MEASURING HYDROLOGIC DROUGHTS IN THE APALACHICOLA-CHATTAHOOCHEE-FLINT RIVER BASIN

Zhi-Yong Yin

AUTHOR: Assistant Professor, Department of Geography, Georgia State University, Atlanta, Georgia 30303.
REFERENCE: *Proceedings of the 1993 Georgia Water Resources Conference,* held April 20 and 21, 1993, at The University of Georgia, Kathryn J. Hatcher, Editor, Institute of Natural Resources, The University of Georgia, Athens, Georgia.

INTRODUCTION

Hydrologic drought is a period of inadequate streamflow to supply established uses (Dracup et al., 1980). In terms of water resources management and planning for a metropolitan area, hydrologic drought is by far the most relevant definition of droughts. When the main source of water supply is surface water, such as in the Atlanta metropolitan area, the severity of hydrologic droughts is best indicated by streamflow or lake level. However, most continuous streamflow records only extend back to the 1930s or even more recent dates. Short data records may impose serious difficulties in frequency analysis for droughts. During the 30-year period 1960 to 1990, for example, only 3 or 4 severe droughts occurred in the upper Chattahoochee River. A common approach to extend streamflow records is to construct a runoff model using climatic data. As monthly streamflow values should provide enough temporal resolution for drought studies (Dracup et al., 1980), simple water balance models can be used. When high quality data are not available, simple models can actually perform equally well as more sophisticated models (World Meteorological Organization, 1975).

In this study, a monthly water balance model will be constructed and calibrated for various sections of the Apalachicola-Chattahoochee-Flint River (ACF) basin. Then a hydrologic drought index is designed for the Atlanta area considering the current water use demand.

METHODS

The model (ACFWB model) has a structure similar to the Thornthwaite water balance model (Thornthwaite and Mather, 1957) and uses monthly temperature and precipitation data for climate divisions. Such data are readily available and continuous from 1895. Runoff estimated by this model is free of the effect of dam regulation. Therefore, it provides the baseline for comparison when the effects of dam regulation or climatic changes are examined. Although the model can be applied to various sections of the ACF basin, the focus of this study is the upper Chattahoochee River basin above Atlanta (Figure 1). The program is written in Turbo Pascal (Borland International, 1990) and runs on IBM-compatible microcomputers.

Model calibration criteria include the mean and standard deviation for the calibration period, coefficient of determination of linear regression (r^2), root-mean-square-error (RMSE), and the coefficient of efficiency (CE) as described by James and Burges (1982):

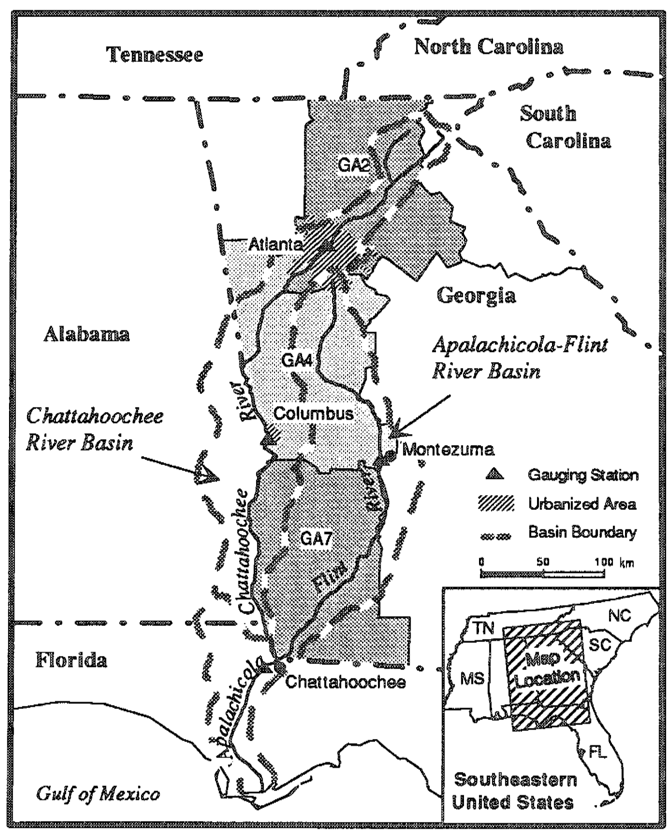

Figure 1. The Apalachicola-Chattahoochee-Flint River basin and the three climate divisions.

$$CE = 1 - \frac{\sum_{i=1}^{N} (Qs_i - Qm_i)^2}{\sum_{i=1}^{N} (Qm_i - \overline{Qm})^2} ;$$

where Qs_i is simulated runoff, Qm_i is measured runoff, and $\overline{Qm}$ is the mean measured runoff. If the two time-series are entirely synchronized, then the value of CE will be 1.0. Low or negative values indicate large errors. Besides verifying the model using the measured streamflow data, the model was also be compared with the Thornthwaite model and Palmer's drought indices.

Based on the definition of hydrologic drought (Dracup, et al., 1980), a given water demand must be specified. In developing a hydrologic drought index, monthly runoff values (R) are first standardized by the required minimum runoff (R_{min}) as $(R-R_{min})/R_{min}$. To incorporate the effect of drought duration, the negative values of the standardized runoff are cumulated. A drought is ended when there are at least two consecutive months with positive standardized runoff values or when the positive standardized runoff value is large enough to equalize the cumulative negative index value. Also, a drought event should last at least two months. During the non-drought period, the index value is zero.

RESULTS AND DISCUSSION

Model Calibration

The values of the calibration criteria for the optimal model parameter are listed below.

Parameter	Value
r^2	0.77
RMSE	14.7
CE	0.77
Simulated Mean	49.4
SD	29.2
Measured Mean	49.4
SD	31.3

The model performed well for the period before 1956 (Figure 2). For the period 1928-1936, 80% of the variation in the measured runoff is explained by the estimated runoff in linear regression. For the period 1928-1955, 78% of the variation in measured runoff is explained. After passing the data with a 3-month linear filter (0.3, 0.4, and 0.3 for t-1, t, t+1), the estimated values become more synchronized with the measured values (Figure 3). However, the filtered series still mainly display seasonal variations. Therefore, this filter may not be very useful in identifying extended droughts. When the model was calibrated in other sections of the ACF basin at Columbus and Montezuma, GA, and Chattahoochee, FL, similar performance was obtained.

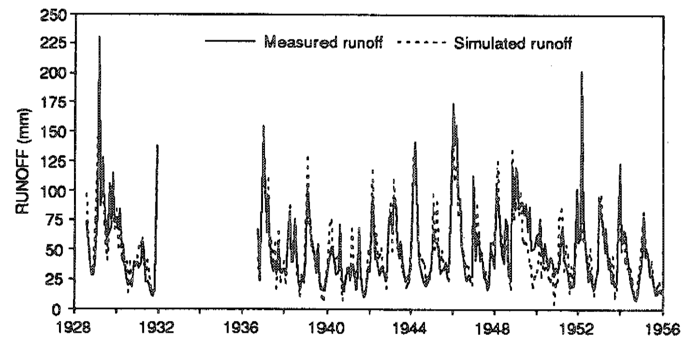

Figure 2. Estimated and measured monthly runoff in the Chattahoochee River Basin above Atlanta during 1928-1955.

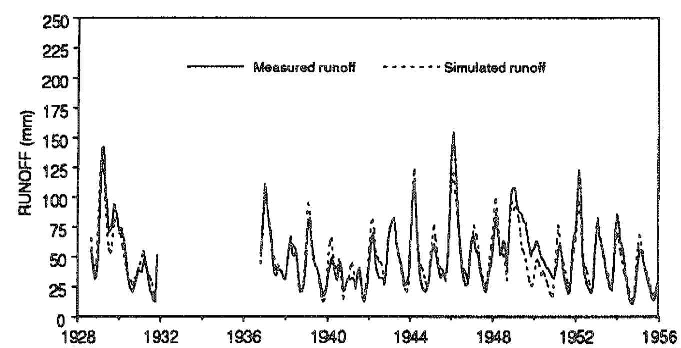

Figure 3. Estimated and measured monthly runoff in the Chattahoochee River basin above Atlanta after passing a 3-month filter, 1928-1955.

Comparison with Other Models

When simulating runoff of the upper Chattahoochee River basin using the Thornthwaite model, it is difficult to determine the available water capacity (AWC) due to the complex soil and vegetation conditions in the area. Therefore, AWC values from 50 mm to 300 mm were tested. A watershed lag of 0.5 was assumed, that is, 50% of the surplus is carried over to the following month while the rest contributes to the runoff. During the period 1937-1955, the highest r^2 value between the measured and estimated values was 0.67 (Table 1). The CE had negative values for all the AWC values tested, indicating large errors. The RMSE of the estimated runoff was also higher than the ACFWB model.

Palmer (1965) developed three drought indices. Z-Index is the Moisture Anomaly Index, describing soil moisture condition. PDSI is Palmer's Drought Severity Index, a meteorological drought index and PHDI is Palmer's Hydrologic Drought Index. During the period before 1955, the r^2 values between the measured runoff and the Palmer's drought indices were much lower than the r^2 value for the estimated runoff by the ACFWB model (Table 2). Even using the lagged monthly values (up to 3 months) of the Palmer's drought indices could not improve the r^2 values very much. The above results indicate that the ACFWB model can better characterize streamflow than both the Thornthwaite model and the Palmer's drought indices.

Long-Term Trends and Droughts During 1895-1988

After the runoff record at Atlanta was extended back to 1895, a 13-month filter was used to eliminate seasonality (Bloomfield, 1976). Sixty-one-month (5-year) moving averages were calculated to reduce short-term inter-annual variations. As shown in Figure 4, these filters seem to be effective in identifying extended droughts and long-term variation patterns. For example, the 1960s and 1970s are clearly wetter than other decades. This may be the result of both low temperature and high precipitation during this period. The droughts in 1981 and 1986 may have been among the worst in recent history. However, the long-term trend represented by the 61-month moving average seems only to return to the condition prior to the wet 1960s-1970s. In terms of the decadal average condition, the 1980s were probably no worse than the 1950s and 1930s in this area.

Table 1. Runoff Simulation Using the Thornthwaite Model during 1937-1955.

AWC (mm)	r^2	RMSE	CE	Simulated MEAN	Simulated SD
50	0.61	35.69	-0.31	48.1	54.2
75	0.62	35.01	-0.26	46.4	53.9
100	0.64	34.31	-0.21	45.2	53.5
125	0.66	33.87	-0.18	44.2	53.2
150	0.66	33.59	-0.16	43.5	53.0
200	0.67	33.28	-0.14	42.5	52.6
250	0.67	33.19	-0.13	41.9	52.5
300	0.67	33.10	-0.13	41.5	52.3

Table 2. Coefficient of Determination (r^2) in Regression Analysis between the Measured Runoff (dependent variable) and Palmer's Drought Indices during 1928-1955.

Independent Variable	Current and Lagged Months	(Multiple) r^2
PDSI	t	0.368
PHDI	t	0.314
Z-Index)	t	0.375
PDSI	t, t-1, t-2	0.406
PHDI	t, t-1, t-2	0.428
Z-Index	t, t-1, t-2, t-3	0.461
Estimated Runoff	t	0.783

In developing the hydrologic drought index for the Atlanta area, the minimum discharge to ensure water quality is considered. The minimum discharge at the Atlanta intake is 15 mm/month (750 CFS) (U.S. Army Corps of Engineers, 1981). This location is about 2 miles downstream of the gauging station and there is no major tributary inflow between the gauging station and the water intake. Therefore, the runoff at the Atlanta gauging station can be used to approximate the runoff at the Atlanta water intake. The maximum withdrawal allowed from the Chattahoochee River above Atlanta is 418 MGD or 13 mm/month of runoff (State of Georgia, 1987). In the worst scenario, e.g., all water withdraw is for consumptive uses, a minimum runoff (R_{min}) of 28 mm/month (15+13) is required at the gauging station to ensure both water supply and water quality. Then the hydrologic drought index was calculated as the cumulative negative values of the standardized runoff. The drought with the greatest severity occurred in 1986-87, while the 1960s and 1970s were characterized by fewer severe droughts than other decades (Figure 5). A further analysis of the drought frequency may provide an insight into the temporal patterns of drought occurrence in the Atlanta area.

SUMMARY

A water balance model (ACFWB model) was constructed to estimate runoff using divisional climatic data for the Apalachicola-Chattahoochee-Flint River basin. This model can extend streamflow records back to 1895.

Compared with the Thornthwaite water balance model, this model can produce better results because it includes a few factors ignored by the Thornthwaite model. Further comparison has shown that the estimated runoff is a better indicator of hydrologic conditions than the Palmer's drought indices.

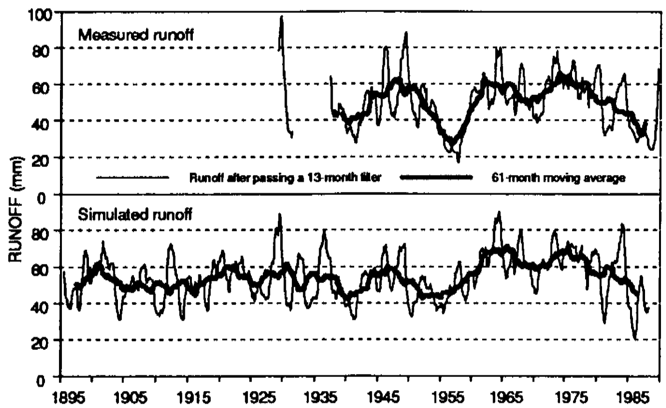

Figure 4. Estimated and measured runoff in the Chattahoochee River basin above Atlanta after passing a 13 month filter and 61-month moving average, 1895-1988. Notice the effect of the Buford Dam after 1955.

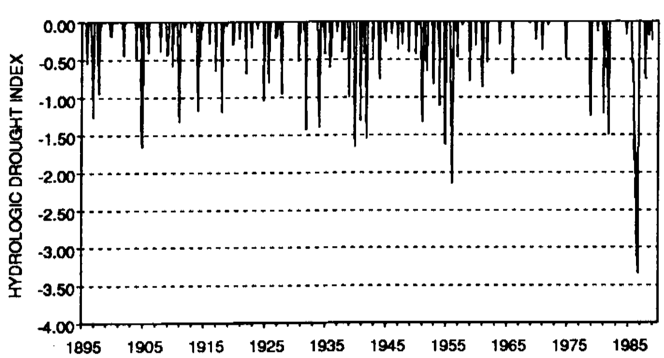

Figure 5. Hydrologic drought index, 1895-1988, for the Atlanta metropolitan area, based on current water demand.

The ACFWB model was applied to several sections of the Apalachicola-Chattahoochee-Flint River basin, with drainage area ranging from 3,754 km^2 to 44,529 km^2. It is expected that the model can be applied to other basins in the southern Piedmont and inner Coastal Plain with similar climatic, geologic and topographic characteristics as the ACF basin. The extended runoff record displayed significant long-term variations. After specifying a water demand for the Atlanta area, a hydrologic drought index was designed based on the estimated runoff record. Severe droughts, such as the one in 1986, can then be examined from a historical perspective.

ACKNOWLEDGMENTS

This study is in part supported by a research grant from the Georgia State University (#92-042).

LITERATURE CITED

Bloomfield, P., 1976. *Fourier Analysis of Time Series, An Introduction*. New York: John Wiley & Sons.

Borland International, 1990. *Turbo Pascal, Version 6.0.* Scotts Valley, CA: Borland International, Inc.

Dracup, J.A., Lee, K.S., and Paulson, E.G., 1980. On the definition of droughts. *Water Resources Research*, Vol. 16, 297-302.

Gleick, P.H., 1987. The development and testing of a water balance model for climate impact assessment: Modelling the Sacramento Basin. *Water Resources Research*, Vol.23,1049-1061.

James, L.D., and Burges, S.J., 1982. Select, calibration, and testing of hydrologic models. In Haan, C.T., Johnson, H.P., and Brakensiek, D.L. (eds.), *Hydrologic Modeling of Small Watersheds. ASAE Monograph No.5.* St. Joseph, MI: American Society of Agricultural Engineers. p.437- 472.

Palmer, W.C., 1965. *Meteorological Drought.* Research Paper No.45, U.S. Weather Bureau. Washington, DC: U.S. Government Printing Office.

State of Georgia, 1987. *Water Resources Management Strategy, Summary Document.* Office of the Governor, Atlanta.

Thornthwaite, C.W., and Mather, J.R., 1957. *Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Publications in Climatology, Vol.X, No.3.* Centerton, NJ: Laboratory of Climatology.

U.S. Army Corps of Engineers, 1981. *Metropolitan Atlanta Area Water Resources Management Study, Final Report.* Savannah, GA.

World Meteorological Organization, 1975. *Intercomparison of Conceptual Models Used in Operational Hydrological Forecasting. Operational Hydrology Report No.7.* Geneva, Switzerland: World Meteorological Organization.