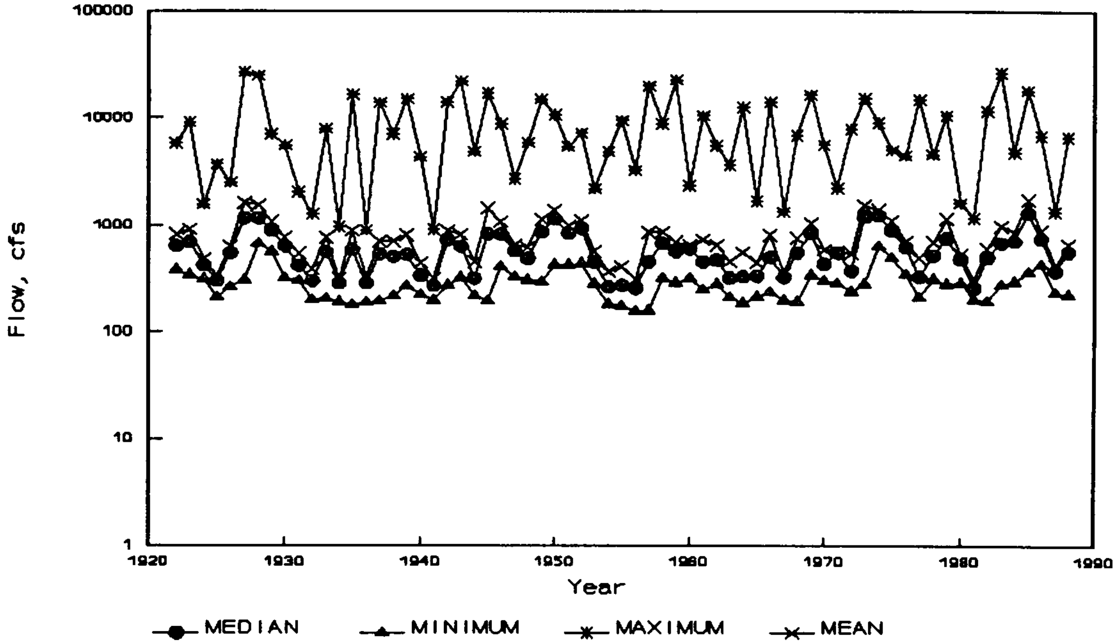


Figure 1. Yearly medians, minima, maxima, and means of selected steamflows in the White River Basin (Arkansas/Missouri). Note that the scale of flow is logarithmic and that recording periods do not include some years


ELEVEN POINT RIVER NEAR BARDLEY, MISSOURI

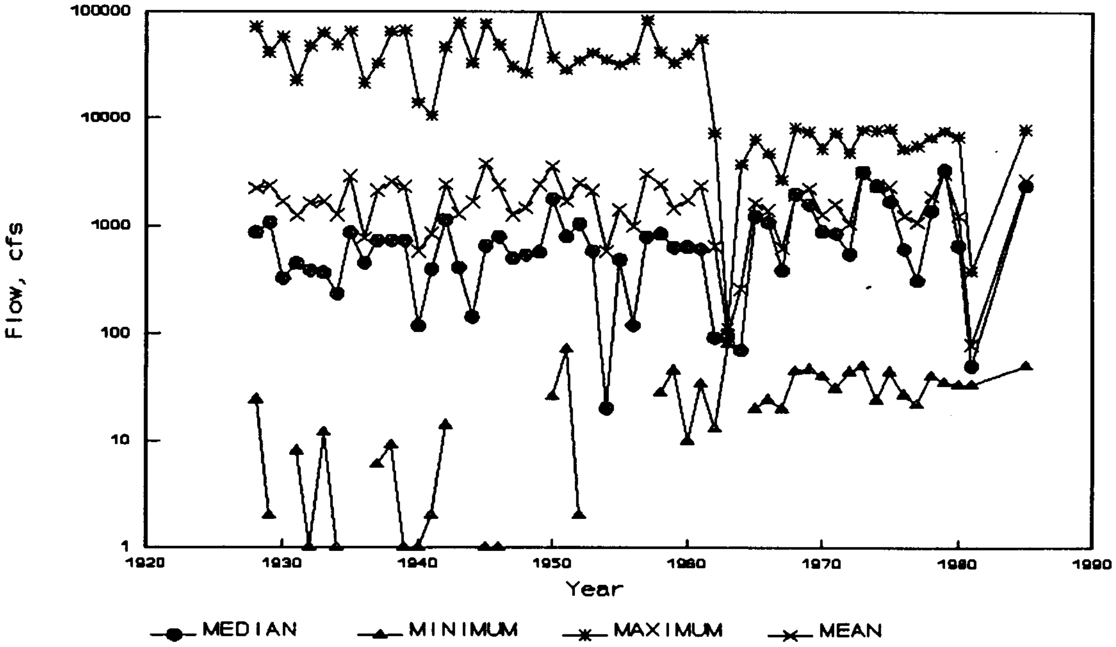

LITTLE RED RIVER NEAR HEBER SPRINGS, ARKANSAS

Figure 1. (Concluded)

Hydrologic time series are known to exhibit fractal properties (Changnon et al. 1991). For the Cache River application, these properties were described using discharge averages, "time dimension," based on different durations instead of rulers of different lengths, "distance dimension." The concept of evaluating information lost as a function of the resolution of measure is similar. Mean monthly flows were calculated for the period of record. Daily flows were then simulated by linear interpolation between adjacent months. The error between the synthesized daily flows based on monthly means (long-term) and the measured daily (short-term) flows represents primarily the contribution of hydrologic processes that occur at a duration greater than one day and less than one month. Examination of these errors between different basins or between different time periods at one site can provide insight into the dynamics of hydrologic processes that operate for a duration of less than one month.

The concept can be expanded to generate synthesized (simulated) daily flows based on many different time durations. The error between each of the synthesized daily flows and the measured daily flows represents the relationship between the different hydrologic processes that blend together to generate a hydrograph. Long-term trends in these errors indicate changes in the relative contribution of different hydrologic processes to the site hydrograph. As part of cumulative impact analysis, this information provides a partial hydrologic explanation for the results obtained using the simple indices and the harmonic analysis.

Complex hydrologic conditions can be quantified by using "root-mean-square error" (RMSE), resulting in measurement units identical to those of the original data, i.e., cubic feet per second (cfs).

Root mean square error (RMSE) calculated as

$$\text{RMSE} = \left[\frac{\sum (S_{i+1} - S_i)^2}{\text{NOBS}} \right]^{1/2}$$

where

S - (synthesized daily discharge based on successive time scales), and
NOBS - (number of observations)

is used to measure errors between recorded and synthesized daily flows based on different durations. By computing the RMSE of the same period lengths with individual daily flow values over decades, one can often identify the time frame in which some profound event affected flows.

Obvious departures from a prevailing trend can be observed in records of streams that have been impounded. For example, the Little Red River near Heber Springs or the Missouri River at Randall Dam (Fig. 2) had RMSE values that decreased markedly after the impoundment. In contrast, the RMSE of the low flow values (<200 cfs) of the Cache River at Patterson, *increased* considerably in later decades, implying a "flashier" (less damped flow) stream than was the case earlier in the century (Fig. 3). This information could provide an important clue regarding where, when, and what change(s) made the difference.

Behavior of the respective RMSE compared decade by decade for several different streams in a region may denote a localized or a global effect regarding short-term vs. long-term fluctuations in flow (Fig. 2). This tool may also be employed on certain flow levels, such as demonstrated with the

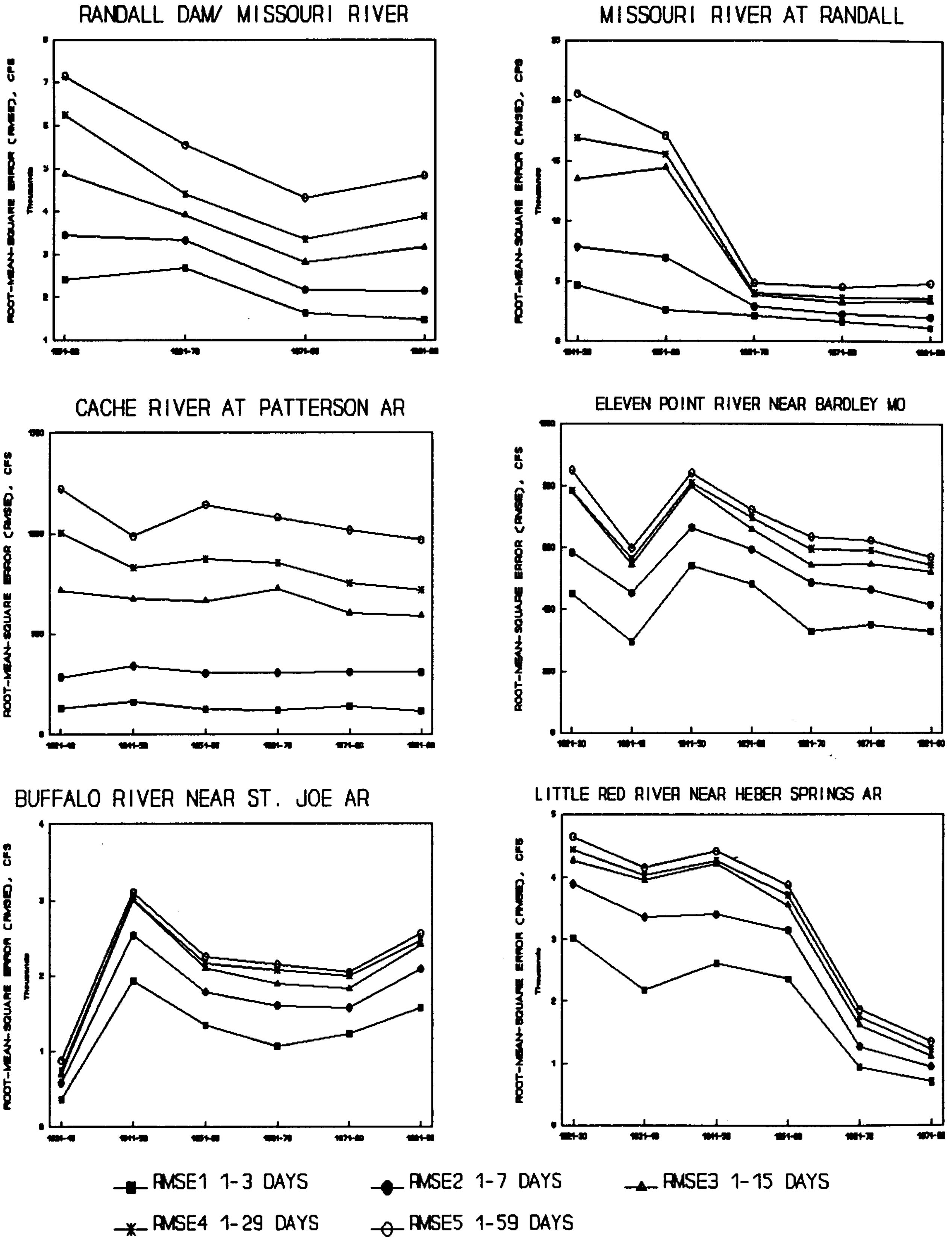


Figure 2. Comparison of respective root-mean-square errors (RMSE) of streams examined with time-scale analysis

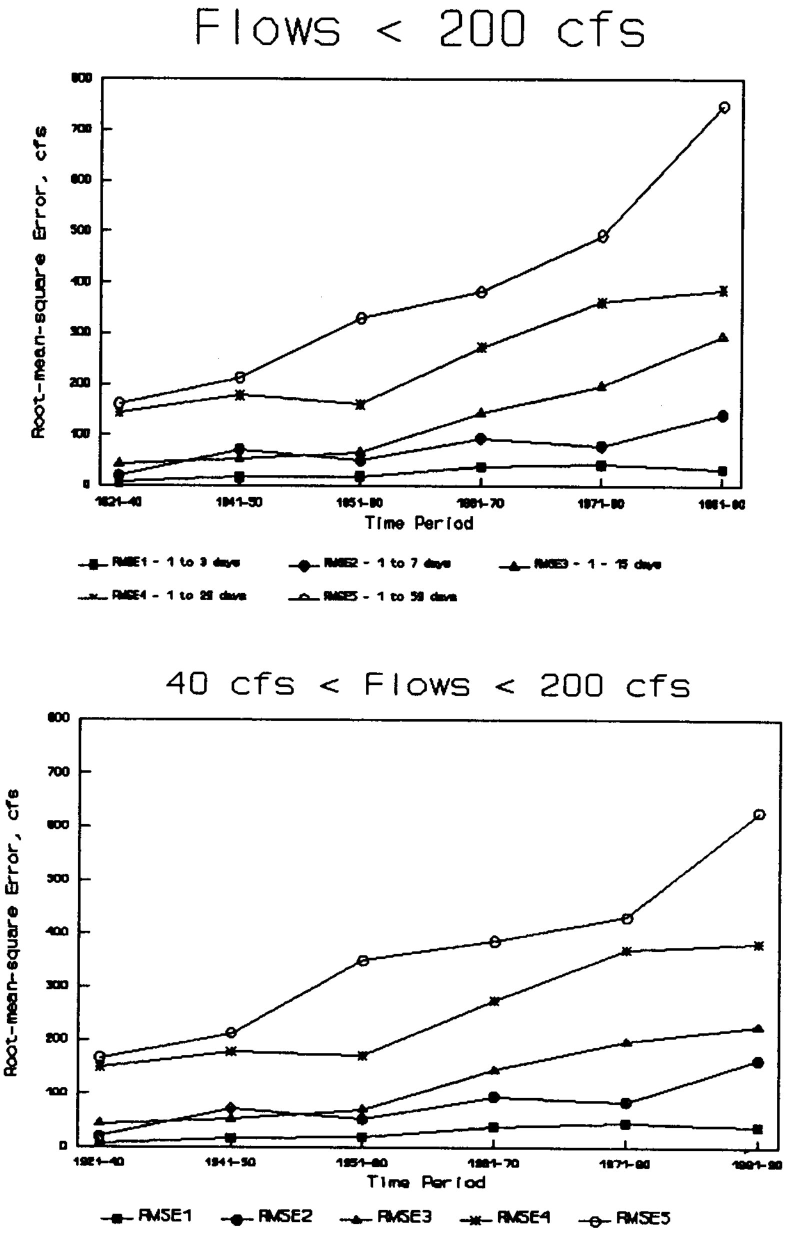


Figure 3. Comparison of root-mean-square error (RMSE) of flows less than 200 cfs of the Cache River at Patterson, Arkansas, with (above) and without (below) flows less than 40 cfs to investigate effects of different recording methods

Cache River flow records (Fig. 3) to explain changes in the lower ranges of flows when level of base flow is of primary interest, e.g., the maintenance of a groundwater level necessary for a particular wetland. No significant changes in the nature of stream flow should yield similar RMSE's for each of the time intervals (days). Additionally, time-scale analyses allow looking at the possible effects of differing recording methods on overall flow analyses. With the recent advent of unattended, automatically recording gages, there might be reason to suppose that more recent measurements might be considered more reliable than earlier ones. Upon examining the record of the Cache River at Patterson, it was observed that low flows seemed to be set at a default value of no less than 40 cfs. Hence, one analysis excluded values less than 40 cfs to see if this suspected "artifact" affected overall results. Examining records with errors summarized and compressed such as one may see in Figure 3 reveals only slight deviation in RMSE when recorded values less than or equal 40 cfs were deleted. Thus, even if the values had been estimated, the effect on results was minimal given the expanse of the study of low flows of the Cache River at Patterson, AR. Simple linear regression on the respective RMSEs of the sets with and without lower values, were correlated.

CONCLUSION: Time-scale analysis is a technique offering promise for assessing cumulative impacts on wetlands. Streamflow (as well as groundwater) records available in many locales, often spanning many years, may yield up a treasure of clues defining present wetlands whose current conditions have been dictated, at least in part, by historic water conditions. In conjunction with land-use practice histories and remote sensing records of present and past conditions, these tools can contribute to cumulative impact analysis integral to overall planning, management, and protection of valuable, dwindling wetland resources.

Data provided by EarthInfo, Inc., U.S. Geological Survey, and the U.S. Army Engineer Districts were used in the formulation and validation of the techniques presented.

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