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A Continuous, Incremental Antecedent Precipitation Index (API) Model for use with the National Weather Service River Forecast System

Eric A. Anderson[1]

Abstract

Event API models have been used for many years by the National Weather Service (NWS) to forecast floods. These models are not amenable to generating extended predictions for water management applications and are difficult to calibrate in conjunction with other hydrologic procedures such as a snowmelt model. Since several NWS offices prefer to use an API-based procedure for calculating runoff, a continuous model based on the API approach was developed for use in the NWS River Forecast System (NWSRFS). This model computes both surface runoff and baseflow. The model was tested on five watersheds with varying climatic conditions and the results were compared to those produced using the Sacramento model.

Introduction

API based procedures have been used for many years by the NWS River Forecast Centers (RFCs) to produce flood forecasts. These API procedures have been applied on a storm basis. The API value at the start of the storm is typically related to time of the year, storm duration, and storm rainfall to compute storm runoff. Incremental runoff is computed by subtracting the storm runoff at the end of each time interval from that at the beginning of the interval. A unit hydrograph is used to convert the incremental runoff into a storm runoff hydrograph. Baseflow, which has a

[1] Senior Research Hydrologist, National Weather Service, Hydrologic Research Laboratory, 1325 East-West Highway, Silver Spring, MD 20910.

minimal impact during floods, is subjectively added to produce the total discharge. Many RFCs have continued to use API models because they are simple to understand and use and generally do a good job forecasting floods when properly applied.

Two problems have arisen related to the use of storm or event API models by the RFCs. First, the need for water management forecasts, involving predictions for weeks or months into the future, is increasing dramatically. Within NWSRFS, the Extended Streamflow Prediction (ESP) method is used to produce such forecasts (Day, 1985). For ESP applications a model must be able to simulate flows of all magnitudes on a continuous basis. This cannot be done by an event API model. Second, it is very difficult to calibrate an event API model in conjunction with other hydrologic procedures such as a snowmelt model. The NWSRFS calibration procedures, which are designed for continuous models cannot be used. Since several RFCs prefer to use an API based rainfall-runoff procedure, the Continuous API model was developed so that an API based model that could be used with the ESP and calibration systems would be available within NWSRFS.

Description of the Model

The Continuous API model basically breaks down into three steps: the computation of surface runoff, the determination of groundwater recharge, and the calculation of the amount of baseflow. In addition, constant impervious area runoff and riparian vegetation losses can be accounted for and an experimental technique is included to compute the degree of frozen ground and its effect on runoff. These additional features are not described in this paper. The computations are performed on an incremental, i.e. time interval, basis rather than on a total event basis. Everything except the computation of the baseflow amount can be represented on a single plot as shown in Figure 1. The four quadrants perform the following functions.

- 1st Quadrant - The current value of the API is related to the time of the year to derive an antecedent index (AI) to the overall soil moisture deficiency. Two curves are shown representing the relationship at the wettest (y=0) and driest (y=1) weeks of the year. A sinusoidal variation is used between the wettest and driest weeks. When going from dry to wet conditions (typically late summer to winter) the sine function can be raised to a power to produce a more rapid transition. This rapid transition is needed in basins where the soil-moisture deficit, built up slowing during the summer, is eliminated over a relatively short period due to fall rains and decreased evapotranspiration (ET). The decrease in ET

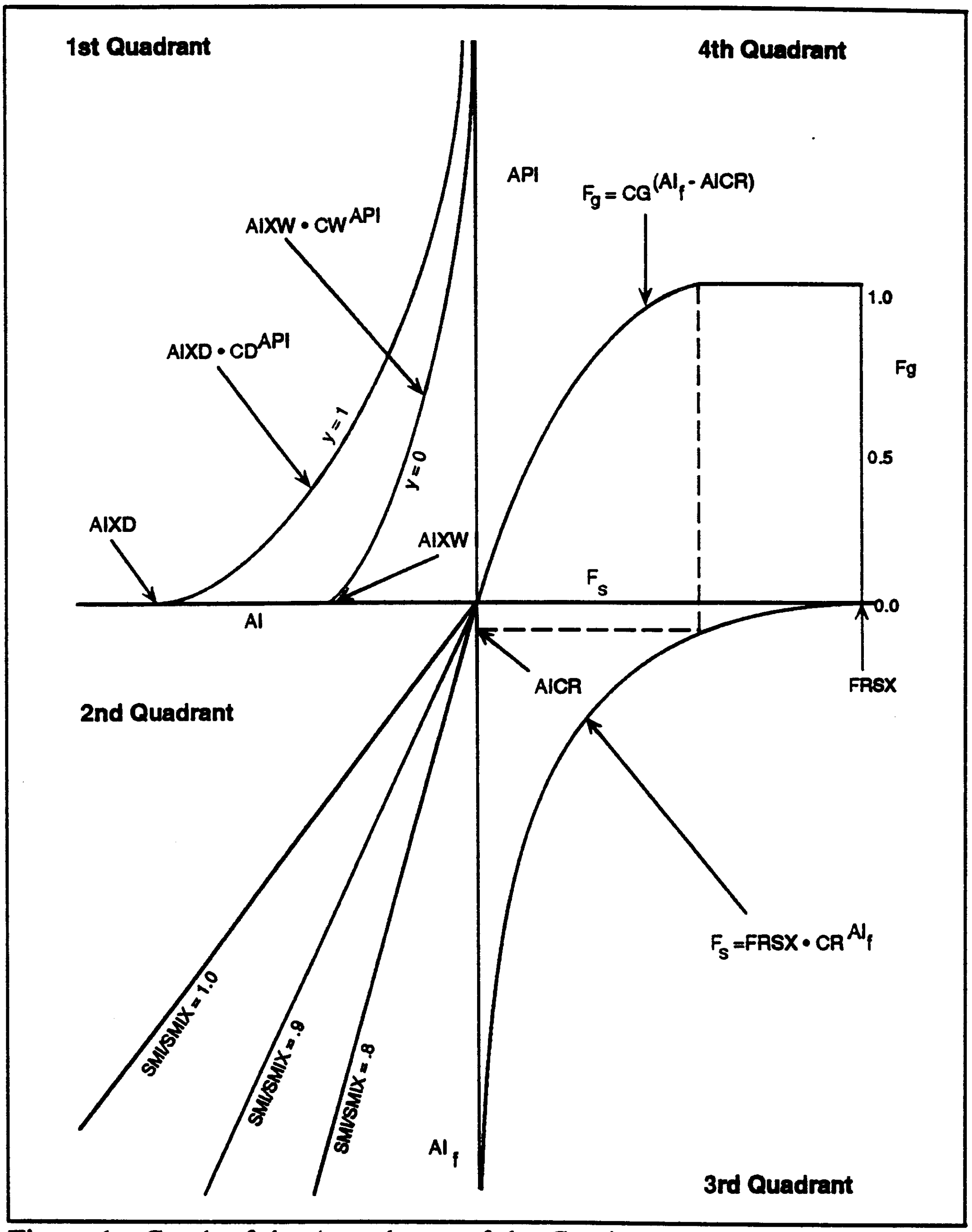

Figure 1. Graph of the 4 quadrants of the Continuous API model.

is accentuated in forested basins where the trees lose their leaves. The 1st quadrant equations and functionality are the same as for an event API model except that in the continuous mode the API, and thus the AI, is changing at each time interval. In an event API model, the API at the start of the storm is used to define the rainfall-runoff relationship used throughout the event.

- 2^{nd} Quadrant - The value of AI is modified based on surface moisture conditions. A surface moisture index (SMI) is computed by adding precipitation and subtracting ET. The ET for the surface layer is equal to potential evaporation (PE) reduced by the ratio of SMI to its maximum value, SMIX. PE is defined by maximum (July) and minimum (February) values and a sinusoidal variation in between. The maximum and minimum PE values are obtained from an evaporation atlas (Farnsworth et al, 1982, Farnsworth and Thompson, 1982). SMIX is the amount of rain that must occur after a prolonged dry period before significant runoff is produced. The 2^{nd} quadrant accounts for the initial abstraction losses that occur at the beginning of a storm. When the surface is dry, the final value of AI (AI_f) is increased over that computed in the 1^{st} quadrant resulting in little or no surface runoff.

- 3^{rd} Quadrant - AI_f, which reflects both the surface moisture and overall moisture deficiencies of the soil is used to compute the fraction of the precipitation that becomes surface runoff (F_s). The maximum value of F_s, which occurs when the soil is completely saturated (i.e. $AI_f = 0.0$), is defined by the parameter FRSX. While many watersheds produce nearly 100 percent surface runoff when the soil is completely saturated, such as in the later stages of a record flood event, other watersheds never approach 100 percent runoff, thus the need for the FRSX parameter.

- 4^{th} Quadrant - The fraction of the remaining water, i.e. precipitation minus surface runoff, that enters groundwater storage (F_g) is computed as a function of AI. The surface moisture must be staturated before recharge occurs. When AI is below a critical amount (AICR), i.e. the soil is sufficiently wet, all of the precipitation that doesn't become surface runoff enters groundwater aquifers (i.e. $F_g = 1.0$). When AI is greater than AICR, only a fraction of the available water becomes recharge.

The withdrawal of water from groundwater storage is based on the equations used in the Stanford Watershed model (Crawford and Linsley, 1966). A primary recession constant is used to compute baseflow after a sufficiently long period with no recharge. After a period of recharge, the baseflow recession increases and then decays after several weeks or months back to the primary recession rate. A supplemental recession constant and a supplemental to primary weighting factor are needed to compute baseflow after a period of groundwater recharge.

Model Results

The Continuous API model was tested on 5 watersheds that represent a variety of climatic and hydrologic conditions. All of the basins were previously calibrated with the Sacramento model (Burnash et al, 1973). The Sacramento model is also part of NWSRFS and is used by several RFCs. The test results are shown in Table 1. The models produced fairly similar results

Table 1 - Comparison of Continuous API and Sacramento Models

Basin	Period	Statistic	Sacramento	Continuous API
Leaf R. nr Collins, MS	10/51-9/69	Drms	15.6	17.6
		Mrms	7.5	12.0
		R	.962	.951
French Broad R. at Rosman, NC	10/53-12/64	Drms	1.51	1.44
		Mrms	9.7	12.4
		R	.970	.971
White R. at W. Hartford VT	10/63-9/71	Drms	12.5	12.6
		Mrms	8.3	9.0
		R	.956	.956
Animas R. at Durango, CO	10/48-9/83	Drms	9.85	9.97
		Mrms	9.8	10.6
		R	.945	.943
Bird Crk. at Sperry, OK	10/55-9/62	Drms	18.0	23.0
		Mrms	4.0	10.6
		R	.968	.950

Statistics: Drms =daily root mean squared error (cms)
Mrms =monthly volume root mean squared error (mm)
R =correlation coefficient of daily flows

for the French Broad, White, and Animas basins. These basins had the highest overall percent runoff and the highest percent of baseflow runoff. For the watersheds in drier regimes (Leaf and Bird basins), the Sacramento model produces better results especially after an extended dry period, although the surface moisture representation of the Continuous API model produces results similar to the Sacramento model for moderate length dry periods. Previous API based models tend to produce too much runoff even after dry periods in the summer lasting only a few weeks. On the Leaf basin bankfull rises were produced by interflow while surface runoff dominates during major floods. The Sacramento model structure allows storm runoff to be divided into surface runoff and interflow. In the Continuous API model there are not multiple storm runoff components. On the Leaf basin this accounted for much of the difference in results.

Summary

A continuous, incremental API-based rainfall-runoff model is now available for use by NWS RFCs as part of the NWSRFS. The model produces a hydrograph containing both storm runoff and baseflow. The model can take advantage of all the NWSRFS calibration features and can be calibrated in conjunction with other procedures, such as a snow model. The Continuous API model can adequately simulate the full range of flow conditions so that it can be used to produce water management forecasts using the ESP procedure.

Appendix I. References

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Key words

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Models
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