Rainfall Generation for Highway Construction Sites

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Abstract

A synthetic rainfall generation (SRG) model was developed to generate rainfall forecasts (in a probablistic sense) for highway construction sites (H.C.S.) in Texas. The output from this model is a rainfall time series on a 15-minute basis. A bootstrapping method, that resamples actual rainfall data, is used to evaluate the parametric SRG model. Significant computer storage space is saved by transferring actual rainfall data into a parametric model.

Introduction

The SRG model is part of rainfall-runoff-solids generation model under development by Department of Civil and Environmental Engineering, University of Houston, to allow a highway engineer to evaluate planned temporary sediment controls (TSC) that may be part of a Storm Water Pollution Prevention Plan. Synthetic daily and 15-minute time series are based on hourly and 15-minute precipitation data provided by EarthInfo Inc. (EarthInfo, Inc., 1995). The model neglects seasonality and may tend to overestimate storm volumes for short construction projects.

Theoretical Background

Arrival time of a storm event (based upon daily basis) is defined as the number of zero rain-days between two consecutive non-zero rain-days. Analysis of the arrival time sequence data for three sites in Texas is well described by a Poisson distribution (Lapin, 1973), and this arrival time model is used as the parametric

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$$Z_{H.C.S.} = \sum_{i=1}^{n} \frac{Zi}{(di)^2} / \sum_{i=1}^{n} \frac{1}{(di)^2} \qquad (2)$$

where $Z_{H.C.S.}$ is precipitation at H.C.S., Zi is precipitation at each rainfall station, and di is distance from H.C.S. to each rainfall station

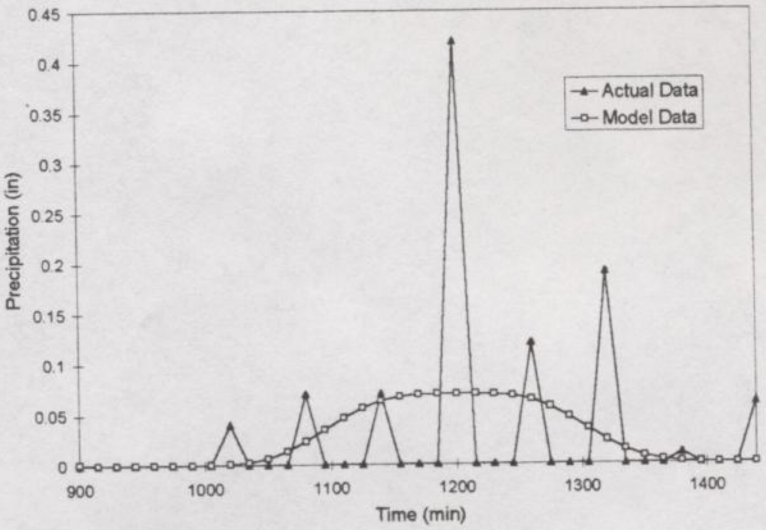

Figure 2. Actual Rainfall Data vs. Its Simulated Model Data

<u>Model Development</u>

The input of this model includes of construction days (N.C.D.), distance between H.C.S. and three selected rainfall stations, and the three station_ID's, which are used to get daily and 15-miute parameter data. The output of this model is 15-minute rainfall sequence of the H.C.S.

The model development was conducted in three steps: 1) Station selection and distance finding algorithm, 2) Daily and 15 minute historical data reduction, 3) Coding and testing the SRG model and user interface.

Step 1: Station selection and distance finding

109 out of 206 rainfall stations were selected, reduced, and stored in a Geographic Information System (GIS) map by their longitude and latitude. The location of the highway H.C.S. is described by its longitude and latitude. Using the distance-finding method provided in GIS, the distance from H.C.S. to these three stations can be found and recorded by the analyst. Figure 3 shows a GIS map near Austin. HCS_1 is a assumed highway construction site. Stations 0428, 8531, and 9815 are three selected rainfall stations to do the synthetic rainfall generation for construction site HCS_1, and the result is shown in figure 5.

approach for generating arrival time sequences. Figure 1 shows the agreement between the Poisson model and actual arrival time at one site in Texas.

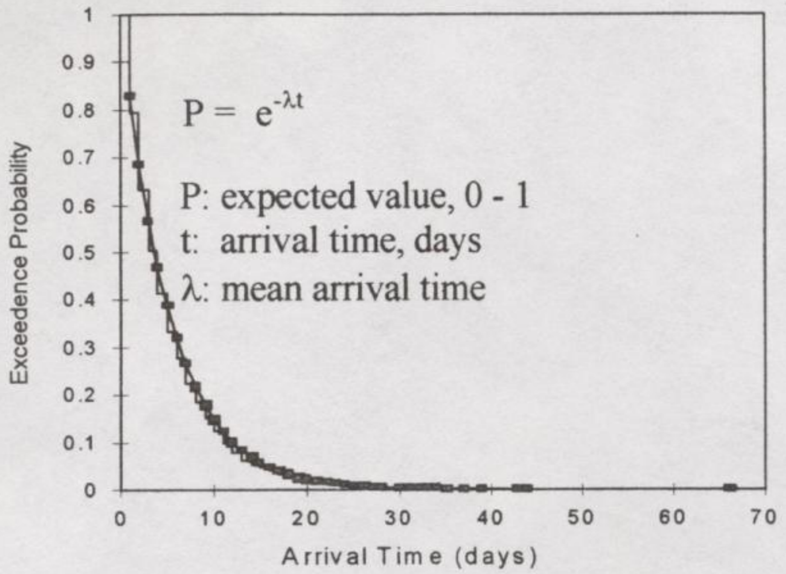

Figure 1. Empirical Cumulative Distribution Function for Arrival Time
Houston, Addicks, Station ID: 4309

Individual non-zero rain days are modeled using a four-parameter exponential convolution equation (Bras, 1990) that can mimic the shape and volume of historical rain events.

$$R(t) = \frac{1}{2}R_o \times \{[\mathrm{erfc}(\frac{t_p - t}{2\sqrt{S_d t}}) + \mathrm{EXP}(\frac{t_p}{S_d})\mathrm{erfc}(\frac{t_p + t}{2\sqrt{S_d t}})] \quad (1)$$

$$- [\mathrm{erfc}(\frac{t_p - (t-\tau)}{2\sqrt{S_d(t-\tau)}}) + \mathrm{EXP}(\frac{t_p}{S_d})\mathrm{erfc}(\frac{t_p + (t-\tau)}{2\sqrt{S_d(t-\tau)}})]\}$$

where R is predicted precipitation, t is the elapsed time since the beginning the rain day, R_0 is the peak rate, t_p is the historical time to peak, τ is the storm duration, and S_d is the storm dispersion coefficient

Figure 2 shows this model applied to one particular rain-day. The model is intended to correctly reproduce time to peak, total storm volume, and roughly the shape of the storm. Exact fit is not expected. This rain-day model is postulated for generating 15-minute rainfall sequences. The precipitation R at any time t is simulated by four parameters: Peak rate, time to peak, rain center, and rain dispersion coefficient. The time unit (t) is 15 minute on a daily basis, or from 15 to 1440 minutes.

An inverse distance algorithm is used to generate 15-minute time series for the H.C.S. by combining 15-minute time series from three nearby stations.

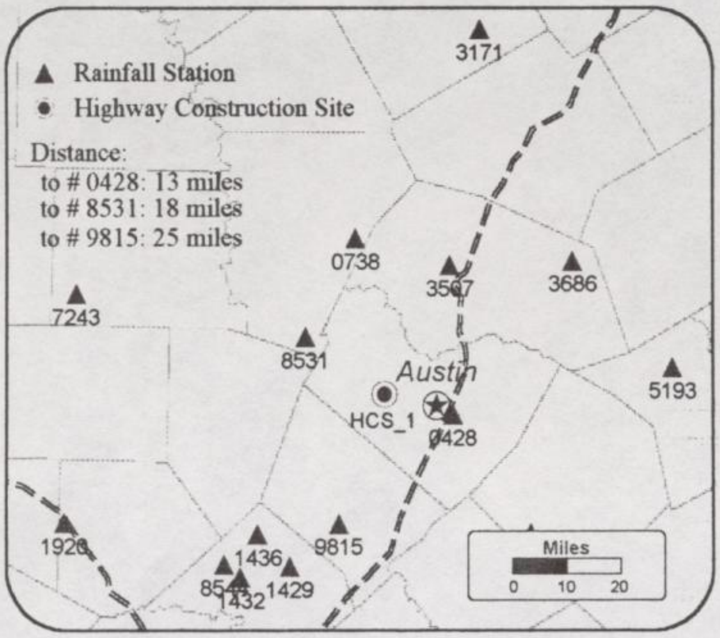

Figure 3. A GIS map near Austin

Step 2: Daily and 15-minute data reduction

This step is the parameter generation process, which includes formatting the actual daily and 15-minute data and use a FOTRAN program to change actual data into parameters that can be used for synthetic rainfall generation.

For daily data reduction, one set of values for the empirical cumulative arrival time function (Equation 3 & 4) is generated for each station. Therefore for any randomly generated number between 0 and 1, a corresponding arrival time can be found.

$$P = 1 - e^{-\lambda t} \qquad (3)$$

$$t = -\frac{1}{2\lambda}\ln(1 - P) \qquad (4)$$

where P is expected value between 0 - 1, t is arrival time in day, λ is mean rate of arrival time.

For 15-minute data reduction, the model equation is fitted to the historical data using a quasi-Newton optimization algorithm (Press, et al., 1986). A strict constraint that the volume of precipitation from real data equal to the volume of precipitation from model data was forced in the fitting process.

After reduction the space needed to store rainfall characteristics in the computer is significantly reduced. For 15-minute data, there is a ten times reduction of the data file size. For daily data, there is a thirty times reduction of the data file size. As a result, daily rainfall model parameters for all of Texas or 15-minute rainfall model parameters for stations around Houston can be stored in a normal high density floppy disk.

Step 3: Coding the SRG model and user interface

Figure 4 shows the flow chart of synthetic rainfall generation model. The input is N.C.D., distance from H.C.S. to three rainfall stations, and station_ID's. Main module calls a random arrival time (RAT) module. This module generates a series of arrival times equal in length to the number of construction days using a random number generator and the empirical cumulative distribution function values for each station. Then Main module calls random rain- day (RRD) module for those non-zero rain-days. RRD module will randomly pick a non-zero rain-day from data parameter file, get 4 model parameters and generate 15 minute rainfall model data from these 4 parameters according to convolution equation. Finally, the main module calls inverse distance module to combine the 15 minute rainfall data from three stations and generate the 15 minute rainfall data for the H.C.S.

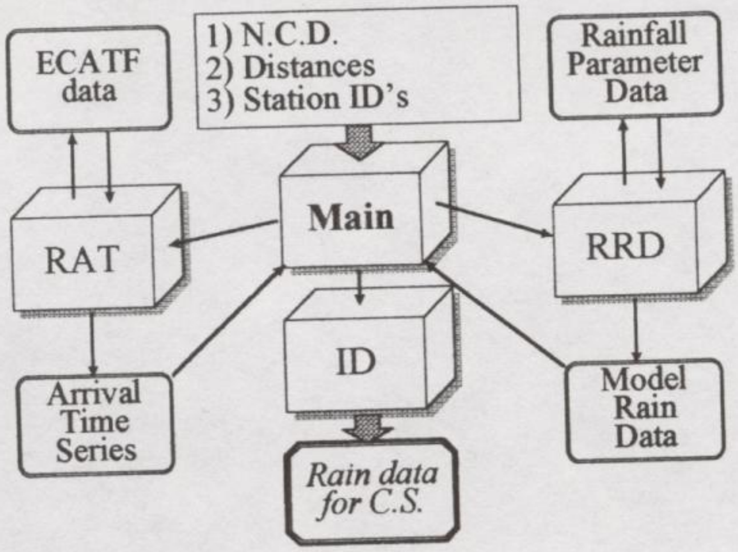

Figure 4. Flow chart of SRG model

Figure 5 shows the 15 minute rainfall sequence from SRG for number of construction days equal to twenty. The time space between each data point is 15 minutes.

A user-friendly interface was built for SRG using Visual Basic. Input, input check, calculation, and brief plotting can be performed through the interface.

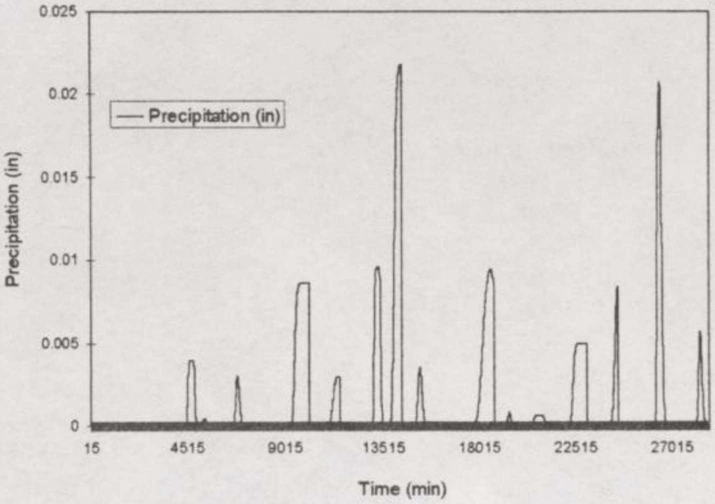

Figure 5. 15-minute rainfall sequence for N.C.D. = 20

Summary

A synthetic rainfall generation model is developed to generate 15-minute time series for highway construction site. Arrival time is modeled using a Poisson distribution. Precipitation from individual non-zero rain days is mimicked by a four-parameter rain-day model. This parametric approach reduces the storage space in computer as compared to traditional bootstrapping. Inverse distance algorithm is used to combine 15-minute rainfall series from three nearby rainfall stations to generate the 15-minute rainfall series for the highway construction site. A Geographic Information System (GIS) is used to store the parametric database and find the distance between H.C.S. and rainfall stations.

Reference

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