Synthetic Rainfall Generation Model for Evaluating Potential Erosion at Highway Construction Sites

A Thesis

Presented to

the Faculty of the Interdisciplinary Graduate Program

in Environmental Engineering

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in Environmental Engineering

by

Gang Qiu

May 1997

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ABSTRACT

An easy-to-use and space-saving synthetic rainfall generation (SRG) model is constructed to generate 15-minute rainfall forecasts (in a probabilistic sense) for the rainfall-runoff-solids generation model, which allows a highway engineer to evaluate the planned temporary sediment controls (TSC) that may be part of the Storm Water Pollution Prevention Plan (SW3P) required for the highway construction project. An arrival time model based upon zero and nonzero raindays is used to generate arrival time series. A four-parameter rainday convolution model is used to mimic the total precipitation and shape of historical rainday events. A Texas GIS (Geographic Information System) map is constructed to find the distances between a highway construction site and selected rainfall stations. The final rainfall sequence at a highway construction site is generated by combining rainfall sequences at three nearby rainfall stations through an inverse distance algorithm. A user-friendly interface is also built to facilitate the use of the SRG model. The statistical test approach is performed to evaluate the SRG model.

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Chapter 1 Introduction

1.1 Research Background

This research is part of the project funded by Texas Department of Transportation, titled "Evaluation of the Impacts, Performance, and Costs of Storm Water Pollution Prevention Plans (SW3P) as Applied to Highway Construction Activities".

The Clean Water Act (CWA) regulates stormwater discharge from construction sites that disturb 5 or more acres (this value may change to 1 or more acres). General permit requirements that apply to construction activities were published in the Federal register, Volume 57, Number 175 on Wednesday, September 9, 1992.

Permittees must provide a site description, identify sources of contaminants that will affect stormwater, design appropriate measures to reduce pollutants in stormwater discharges, and implement these measures. The appropriate measures are further divided into four classes: erosion and sediment control, stabilization practices, structural practices, and stormwater management. Collectively the site description and accompanying measures are known as the facility Storm Water Pollution Prevention Plan (SW3P). The focus of SW3P is on erosion control and prevention of suspended solids leaving a construction site.

The permit contains no specific performance measures for construction activities, but states that "EPA anticipates that stormwater management will be able to provide for the removal of at least 80% of the total suspended solids (TSS)." In terms of reducing solids load to a receiving stream, the emphasis on solids control is well supported by past studies. In an early study of TSS as a function of land use in Virginia, highway construction areas, varying from less that 1% to more than 10% of the basin contributed 85% of the sediment load. The sediment yield of the highway construction area was 10 times that of cultivated land, 200 times that for grassland, and 2000 times that of forest land. (Vice, 1969). Other investigators found that runoff from highway construction sites causes a temporary degradation of stream water quality with respect to turbidity and suspended solids (Hainly, 1980; Embler and Fletcher, 1981; Helm, 1978).

The goals of this project are to gather, analyze, and interpret existing data to infer the effect of sedimentation on receiving water ecosystems, infer the effects of SW3P on sediment transfer, determine the types and quantities of contaminants associated with highway construction activities, develop useful predictive tools to be used for cost/benefit analysis, and document all activities so that TXDOT can maintain, update and operate database and models as new information becomes available.

1.2 Rainfall-Runoff-Solids Generation Model

One tool under development is a rainfall-runoff-solids generation model to calculate the mass loadings to receiving stream, and identify the effectiveness of SW3P techniques, especially temporary sediment controls (TSC). The model considers two components: detachment and transport by rainfall and detachment and transport by overland flow. The rainfall induced surface erosion, in general, is a power function of rainfall intensity.

The sediments scoured in the overland flow are also assumed to be a power function of the overland flow rate. During a runoff producing storm, the user will be able to predict sediment mobilization and the effects of manmade controls on sediment transport using these modeling tools.

This thesis is the very first step of the model, that is to design a rainfall model which can generate 15-minute rainfall sequence for a highway construction site, which will be used in runoff and solids transport model.

1.3 The Organization of This Thesis

This thesis begins by considering the background of the research. The second chapter reviews the literature of rainfall models and concludes that there is no appropriate rainfall generation model for highway engineers to evaluate effect of SW3P on highway construction sites. Chapter 3 clearly states the problem to be addressed in this thesis.

Chapter 4 presents the synthetic rainfall generation (SRG) model and bootstrapping method development procedure. Model application and limitations are illustrated in Chapter 5. Three assumed highway construction sites, near Austin, Houston and Lubbock, are used to perform the model and statistical test. The effect of number of construction days and number of repeats of SRG model on evaluating mean value of precipitation from statistically generated 15-minute model rainfall sequences is test. Fifteen-minute rainfall sequences from SRG model and bootstrapping method is tested for their likeness and compared for their sediment production.

Chapter 6 presents the conclusions and limitations. Finally Visual Basic and FORTRAN programs source code for the SRG model are attached as appendices as well.

Chapter 2 Literature Review

A rainfall sequence is a type of time series where rainfall depths are recorded in time. The sequence is unidimensional, hydrologic, stochastic process (Yevjevich, 1972). A stochastic process is defined as a mathematical abstraction of a process that can be characterized by statistical properties. The stochastic process is considered as being mathematically described through three steps: a) distribution functions are postulated, b) parameters of distribution functions are estimated, c) proper statistical tests of hypotheses are performed. The number and kinds of stochastic models applicable in rainfall generation are nearly unlimited.

Haan (1977) stated that synthetic rainfall from a model that is based solely on historical record of rainfall is but one realization of a stochastic time series and the future realizations will resemble the historical record only in a statistical sense. Stochastic rainfall is neither historical rainfall nor predictions of future rainfall, but a representative of possible future rainfall in a statistical sense.

Pattson (1964) states that stochastic rainfall model implies a repetition in the future of the historical events and in some cases that these future occurrences will take place in the same order as that which has occurred historically. This assumption becomes more valid and the estimates are improved as the length of the historical record is increased.

Haan (1977) describes a purely random stochastic model, which the rain and no-rain events are assumed to occur at discrete times with constant time interval. The events at any time are independent of the events at any other time. The time between storms might be modeled as an independent Poisson process and the amount of rain might be modeled as a gamma variable.

Rodriguez-Iturbe et al. (1984) used a compound Poisson model to analyze the parameter estimation problems for the aggregation of rainfall at hourly and daily scales. This model considered rainfall events in the form of instantaneous burst in time. The occurrence times of the bursts are modeled by a Poisson process. Then to each burst occurrence time an independent rainfall amount is attached. This results in a compound Poisson process for the rainfall amounts in time.

Chang et al. (1984) proposed various models from discrete autoregressive moving average (DARMA) family and applied these models to occurrence of daily rainfall data of Indiana. The most popular approach of these approaches is to consider the precipitation occurrence process to be described by a finite state (typically a value of 2, a day is wet W or dry D) Markov Chain (MC) with seasonally (or time-varying) transition probabilities.

The transition probabilities from transitions (i.e., WW, WD, DW, DD) between the two states (W or D) are estimated directly from the data through a counting process. If the probability law that governs the future development of the process at some point depends only on that point and not on the prior evolution of the process, such a process is called a first-order Markov chain. If, however, the probability law depends on the current state and also on the immediately preceding state then it is called a second-order Markov chain. Chains of Nth-order are defined in the same way. They concluded that the DARMA family of models can preserve various desirable statistical properties of the daily rainfall process.

Roldan and Woolhiser (1982) proposed a wet-dry spell approach for daily precipitation occurrence. This approach is called the alternating renewal model (ARM). No transition to the same state is possible for this approach. An advantage of this approach is that it allows direct consideration of a composite precipitation event, rather than its discontinuous truncation into arbitrary daily segments. Spell length is modeled by a geometric or a negative binomial distribution.

Slade (1936) was the first to fit a continuous probability distribution to rainfall data. He made use of a logarithmic transformation of the normal to fit the annual rainfall amounts.

Skees and Shenton (1974) noted that annual and monthly rainfall were successfully modeled as random variables with gamma, normal, and logarithmic normal distributions. For shorter intervals (weeks, days, hours), satisfactory distributions were more difficult to obtain.

The S-curve is used in hydrology to model an infinite sequential series of fixed duration storms, which is a step response process (Bras, 1990). This curve is the infinite summation of unit amount of the given duration. The S-curve is obtained by adding corresponding unit hydrograph, each lagged by one unit time.

Dempster (1993) states that a time course fitting procedure can be implemented by defining a suitable step response function for single channel currents. A channel opening can be represented by the sum of an opening step $S(t, t_0)$ and a closing step represented by an inverted form $(1 - S(t, t_0+\tau))$, where S is the amount, t is time, t_0 is starting time, τ is delay time. The equation of this form is called a convolution equation, and parameters in this equation can be evaluated by optimization method and user-defined criteria.

McCuen (1986) described three types of parameters used to define the distribution of time series as location, scale and shape parameters (i.e., parameters of a distribution control the geometric characteristics of the distribution). Location parameter means location of center. Scale parameter indicates various fractiles of the distribution. Shape parameter is geometric configuration of a distribution, used to distinguish one from another in a family of distributions.

The WEPP USER Requirement (Foster and Lane, 1987) suggested that the maximum information required to represent a design storm consist of the following: (a) storm amount, (b) average intensity, (c) ratio of peak intensity to average intensity, and (d) time to peak intensity.

Tabios and Salas (1985) examine several commonly used spatial interpolation techniques for point annual precipitation at 29 stations located in North Central continental United States. The techniques considered were the followings: Theissen, polynomial, inverse distance, multiquadratic, Gandin, and Kriging. The comparison is based on the following criteria: the mean and variance of the observed and interpolated annual precipitation, the sum of square errors between the observed and interpolated vales of annual precipitation, the proportion of the variance accounted for by the interpolator, the coefficient of determination between the observed and interpolated values and the standard deviation of the error of interpolation.

The result from this study shows that the optimal-interpolation and Kriging techniques are the best among all techniques analyzed considering various performance criteria used by the study. The inverse distance method is not as good as Kriging and optimal-interpolation techniques, but is better than the Theissen and multiquadratic methods.

There exist many rainfall models, but very rarely is the hydrologist interested in rainfall as an isolated phenomenon. Evaporation, transportation and the antecedent moisture are always considered in a model. Also considered are pertinent characteristics of the basin itself, such as its geology, topography etc. For example the Stanford Watershed Model

(Pattison, A, 1964) and the USDA WEPP model (Foster and Lane, 1987) consider all these features.

From the literature reviewed, one concludes that there are many stochastic models based upon historical data to generate a rainfall sequence, but there is no rainfall generation model that meets the requirement for this project: generate 15-minute sequences, economical data storage so the entire state of Texas can be stored, and easy to use for highway engineers (user-friendly).

The subject of this thesis is the design of an easy-to-use synthetic rainfall generation model for a highway engineer to generate 15-minute rainfall sequences which can preserve total volume of precipitation and some characteristics of intensity of historical data.

Chapter 3 Problem Statement

EPA requires a Storm Water Pollution Prevention Plan (SW3P) to be in effect for highway construction activities. SW3P focus on erosion control and prevention of suspended sediments leaving construction sites.

Sediments produced by storms from highway construction activities effect water body ecosystems by both its sedimentation and as a medium of transporting contaminants. Simplified models to infer effects of sedimentation and SW3Ps on sediment transfer are desired. The first step of these models is a simulation model to relate rainfall to runoff and total suspended solids generation, which allows a highway engineer to evaluate the planned temporary sediment controls (TSC) that may be part of the Storm Water Pollution Prevention Plan (SW3P).

Many stochastic models exist, but most of them use rainfall data with time space equal or larger than 1 hour, involve information other than just rainfall, and are not easy to use. Furthermore there is no specific synthetic rainfall generation model for highway construction activities in Texas.

The purpose of this synthetic rainfall model is to generate rainfall forecasts (in a probabilistic sense) for the rainfall-runoff-solids generation model. This model uses historical daily and 15-minute rainfall data to predict the precipitation during a highway construction period in a probabilistic sense. Some features of this model will be the following: generation of 15-minute sequences for the whole proposed construction period, economical data storage so the parameter for the entire state of Texas can be stored, and easy-to-use information for highway engineers (user-friendly).

Occurrence of rainfall events in each station is modeled by a sequence of days of zero rain and nonzero rain properties through a statistical distribution function. Each rainday is modeled by a step response function focusing on the volume, intensity, duration and overall shape of precipitation. A final rainfall sequence at highway construction site is generated from three nearby stations by spatial interpolation. A user-friendly Visual Basic Interface for SRG model was generated. Model tests and hypothesis tests are performed to check if this model is valid and what the suggested procedures are to use this model.

Chapter 4 Model Development

The SRG model development was divided into three steps: Geographic Information System (GIS) mapping of rainfall stations in Texas and development of a distance finding procedure, analysis and reduction of historical records into a database, and design of an interface that allows a user to access the data base.

The first step was the construction of a GIS map for rainfall stations in Texas. One hundred and nine out of 206 stations in Texas were selected to build a network of rainfall stations so that there are always some nearby stations around any possible highway construction site in Texas. The distance between the highway construction site and the rainfall stations can be found from this map , and this distance information is used in the SRG model to combine synthetic 15-minute rainfall sequences for each station to generate a 15-minute rainfall sequence for the highway construction site by spatial interpolation.

The second step was daily and 15 minute rainfall data analysis and database construction. Actual daily rainfall data files were analyzed to create empirical cumulative arrival time function (ECATF) parameter data files. Actual 15-minute data files were analyzed to create rainday parameter data files for use in a convolution equation. These parameter data are one option in the SRG model to generate synthetic 15-minute rainfall sequences for each station. Another option in the model is to resample the original data (bootstrap).

The third step was to develop a Visual Basic interface to allow the user to access the data files and generate rainfall sequences.

4.1 Construction of GIS Map and Distance Finding

In order to easily select three nearby stations and find the distances between stations and highway construction site, a Geographic Information System (GIS) (Strategic Mapping Inc., 1994) computer program was used to construct a map of Texas so that both rainfall stations and highway construction site can be viewed in the map and the distances between them can be calculated automatically.

The map was constructed by selecting 109 out of 206 stations from the original rainfall database using the following criteria:

1) All stations around major cities are available on the map.
2) Stations far away from cities are selected so that there are always at least three stations within 100 miles around any possible HCS site in Texas.
3) Choose existing stations with a longer historical record.

The longitude and latitude data of rainfall stations are extracted from the original database and are formatted so that rainfall stations can be displayed on the GIS map. Figure 4-1 shows the GIS map for the 109 selected rainfall stations in Texas. On this map, counties, major cities, and interstate highways are displayed so that a location is easy to find. Each rainfall station is represented by a cross flag. A user can zoom in on a map section to see more detail as needed.

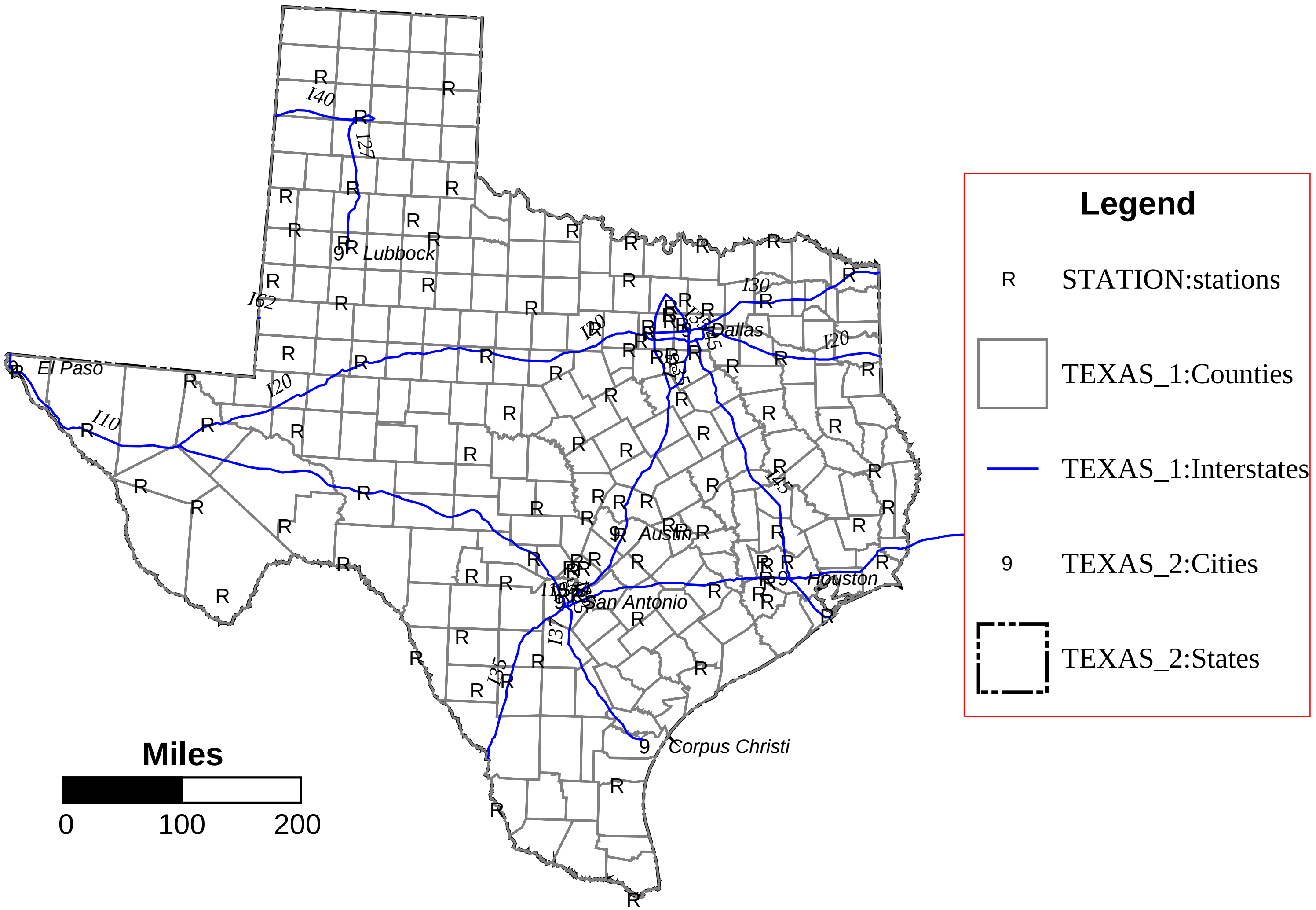

Figure 4-1 GIS Map Showing Rainfall Stations in Texas

Distances between rainfall stations and highway construction sites are computed in the GIS using the calculate column algorithm (Appendix A2). These distances are used in subsequent calculations.

A spatial interpolation method is used to generate a 15-minute time series for the HCS by averaging 15-minute time series from the three nearby stations using an inverse distance algorithm,

$$Z_{H.C.S.} = \sum_{i=1}^{n} \frac{Z_i}{(d_i)^2} / \sum_{i=1}^{n} \frac{1}{(d_i)^2} , \qquad (4\text{-}1)$$

where Z_{HCS} is precipitation at the HCS, Z_i is precipitation at each rainfall station, and d_i is distance from the HCS to each rainfall station.

The inverse distance method belongs to a family of weighting techniques, that instead of simple averaging of the rainfall data applies more weight to the rainfall data that from the stations closer to the highway construction site.

4.2 Daily and 15-Minute Rainfall Data Reduction

The historical daily and 15-minute rainfall data were obtained from EarthInfo, Inc. (EarthInfo, Inc., 1995). The length of records varied from 10 to 50 years at the different stations.

The procedure of data treatment is depicted in Figure 4-2. Actual daily and 15-minute data (the upper left box) are first extracted from original database and then formatted by manually deleting bad records and changing the data files into the proper format (the upper right 3-D box). For both daily and 15-minute rainfall data, there were up to 10% missing or improperly formatted records. These "bad" records were deleted manually so that the data files are readable by FORTRAN programs. Finally parameter generation (the lower middle 3-D box) programs are used to generate daily and 15-minute parameters (model data) represented by the lower right box.

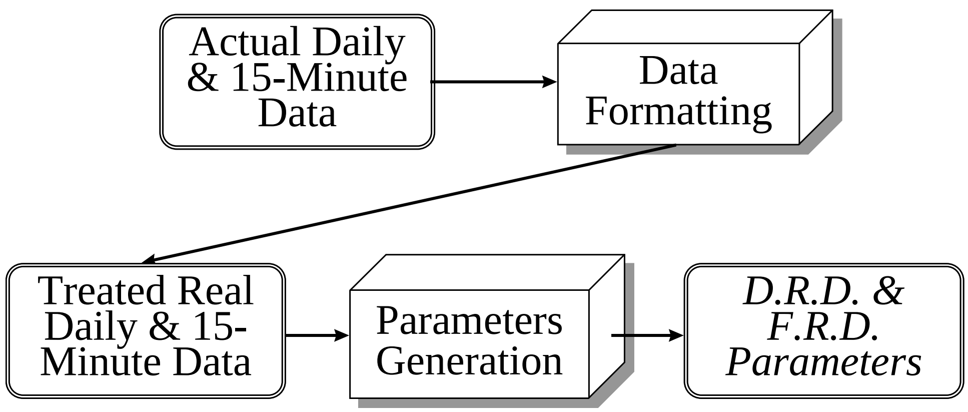

Figure 4-2 Procedure of Data Treatment

D.R.D.: daily rainfall data; F.R.D.: 15-minute rainfall data

A typical portion of an original daily rainfall record set for one particular year is illustrated in Figure 4-3. The separation mark between records is "|". The first record is the station ID ("428"), and the second record is the record year ("1942"). This particular record set has too many missing records (indicated by consecutive "||"), so it is entirely deleted from the database.

```
428|1942||||||||||||||||||||||||||||||||||||||||||||||
||||||||||||||||||||||||||||||||||||||||||||||||||||||
||||||||||||||||||||||||||||||||||||||||||||||||||||||
||||||||||||||||||||||||||||||||||||||||||||||||||||||
```

```
||||||||||||||||||||||||||0.07|0.00|0.00|0.00|0.00|0.
00|0.00|0.00|0.20|0.00|0.00|0.00|1.89|0.00|0.12|0.00|2
.60|2.32|0.49|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|
0.34|0.00|0.65|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00
|0.00|0.00|0.00|0.01|0.01|2.15|0.00|0.00|0.00|0.00|0.0
0|0.00|0.00|0.00|0.00|0.00|1.61|0.00|0.20|0.71|0.01|0.
00|0.00|0.00|0.00|0.00|0.00|0.00|0.01|0.00|0.01|0.42|0
.00|0.00|0.00|0.00|0.74|0.01|0.00|0.00|0.00|0.00|0.00|
0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.02|1.21
|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.0
0|0.00|0.00|0.00|0.02|0.02|0.00|0.09|0.06|0.00|0.00|0.
00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|1.21|0.00|0.00|0
.00|0.02|0.11|0.00|0.00|0.00|0.00|0.00|
```

Figure 4-3 A Typical “Bad” Original Daily Data Record Set

Next, data sets that are completed, such as the example in Figure 4-4, are reformatted to remove the separation marks, and to have a four-character station ID. Figure 4-5 illustrates how a completed, reformatted data set appears.

A similar procedure is applied to the 15-minute rainfall records in these data files. Figure 4-6 shows a typical “bad” data set. Separation marks are “||” for 96 rainfall records, and “|” for other supplementary records. The first record is the state ID (“TX” for Texas), the second record is the station ID (“8531”), and the fifth record is the date (“01/02/1984). The mark “---“ indicate a missing records. The character “A” after the number (“1.07”) indicates that 1.07 is an accumulative rainfall record from an unknown time interval (not 15-minute interval). The character “I” after the number (“1.07”)

```
428|1943|0.00|0.00|0.00|0.00|0.03|0.32|0.00|0.00|0.00|
0.00|0.05|0.38|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00
|0.00|0.00|0.00|0.00|0.02|0.00|0.00|0.00|0.00|0.00|0.0
0|0.00|0.15|0.01|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.
00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.29|0
.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|
0.00|0.01|0.00|0.00|0.00|0.00|0.00|0.00|0.01|0.00|0.00
|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|2.52|0.0
0|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.
00|0.00|0.00|2.65|0.00|0.00|0.03|0.00|0.00|0.00|0.00|0
.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|
0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.43|0.00
|0.00|0.00|2.05|0.00|0.00|0.00|0.00|0.01|0.00|0.00|0.0
0|0.00|0.00|0.00|0.49|0.78|0.17|0.00|0.00|0.00|0.23|0.
63|0.59|0.00|0.00|0.00|0.01|0.28|0.17|0.03|0.00|0.00|0
.00|0.00|0.00|0.31|0.06|0.01|0.00|0.00|0.00|0.00|0.00|
0.00|0.00|0.00|0.00|0.00|0.05|0.00|0.00|0.00|0.13|0.22
|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.0
1|1.17|0.45|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.
00|0.00|0.00|0.00|0.04|0.01|0.01|2.17|0.05|0.00|0.00|0
.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.16|0.00|
0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00
|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.76|0.00|0.18|0.1
6|0.01|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.
00|0.11|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0
.37|1.07|1.00|0.15|0.23|0.03|0.00|0.04|0.00|0.00|0.00|
0.00|0.00|0.00|0.00|0.00|0.00|0.06|0.23|0.00|0.00|0.00
|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.0
0|0.00|0.00|0.00|0.00|0.00|0.81|0.00|0.00|0.00|0.00|0.
00|0.00|0.00|0.00|0.00|0.00|0.00|0.10|0.00|0.00|0.00|0
.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.33|0.39|0.10|
0.00|0.00|0.00|0.00|0.00|0.00|0.11|0.00|0.25|0.03|0.00
|0.08|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.00|0.0
0|0.00|0.11|0.21|0.20|0.00|0.00|0.42|0.00|0.00|0.00|0.
01|
```


Figure 4-4 A Typical Acceptable Original Daily Data Set

0428	1943	0.00	0.00	0.00	0.00	0.03	0.32
0.00	0.00	0.00	0.00	0.05	0.38	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.15	0.01	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	2.52	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	2.65	0.00	0.00	0.03
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.43	0.00	0.00	0.00	2.05	0.00	0.00	0.00
0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.49	0.78	0.17	0.00	0.00	0.00	0.23	0.63
0.59	0.00	0.00	0.00	0.01	0.28	0.17	0.03
0.00	0.00	0.00	0.00	0.00	0.31	0.06	0.01
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.05	0.00	0.00	0.00	0.13	0.22
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.01	1.17	0.45	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.04	0.01	0.01	2.17	0.05	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.18
0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.37	1.07
1.00	0.15	0.23	0.03	0.00	0.04	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.81	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.33	0.39	0.10	0.00
0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.25
0.03	0.00	0.08	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.21
0.20	0.00	0.00	0.42	0.00	0.00	0.00	0.01

Figure 4-5 A Typical Reformatted Daily Data Set

indicates that 1.07 is an accumulative rainfall record for the whole day. This particular day has too many missing data, so it is deleted entirely from the database.

```
TX|8531|6|in|01/09/1984|---||---||---||---||---||---
||---||---||---||---||---||---||---||---||---||---||--
-||---||---||---||---||---||---||---||---||---||---||-
--||---||---||---||---||---||---||---||---||---||---
||---||---||---||---||---||---||---||---||---
||1.07|A|.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||
.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||
.||.||.||.||.||.||.||.||.||.||.||.||.||.||1.07|I|
```

Figure 4-6 A Typical “Bad” Original 15-min. Data Record Set

Figure 4-7 illustrates an acceptable day for data from rainfall station 8531 near Austin.

```
TX|8531|6|in|05/19/1984|.||.||.||.||.||.||.||.||.||.||
.||.||.||.||.||.||.||.||.||.||.||.||0.01||0.01||0.0
1||0.01||0.02||0.02||0.02||0.02||0.02||0.04||0.10||0.0
9||.||.||0.01||.||.||.||.||.||.||.||.||.||.||.||.||.||
.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||
.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||.||
.||.||.||.||.||.||.||.||0.38||
```

Figure 4-7 A Typical Acceptable Original 15-min. Data Set

This data set is reformatted by replacing the separation marks “||” and “|” with two spaces and replacing “.” (an abbreviation for 0.00) with “0.00”. Figure 4-8 illustrates the result of reformatting.

```
TX   8531   6   in   05/19/1984   0.00   0.00   0.00   0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.01  0.01  0.01  0.01  0.02  0.02  0.02  0.02
0.02  0.04  0.10  0.09  0.00  0.00  0.01  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.38
```

Figure 4-8 A Typical Reformatted 15-min. Data Set

After the data are reformatted, the database is analyzed to construct rainfall data parameters and 15-minute data parameters.

The concept of arrival time and an arrival time series is shown in Figure 4-9. A nonzero rainday (a day when rain occurs) is represented by a shaded box, and a zero rainday is represented by a plain box. The arrival time is defined as the number of consecutive zero raindays, and is equal to zero for a nonzero rainday. An arrival time series is a sequence of arrival times. For the daily rainfall sequence shown in Figure 4-9, the arrival time series is 0, 1, 0, 0, 3, 0, 2, 0.

Analysis of arrival times from historical real daily rainfall data for Texas indicates that arrival times appear to be Poisson distributed (Lapin, 1973). In Figure 4-10, the y-axis is the relative frequency f(t) and the x-axis is arrival time t in days. The relationship between relative frequency and arrival time shown in Figure 4-6 can be described by

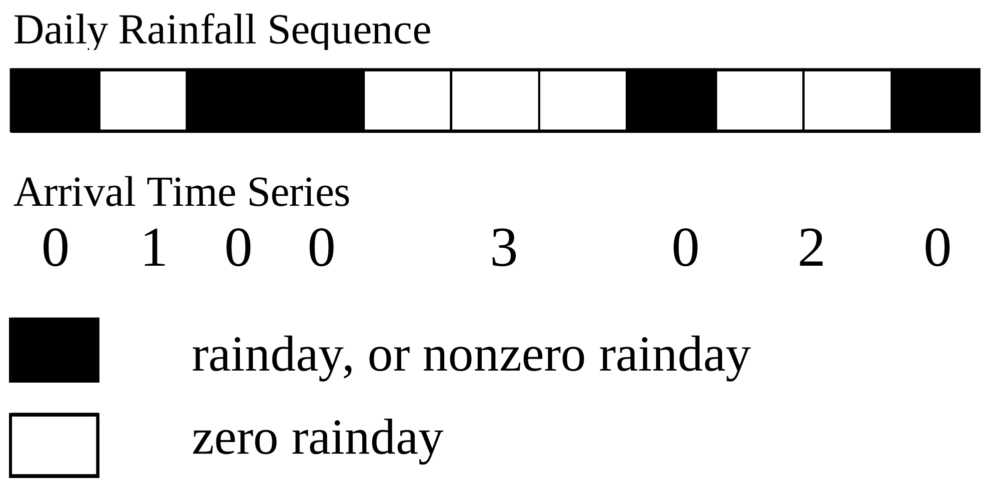

Figure 4-9 Definition of Arrival Time Series

$$f(t) = e^{-\lambda t}, \qquad (4\text{-}2)$$

where f(t) is relative frequency, λ is the mean rate of arrival time, and t is arrival time.

Another way to represent this information is by a cumulaltive distribution approach as shown in Figure 4-11. The y-axis is the cumulative frequency and the x-axis is arrival time t in days. This type of distribution is described by a cumulative arrival time function, which is

$$P = 1 - e^{-\lambda t}, \qquad (4\text{-}3)$$

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

where P is the cumulative probability from 0 - 1; t is arrival time in days; and λ is the mean rate of arrival time, 1/day. One way to interpret this distribution is in terms of exceedance probabilities. Figure 4-11 shows the probability that the arrival time of the

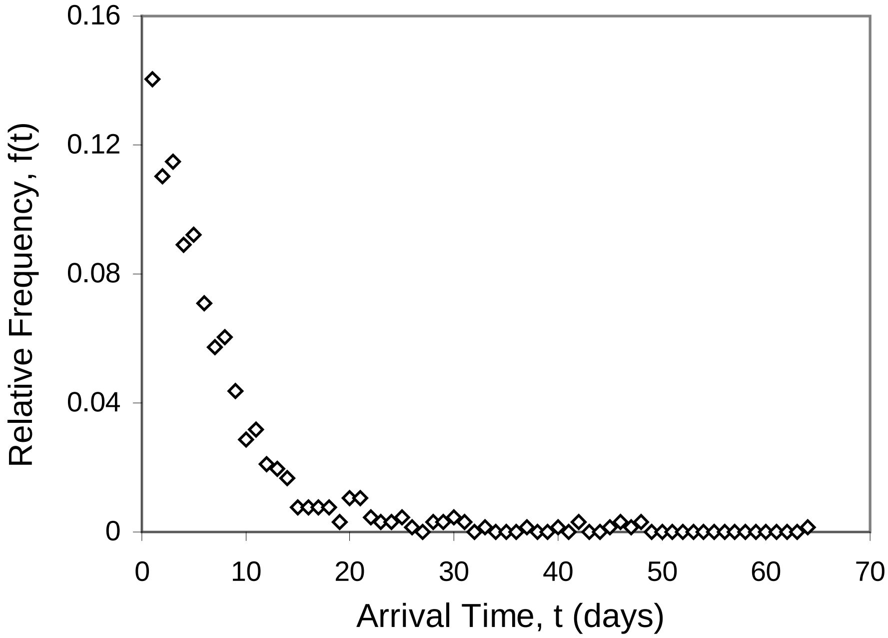

Figure 4-10 Relative Frequency Function of Arrival Time

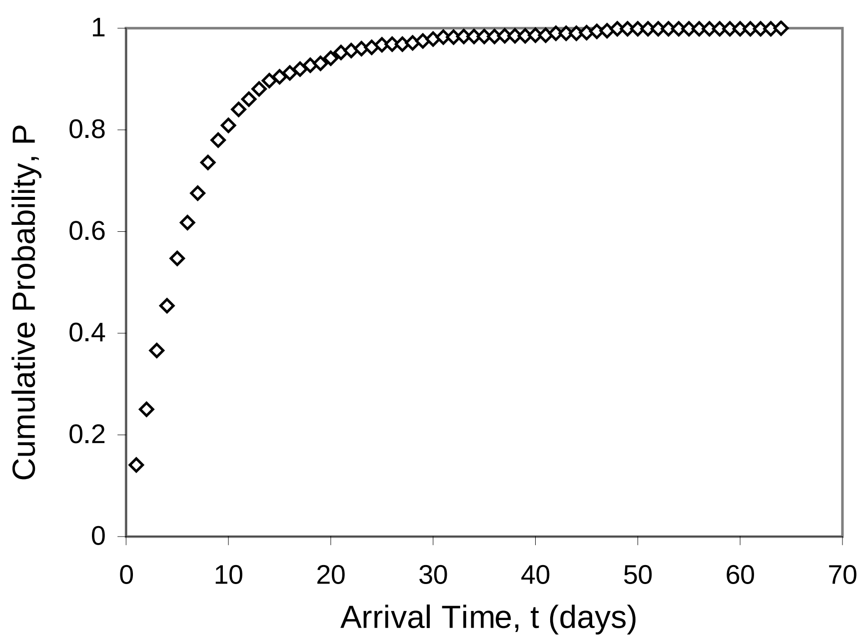

Figure 4-11 Empirical Cumulative Arrival Time Function

next nonzero rainday being less than or equal to 70 is nearly 1 (very likely).

These cumulative arrival-time function (ECATF) parameters are generated for each station by the ECATFPG model (Appendix A4). That is, a set of arrival times with a set of corresponding numbers between 0 and 1 is obtained.

To sample from these distributions a randomly generated number between 0 and 1 is associated with a corresponding arrival time. For example, if the P value is 0.6, then the arrival time is 6 days. This inverse transformation is the idea used in the random arrival time module in the SRG model to generate arrival times sequences. The simulated arrival time series is generated by adding zero raindays and nonzero raindays so that total number of days in the arrival-time sequence is equal to the number of construction days.

The mean rate of arrival time is the reciprocal of mean arrival time. Therefore a larger mean rate of arrival time is equivalent to a short arrival time, or more frequent rain events. Figure 4-12 shows the calculated mean rates of arrival times for the 109 rainfall stations in Texas. The mean rates of arrival times are larger in the east of Texas as compared to that of western Texas. In another words, there are fewer days between rain events in the eastern part of Texas than that in the western part of Texas. The shortest mean arrival time is 3.5 days near the Texas-Louisiana border, and the longest is 14.2 days near Del Rio on the Texas-Mexico border.

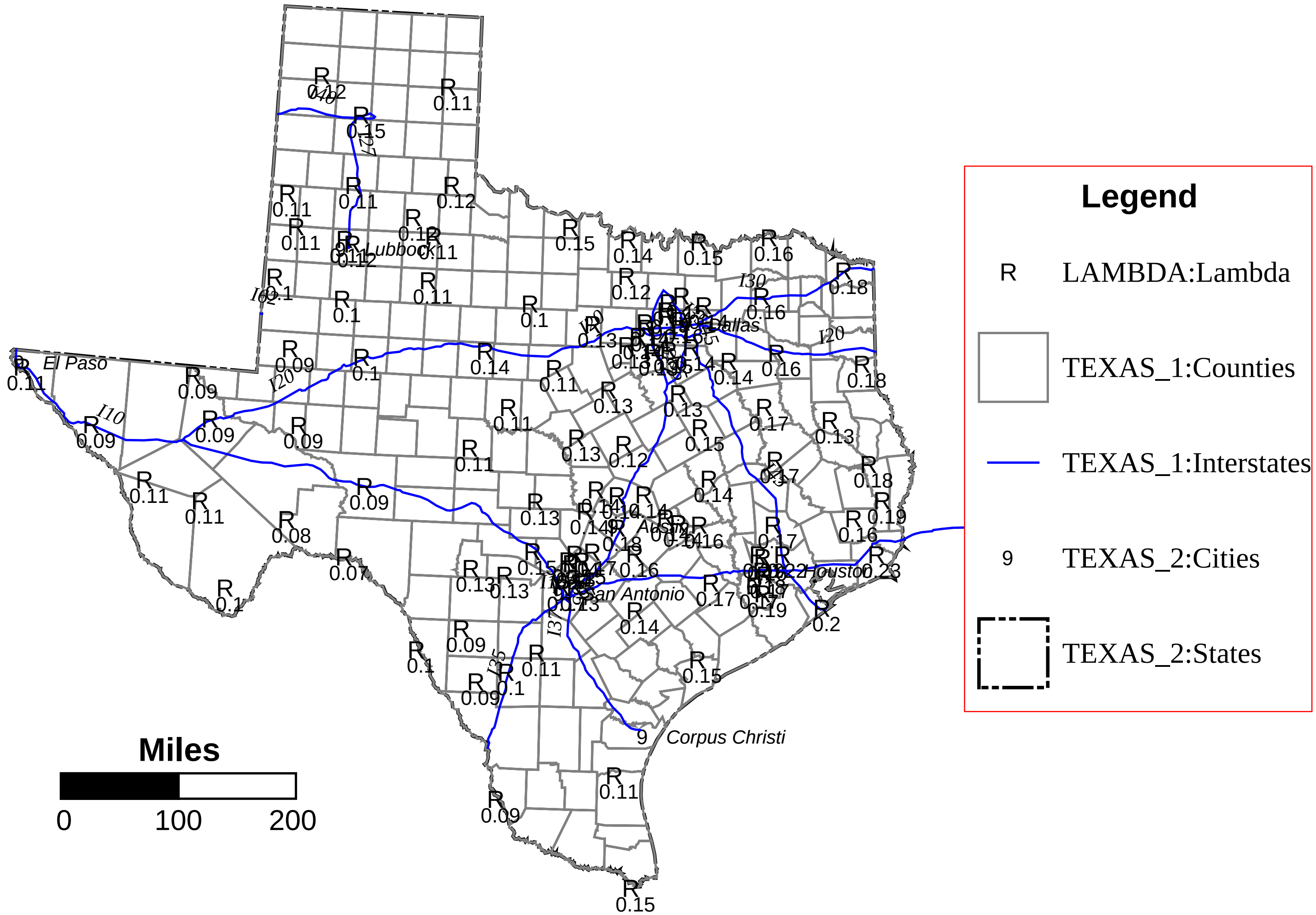

Figure 4-12 GIS Map Showing the Mean Rates of Arrival Times in Texas

Individual behavior on nonzero rain days are modeled using a four-parameter equation (Bras, 1990 and Dampster, 1993) that can roughly mimic overall shape, rain duration, and total precipitation of historical rain events on a daily basis. An exact fit is not expected. The equation is based on the concept of convolution where individual unit inputs are integrated to produce an overall response. The S-curve method in hydrology is an example of convolution applied to runoff hydrographs.

Figure 4-13 shows the concept of convolution. Figure 4-13(a) shows the starting of a rain event as a diffuse step response function (eqn. (4-5)) with an ultimate value of R_0, t_p is the time for rain event to reach this value. Figure 4-13(b) shows the ending of a rain event by as the inverse response of Figure 4-13(a) with a lag time of τ (eqn. (4-6)). Figure 4-13(c) is synthesized from the sum of Figure 4-13(a) and 4-13(b).

The symbols r1(t) and r2(t) represent two step-response function:

$$r1(t) = \frac{R_0}{\sqrt{4\pi S_d t}} \exp\left(-\frac{(t_p - t)^2}{4S_d t}\right), \qquad (4\text{-}5)$$

$$r2(t) = -\, r1(t) \text{ with a lag time of } \tau. \qquad (4\text{-}6)$$

Let

$$F1(t) = \int_0^t r1(t^*)\,dt^*, \qquad (4\text{-}7)$$

$$F2(t) = \int_0^{t-\tau} r2(t^*)\,dt^*, \qquad (4\text{-}8)$$

Then, we get

$$R(t) = F1(t) + F2(t). \qquad (4\text{-}9)$$

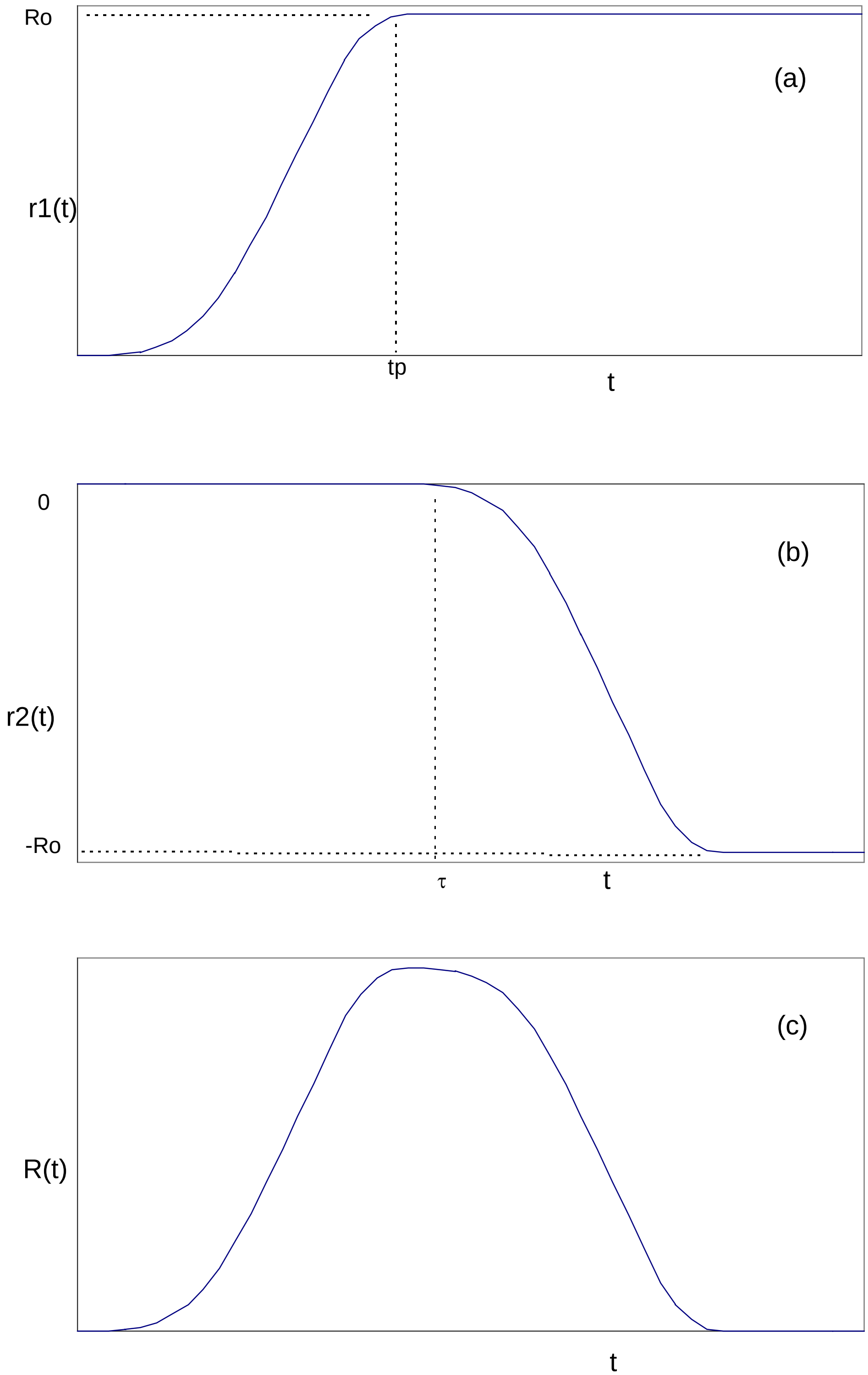

Figure 4-13 Graphic Representation of Convolution Equation

To find F1(t), we integrate

$$F1(t) = \int_0^t r(t^*)dt^* = \int_0^t \frac{R_0}{\sqrt{4\pi S_d t^*}} \exp[-\frac{(t_p - t^*)^2}{4S_d t^*}]dt^* \qquad (4\text{-}10)$$

Let

$$u = \frac{t_p - t^*}{2\sqrt{S_d t^*}},$$

$$\sqrt{t^*} = \sqrt{S_d u^2 + t_p} - \sqrt{S_d}\, u, \qquad (4\text{-}11)$$

$$\frac{dt^*}{\sqrt{t^*}} = 2[\frac{S_d u}{\sqrt{S_d u^2 + t_p}} - \sqrt{S_d}]du. \qquad (4\text{-}12)$$

Then, we have

$$F1(t) = \int_{+\infty}^{\frac{t_p - t}{2\sqrt{S_d t}}} \frac{R_0}{2\sqrt{\pi}\sqrt{S_d}} \times \exp(-u^2) \times 2 \times (\frac{S_d u}{\sqrt{S_d u^2 + t_p}} - \sqrt{S_d})du, \qquad (4\text{-}13)$$

$$= -\frac{R_0}{2}\frac{2}{\sqrt{\pi}}\int_{+\infty}^{\frac{t_p - t}{2\sqrt{S_d t}}} \exp(-u^2)du + \int_{+\infty}^{\frac{t_p - t}{2\sqrt{S_d t}}} \frac{R_0 S_d}{\sqrt{\pi}\sqrt{S_d}} \frac{u}{\sqrt{S_d u^2 + t_p}} \exp(-u^2)du,$$

$$= \frac{R_0}{2}\mathrm{erfc}[\frac{t_p - t}{2\sqrt{S_d t}}] + \int_{+\infty}^{\frac{t_p - t}{2\sqrt{S_d t}}} \frac{R_0}{\sqrt{\pi}\sqrt{S_d}} \exp(-u^2)\frac{S_d}{S_d} d\sqrt{(u^2 S_d + t_p)}, \qquad (4\text{-}14)$$

Let

$$w = \frac{\sqrt{u^2 S_d + t_p}}{\sqrt{S_d}}. \qquad (4\text{-}15)$$

Then, we have

$$F1(t) = \frac{R_0}{2}\mathrm{erfc}[\frac{t_p - t}{2\sqrt{S_d t}}] + \int_{+\infty}^{\frac{t_p - t}{2\sqrt{S_d t}}} \frac{R_0}{\sqrt{\pi}} \exp(-w^2 + \frac{t_p}{S_d})dw, \qquad (4\text{-}15)$$

$$= \frac{R_0}{2}\text{erfc}[\frac{t_p - t}{2\sqrt{S_d t}}] - \frac{R_0}{2}\exp(\frac{t_p}{S_d})\text{erfc}[\frac{t_p + t}{2\sqrt{S_d t}}]. \quad (4\text{-}16)$$

Similarly, F2(t) is

$$F2(t) = -\frac{R_0}{2}[\text{erfc}(\frac{t_p - (t-\tau)}{2\sqrt{S_d(t-\tau)}}) - \exp(\frac{t_p}{S_d})\text{erfc}(\frac{t_p + (t-\tau)}{2\sqrt{S_d(t-\tau)}})]. \quad (4\text{-}17)$$

From eqn. (4-9), we have

$$R(t) = F1(t) + F2(t).$$

Then, R(t) is equal to

$$\begin{aligned} R(t) = \frac{1}{2}R_0 \times \{[&\text{erfc}(\frac{t_p - \tau}{2\sqrt{S_d t}}) - \exp(\frac{t_p}{S_d})\text{erfc}(\frac{t_p + \tau}{2\sqrt{S_d t}})] \\ - [&\text{erfc}(\frac{t_p - (t-\tau)}{2\sqrt{S_d(t-t)}}) - \exp(\frac{t_p}{S_d})\text{erfc}(\frac{t_p + (t-\tau)}{2\sqrt{S_d(t-t)}})]\} \end{aligned}, \quad (4\text{-}18)$$

where R is the predicted precipitation (in.), t is the elapsed time (15-minute on a daily basis, or from 15 minutes to 1440 minutes) since the beginning of the rain day, and four rainday parameters are the following: R_0, peak rainfall amount (in.); t_p, historical time to peak; τ, rain duration; and R_d, rain dispersion coefficient.

The four rainday parameters in this model are found by minimizing the sum of squared differences between the observed and modeled rainfall values. This minimization is performed using a constrained Quasi-Newton method (Press, 1986) with the criterion that total volume of rainfall is preserved in the model. Figure 4-14 shows the results of this model approach for three different cases. The y-axis is the amount of precipitation in inches, and the x-axis is time in minutes. As the complexity of the rainfall pattern increases in one day (From Figure 4-14(a) to 4-14(c)), the model loses the ability to simulate the real rainfall intensity, but total volume, overall shape, and rain duration are preserved. This rainday model to calculate 15-minute rainfall data from four rainday parameters is the parametric based option for generating 15-minute rainfall data in the SRG model.

Figure 4-15 shows that one benefit from data reduction is the space needed to store data in a computer is significantly reduced. For daily data, there is a reduction of the file size by a factor of 30. For 15-minute data, there is a reduction of the file size by a factor of

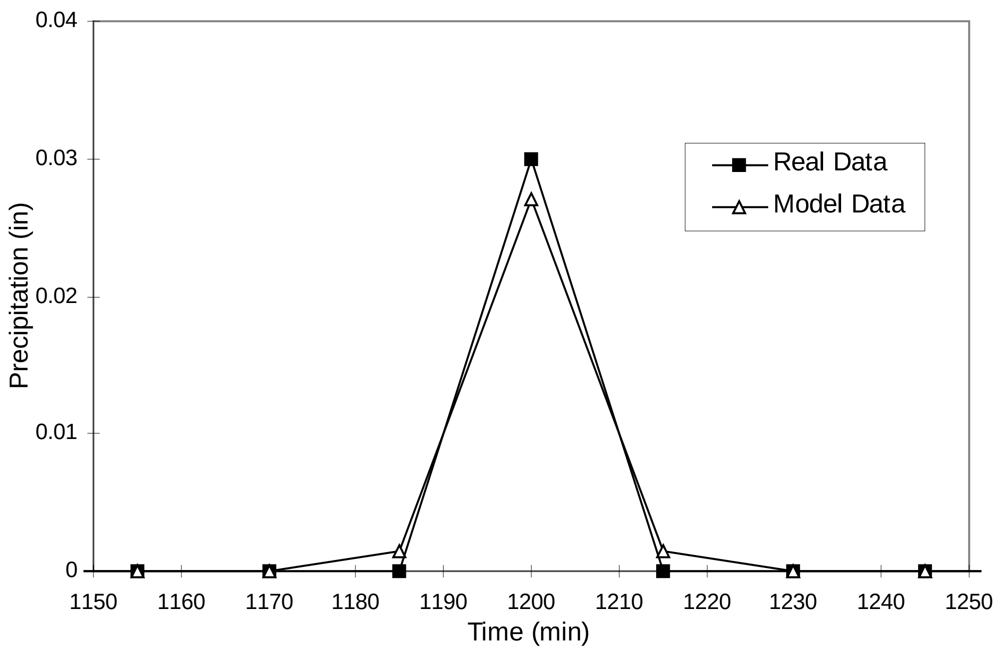

Figure 4-14(a) 15-minute Model vs. Real Data

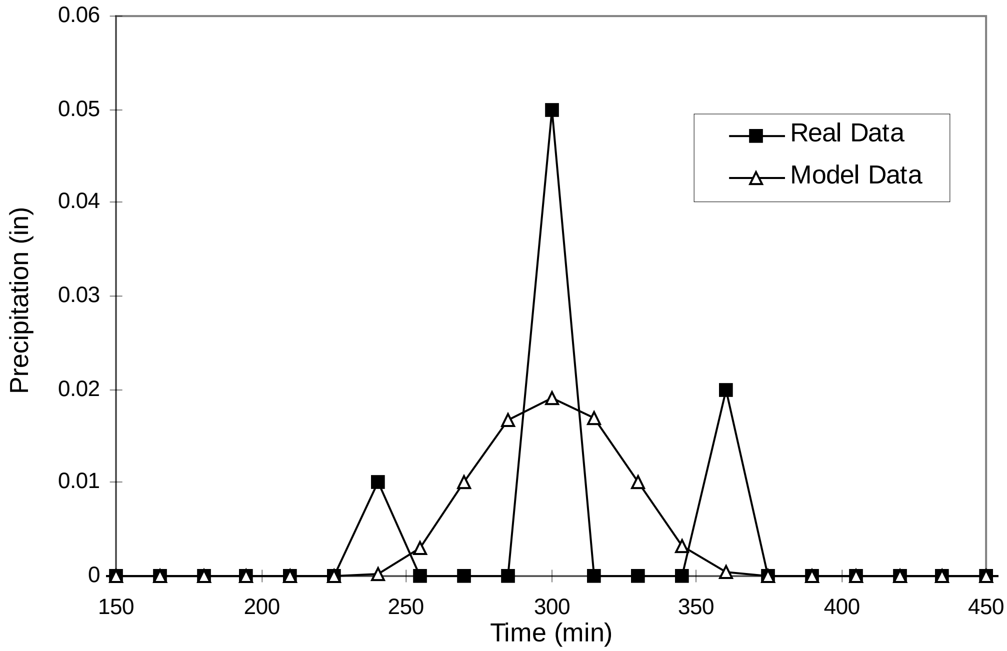

Figure 4-14(b) 15-minute Model vs. Real Data

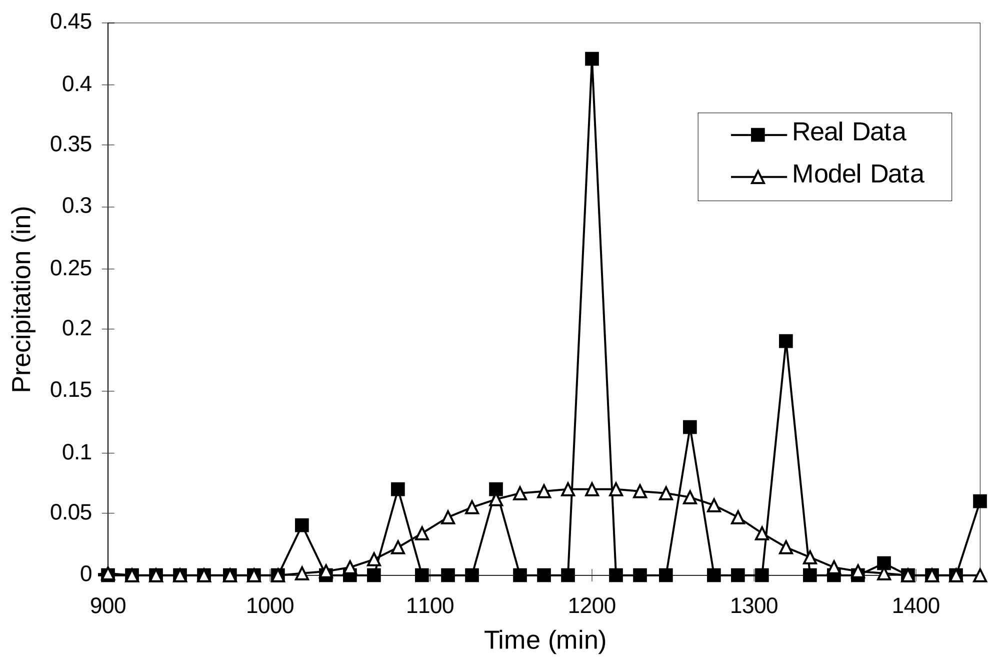

Figure 4-14(c) 15-minute Model vs. Real Data

10. So after the parametric analysis, daily data files for all stations in Texas can be stored on one floppy disk. Similarly, 15-minute data all for stations around Houston can be stored on one high-density floppy disk.

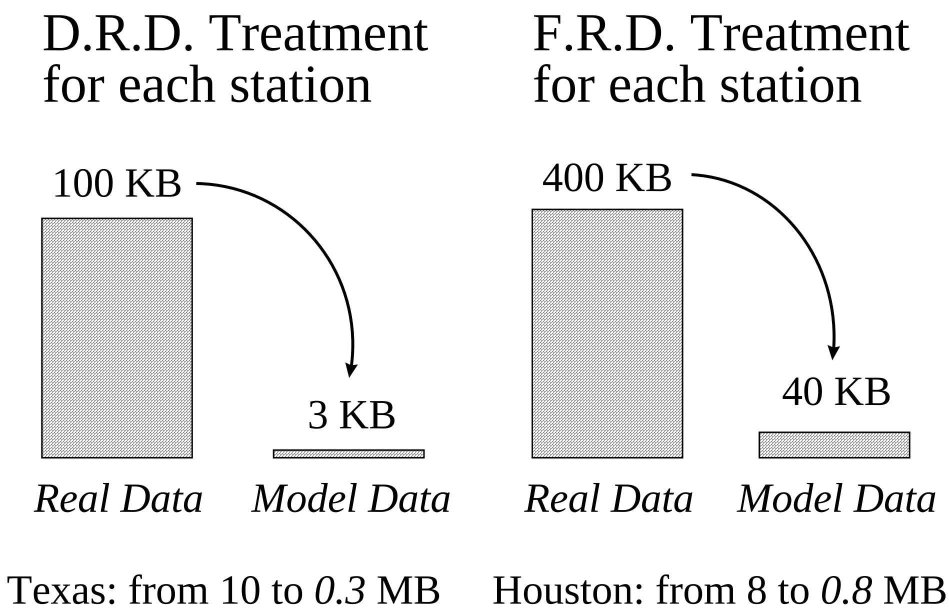

Figure 4-15 Comparison of Storage Space for Model and Real Data

D.R.D.: daily rainfall data; F.R.D.: 15-minute rainfall data

4.3. SRG Model Interface Design

The SRG model operates on the data developed in the previous two steps. Figure 4-16 shows the flow chart of SRG model to use the 15-minute model data.

The user supplied data required for the SRG model is entered through the interface (the upper central box). These data are: number of construction days, distances from construction sites to selected stations, and station identification numbers of those stations. Station ID numbers are used by the SRG model to find corresponding daily and 15-minute parameter data files from the database. The model accesses these data to construct a rainfall sequence for the highway construction site being studied..

The computational sequence in the SRG model is (Figure 4-16):

1) The main module (the central upper 3-D box) will first call the random arrival time (RAT) module (the middle left 3-D box). The RAT module will read the ECATF parameters from the corresponding ECATF parameter data file (the upper left box), create a series of random numbers between zero and one according to the number of construction days; and then, generate an arrival time series (the lower left box) for each station identified in the input.
2) For those days in the generated arrival time series that are identified as raindays, the main module will call the random rainday (RRD) module (the middle right 3-D box). The RRD module will randomly select four rainday parameters from the 15-minute parameter data files (the upper right box), and produce 15-minute rainday sequence (the lower right box) from the convolution equation.
3) Finally, the main module will call the inverse distance (DIST) module (the central lower 3-D box) to generate the 15-minute rainfall sequence (the lower central box) for the construction site by combining the 15-minute rainfall sequences from the three used identified stations.

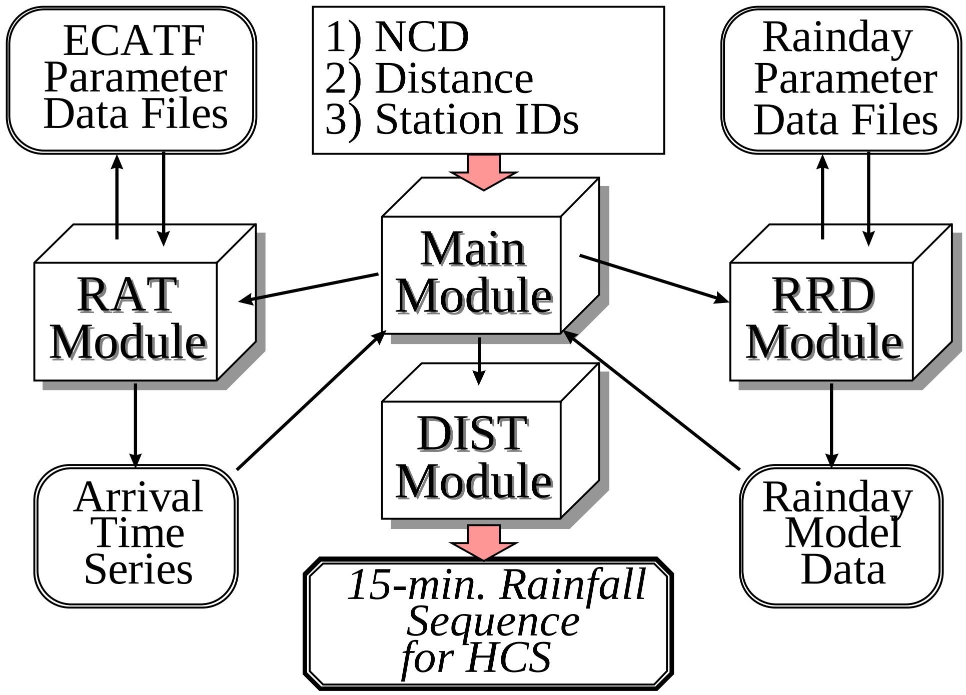

Figure 4-16 Flow Chart of the SRG Model

Most of the computational functionality and database information in the SRG model is coded in FORTRAN. A Visual Basic Interface is constructed to simplify the use of the SRG model. Figure 4-17 shows the relationship among user, interface and the SRG model. Instead of creating an input file and running the SRG model directly, the user (the left box) inputs the required site specific information and executes the SRG model calculations (the right box) through several labeled information boxes and command buttons on the interface (the central box).

Figure 4-18 shows the structure of the Visual Basic Interface. The main module (the left box) is used for information input and program control. From the main module, three

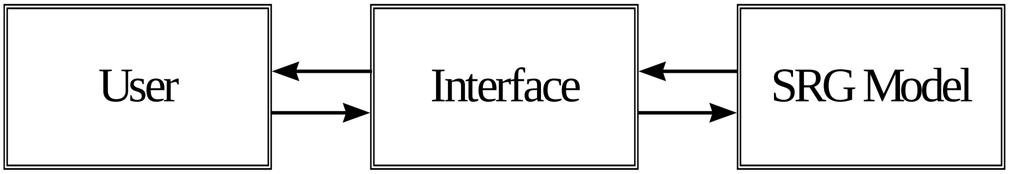

Figure 4-17 Overall Structure of the SRG Model

functions are available. The input file creation function (the right upper box) is used to create the input file for the SRG model calculations. The help function (the right central box) is available to assist the model user. The graphics function (the right lower box) is used to generate a plot of 15-minute rainfall sequence for the user to inspect.

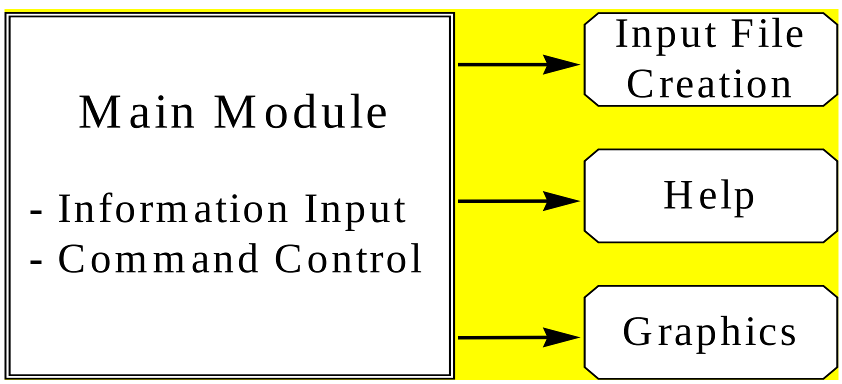

Figure 4-18 Flow Chart of the SRG Model Interface

Figure 4-19 shows the SRG model Interface. A user enters required data in the nine boxes. The interface program checks the validity of input information, and performs calculations based upon the user's choice of the parametric or the bootstrapping method. A user can also generate a plot of 15-minute rainfall sequence and get help using the SRG model.

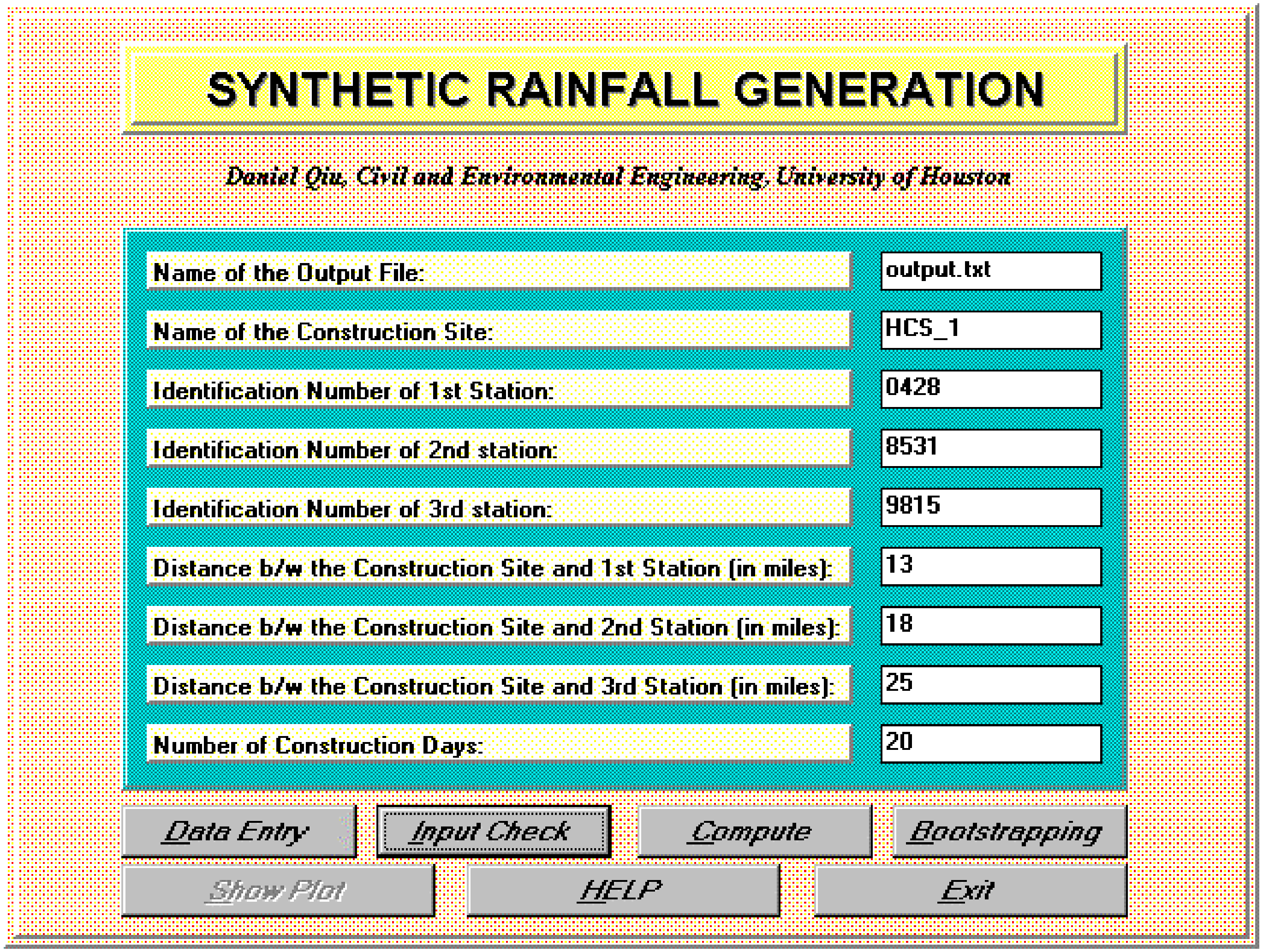

Figure 4-19 SRG model Interface

Figure 4-20 shows a typical 15-minute rainfall sequence from the SRG model. The number of construction days is equal to 20. The y-axis is the amount of precipitation in inches, and the x-axis is the time in days. From these rainfall sequence diagrams, possible occurrence of rain events, rain intensity and volume of rain precipitation can be estimated.

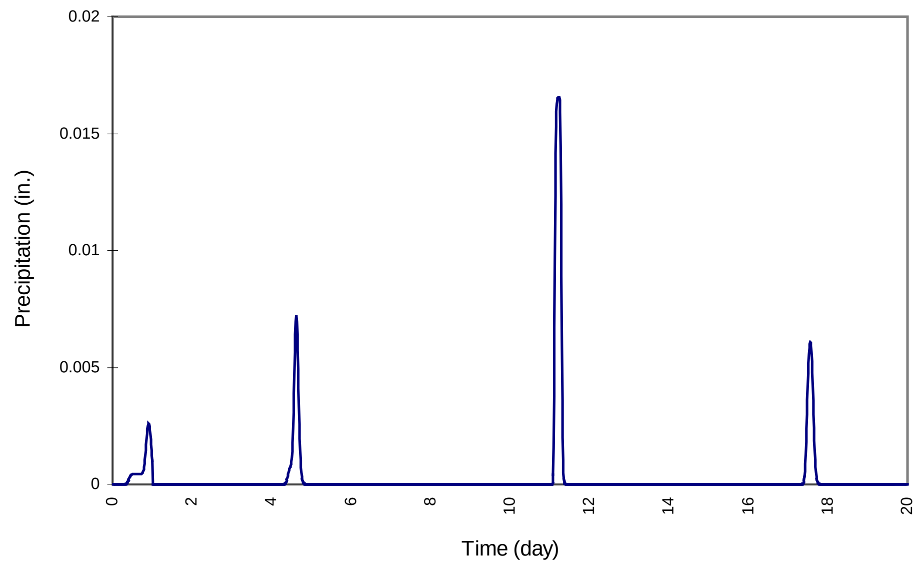

Figure 4-20 Rainfall Sequence from the SRG model

Chapter 5 Bootstrapping Method

Bootstrapping is a generic name used to describe the process of resampling historical data. It differs from the SRG model (a parametric approach) in that it models the characteristics of a population strictly from the sample at hand, rather than by making assumptions (possibly unrealistic) about the population, distribution equations, and descriptive parameters.

At the beginning of this research, the primary concern about using bootstrapping was how to effectively resample from a huge data set. In particular, there were 10 to 50 years of historical daily and 15-minute rainfall records from the 109 rainfall stations, with a total number of rainfall data points exceeding 10 million. As many as 10% of the records were missing or irregularly formatted. The parametric SRG model was created to learn how to manage a large data set and treat missing or bad records, and change them to useable format. Once the SRG model was constructed, the bootstrapping method to resample real data was designed.

Figures 5-1(a-c) illustrate that the model preserves the overall duration, overall shape and total amount of precipitation, and does not preserve peak intensity. Alternatively, if preservation of peak intensity is emphasized, then it is impossible for any smooth and continuous curve to preserve overall duration, overall shape, and total amount of precipitation. Jilani (1997) and Liu (1997) suggest that intensity is more important than total amount of precipitation in predicting erosion. To preserve precipitation intensity

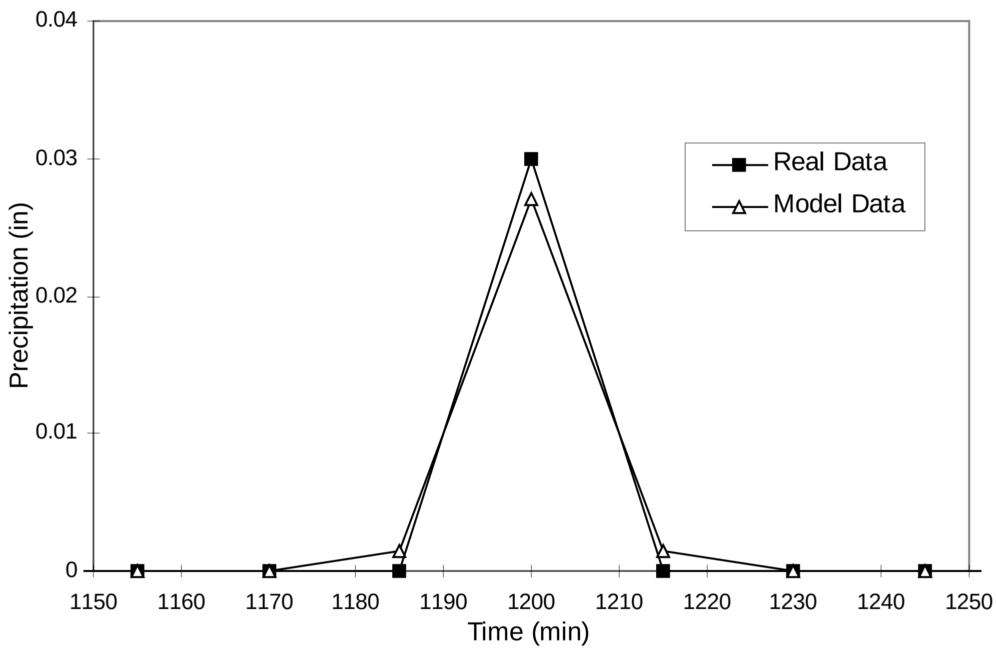

Figure 5-1(a) 15-minute Model vs. Real Data

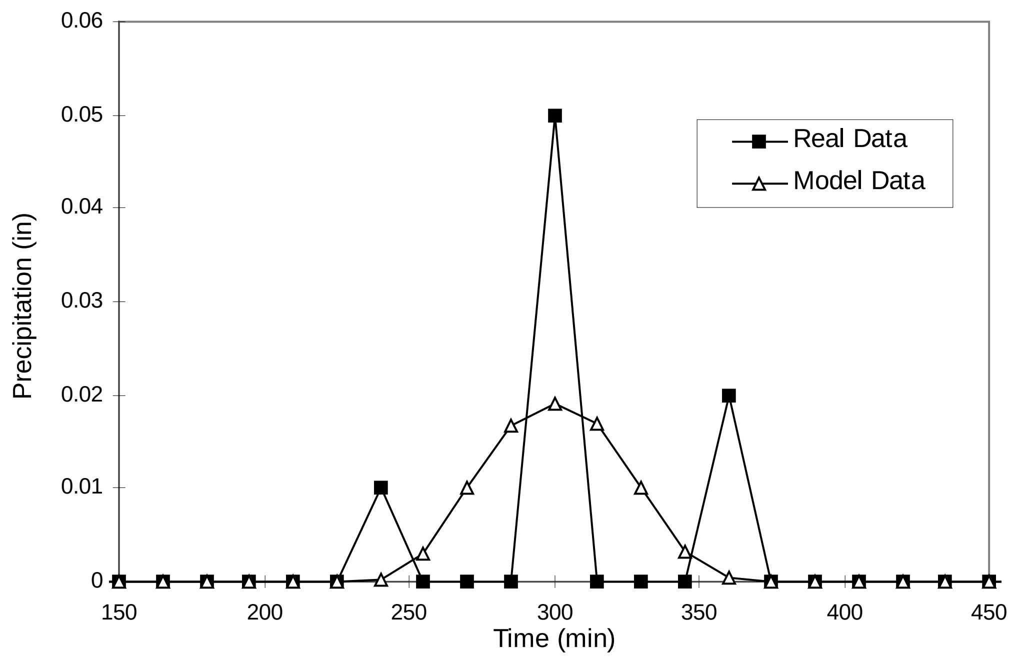

Figure 5-1(b) 15-minute Model vs. Real Data

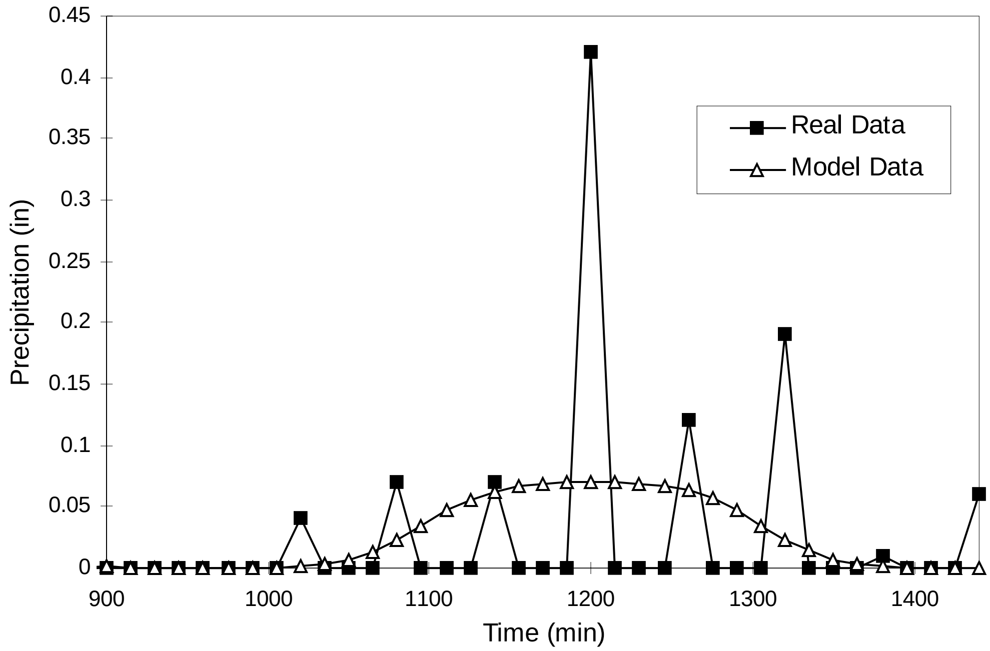

Figure 5-1(c) 15-minute Model vs. Real Data

information, the bootstrapping method was designed and added to the model as an alternative way to generate rainfall sequences.

The bootstrapping method in this thesis selects raindays during a construction using the empirical cumulative arrival time distributions in the first step. Then the rainday behavior is modeled by selecting a historical day from the database and using the rainfall data for that day. Seasonal effects, wet/dry year effects are ignored in this method.

The computational sequence for the bootstrapping method is illustrated in Figure 5-2. The procedures is nearly identical to the parametric SRG model except for how the rainday 15-minute precipitation values are computed.

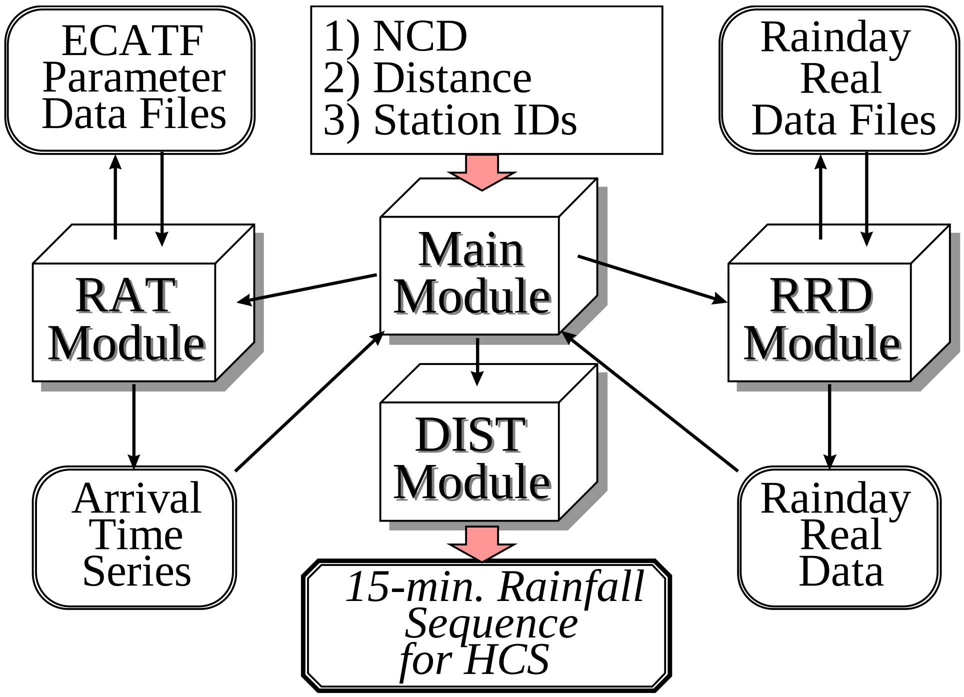

Figure 5-2 Flow Chart of the Bootstrapping Method

The sequence of computations is

1) The main module (the central upper 3-D box) will first call the random arrival time (RAT) module (the middle left 3-D box). For each station, the RAT module reads the ECATF parameters from the corresponding ECATF parameter data file (the upper left box). Then the RAT module generates a random number between 0 and 1, and identifies the corresponding arrival time according to ECATF parameter. The RAT module repeats these steps in order to form an arrival time series (the lower left box) in which the total number of

raindays and zero raindays is equal to the number of construction days. Three simulated arrival time series (one for each station) are sent back to the main module.

2) The main module analyzes the simulated arrival time series created from the RAT module. For each rainday in the generated arrival time series, the main module will call the random rainday (RRD) module (the middle right 3-D box). The RRD module will generate a random number between 1 and the total number of 15-minute data sets for a particular station (One data set stores 96 15-minute rainfall data points for one rainday.). The module then selects the corresponding rainday from 15-minute data files (the upper right box), and reads 96 rainfall data values for that rainday (the lower right box). These rainfall data values for each rainday are returned to the main module. For each zero rainday, the main module will assign 96 zero values. The main module joins these zero and nonzero precipitation data points together on a 15-minute basis to form three rainfall sequences (one for each station) according to the order of generated arrival time series from the RAT module.

3) Finally, the main module will call the inverse distance (DIST) module (the central lower 3-D box). The DIST module will take three real rainfall data values of the same time from the three different sequences (one rainfall data value from each sequence) and calculate the rainfall data value of highway construction site from these three data values by the inverse distance

algorithm (eqn. (4-1)). Then the DIST module will join the generated rainfall data values for highway construction site one by one and form 15-minute rainfall sequence (the lower central box) for the construction site.

To illustrate the procedure of the bootstrapping method with an example, the assumed highway construction site HCS_1 near Austin is used (Figure 5-3). The required information to use the bootstrapping method is entered through the Visual Basic Interface (Figure 4-19): the number of construction days is set to be equal to 20; three stations used to perform rainfall generation for HCS_1 are 0428, 8531, and 9815; distances from HCS_1 to these three stations are 15, 18, and 25 miles, respectively.

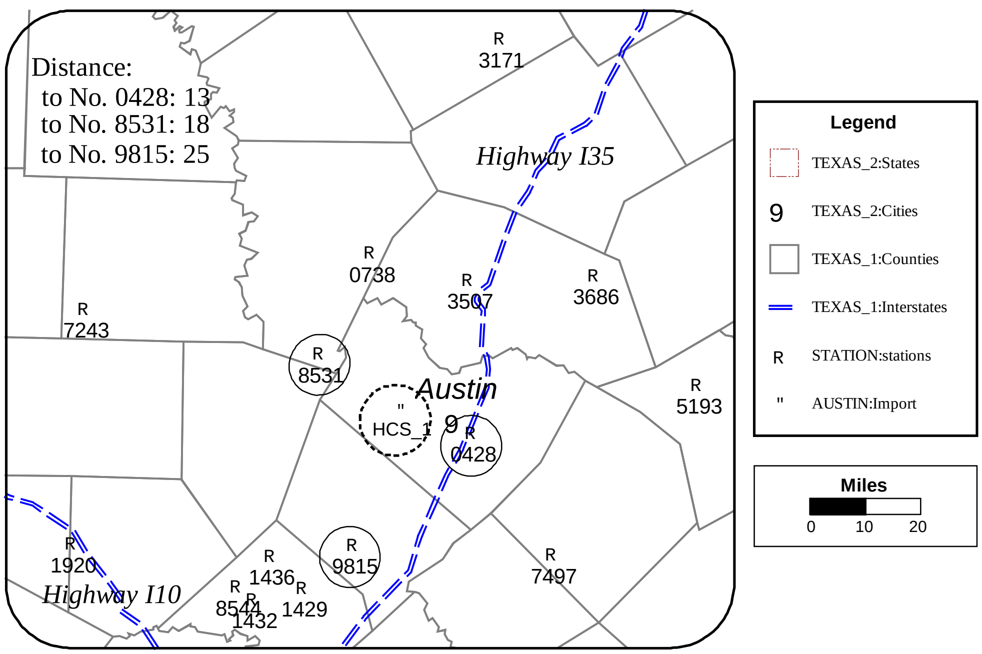

Figure 5-3 GIS Map Showing HCS_1 near Austin

Figure 5-4 shows a 15-minute rainfall sequence for the assumed highway construction site HCS_1. The y-axis is the amount of precipitation in inches, and the x-axis is the time in days.

In principle this bootstrapping method will preserve historical rainfall intensity. The pattern of Figure 5-4 is identical to that of Figure 4-20, but the intensities are greater. In fact the values in Figure 4-20 cannot even be measured using standard rain gages.

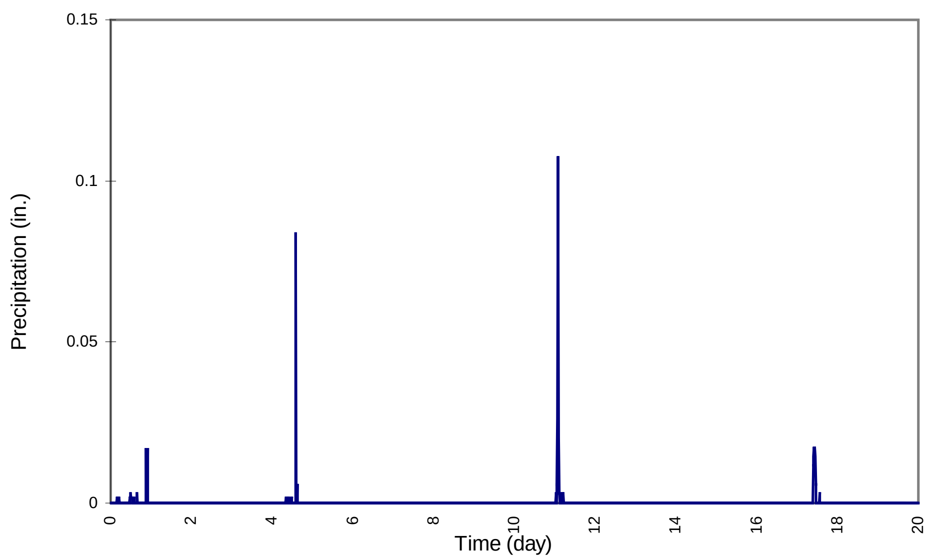

Figure 5-4 Rainfall Sequence from the Bootstrapping Method

Chapter 6 Model Test

The parametric SRG model presented in Chapter 3 and 4 was tested by asking the following questions: 1) What is the effect of the number of construction days and the number of repeats on SRG model's mean value of precipitation? 2) Is the parametric model sequence distinguishable from a rainfall sequence generated by the bootstrapping method (real rainfall sequence)? 3) If the answer to the second question is yes, then, will the model and real rainfall sequences produce the same amount of soil loss using the soil production model (Jilani, 1997)?

6.1 Introduction

Three assumed highway construction sites near Austin, Houston and Lubbock are selected to test the SRG model. Table 6-1 shows location information for these three sites. Figures 6-1(a), (b) and (c) show location of these sites (solid triangle enclosed by solid circle) along with selected rainfall stations for 15-minute rainfall sequence

Table 6-1 Site Information Sheet for HCS

Site Name	Site ID	Latitude	Longitude
AUSTIN No.1	HCS_1	30.33	95.91
HOUSTON No.1	HCS_2	29.83	95.50
LUBBOCK No.1	HCS_3	33.83	101.17

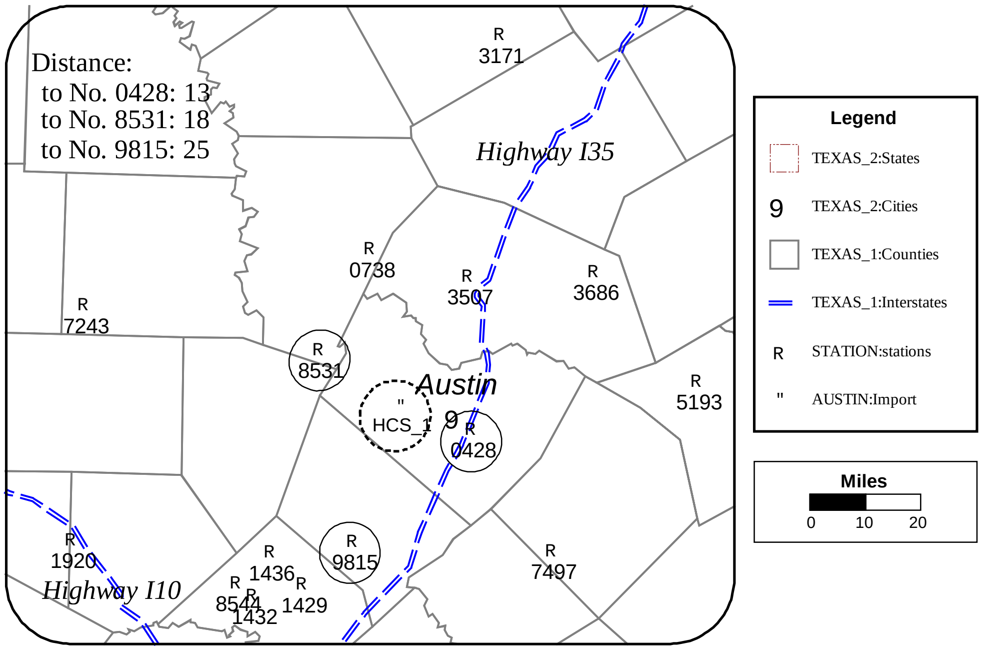

Figure 6-1(a) GIS Map Showing HCS_1 near Austin

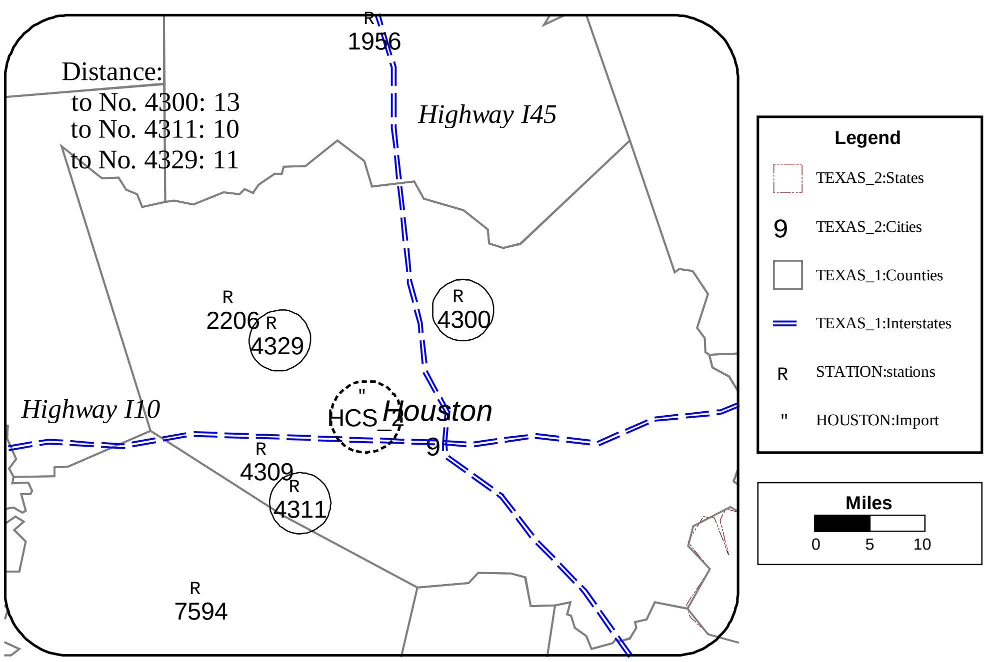

Figure 6-1(b) GIS Map Showing HCS_2 near Houston

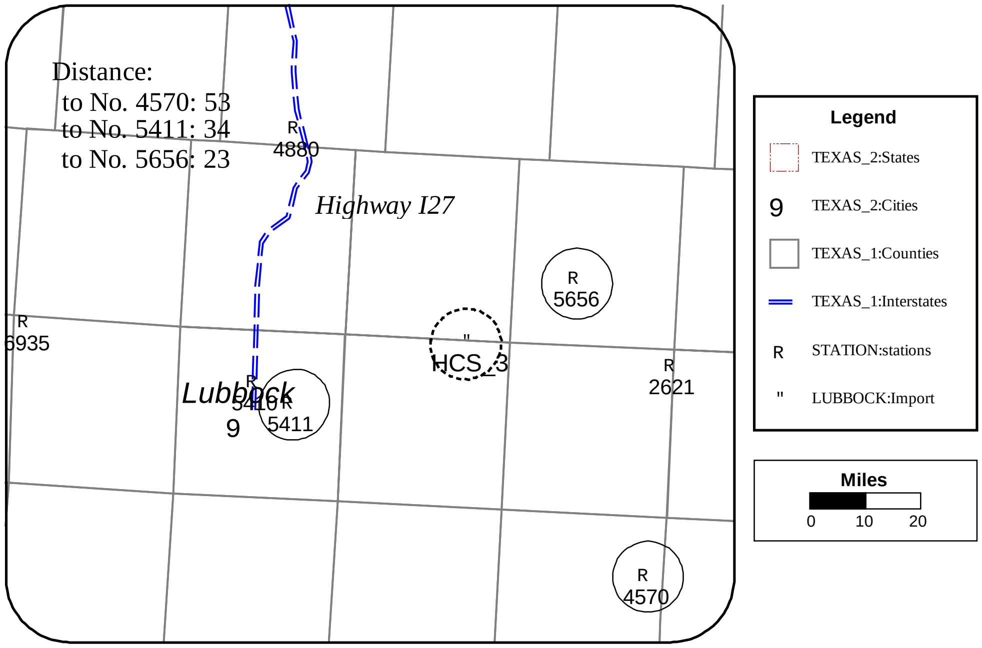

Figure 6-1(c) GIS Map Showing HCS_3 near Lubbock

generation (cross flag enclosed by dashed circle) on the GIS map. Also the distances from HCS to selected rainfall stations are shown on the map.

To perform a statistical test, two commonly used statistical parameters, mean and variance, will be used throughout the model test procedure. The mean is the arithmetic average of a set of data, which is defined as

$$\mu = \frac{\sum x_i}{n}, \quad (5\text{-}1)$$

where μ is the mean value, x_i is the sample data, n is number of data points. The variance is used to define the width (spread) or variability around a central value, and is determined by

$$s^2 = \frac{\sum (x_i - \mu)^2}{n}. \quad (5\text{-}2)$$

where s^2 is the variance, x_i is the sample data, μ is the mean or mean value, and n is number of data points.

6.2 Model Testing for the Effect on Number of Construction Days and Number of Repeats

The purpose of the first test is to determine whether the number of construction days (NCD) and number of repeated runs (NR) of the SRG model will affect the mean values of precipitation for parametrically generated rainfall sequences. The numbers of construction days used are 10, 20, 30, 60, 90 and 120, and the number of repeats are 10, 20, 30, 40, 50, and 60.

The assumed highway construction site HCS_1 and three surrounding rainfall stations are selected for this test (Figure 6-1(a)). For each NCD, a number of model rainfall sequences are generated according to NR by the SRG model. For example, if NR equals to 10, then ten sets of rainfall sequences are generated, or the SRG model is run ten times. Then the average value for each time unit (15-minute) from these rainfall sequences is computed one by one. Then these average values are connected together in the same order in time, forming the parametrically generated rainfall sequence for that NR. Table 6-2 shows the mean and variance of precipitation for the statistically generated model rainfall sequences for different NCD and NR combinations.

Figure 6-2 shows the mean values of precipitation for the parametrically generated model rainfall sequences from different NCD and NR. This figure shows that for values of NCD less than 60 days, there is large fluctuation among mean values for different numbers of repeats. For each proposed NCD, the variances for the mean values of precipitation from different NR are calculated and are shown in Table 6-3. The variances for mean values of precipitation decrease steadily with increasing NCD. For any NCD equal to or larger than 60 days, the variances are in the order of 10^{-10}. The reasons for this result are: 1) As sample size increases (NCD becomes larger), the mean of sample approaches the mean of population; 2) Analysis of the arrival times for rainfall events in Texas shows that maximum arrival time is around 60 days. Therefore, to run the SRG model, the NCD equal to or larger than 60 are needed so that all the probabilities of arrival times will be considered in the modeling process.

For values of NCD equal to and larger than 60, the variances of the mean values of precipitation for NR equal to 10, 20, 30, 40, 50 and 60 are calculated and shown in Table 6-4. In Figure 6-2 and Table 6-4, there exists no clear trend of variance change, and the difference in variances is within three times except for NR equal to 10. Therefore a value of NR equal to or larger than 20 is suggested to run the SRG model to get the mean value of precipitation for statistically generated rainfall sequences. The total volume of precipitation expected during a construction period can be calculated by multiplying the mean values of precipitation by duration.

Table 6-2 Result from Different NCD and NR

Number of Construction Days	Number of Data	Number of repeats	Mean (in.) for Model Data	Variance for Model Data	Mean (in.) for Real Data	Variance for Real Data
10	960	*10*	6.16E-04	1.11E-06	4.99E-04	4.58E-06
		20	7.98E-04	5.41E-07	5.29E-04	3.17E-06
		30	5.98E-04	3.04E-07	5.78E-04	2.08E-06
		40	7.99E-04	2.94E-07	7.55E-04	2.31E-06
		50	5.41E-04	1.54E-07	5.06E-04	9.35E-07
		60	7.04E-04	2.34E-07	6.65E-04	1.04E-06
20	1920	*10*	6.41E-04	9.53E-07	6.12E-04	6.63E-06
		20	6.66E-04	4.65E-07	6.51E-04	3.54E-06
		30	5.41E-04	2.57E-07	5.32E-04	1.96E-06
		40	5.63E-04	2.35E-07	5.56E-04	1.56E-06
		50	5.54E-04	1.58E-07	5.43E-04	1.09E-06
		60	5.69E-04	2.41E-07	5.35E-04	1.27E-06
30	2880	*10*	4.50E-04	5.48E-07	4.11E-04	4.97E-06
		20	5.97E-04	5.78E-07	5.88E-04	3.94E-06
		30	6.07E-04	4.17E-07	5.55E-04	2.38E-06
		40	5.89E-04	3.08E-07	5.55E-04	1.76E-06
		50	5.73E-04	2.44E-07	5.37E-04	1.27E-06
		60	6.59E-04	2.43E-07	6.24E-04	1.31E-06
60	5760	*10*	6.51E-04	1.19E-06	6.02E-04	5.72E-06
		20	5.92E-04	4.91E-07	5.54E-04	3.17E-06
		30	5.84E-04	3.84E-07	5.39E-04	2.44E-06
		40	5.83E-04	2.75E-07	5.59E-04	1.53E-06
		50	5.95E-04	2.66E-07	5.49E-04	1.46E-06
		60	5.74E-04	1.86E-07	5.36E-04	1.18E-06
90	8640	*10*	6.03E-04	1.05E-06	5.51E-04	5.11E-06
		20	5.68E-04	4.41E-07	5.39E-04	2.77E-06
		30	5.81E-04	3.56E-07	5.49E-04	2.15E-06
		40	5.78E-04	2.88E-07	5.41E-04	1.66E-06
		50	5.76E-04	1.94E-07	5.34E-04	1.03E-06
		60	6.04E-04	2.61E-07	5.77E-04	1.53E-06
120	11520	*10*	5.88E-07	7.67E-04	5.02E-04	4.72E-06
		20	5.67E-04	4.68E-07	5.30E-04	2.88E-06
		30	6.02E-04	3.74E-07	5.63E-04	2.16E-06
		40	6.02E-04	3.07E-07	5.67E-04	1.70E-06
		50	5.92E-04	2.42E-07	5.57E-04	1.28E-06
		60	5.87E-04	2.17E-07	5.53E-04	1.23E-06

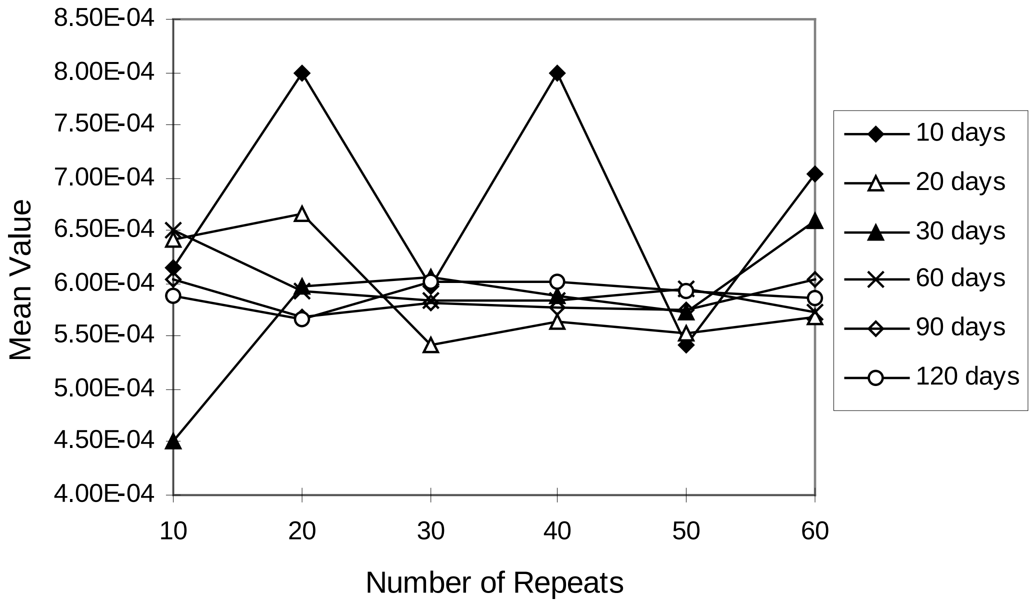

Figure 6-2 Mean Value vs. Number of Repeat

Table 6-3 Variance of Mean Values of Precipitation from Each Proposed NCD

NCD	10	20	30	60	90	120
Variance of Means	1.2E-08	2.6E-09	4.9E-09	7.7E-10	2.2E-10	1.7E-10

Table 6-4 Variance of Mean Values from Each Proposed NR

Number of Repeats	10	20	30	40	50	60
Variance of Mean Value of Precipitation	7.2E-10	1.3E-10	8.6E-11	1.1E-10	6.9E-11	1.5E-10

6.3 Model Testing for Model and Real Sequences

The purpose of the second test is to determine is the model rainfall sequence is distinguishable from the real rainfall sequence generated from the bootstrapping method.

A value of NCD equal to 60 is used as input.

From Table 6-2, the variances of precipitation for the model and real rainfall sequences are quite different, and that is because an exact fit of the 15-minute real and model data on daily basis is not expected. As shown in Figure 4-14, though the model sequence preserves the overall shape and total volume of the real sequence, it produces a continuous and uniform curve for the discontinuous and spike-like real sequence on each day. Therefore the variance, which indicates the width or variability around a central value, is decreased for the model sequence.

An unequal t-test (Blaisdell, 1992) is used to test whether real and model rainfall sequences have the same mean values of precipitation. This test method is used to test whether two populations have the same mean values when their variances are different.

1. Assumptions for the test are as follows:

    a) independent random samples,

    b) each population has a normal distribution.

2. Hypothesis and test statistics are as follows:

    a) The null hypothesis (H_0) is

$$H_0: (\mu_1 - \mu_2) = 0, \tag{6-3}$$

where μ_1 is the mean of precipitation for the model rainfall sequence, and μ_2 is the mean of precipitation for the real rainfall sequence.

b) The test statistic for H_0 is

$$t = \frac{(\mu_1 - \mu_2) - 0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}, \qquad (6\text{-}4)$$

where t is the t-test value or t value, s_1^2 is the variance of precipitation for the model sequence, s_2^2 is the variance of precipitation for the real sequence, n_1 is the number of data points for the model rainfall sequence, and n_2 is the number of data points for the real rainfall sequence.

c) Alternative hypothesis is given by

$$H_\alpha: (\mu_1 - \mu_2) \neq 0, \qquad (6\text{-}5)$$

where the mean of precipitation for the model rainfall sequence is not the same as that of the real rainfall sequence. The rejection region for H_0 is defined as $t < - t_{\alpha/2}$ or $t > t_{\alpha/2}$. In other words, when $t < - t_{\alpha/2}$ or $t > t_{\alpha/2}$, H_α is accepted, and H_0 is rejected.

d) The degrees of freedom of the t-distribution are given by

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}}, \qquad (6\text{-}6)$$

where df is the value of the degrees of freedom, and is rounded down to the nearest integer to make a more conservative approach.

3. The test procedure is as follows:

a) Significance level is set to be 0.1.

b) The t values are calculated.

Table 6-5 shows the values of the t-test and degrees of freedom (df) for nine cases from three assumed highway construction sites. The t values vary from 0.000 to 0.354.

c) Conclusion

From a statistical table (Daniel and Terrell, 1978), for percentiles of the t distribution, $t_{\alpha/2}$ ($t_{0.05}$) = 1.645, so $t < t_{\alpha/2}$.

The null hypothesis is accepted since t = 0.000 to 0.354 does not lie in the rejection region. Thus, with $\alpha = 0.1$, there is sufficient evidence to conclude that the means of precipitation for the model and real data are equal.

Table 6-5 Statistical Test for Rainfall Sequence

Site ID	Trial Number	Mean (in.) for Model Data	Variance for Model Data	Mean (in.) for Real Data	Variance for Real Data	t value	df value
HCS_1	1	9.13E-04	1.06E-05	9.12E-04	4.45E-05	0.010	8355
	2	6.64E-04	1.10E-05	6.63E-04	9.90E-05	0.007	7023
	3	3.35E-04	2.29E-06	3.35E-04	1.48E-05	0.000	7500
HCS_2	1	7.99E-04	7.15E-06	7.57E-04	7.88E-05	0.344	6796
	2	1.04E-03	4.13E-05	9.93E-04	6.05E-05	0.354	11122
	3	4.86E-04	2.02E-05	4.86E-04	3.72E-05	0.000	10589
HCS_3	1	1.12E-04	1.59E-06	1.12E-04	4.31E-06	0.000	9499
	2	3.18E-04	1.27E-05	3.18E-04	1.97E-05	0.000	11004
	3	2.75E-04	8.49E-06	2.74E-04	1.61E-05	0.015	10511

6.4 Model Testing Using VISIOSED Model

The soil production model VISIOSED designed by Jilani (1997) is used to test whether the soil production from the model and real rainfall sequences are identical.

This VISIOSED model is developed from the Universal Soil Loss Equation (USLE) and calculates the mass of sediment leaving a highway construction site depending on the rainfall intensity, land slope, type of soil, type of control practice, and type of vegetation cover used to control erosion.

The field constraints entered for this model are as follows:

Temporary sediment controls (TCS): rock filter dam vs. silt fence

Soil type: silty clay/clay with organic contents equal to 0.5%

Type of cover: seeding after 60 days

Length from the point of origin of overland flow to the point where the runoff enters a defined channel: 5280 ft (1 mile)

Average overland slope from the point of origin of overland flow to the point where the runoff enters a defined channel: 0.01

Construction area: 2560 acres (4 sq. mile)

Six paired model and real rainfall sequences from trial number 1 and 2 in Table 6-5 for each assumed highway construction sites (HCS_1, HCS_2, and HCS_3) are used as input data for the VISIOSED model. The result is shown in Table 6-6. A statistical test is performed to see whether these six paired model and real rainfall sequences produce identical soil production in statistical sense.

Table 6-6 Soil Production from Model and Real Sequences

TSC Type	Site ID	Soil Production from Model Rainfall Sequence (kg)	Soil Production from Real Rainfall Sequence (kg)
Rock Filter Dam	HCS_1	243	243
	HCS_2	393	372
	HCS_3	55	55
Silt Fence	HCS_1	398	399
	HCS_2	644	610
	HCS_3	90	90

The same unequal t-test is performed here as the one performed in Section 6.3, except that the null hypothesis here shows the mean of soil production from six model rainfall sequences to be the same as that from six real rainfall sequences (H_0: (μ_1-μ_2) = 0).

The result of this test is shown in Table 6-7. From statistical table (Daniel and Terrell, 1978), for percentiles of the t distribution, $t_{\alpha/2}$ ($t_{0.05}$) = 1.645. The null hypothesis is accepted since t = 0.549 (< $t_{\alpha/2}$ = 1.645) does not lie in the rejection region. Thus, with α = 0.1, there is sufficient evidence to conclude that the means of soil production from the model and the real sequences are equal.

Table 6-7 Statistical Test for Soil Production

Mean from Model Data	Mean from Real Data	Variance from Model Data	Variance from Real Data	t value	df
365	295	53206	43659	0.549	9

6.5 Conclusions from Model Tests

The first model test (Section 6.2) shows that to have a valid mean of precipitation from the SRG model, number of construction days equal to or larger than 60 and number of repeats equal to or larger than 20 are desired. The number of repeats does not show any obvious effect on the result of the SRG model except that it needs to be equal to or larger than 20 to avoid the system error problem in statistical sense.

Based on nine cases from three sites in Texas, rainfall sequences generated from the SRG model and bootstrapping method can not be distinguished from each other by their mean values for a significance level equal of 0.1. Based on six cases from three sites in Texas, the soil productions predicted by rainfall sequences generated from the SRG model and bootstrapping method are also identical to each other for a significance level equal of 0.1.

Chapter 7 Summary and Conclusions

The literature review led to the conclusion that, even though a number of models were developed to simulate rainfall, they are complicated, and difficult to use. There is no specific synthetic rainfall generation model using historical rainfall data for highway construction activities in Texas.

To evaluate the impact of the Storm Water Pollution Prevention Plans on highway construction activities, a simple-to-use rainfall generation model (the SRG model) is constructed to generate a 15-minute rainfall sequence, that can be used to evaluate the soil production and contaminant production associated with highway construction.

The Geographic Information System is used to construct a map of Texas showing all the available rainfall stations. Proposed highway construction sites can be placed on this map, and distances between highway construction sites and selected rainfall stations can be easily found. A Poisson distribution model is found to describe arrival-time distributions very well for raingage stations in Texas. A simulated arrival-time series is generated based upon this Poisson model. A convolution equation is used to generate 15-minute rainfall sequences based on four rainday parameters that preserve total precipitation amount, overall shape, and rain duration of historical data. As the duration and complexity of the historical rainfall patterns on each day increase, the fit between the model and real data deteriorates. This procedure of changing real data to model parameter data saves significant storage space in computer. For daily data, there is a reduction of the data file size by a factor of 30. For 15-minute data, there is a reduction of the data file size by a factor of 10. An inverse distance algorithm is used to combine rainfall sequences from three nearby rainfall stations to generate the rainfall sequence for highway construction sites. A user-friendly interface is built for the SRG model so that user can easily perform data input, calculation and viewing of 15-minute rainfall sequence.

A bootstrapping method was designed to generate 15-minunte rainfall sequence by resampling real 15-minute rainfall data. This option can be executed from the SRG model interface and used to faithfully produce information on intensity from historical rainfall events.

Parametrically generated rainfall sequences from three assumed highway construction sites are used to compare the effect of the number of construction days and of the number of repeats to run the SRG model on the mean values of precipitation. It is found that number of construction days equal to or larger than 60 and number of repeats equal to or larger than 20 will generate 15-minute rainfall sequences that have good statistical stability of the mean values of precipitation during a construction period.

The mean values of precipitation for rainfall sequences generated from the SRG model and bootstrapping method are indistinguishable from each other when the significance level equals 0.1. The soil productions predicted by rainfall sequences generated from the SRG model and bootstrapping method are identical for a significance level of 0.1.

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Appendices

A1. Selected 109 Rainfall Stations for SRG Model in Texas

Station Name	Station ID	Record Years	Latitude	Longitude
ABILENE MUNI AP	0016	10	N32:25:00	W099:41:00
ALPINE	0174	17	N30:22:00	W103:40:00
ALVARADO 2	0202	9	N32:27:00	W097:13:00
ALVORD 3 NE	0206	24	N33:23:00	W097:38:00
AMARILLO INTL ARPT	0211	10	N35:14:00	W101:42:00
ANDREWS	0248	23	N32:19:00	W102:32:00
AUSTIN MUNICIPAL AP	0428	10	N30:17:00	W097:42:00
BENBROOK DAM	0691	11	N32:39:00	W097:27:00
BERTRAM 3 ENE	0738	11	N30:45:00	W098:01:00
BIG SPRING FIELD STN	0784	24	N32:16:00	W101:29:00
BONITA 4 NW	0926	17	N33:50:00	W097:37:00
BROWNSVILLE INTL AP	1136	10	N25:54:00	W097:26:00
CANYON DAM	1429	11	N29:52:00	W098:12:00
CANYON DAM 2	1432	6	N29:50:00	W098:21:00
CANYON DAM 6	1436	11	N29:57:00	W098:18:00
CATARINA	1528	17	N28:20:00	W099:38:00
CHANNING	1646	24	N35:41:00	W102:20:00
CHEAPSIDE	1671	19	N29:16:00	W097:26:00
CHILDRESS MUNI AP	1698	20	N34:26:00	W100:17:00
COMFORT 2	1920	5	N29:58:00	W098:54:00
CONROE	1956	17	N30:20:00	W095:29:00
COTULLA	2048	20	N28:28:00	W099:13:00
CRANE	2082	20	N31:23:00	W102:20:00
CRESSON	2096	15	N32:32:00	W097:37:00
CYPRESS	2206	4	N29:58:00	W095:42:00
DALLAS LOVE FIELD	2244	20	N32:51:00	W096:51:00
DALLAS/FT WORTH AP	2242	10	N32:54:00	W097:02:00
DEBERRY	2312	11	N32:18:00	W094:10:00
DENISON DAM	2394	11	N33:49:00	W096:34:00
DIME BOX	2462	11	N30:21:00	W096:50:00
DUMONT	2621	11	N33:48:00	W100:31:00
EAGLE LAKE RES CTR	2676	9	N29:37:00	W096:22:00
EAGLE PASS	2679	24	N28:42:00	W100:29:00
EDEN 2	2744	16	N31:13:00	W099:51:00
EL PASO INTL ARPT	2797	10	N31:48:00	W106:24:00
FERRIS	3133	11	N32:31:00	W096:40:00

A1. Selected 109 Rainfall Stations for SRG Model in Texas (Cont'd)

Station Name	Station ID	Record Years	Latitude	Longitude
FLAT	3171	11	N31:19:00	W097:38:00
FORT WORTH FED BLDG	3285	24	N32:45:00	W097:20:00
FORT WORTH MEACHAM F	3284	24	N32:49:00	W097:21:00
FRISCO	3370	11	N33:09:00	W096:49:00
GAGEBY 3 WNW	3410	21	N35:38:00	W100:24:00
GALVESTON	3430	10	N29:18:00	W094:48:00
GEORGETOWN LAKE	3507	11	N30:41:00	W097:43:00
GORMAN 2 NNE	3646	11	N32:14:00	W098:40:00
GRANGER DAM	3686	11	N30:42:00	W097:20:00
GRAPEVINE DAM	3691	24	N32:58:00	W097:03:00
GROESBECK 2	3771	18	N31:32:00	W096:32:00
HINDES	4191	18	N28:43:00	W098:48:00
HOUSTON ADDICKS	4309	11	N29:46:00	W095:39:00
HOUSTON ALIEF	4311	11	N29:43:00	W095:36:00
HOUSTON INT'CNTNL AP	4300	10	N29:58:00	W095:21:00
HOUSTON SATSUMA	4329	7	N29:56:00	W095:38:00
IREDELL	4476	20	N31:59:00	W097:52:00
JAYTON	4570	24	N33:15:00	W100:34:00
KIRBYVILLE	4819	5	N30:37:00	W093:55:00
KOUNTZE	4876	4	N30:24:00	W094:20:00
KRESS	4880	17	N34:22:00	W101:45:00
LA PRYOR	4920	18	N28:59:00	W099:52:00
LANGTRY	5048	24	N29:48:00	W101:34:00
LAVON DAM	5094	24	N33:02:00	W096:29:00
LEAKEY	5113	20	N29:44:00	W099:46:00
LEWISVILLE DAM	5192	11	N33:04:00	W097:01:00
LEXINGTON	5193	17	N30:25:00	W097:01:00
LOVELADY	5398	8	N31:08:00	W095:27:00
LUBBOCK 9 N	5410	24	N33:42:00	W101:50:00
LUBBOCK REGIONAL AP	5411	10	N33:39:00	W101:49:00
MABANK 4 SW	5463	18	N32:21:00	W096:07:00
MALONE 3 ENE	5528	11	N31:57:00	W096:51:00
MATADOR 2	5656	24	N34:01:00	W100:50:00
MIDLOTHIAN 2	5897	19	N32:29:00	W097:00:00
MINERAL WELLS 1 SSW	5957	24	N32:47:00	W098:07:00
MOLINE	5996	17	N31:23:00	W098:19:00
MULESHOE 2	6136	24	N34:13:00	W102:44:00

A1. Selected 109 Rainfall Stations for SRG Model in Texas (Cont'd)

Station Name	Station ID	Record Years	Latitude	Longitude
NACOGDOCHES	6177	21	N31:37:00	W094:39:00
NEW BOSTON	6270	22	N33:27:00	W094:25:00
O DONNELL	6504	24	N32:58:00	W101:49:00
OZONA 8 WSW	6736	22	N30:41:00	W101:20:00
PALESTINE 2 NE	6757	11	N31:47:00	W095:36:00
PANTHER JUNCTION	6792	23	N29:19:00	W103:13:00
PAT MAYSE DAM	6834	24	N33:52:00	W095:31:00
PECOS 8 W	6893	18	N31:23:00	W103:37:00
PEP	6935	24	N33:49:00	W102:34:00
PLAINS	7074	24	N33:11:00	W102:50:00
POINT COMFORT	7140	11	N28:40:00	W096:33:00
PORT ARTHUR JEFFERSN	7174	10	N29:57:00	W094:01:00
PRAIRIE MOUNTAIN	7243	24	N30:35:00	W098:53:00
RANDOLPH AFB	7422	20	N29:32:00	W098:17:00
RED BLUFF DAM	7481	14	N31:54:00	W103:55:00
RED ROCK	7497	20	N29:58:00	W097:27:00
RICHMOND	7594	11	N29:35:00	W095:45:00
SAM RAYBURN DAM	7936	16	N31:04:00	W094:06:00
SAN ANTONIO INTL AP	7945	10	N29:32:00	W098:28:00
SANDERSON 5 NNW	8023	13	N30:13:00	W102:25:00
SANTA ANNA	8047	15	N31:44:00	W099:19:00
SARITA 7 E	8081	17	N27:13:00	W097:41:00
SIERRA BLANCA 2 E	8305	17	N31:11:00	W105:19:00
SOMERVILLE DAM	8446	21	N30:20:00	W096:32:00
SPICEWOOD	8531	11	N30:29:00	W098:10:00
SPRING BRANCH	8544	7	N29:52:00	W098:24:00
SULPHUR SPRINGS	8743	17	N33:09:00	W095:38:00
SWAN 4 NW	8778	21	N32:27:00	W095:25:00
TARPLEY	8845	19	N29:40:00	W099:17:00
THOMPSONS 3 WSW	8996	11	N29:29:00	W095:38:00
VALENTINE	9270	15	N30:34:00	W104:29:00
WHEELOCK	9665	16	N30:54:00	W096:24:00
WICHITA FALLS MUN AP	9729	10	N33:58:00	W098:29:00
WIMBERLEY 2	9815	6	N29:59:00	W098:03:00
WOODSON	9893	15	N33:01:00	W099:03:00
ZAPATA 3 SW	9976	19	N26:53:00	W099:18:00

A2. Distance Finding

To illustrate the steps a user applies to locate a station, assuming that a highway construction site the west of Austin. Let the site be named AUSTIN #1. Its site ID will be HCS_1.

A2.1. Construct location information and site location file.

i) Create a GIS file to work with

1) Start the GIS.

2) Choose *FILE|OPEN* to activate the *Open Dialog* box.

3) In the *Drives* list box, choose the drive that contains the directories of the GIS files for the SRG model. Typically, drive C:.

4) In *Directories* list box, choose the directory that contains GIS map files for the SRG model.

5) In the *File Name* list box, choose the **map.prj** project file. By default, the *Files of Type* list box displays the '**Project (*.prj, *.map)**' option.

6) Click *OK* from the menu options.

7) Choose *FILE|SAVE* AS to save this **map.prj** as another project file that you will work with in the same target directory. For example, save **map.prj** as **AUSTIN.PRJ**.

ii) Locate the construction site and create the site location file

1) Start the Microsoft Excel^{TM} computer program.

2) Choose *File|Save* As to save this *site.xls* as another Microsoft Excel file in the same target directory in Microsoft EXCEL version 3.0 format. For example, save *site.xls* as *HCS_1.xls*.

3) Arrange the windows for the GIS and Microsoft Excel as shown on next page.

4) Move the pointer to the proposed highway construction site and read the longitude and latitude information from the lower right corner of the GIS window (labeled as “Lon” and “Lat”, respectively).

4) Enter the following information into the Microsoft Excel spreadsheet: name of the construction site (“AUSTIN #1” under “SITE_NAME”), site ID (“HCS_1” under “SITE_ID”), whole degree portion of longitude (“30” under “LON_DEG”), fractional portion of longitude in minutes (“20” under “LON_MIN”), whole degree portion of latitude (“97” under “LAT_DEG”), and fractional portion of latitude in minutes (“55” under “LAT_MIN”). The number under the labels “LON” and “LAT” will be calculated by the EXCEL automatically.

5) Save **site.xls** again in Microsoft EXCEL version 3.0 format and close this file.

Once this last step is completed, the GIS can be used to calculate distances from highway construction site to the rainfall stations.

A2.2 Finding distances in the GIS

i) Import the site location file

1) From the GIS window, choose *FILE|OPEN* to activate the *Open* dialog box.

2) In *List of Files Type* box, choose Excel (*. xls).

3) In the *File Name* list box, choose the ‘**HCS_1.XLS**’ Excel file.

4) Click *OK* from the menu options.

5) In the ‘*Table Import*’ dialog box, change the imported name to the table name you want. (The table created for HCS_1.XLS in the GIS format is named as

HCS_1.DBF by default.) For example, change this name to 'HCS_1.DBF' and choose *OK* from the options menu.

6) In the '*Spreadsheet Options'* dialog box, choose *OK*.

7) In the *Table Link* dialog box:

a) In the '*Table Type*' menu options on the left, choose '*Contains Points'*.

b) In the *Layer Name* box, enter the layer name you want for this construction site. For example, HCS_1.

c) In the '*Key Column'* list box, select the '*STATION_ID'* as key column.

d) In the '*Longitude or X'* list box, select '*LON*'.

e) In the '*latitude or Y'* list box, select '*LAT*'.

f) In the '*Values Are'* list box, select '*LL*'.

g) Choose *OK* from the options remaining in the menu.

h) In the *'Open'* dialog box which should state '*File projection does not match current working set. Change file projection?*', choose *OK*.

i) In the '*Open*' dialog box which reads '*One or more index files are missing. OK to build index files?*', choose *OK*.

ii) Turn on the label of the construction site

1) Click on the right button of the mouse on the map to pop up the '*Layers and Themes*' dialog box.

2) In the '*Layers*' box on the top, click '*Label | On'* switch on the last layer, which has the '*Order*' of '*7*' and has the name you previously selected. This label was '*No*' before, it should be '*Yes*' after this step.

3) Choose the ‘*Labels*’ option on the left bottom of the layer of *this ‘Layers and Themes’* dialog box.

4) In the ‘*Label Expression’* part, click on the ‘…’ button at the end of the ‘*Line 1*’ text box. The ‘*Expression Builder*’ dialog box is then active.

5) In the ‘*Columns’* list box, choose *STATION_ID*.

6) Choose *OK* on this last box and also on the ‘*Layers and Themes*’ dialog box.

iii) View the construction site and select three nearby stations

1) Choose ‘*Zoom Out’* tool on the Tool bar.

2) Place the ‘Zoom Out’ tool on the construction site location, and select (by clicking the mouse button) the location.

3) Repeat step 2 as needed to give a detailed view of the construction site and nearly rain gage stations. The H.C.S. is marked by a solid triangle and its ID.

4) Choose the three nearest stations. For HCS_1, stations 0428, 8531 and 9815 are selected (See the Figure on next page).

iv) Calculate distances using the “Calculate Column” option.

1) Select the construction site. A solid square will mark the construction site.

2) Click on *WINDOW|NEW TABLE WINDOW* to activate the ‘*Window Layer’* list box.

3) Choose *STATIONS:station*, and click *OK*.

4) In the Table called *STATIONS:station*, click on the three stations which will be used to generate the synthetic rainfall data for the construction site. The first station is selected by clicking the mouse button, the second and third stations are selected by clicking the mouse button while pressing the Shift

key.

5) Choose *TABLE | CALCULATE COLUMN* to activate the *Calculate Column* dialog box.

6) In the *Table* list box, choose *STATION:stations.*

7) In the *Column to Fill* dialog box, choose *DISTANCE*, which is the column to be filled with the calculated distances.

8) Click on the *Distance to Selected Feature* option button. This button is dimmed if there are no open layers with exactly one feature selected.

9) In the *Layer* list box, choose the layer that contains the single, selected map feature.

10) In the *Rows* group box, check the *Selected Rows Only* box.

11) Choose *OK.*

12) Look at the table and record the corresponding distances from the highway construction site to the rainfall stations.

The Figure on Page 71 shows the result of these steps applied to a highway construction site near Austin. The assumed highway construction site HCS_1 is marked by an solid triangle and encircled by an dashed circle and three selected rainfall stations are marked by cross flags and encircled by solid circles. The distances from HCS_1 to these stations are found to be 13, 18 and 25 miles respectively.

A3. SRG Model Calculation Source Code And Input/Output Files

A3.1 SRG model (parametric method) FORTRAN source code

A3.1.1 main.for

```
C      SYNTHETIC RAINFALL GENERATION (SRG) MODEL
C      MAIN.FOR
C      CONTROL PROGRAM


C      SOME ABREVIATION USED:
C      H.C.S.: HIGHWAY CONSTRUCTION SITE
C      N.C.D.: NUMBER
C      ECATF : EMPIRICAL CUMULATIVE ARRIVAL TIME FUCNTION
C      DPD: DAILY PARAMETER DATA
C      FPD: 15-MINUTE PARAMETER DATA

C      DECLARE VARIABLES

C      NCD: NUMBER OF CONSTRUCTION DAYS
       INTEGER NCD
C      INDEX_NCD: INDEX FOR HOW MANY NCD HAS BEEN CALCULATED
       INTEGER INDEX_NCD
C      FLAG_STATION: INDEX FOR THE STATION BEING PROCESSED
       INTEGER FLAG_STATION
C      ARR_TIME: SIMULATED ARRIVAL TIME SERIES
       INTEGER ARR_TIME (1:5)
C      FMRS_STTN: 15-MIN RAINFALL SEQUENCE AT STATIONS
       REAL FMRS_STTN(1:3, 1:2000, 1:100)
C      FMRS_SITE: 15-MINUTE RAINFALL SEQUENCE AT H.C.S.
       REAL FMRS_SITE(1:2000, 1:100)
C      RAIN_MODEL: 15-MIN RAINFALL MODEL DATA
       REAL RAIN_MODEL(1:3, 1:100)


C      COMMONLY  USED VARIABLES IN FILES
       COMMON /COM_1/  ARR_TIME
       COMMON /COM_3/  RAIN_MODEL
       COMMON /COM_7/  FMRS_STTN
       COMMON /COM_8/  FMRS_SITE
       COMMON /COM_10/ FLAG_STATION
       COMMON /COM_11/ NCD


C      CALL FIEEIO.FOR TO GET FPD AND HPD DATA
       CALL FILEIO

C      A SCREEN MEMO FOR USER
       WRITE (*,*) 'Program is Running, Please wait.'

C      CALL ECATF.FOR TO GET ECATF PARAMETERS FOR STATIONS
       CALL ECATF
C      THIS CALL IS REQUIRED FOR RANDOM NUMBER GENERATOR
       CALL GET_SEED

C      LOOP THROUGH THREE SELECTED STATIONS
       DO 3000, N = 1,3
```

```
       FLAG_STATION = N

C     GET FIRST SIMULATED ARRIVAL TIME FOR RAINFALL STATIONS
       CALL RAT

C     IF NO RAIN IN THE WHOLE NCD TIME
C     ARRVAL TIME > N.C.D. CASE, THEN NO RAIN
       IF (ARR_TIME(N) .GE. NCD) THEN
        DO I = 1, NCD
         DO J = 1, 96
          FMRS_STTN(N, I, J) = 0.00
         END DO
         DAY = I
        END DO
        INDEX_NCD = NCD
        GOTO 3000
       ELSE
        INDEX_NCD = 1
        GOTO 2200
       END IF

C     IF THERE ARE RAINS DURING N.C.D.
      INDEX_NCD = 1
2000  IF (INDEX_NCD .LE. NCD) THEN
       GOTO 2100
      ELSE
       GOTO 3000
      END IF

C     CALL RAT.FOR TO GET MORE GENERATED ARRIVAL TIMES
2100  CALL RAT

C     IF NO RAIN DURING FURTHER DAYS
C     CUMULATIVE SIMULATED ARRIVAL TIMES > N.C.D. CASE
2200  IF (ARR_TIME(N) .GE. (NCD - INDEX_NCD + 1)) THEN
       DO I = INDEX_NCD, NCD
        DO J = 1, 96
         FMRS_STTN(N, I, J) = 0.00
        END DO
        DAY = I
       END DO
      GOTO 3000
      END IF

C     WHEN NO RAIN FOR THESE DAYS
C     ARRIVAL TIME < N.C.D. CASE AND <> 0
      IF ( ( ARR_TIME(N) .LT. (NCD - INDEX_NCD + 1))
     + .AND. (ARR_TIME(N) .NE. 0) ) THEN
       DO I = INDEX_NCD, INDEX_NCD + ARR_TIME(N) - 1
        DO J = 1, 96
         FMRS_STTN(N, I, J) = 0.00
        END DO
        DAY = I
       END DO

       INDEX_NCD = INDEX_NCD + ARR_TIME(N)
C     CALL RRD.FOR TO RANDOMLY GENERATE MODEL RAINFALL DATA
       CALL RRD
       DO J = 1, 96
        FMRS_STTN(N, INDEX_NCD, J) =
```

```
     +   RAIN_MODEL(FLAG_STATION, J)
       END DO
       DAY = INDEX_NCD
       INDEX_NCD = INDEX_NCD + 1
       GOTO 2000
      END IF

C     ARRIVAL TIME < NCD CASE AND ARRIVAL TIME = 0
      IF ( ( ARR_TIME(N) .LT. (NCD - INDEX_NCD + 1))
     + .AND. (ARR_TIME(N) .EQ. 0) ) THEN
       CALL RRD
       DO J = 1, 96
        FMRS_STTN(N, INDEX_NCD, J)
     +   = RAIN_MODEL(FLAG_STATION, J)
       END DO
       DAY = INDEX_NCD
       INDEX_NCD = INDEX_NCD + 1
      GOTO 2000
      END IF

3000  CONTINUE

C     GET 15-MIN RAINFALL SEQUENCE FOR H.C.S.
      CALL DIST

C     OUTPUT OF SRG MODEL
      WRITE (100, *) ' '
      WRITE (100, *) ' '
      WRITE (100, 6910) 'TIME(MIN)', 'RAINFALL'
      DO I = 1, NCD
       WRITE (100, 6750) 'DAY NUMBER:', I
6750  FORMAT(/ A12, I9)
6910   FORMAT (A12, A9)
       DO J = 1, 96
        WRITE (100, 6920) (I-1) * 1440 + (J*15),
     +   FMRS_SITE(I,J)
        WRITE (900, 6950) (I-1) * 1440 + (J*15),
     +   FMRS_SITE(I,J)
6920    FORMAT (I12, F9.6)
6950    FORMAT (I12, F9.6)

       END DO
      END DO
6060  FORMAT (1X, F9.4)
6080  FORMAT (1X, F9.4)

      CLOSE (100)
      CLOSE (900)

      END
```

A3.1.2 fileio.for

```
C     SYNTHETIC RAINFALL GENERATION (SRG) MODEL
C     FILEIO.FOR
C     CHECK INPUT AND OUTPUT FILES


      SUBROUTINE FILEIO

C     DECLARE VARIABLES

C     FILEIN: INPUT FILENAME
      CHARACTER*4  FILEIN
C     FILEOUT: OUTPUT FILENAME
      CHARACTER*11 FILEOUT
C     STIE_NAME: H.C.S. NAME
      CHARACTER*11 SITE_NAME
C     DPD, FPD: DPD AND FPD PARAMETER FILES
      CHARACTER*11 DPD, FPD
C     FLAG_DPD, FLAG_FPD, FLAG_INPUT: LOGIC VARIABLES
      LOGICAL FLAG_DPD, FLAG_FPD, FLAG_INPUT
C     UNIT_DPD, UNIT_FPD: DPD, FPD FILE I/O CONTROLER
      INTEGER UNIT_DPD, UNIT_FPD
C     T_RAIN: TOTAL NUMBER OF RAIN-DAYS
      INTEGER T_RAIIN(1:5)
C     MAX_WTIME: MAXIMUM ARRIVAL TIME
      INTEGER MAX_WTIME(1:5)
C     NCD: NUMBER OF CONSTRUCTION SITE
      INTEGER NCD
C     DISTANCE: DISTANCE B/W H.C.S. AND RAINFALL STATIONS
      INTEGER DISTANCE(1:5)

C     COMMONLY USED VARAIBLES IN FILES
      COMMON /COM_2/  T_RAIIN
      COMMON /COM_5/  MAX_WTIME
      COMMON /COM_6/  DISTANCE
      COMMON /COM_11/ NCD


C     CHECK WHETHER THE INPUT.TXT FILE AVAIALBE
      INQUIRE (FILE='INPUT.TXT', EXIST=FLAG_INPUT)
      IF (FLAG_INPUT .EQV. .TRUE.) THEN
       GOTO 40
      ELSE
       WRITE (100,*) 'INPUT.TXT FILE CAN NOT BE FOUND.'
       STOP
      END IF

C     OPEN INPUT.TXT
40    OPEN(UNIT = 500, FILE = 'INPUT.TXT', ERR = 20000)
      READ (500, 5100) FILEOUT
5100  FORMAT (14x, A11)

C     OPEN OUTPUT FILE
      OPEN(UNIT = 100, FILE = FILEOUT, ERR = 20000)
      WRITE (100, 6650) 'SYNTHETIC RAINFALL GENERATION'
6650  FORMAT(A29)

C     OPEN OUTPUT FILE FOR PLOT IN VISUAL BASIC INTERFACE
      OPEN(UNIT = 900, FILE = 'source.out', ERR = 20000)

C     READ CONSTRUCTION SITE NAME
```

```
      READ (500,5610) SITE_NAME
      WRITE (100, *) ' '
      WRITE (100, 6610) 'SITE NAME:', SITE_NAME
5610  FORMAT (14x, A11)
6610  FORMAT (A10,2X, A11)

C     READ 15 MINUTE AND DAILY DATA FILE NAME
      DO 3000, N = 1, 3
      READ (500,5000) FILEIN
5000  FORMAT (14x, A4)

C     CREATE PARAMETER DATA FILES
      DPD = (FILEIN // 'D_3.TXT')
      FPD = (FILEIN // 'F_3.TXT')

C     CHECK INPUT FILE STATUS
      INQUIRE (FILE=DPD, EXIST=FLAG_DPD)
      INQUIRE (FILE=FPD, EXIST=FLAG_FPD)
      IF ( (FLAG_DPD .EQV. .TRUE.) .AND.
     + (FLAG_FPD .EQV. .TRUE.) ) THEN
       GOTO 1000
      ELSE
       WRITE (100, *) 'DATA FILE(S) DOES NOT EXITS.'
       STOP
      END IF

C     IF STATUS OF INPUT FILES IS OK, THEN OPEN THE FILE.
1000  UNIT_DPD = N * 10 + 1
      UNIT_FPD = N * 10 + 2
      WRITE (100, 6710) 'STATION #', N, ':', FILEIN
6710  FORMAT (A9, I1, A1, 1X, A4)
      OPEN(UNIT=UNIT_DPD, FILE=DPD,STATUS='OLD', ERR=20000)
      OPEN(UNIT=UNIT_FPD, FILE=FPD,STATUS='OLD', ERR=20000)

C     READ VARIABLES FROM DATA FILES
      READ (UNIT_DPD, 5510) MAX_WTIME(N)
5510  FORMAT (/ 9X, I9 /)

      READ (UNIT_FPD, 5520) T_RAIIN(N)
5520  FORMAT (/ 9X, I9 /)

3000  CONTINUE

C     READ DISTANCE FROM INPUT FILE
      DO N = 1, 3
       READ (500, 5530) DISTANCE(N)
      END DO
5530  FORMAT (14X, I3)
      WRITE (100, 5610) ' '
      WRITE(100,6810) 'DISTANCE TO SITE:'
6810  FORMAT(A17)
      DO I = 1, 3
       WRITE (100, 6660) 'STATION #', I, ':', DISTANCE(I)
      END DO
6660  FORMAT(A9, I1, A1, 1X, I3)

C     READ NUMBER OF CONSTRUCTION DAYS
      READ (500, 5540) NCD
5540  FORMAT(14x, I4)
```

```
      GOTO 99999

C     ERROR HANDLER
20000 PRINT*, 'ERROR HAPPENS WHEN OPENING THE FILE.'
      GOTO 99999

99999 END
```

A3.1.3 ecatf.for

```
C     SYNTHETIC RAINFALL GENERATION (SRG) MODEL
C     ECATF.FOR
C     GET ECATF PARAMETERS FROM DAILY PARAMETER DATA FILES


      SUBROUTINE ECATF

C     DECLARE VARAIBLES

C     MAX_WTIME: MAXIMUM WAITING TIME
      INTEGER MAX_WTIME(1:5)
C     ECATF_DATA: ECATF PARAMETERS
      REAL ECATF_DATA(1:3, 0:1000)
C     UNIT_DPD: DPD FILE I/O CONTROLER
      INTEGER UNIT_DPD


C     COMMONLY USED VARIABLES IN FILES
      COMMON /COM_4/ ECATF_DATA
      COMMON /COM_5/MAX_WTIME


C     READ ECATF PARAMETERS FROM DPD FILES
      DO N = 1, 3
        UNIT_DPD = N * 10 + 1
        DO K = 1, MAX_WTIME(N)
C     THIS READ FOLLOWS THE READ COMMAND IN FILEIO.FOR
          READ (UNIT_DPD, 5010) ECATF_DATA(N, K)
        END DO
        ECATF_DATA(N,0) = 0.0000
      END DO

5010  FORMAT (9X, F9.4)

      END
```

A3.1.4 rat.for

```
C     SYNTHETIC RAINFALL GENERATION (SRG) MODEL
C     RAT.FOR
C     GENERATE A ARRIVAL TIME RANDOMLY


      SUBROUTINE RAT

C     DECLARE VARAIBLES

C     RAN_DAY: RANDOM NUMBER FOR ECATF
      REAL RAN_DAY
C     LIM_LOW, LIM_HIGH: INTERMEDIATES TO FIND ECATF
      REAL LIM_LOW, LIM_HIGH
C     MAX_WTIME: MAXIMUM WAITING TIME OR ARRIVAL TIME
      INTEGER MAX_WTIME(1:5)
C     ARR_TIME: ARRIVAL TIME
      INTEGER ARR_TIME(1:3)
C     ECATF_DATA: ECATF PARAMETERS
      REAL ECATF_DATA(3, 0:1000)
C     FLAG_STATION: INDEX FOR THE STATION BEING PROCESSED
      INTEGER FLAG_STATION
C     TEMP1: VARAIBLE USED FOR RANDOM NUMBER GENERATION
      REAL TEMP1

C     COMMONLY USED VARAIBLES IN FILES
      COMMON /COM_1/  ARR_TIME
      COMMON /COM_4/  ECATF_DATA
      COMMON /COM_5/  MAX_WTIME
      COMMON /COM_10/ FLAG_STATION


C     GET A RANDOM NUMBER BETWEEN 0 AND 1
      CALL RANDOM(TEMP1)
      RAN_DAY = TEMP1

C     FIND ARRIVAL TIME ACCORDING TO ECATF AND RAN_DAY
      DO 2000, I = 0, MAX_WTIME(FLAG_STATION)

C     CASE 1: ARRIVAL TIME = 0
       IF (I .EQ. 0) THEN
        IF ( RAN_DAY .LT. (ECATF_DATA(FLAG_STATION,1)/2) ) THEN
         ARR_TIME(FLAG_STATION) = 0
         GOTO 2100
        ELSE
         GOTO 2000
        END IF
       END IF

C     CASE 2: ARRIVAL TIME = MAXIMUM WAITING TIME
       IF (I .EQ. MAX_WTIME(FLAG_STATION)) THEN
        ARR_TIME = MAX_WTIME(FLAG_STATION)
        GOTO 2100
       END IF

C     GENERAL CASE
C     CREATE THE PROBABILITY DENSITY RANGE
       LIM_LOW = ( ECATF_DATA(FLAG_STATION,I-1) +
     +  ECATF_DATA(FLAG_STATION,I) ) / 2
       LIM_HIGH = ( ECATF_DATA(FLAG_STATION,I) +
     +  ECATF_DATA(FLAG_STATION,I+1) ) / 2
```

```
C     GET CORRESPINDING ARRIVAL TIME
       IF ((RAN_DAY .GE. LIM_LOW) .AND. (RAN_DAY .LT. LIM_HIGH)) THEN
        ARR_TIME(FLAG_STATION) = I
        GOTO 2100
       END IF

2000  CONTINUE

2100  RETURN
      END
```

A3.1.5 rrd.for

```
C     SYNTHETIC RAINFALL GENERATION (SRG) MODEL
C     RRG.FOR
C     RANDOMLY PICK A RAIN-DAY AND GENERATE MODEL RAINFALL DATA


      SUBROUTINE RRD()

C     DECLARE VARIABLES

C     RAIN_MODEL: RAIN MODEL DATA ON DAILY BASIS
      REAL RAIN_MODEL(1:3, 1:100)
C     RAN_RAIN: RANDOM NUMBER USED TO PICK A RAIN-DAY; RAIN_NUM: ORDERED
RAIN NUMBER IN FPD FILES
      INTEGER RAN_RAIN, RAIN_NUM
C     STATION_ID: STATION IDENTIFICATION NUMBER
      INTEGER STATION_ID
C     T_RAIN: TOTAL NUMBER OF RAIN-DAYS IN FPD FILES
      INTEGER T_RAIN(1:5)
C     UNIT_FPD: FPD FILE I/O CONTROLER
      INTEGER UNIT_FPD
C     FLAG_STATION: INDEX FOR THE STATION BEING PROCESSED
      INTEGER FLAG_STATION
C     T: TIME
      REAL T
C     X: 4 RAIN-DAY PARAMETERS
      REAL X(1:4)
C     INTERMEDIATES IN CONVOLUTION
      REAL*8 TERM1, TERM2
      REAL*8 Y1, Y2, Y3, Y4, Y5, Y6
      REAL*8 Z1, Z2, Z3, Z4, Z5, Z6
C     TEMP1: VARIABLE FOR RANDOM NUMBER GENERATION
      REAL TEMP1

C     COMMONLY USED VARIABLES IN FILES
      COMMON /COM_3/  RAIN_MODEL
      COMMON /COM_2/  T_RAIN
      COMMON /COM_10/ FLAG_STATION


C     INITIALIZE VARIABLES
      RAN_RAIN = 0
```

```
C     GET A RANDOM RAIN NUMBER
      CALL RANDOM(TEMP1)
      RAN_RAIN = 1 + INT(TEMP1 * (T_RAIN(FLAG_STATION)-1))

C     READ COMMAND HERE IS JUST FOR FILE I/O READING CONVINIENT
      UNIT_FPD = FLAG_STATION * 10 + 2
      REWIND (UNIT_FPD)
      READ (UNIT_FPD, 5610) STATION_ID
5610  FORMAT (9X, I9 //)

C     READ 4 RAIN-DAY PARAMETERS FROM FPD FILE RANDOMLY
      DO 100, I = 1, RAN_RAIN
       READ (UNIT_FPD, 5520) RAIN_NUM, X(1), X(2),X(3),X(4)
       IF (I .EQ. RAN_RAIN) THEN
        GOTO 1000
       ELSE
        GOTO 100
       END IF
100   CONTINUE
5520  FORMAT (I9, F9.2, F9.2, F9.2, F9.4)

C     GENERATE RAIN DATA BASED ON THE MODEL PARAMETERS
1000  DO 2010, I = 1, 96
      T = I * 15.0

      Y1 = X(1) - T
      Y2 = X(1) + T
      Y3 = 2 * SQRT(X(2) * T)
      Y4 = EERFC(Y1/Y3)
      Y5 = EERFC(Y2/Y3)
      Y6 = EEXP((X(1)) / X(2))

      TERM1 = 0.5 * X(4) * (Y4 - Y6 * Y5)

      IF ((T - X(3)) .LE. 0.00) THEN
       TERM2 = 0.00
       GOTO 300
      ELSE
       Z1 = X(1) - (T - X(3))
       Z2 = X(1) + (T - X(3))
       Z3 = 2*SQRT(X(2)*(T - X(3)))
       Z4 = EERFC(Z1/Z3)
       Z5 = EERFC(Z2/Z3)
       Z6 = EEXP((X(1)) / X(2))
       TERM2 = 0.5 * X(4) * (Z4 - Z6 * Z5)
      END IF

300   IF ( (TERM1-TERM2) .LE. 1E-15 ) THEN
       RAIN_MODEL(FLAG_STATION, I) = 1E-15
      ELSE
       RAIN_MODEL(FLAG_STATION, I) = TERM1 - TERM2
      END IF

2010  CONTINUE

      RETURN
      END

C     CONDITIONAL ERROR FUNCTION
```

```
      REAL FUNCTION EERFC(Q1)
      REAL*8 Q1

      IF (Q1 .GE. 4.0) THEN
       EERFC = 0.00
       GOTO 400
      END IF
      IF (Q1 .LE. -4.0) THEN
       EERFC = 2.00
       GOTO 400
      END IF
      IF (Q1 .LT. 0.00) THEN
       EERFC = 2.00 - ERFC(-1.0*Q1)
       GOTO 400
      END IF
      IF ((Q1 .GE. 0.00) .AND. (Q1 .LT. 4.00)) THEN
       EERFC = ERFC(Q1)
       GOTO 400
      END IF

400   RETURN
      END

C     APPROXIMATE ERROR FUNCTION
      REAL FUNCTION ERFC(Q2)
      REAL A1, A2, A3, A4, A5, A6
      REAL *8 Q2, TEMP1, TEMP2

      A1 = 0.0705230784
      A2 = 0.0422820183
      A3 = 0.0092705272
      A4 = 0.0001520143
      A5 = 0.0002765672
      A6 = 0.0000430638

      TEMP1=1+(A1*Q2)+(A2*(Q2**2))+(A3*(Q2**3))
     +      +(A4*(Q2**4))+(A5*(Q2**5))+(A6*(Q2**6))
      IF (TEMP1 .EQ. 0.00) THEN
       TEMP1 = 1.0E-2
      END IF
      TEMP2= TEMP1**16
      ERFC = 1 / TEMP2

      RETURN
      END

C     CONDITIONAL EXPONENTIAL FUNCTION
      FUNCTION EEXP(Q3)
      REAL Q3

      IF (Q3 .LT. -100.0) THEN
       EEXP = 0.0000
       GOTO 500
      END IF
      IF (Q3 .GT. 85.0) THEN
       EEXP = EXP(85.0)
       GOTO 500
      END IF
      EEXP = EXP(Q3)
```

```
500   RETURN
      END
```

A3.1.6 dist.for

```
C     SYNTHETIC RAINFALL GENERATION (SRG) MODEL
C     DIST.FOR
C     INVERSE DISTANCE METHOD


      SUBROUTINE DIST


C     DECLARE VARAIBLES

C     FMRS_STTN: 15-MINUTE RAINFALL SEQUENCE FOR STATION
      REAL RATM(1:3, 1:2000, 1:100)
C     FMRS_SITE: 15-MINUTE RAINFALL SEQUENCE FOR H.C.S.
      REAL RATM_SITE(1:2000, 1:100)
C     DISTANCE: DISTANCE BETWEEN H.C.S. AND SELECTED STATIONS
      INTEGER DISTANCE (1:5)
C     POWER: POWER USED IN THE INVERSE DISTANCE EQUATION
      REAL POWER
C     DIST_POWER: AN INTERMEDIATE IN CALCULATION
      REAL DIST_POWER (1:5)
C     INTERMEDIATES IN CALCULATION
      INTEGER M1, M2, INDEX

C     COMMONLY USED VARAIBLES IN FILES
      COMMON /COM_6/  DISTANCE
      COMMON /COM_7/  RATM
      COMMON /COM_8/  RATM_SITE
      COMMON /COM_11/ NCD

C     INITIALIZE VARIABLES
      POWER = 2.0
      N = 0
      INDEX = 0
      M1 = 0
      M2 = 0

C     CASE 1: IF EQUAL DISTANCE, TAKE AVERAGE
      IF ( (DISTANCE(1) .EQ. DISTANCE(2)) .AND.
     +    (DISTANCE(1) .EQ. DISTANCE(3)) ) THEN
        GOTO 200
      END IF

C     CASE 2: IF ONE AND ONLY ONE OF THREE STATIONS
C     IS WITHIN 5 MILES OF H.C.S.,
C     USE DATA FROM THIS STATION DIRECTLY.
      IF ( (DISTANCE(1) .LE. 5.0) .AND. (DISTANCE(2) .GT. 5.0)
     + .AND. (DISTANCE(3) .GT. 5.0) ) THEN
        INDEX = 1
        GOTO 100
```

```
      ELSE IF ( (DISTANCE(2) .LE. 5.0) .AND.
     + (DISTANCE(1) .GT. 5.0)
     + .AND. (DISTANCE(3) .GT. 5.0) ) THEN
        INDEX = 2
        GOTO 100
      ELSE IF ( (DISTANCE(3) .LE. 5.0) .AND.
     + (DISTANCE(1) .GT. 5.0)
     + .AND. (DISTANCE(2) .GT. 5.0) ) THEN
        INDEX = 3
        GOTO 100

C     CASE 3: IF TWO AND ONLY TWO OF THREE STATIONS
C     IS WITHIN 5 MILES OF H.C.S.,
C     TAKE AVERAGE OF THESE TWO STATIONS.
      ELSE IF ( (DISTANCE(1) .LE. 5.0) .AND.
     + (DISTANCE(2) .LE. 5.0)
     + .AND. (DISTANCE(3) .GT. 5.0) ) THEN
        M1 = 1
        M2 = 2
        GOTO 400
      ELSE IF ( (DISTANCE(1) .LE. 5.0) .AND.
     + (DISTANCE(3) .LE. 5.0)
     + .AND. (DISTANCE(2) .GT. 5.0) ) THEN
        M1 = 1
        M2 = 3
        GOTO 400
      ELSE IF ( (DISTANCE(2) .LE. 5.0) .AND.
     + (DISTANCE(3) .LE. 5.0)
     + .AND. (DISTANCE(1) .GT. 5.0) ) THEN
        M1 = 2
        M2 = 3
        GOTO 400
      ELSE IF ( (DISTANCE(1) .LE. 5.0) .AND.
     + (DISTANCE(2) .LE. 5.0)
     + .AND. (DISTANCE(3) .LE. 5.0) ) THEN
        GOTO 200
      END IF

C     MORMAL CONDITION
      DO N = 1, 3
       DIST_POWER(N) = DISTANCE(N) ** (POWER)
      END DO

      DO 3000, I = 1, NCD
       DO 3010, J = 1, 96
        IF ( (RATM(1, I, J) .EQ. RATM(2, I, J)) .AND.
     +       (RATM(1, I, J) .EQ. RATM(3, I, J)) ) THEN
         RATM_SITE(I, J) = RATM(1, I, J)
         GOTO 3010
        END IF

        RATM_SITE(I, J) = ( RATM(1, I, J) / DIST_POWER(1) +
     +   RATM(2, I, J) / DIST_POWER(2) +
     +   RATM(3, I, J) / DIST_POWER(3) )
     +   / ( 1.0/DIST_POWER(1) + 1.0/DIST_POWER(2) +
     +   1.0/DIST_POWER(3) )
3010  CONTINUE
3000  CONTINUE
      GOTO 99999
```

```
C     CALCULATION OF SPECIAL CASES 1-3
100   DO I = 1, NCD
       DO J = 1, 96
        RATM_SITE(I, J) = RATM(INDEX, I, J)
       END DO
      END DO
      GOTO 99999

200   DO I = 1, NCD
       DO J = 1, 96
        RATM_SITE(I, J) = (RATM(1,I,J)+
     +   RATM(2,I,J)+RATM(3,I,J))/3
       END DO
      END DO
      GOTO 99999

400   DO I = 1, NCD
       DO J = 1, 96
        RATM_SITE(I, J) = ( RATM(M1, I, J) +
     +   RATM(M2, I, J) ) / 2
       END DO
      END DO
      GOTO 99999

99999 RETURN
      END
```

A3.1.7 library.for

```
C     SYNTHETIC RAINFALL GENERATION (SRG) MODEL
C     LIBRARY.FOR: STORE THE FUNCTIONS NEEDED IN THE PROGRAM
C     RANDOM NUMBER GENERATOR


      SUBROUTINE GET_SEED()
      INTEGER MOVINGTIME
      INTEGER*2 TMPHOUR, TMPMINUTE, TMPSECOND, TMPHUND

      CALL GETTIM(TMPHOUR , TMPMINUTE , TMPSECOND , TMPHUND)
      MOVINGTIME = TMPHOUR + TMPMINUTE + TMPSECOND + TMPHUND
      CALL SEED(MOVINGTIME)

      RETURN
      END
```

A3.2 SRG_1.exe (bootstrapping method) FORTRAN source code

A3.2.1 main.for

```
C     SYNTHETIC RAINFALL GENERATION ADDITIONAL (SRG_1) MODEL
```

```
C     MAIN.FOR
C     CONTROL PROGRAM


C     SOME ABREVIATION USED:
C     H.C.S.: HIGHWAY CONSTRUCTION SITE
C     N.C.D.: NUMBER
C     DPD: DAILY PARAMETER DATA
C     FPD: 15-MINUTE PARAMETER DATA

C     DECLARE VARIABLES

C     NCD: NUMBER OF CONSTRUCTION DAYS
      INTEGER NCD
C     INDEX_NCD: INDEX FOR HOW MANY NCD HAS BEEN CALCULATED
      INTEGER INDEX_NCD
C     FLAG_STATION: INDEX FOR THE STATION BEING PROCESSED
      INTEGER FLAG_STATION
C     ARR_TIME: SIMULATED ARRIVAL TIME SERIES
      INTEGER ARR_TIME (1:5)

C     STTN_REAL: 15-MIN RAINFALL SEQUENCE AT STATIONS FROM REAL DATA
      REAL STTN_REAL(1:3, 1:2000, 1:100)
C     HCS_REAL: 15-MINUTE RAINFALL SEQUENCE AT H.C.S. FROM REAL DATA
      REAL HCS_REAL(1:2000, 1:100)
C     RAIN_REAL: 15-MIN RAINFALL MODEL DATA
      REAL RAIN_REAL(1:3, 1:100)



C     COMMONLY  USED VARIABLES IN FILES
      COMMON /COM_1/  ARR_TIME
      COMMON /COM_23/ RAIN_REAL
      COMMON /COM_27/ STTN_REAL
      COMMON /COM_28/ HCS_REAL
      COMMON /COM_10/ FLAG_STATION
      COMMON /COM_11/ NCD


C     CALL FIEEIO.FOR TO GET FPD AND HPD DATA
      CALL FILEIO


C     A SCREEN MEMO FOR USER
      WRITE (*,*) 'Program is Running, Please wait.'

C     CALL ECATF.FOR TO GET ECATF PARAMETERS FOR STATIONS
      CALL ECATF

C     THIS CALL IS REQUIRED FOR RANDOM NUMBER GENERATOR
      CALL GET_SEED


C     LOOP THROUGH THREE SELECTED STATIONS
      DO 3000, N = 1,3
       FLAG_STATION = N

C     GET FIRST SIMULATED ARRIVAL TIME FOR RAINFALL STATIONS
       CALL RAT
C       WRITE (100, *) ARR_TIME
```

```
C     IF NO RAIN IN THE WHOLE NCD TIME
C     ARRVAL TIME > N.C.D. CASE, THEN NO RAIN
       IF (ARR_TIME(N) .GE. NCD) THEN
        DO I = 1, NCD
         DO J = 1, 96
          STTN_REAL(N, I, J) = 0.00
         END DO
         DAY = I
        END DO
        INDEX_NCD = NCD
        GOTO 3000
       ELSE
        INDEX_NCD = 1
        GOTO 2200
       END IF

C     IF THERE ARE RAINS DURING N.C.D.
      INDEX_NCD = 1
2000  IF (INDEX_NCD .LE. NCD) THEN
       GOTO 2100
      ELSE
       GOTO 3000
      END IF

C     CALL RAT.FOR TO GET MORE GENERATED ARRIVAL TIMES
2100  CALL RAT
C      WRITE (100, *) ARR_TIME

C     IF NO RAIN DURING FURTHER DAYS
C     CUMULATIVE SIMULATED ARRIVAL TIMES > N.C.D. CASE
2200  IF (ARR_TIME(N) .GE. (NCD - INDEX_NCD + 1)) THEN
       DO I = INDEX_NCD, NCD
        DO J = 1, 96
         STTN_REAL(N, I, J) = 0.00
        END DO
        DAY = I
       END DO
      GOTO 3000
      END IF

C     WHEN NO RAIN FOR THESE DAYS
C     ARRIVAL TIME < N.C.D. CASE AND <> 0
      IF ( ( ARR_TIME(N) .LT. (NCD - INDEX_NCD + 1))
     + .AND. (ARR_TIME(N) .NE. 0) ) THEN
       DO I = INDEX_NCD, INDEX_NCD + ARR_TIME(N) - 1
        DO J = 1, 96
         STTN_REAL(N, I, J) = 0.00
        END DO
        DAY = I
       END DO

C     CALL RRD.FOR TO RANDOMLY GENERATE MODEL RAINFALL DATA
       CALL RRD

       INDEX_NCD = INDEX_NCD + ARR_TIME(N)
       DO J = 1, 96
        STTN_REAL(N, INDEX_NCD, J) =
     +   RAIN_REAL(FLAG_STATION, J)
       END DO
       DAY = INDEX_NCD
```

```
        INDEX_NCD = INDEX_NCD + 1
        GOTO 2000
       END IF

C      ARRIVAL TIME < NCD CASE AND ARRIVAL TIME = 0
       IF ( ( ARR_TIME(N) .LT. (NCD - INDEX_NCD + 1))
     + .AND. (ARR_TIME(N) .EQ. 0) ) THEN
         CALL RRD
         DO J = 1, 96
          STTN_REAL(N, INDEX_NCD, J)
     +    = RAIN_REAL(FLAG_STATION, J)
        END DO
        DAY = INDEX_NCD
        INDEX_NCD = INDEX_NCD + 1
       GOTO 2000
       END IF

3000   CONTINUE

C      GET 15-MIN RAINFALL SEQUENCE FOR H.C.S.
       CALL DIST

       WRITE (100, *) ' '
       WRITE (100, *) ' '
       WRITE (100, 6910) 'TIME(MIN)', 'RAINFALL'
6910   FORMAT (A12, A9)

C      OUTPUT OF SRG MODEL
       DO I = 1, NCD
        DO J = 1, 96
         WRITE (100, 6950) (I-1) * 1440 + (J*15),
     +    HCS_REAL(I,J)

         WRITE (900, 6950) (I-1) * 1440 + (J*15),
     +    HCS_REAL(I,J)
        END DO
       END DO

6950   FORMAT (I12, F9.3)

       CLOSE (100)
       CLOSE (900)

       END
```

A3.2.2 fileio.for

```
C      SYNTHETIC RAINFALL GENERATION ADDITIONAL (SRG_1) MODEL
C      FILEIO.FOR
C      CHECK INPUT AND OUTPUT FILES
```

```
      SUBROUTINE FILEIO

C     DECLARE VARIABLES

C     FILEIN: INPUT FILENAME
      CHARACTER*4  FILEIN
C     FILEOUT: OUTPUT FILENAME
      CHARACTER*11 FILEOUT
C     STIE_NAME: H.C.S. NAME
      CHARACTER*11 SITE_NAME
C     DPD, FPD: DPD AND FPD PARAMETER FILES
      CHARACTER*11 DPD, FPD_2, FPD_3
C     FLAG_DPD, FLAG_FPD, FLAG_INPUT: LOGIC VARIABLES
      LOGICAL FLAG_DPD, FLAG_FPD_2, FLAG_FPD_3, FLAG_INPUT
C     UNIT_DPD, UNIT_FPD: DPD, FPD FILE I/O CONTROLER
      INTEGER UNIT_DPD, UNIT_FPD_2, UNIT_FPD_3
C     T_RAIN: TOTAL NUMBER OF RAIN-DAYS
      INTEGER T_RAIN(1:5)
C     MAX_WTIME: MAXIMUM ARRIVAL TIME
      INTEGER MAX_WTIME(1:5)
C     NCD: NUMBER OF CONSTRUCTION SITE
      INTEGER NCD
C     DISTANCE: DISTANCE B/W H.C.S. AND RAINFALL STATIONS
      INTEGER DISTANCE(1:5)

C     COMMONLY USED VARAIBLES IN FILES
      COMMON /COM_2/  T_RAIN
      COMMON /COM_5/  MAX_WTIME
      COMMON /COM_6/  DISTANCE
      COMMON /COM_11/ NCD


C     CHECK WHETHER THE INPUT.TXT FILE AVAIALBE
      INQUIRE (FILE='INPUT.TXT', EXIST=FLAG_INPUT)
      IF (FLAG_INPUT .EQV. .TRUE.) THEN
       GOTO 40
      ELSE
       PRINT *, 'INPUT FILE NOT FOUND.'
       STOP
      END IF

C     OPEN INPUT.TXT
40    OPEN(UNIT = 500, FILE = 'INPUT.TXT', ERR = 20000)
      READ (500, 5100) FILEOUT
5100  FORMAT (14x, A11)

C     OPEN OUTPUT FILE
      OPEN(UNIT = 100, FILE = FILEOUT, ERR = 20000)
      WRITE (100, 6650) 'SYNTHETIC RAINFALL GENERATION'
6650  FORMAT(A29)

C     OPEN OUTPUT FILE FOR VISUAL BASIC GRAPHIC FUNCTION
      OPEN(UNIT = 900, FILE = 'SOURCE.OUT', ERR = 20000)

C     READ CONSTRUCTION SITE NAME
      READ (500,5610) SITE_NAME
                                                                    WRIT
E (100, *) ' '
      WRITE (100, 6610) 'SITE NAME:', SITE_NAME
5610  FORMAT (14x, A11)
```

```
6610  FORMAT (A10,2X, A11)

C     READ 15 MINUTE AND DAILY DATA FILE NAME
      DO 3000, N = 1, 3
      READ (500,5000) FILEIN
5000  FORMAT (14x, A4)

C     CREATE PARAMETER DATA FILES
      DPD = (FILEIN // 'D_3.TXT')
      FPD_2 = (FILEIN // 'F_2.TXT')
      FPD_3 = (FILEIN // 'F_3.TXT')

C     CHECK INPUT FILE STATUS
      INQUIRE (FILE=DPD, EXIST=FLAG_DPD)
      INQUIRE (FILE=FPD_2, EXIST=FLAG_FPD_2)
      INQUIRE (FILE=FPD_3, EXIST=FLAG_FPD_3)
      IF ( (FLAG_DPD .EQV. .TRUE.) .AND.
     + (FLAG_FPD_2 .EQV. .TRUE.) .AND. (FLAG_FPD_3 .EQV. .TRUE.)) THEN
       GOTO 1000
      ELSE
       STOP
      END IF

C     IF STATUS OF INPUT FILES IS OK, THEN OPEN THE FILE.
1000  UNIT_DPD = N * 10 + 1
      UNIT_FPD_2 = N * 10 + 2
      UNIT_FPD_3 = N * 10 + 3
                                                              WRIT
E (100, 6710) 'STATION #', N, ':', FILEIN
      6710  FORMAT (A9, I1, A1, 1X, A4)

      OPEN(UNIT=UNIT_DPD, FILE=DPD,STATUS='OLD', ERR=20000)
      OPEN(UNIT=UNIT_FPD_2, FILE=FPD_2,STATUS='OLD', ERR=20000)
      OPEN(UNIT=UNIT_FPD_3, FILE=FPD_3,STATUS='OLD', ERR=20000)

C     READ VARIABLES FROM DATA FILES
      READ (UNIT_DPD, 5510) MAX_WTIME(N)
5510  FORMAT (/ 9X, I9 /)

      READ (UNIT_FPD_3, 5520) T_RAIN(N)
5520  FORMAT (/ 9X, I9 /)

3000  CONTINUE

C     READ DISTANCE FROM INPUT FILE
      DO N = 1, 3
       READ (500, 5530) DISTANCE(N)
      END DO
5530  FORMAT (14X, I3)
      WRITE (100, 5610) ' '
      WRITE(100,6810) 'DISTANCE TO SITE:'
6810  FORMAT(A17)
      DO I = 1, 3
       WRITE (100, 6660) 'STATION #', I, ':', DISTANCE(I)
      END DO
6660  FORMAT(A9, I1, A1, 1X, I3)


C     READ NUMBER OF CONSTRUCTION DAYS
      READ (500, 5540) NCD
```

```
5540  FORMAT(14x, I4)

      GOTO 99999

C     ERROR HANDLER
20000 PRINT*, 'ERROR HAPPENS WHEN OPENING THE FILE.'
      GOTO 99999

99999 END
```

A3.2.3 ecatf.for

```
C     SYNTHETIC RAINFALL GENERATION ADDITIONAL (SRG_1) MODEL
C     ECATF.FOR
C     GET ECATF PARAMETERS FROM DAILY PARAMETER DATA FILES


      SUBROUTINE ECATF

C     DECLARE VARAIBLES

C     MAX_WTIME: MAXIMUM WAITING TIME
      INTEGER MAX_WTIME(1:5)
C     ECATF_DATA: ECATF PARAMETERS
      REAL ECATF_DATA(1:3, 0:1000)
C     UNIT_DPD: DPD FILE I/O CONTROLER
      INTEGER UNIT_DPD


C     COMMONLY USED VARIABLES IN FILES
      COMMON /COM_4/ ECATF_DATA
      COMMON /COM_5/MAX_WTIME


C     READ ECATF PARAMETERS FROM DPD FILES
      DO N = 1, 3
        UNIT_DPD = N * 10 + 1
        DO K = 1, MAX_WTIME(N)
C     THIS READ FOLLOWS THE READ COMMAND IN FILEIO.FOR
          READ (UNIT_DPD, 5010) ECATF_DATA(N, K)
        END DO
        ECATF_DATA(N,0) = 0.0000
      END DO

5010  FORMAT (9X, F9.4)

      END
```

A3.2.4 rat.for

```
C     SYNTHETIC RAINFALL GENERATION ADDITIONAL (SRG_1) MODEL
C     RAT.FOR
C     GENERATE A ARRIVAL TIME RANDOMLY


      SUBROUTINE RAT

C     DECLARE VARAIBLES

C     RAN_DAY: RANDOM NUMBER FOR ECATF
      REAL RAN_DAY
C     LIM_LOW, LIM_HIGH: INTERMEDIATES TO FIND ECATF
      REAL LIM_LOW, LIM_HIGH
C     MAX_WTIME: MAXIMUM WAITING TIME OR ARRIVAL TIME
      INTEGER MAX_WTIME(1:5)
C     ARR_TIME: ARRIVAL TIME
      INTEGER ARR_TIME(1:3)
C     ECATF_DATA: ECATF PARAMETERS
      REAL ECATF_DATA(3, 0:1000)
C     FLAG_STATION: INDEX FOR THE STATION BEING PROCESSED
      INTEGER FLAG_STATION
C     TEMP1: VARAIBLE USED FOR RANDOM NUMBER GENERATION
      REAL TEMP1

C     COMMONLY USED VARAIBLES IN FILES
      COMMON /COM_1/  ARR_TIME
      COMMON /COM_4/  ECATF_DATA
      COMMON /COM_5/  MAX_WTIME
      COMMON /COM_10/ FLAG_STATION


C     GET A RANDOM NUMBER BETWEEN 0 AND 1
      CALL RANDOM(TEMP1)
      RAN_DAY = TEMP1

C     FIND ARRIVAL TIME ACCORDING TO ECATF AND RAN_DAY
      DO 2000, I = 0, MAX_WTIME(FLAG_STATION)

C     CASE 1: ARRIVAL TIME = 0
       IF (I .EQ. 0) THEN
        IF ( RAN_DAY .LT. (ECATF_DATA(FLAG_STATION,1)/2) ) THEN
         ARR_TIME(FLAG_STATION) = 0
         GOTO 2100
        ELSE
         GOTO 2000
        END IF
       END IF

C     CASE 2: ARRIVAL TIME = MAXIMUM WAITING TIME
       IF (I .EQ. MAX_WTIME(FLAG_STATION)) THEN
        ARR_TIME = MAX_WTIME(FLAG_STATION)
        GOTO 2100
       END IF

C     GENERAL CASE
C     CREATE THE PROBABILITY DENSITY RANGE
       LIM_LOW = ( ECATF_DATA(FLAG_STATION,I-1) +
     +  ECATF_DATA(FLAG_STATION,I) ) / 2
       LIM_HIGH = ( ECATF_DATA(FLAG_STATION,I) +
```

```
     +  ECATF_DATA(FLAG_STATION,I+1) ) / 2
C      GET CORRESPINDING ARRIVAL TIME
        IF ((RAN_DAY .GE. LIM_LOW) .AND. (RAN_DAY .LT. LIM_HIGH)) THEN
         ARR_TIME(FLAG_STATION) = I
         GOTO 2100
        END IF

2000  CONTINUE

2100  RETURN
      END
```

A3.2.5 rrd.for

```
C      SYNTHETIC RAINFALL GENERATION ADDITIONAL (SRG_1) MODEL
C      RRD.FOR
C      RANDOMLY PICK A RAIN-DAY AND GET REAL RAINFALL DATA


       SUBROUTINE RRD()

C      DECLARE VARIABLES

       REAL RAIN_REAL(1:3, 1:100)
C      RAN_RAIN: RANDOM NUMBER USED TO PICK A RAIN-DAY; RAIN_NUM: ORDERED
RAIN NUMBER IN FPD FILES
       INTEGER RAN_RAIN, RAIN_NUM
C      STATION_ID: STATION IDENTIFICATION NUMBER
       INTEGER STATION_ID
C      T_RAIN: TOTAL NUMBER OF RAIN-DAYS IN FPD FILES
       INTEGER T_RAIN(1:5)
C      UNIT_FPD: FPD FILE I/O CONTROLER
       INTEGER UNIT_FPD_2, UNIT_FPD_3
C      FLAG_STATION: INDEX FOR THE STATION BEING PROCESSED
       INTEGER FLAG_STATION

C      TEMP1: VARIABLE FOR RANDOM NUMBER GENERATION
       REAL TEMP1

C      COMMONLY USED VARIABLES IN FILES
       COMMON /COM_23/  RAIN_REAL
       COMMON /COM_2/   T_RAIN
       COMMON /COM_10/  FLAG_STATION


C      INITIALIZE VARIABLES
       RAN_RAIN = 0

C      GET A RANDOM RAIN NUMBER
       CALL RANDOM(TEMP1)
       RAN_RAIN = 1 + INT(TEMP1 * (T_RAIN(FLAG_STATION)-1))

C      READ COMMAND HERE IS JUST FOR FILE I/O READING CONVINIENT
       UNIT_FPD_2 = FLAG_STATION * 10 + 2
```

```
      UNIT_FPD_3 = FLAG_STATION * 10 + 3
      REWIND (UNIT_FPD_2)
      REWIND (UNIT_FPD_3)
      READ (UNIT_FPD_3, 5610) STATION_ID
5610  FORMAT (9X, I9 //)

C     READ 15-MIN. RAINFALL DATA FROM FPD FILE RANDOMLY
      DO 100, I = 1, RAN_RAIN
       READ (UNIT_FPD_3, 5520) RAIN_NUM
       READ (UNIT_FPD_2, 5525) (RAIN_REAL(FLAG_STATION, M), M= 1, 96)
       IF (I .EQ. RAN_RAIN) THEN
        GOTO 1000
       ELSE
        GOTO 100
       END IF
100   CONTINUE
5520  FORMAT (I9)
5525  FORMAT (29X, 96(1X, F5.2), 8X)

1000  RETURN
      END
```

A3.2.6 dist.for

```
C     SYNTHETIC RAINFALL GENERATION ADDITIONAL (SRG_1) MODEL
C     DIST.FOR
C     INVERSE DISTANCE METHOD


      SUBROUTINE DIST


C     DECLARE VARAIBLES

C     FMRS_STTN: 15-MINUTE RAINFALL SEQUENCE FOR STATION
      REAL STTN_REAL(1:3, 1:2000, 1:100)
C     FMRS_SITE: 15-MINUTE RAINFALL SEQUENCE FOR H.C.S.
      REAL HCS_REAL(1:2000, 1:100)
C     DISTANCE: DISTANCE BETWEEN H.C.S. AND SELECTED STATIONS
      INTEGER DISTANCE (1:5)
C     POWER: POWER USED IN THE INVERSE DISTANCE EQUATION
      REAL POWER
C     DIST_POWER: AN INTERMEDIATE IN CALCULATION
      REAL DIST_POWER (1:5)
C     INTERMEDIATES IN CALCULATION
      INTEGER M1, M2, INDEX

C     COMMONLY USED VARAIBLES IN FILES
      COMMON /COM_6/  DISTANCE
      COMMON /COM_27/ STTN_REAL
      COMMON /COM_28/ HCS_REAL
      COMMON /COM_11/ NCD

C     INITIALIZE VARIABLES
```

```
      POWER = 2.0
      N = 0
      INDEX = 0
      M1 = 0
      M2 = 0


      IF (DISTANCE(1) .EQ. 0) THEN
       INDEX = 1
       GOTO 200
      ELSE IF (DISTANCE(2) .EQ. 0) THEN
       INDEX = 2
       GOTO 200
      ELSE IF (DISTANCE(3) .EQ.0 ) THEN
       INDEX = 3
       GOTO 200
      END IF

C     NORMAL CONDITION
      DO N = 1, 3
       DIST_POWER(N) = DISTANCE(N) ** (POWER)
      END DO

      DO 3000, I = 1, NCD
       DO 3010, J = 1, 96

        HCS_REAL(I, J) = ( STTN_REAL(1, I, J) / DIST_POWER(1) +
     +   STTN_REAL(2, I, J) / DIST_POWER(2) +
     +   STTN_REAL(3, I, J) / DIST_POWER(3) )
     +   / ( 1.0/DIST_POWER(1) + 1.0/DIST_POWER(2) +
     +   1.0/DIST_POWER(3) )
3010  CONTINUE
3000  CONTINUE
      GOTO 99999

200   DO I = 1, NCD
       DO J = 1, 96
        HCS_REAL(I, J)  = (STTN_REAL(INDEX,I,J))
       END DO
      END DO
      GOTO 99999

99999 RETURN
      END
```

A3.2.7 library.for

```
C     SYNTHETIC RAINFALL GENERATION ADDITIONAL (SRG_1) MODEL
C     LIBRARY.FOR: STORE THE FUNCTIONS NEEDED IN THE PROGRAM
C     RANDOM NUMBER GENERATOR


      SUBROUTINE GET_SEED()
      INTEGER MOVINGTIME
```

```
INTEGER*2 TMPHOUR, TMPMINUTE, TMPSECOND, TMPHUND

CALL GETTIM(TMPHOUR , TMPMINUTE , TMPSECOND , TMPHUND)
MOVINGTIME = TMPHOUR + TMPMINUTE + TMPSECOND + TMPHUND
CALL SEED(MOVINGTIME)

RETURN
END
```

A3.3 input.txt

Input.txt is generated by SRG model interface and is used by srg.exe to do model calculation.

```
OPTF NAME     output.txt
SITE NAME     HCS_1
STATION #1    0428
STATION #2    8531
STATION #3    9815
DISTANCE #1   13
DISTANCE #2   18
DISTANCE #3   25
N.C.D.        20
```

```
OPTF NAME: output filename
SITE NAME: name of highway construction site
STATION #1: first rainfall station_ID
STATION #2: second rainfall station_ID
STATION #3: third rainfall station_ID
DISTANCE #1: distance from H.C.S. to first station
DISTANCE #2: distance from H.C.S. to second station
DISTANCE #3: distance from H.C.S. to third station
N.C.D.: number of construction days
```

A3.4 output.txt

Output.txt is generated by SRG.exe, which includes detailed 15-minute rainfall sequence.

```
SYNTHETIC RAINFALL GENERATION

SITE NAME:  HCS_1
```

```
STATION #1: 0428
STATION #2: 8531
STATION #3: 9815

DISTANCE TO SITE:
STATION #1:  13
STATION #2:  18
STATION #3:  25


   TIME(MIN) RAINFALL

 DAY NUMBER:        1
          15  .000000
          30  .000000
          45  .000000
          60  .000000
          75  .000000
          90  .000000
         105  .000000
         120  .000000
           .      ..
           .      ..
DAY NUMBER:       20
       27375  .000000
       27390  .000000
       27405  .000000
       27420  .000000
       27435  .000000
          .      ..
          .      ..
       28725  .000000
       28740  .000000
       28755  .000000
       28770  .000000
       28785  .000000
       28800  .000000
```

A3.5 source.out

source.txt is generated by SRG.exe, which includes 15-minute rainfall sequence for plot.exe.

```
          15  .000000
          30  .000000
          45  .000000
          60  .000000
          75  .000000
          90  .000000
         105  .000000
         120  .000000
         .      ..
         .      ..
```

```
28680  .000000
28695  .000000
28710  .000000
28725  .000000
28740  .000000
28755  .000000
28770  .000000
28785  .000000
28800  .000000
```

A4. ECATFPG model source code and input/output files

A4.1 ECATFPG model FORTRAN source code

A4.1.1 main.for

```
C      ECATFPG MODEL
C      MAIN.FOR
C      PROGRAM CONTROL AND GENERATE ECATF PARAMETERS


C      DECLARE VARIABLES

C      STATION_ID: STATION IDENTIFICATION NUMBER
       INTEGER STATION_ID
C      MAX_ARRTIME: MAXIMUM ARRIVAL TIME
       INTEGER MAX_ARRTIME
C      MYEARS: MAXIMUM POSSIBLE NUMBER OF YEARS
       INTEGER MYEARS
C      NYEARS: COUNTER OF YEARS
       INTEGER NYEARS
C      ACTUAL NUMBER OF YEARS IN DAILY RAINFALL DATA
       INTEGER YEARS
C      RAINYEAR: YEAR RECORD OF DAILY RAINFALL DATA
       INTEGER RAINYEAR(1:100)
C      RAINDATA: DAILY RAINFALL DATA
       REAL RAINDATA(100,1:400)
C      NDAYS: NUMBER OF DAILY RAINFALL RECORDS
       INTEGER NDAYS(1:5000)
C      N_RAIN: NUMBER OF WAITING EVENT WRT ARRIVAL TIME
       INTEGER N_RAIN(1:1000)
C      N_RAIN_NORM: NORMALIZED N_RAIN BY NDAYS
       REAL N_RAIN_NORM(1:1000)
C      INDEX_WTEVT: COUNTER and INDEX  FOR WAITING EVENTS
       INTEGER INDEX_WTEVT
C      ECATF PARAMETERS
       REAL ECATF_1(1:1000)
```

```
C     VARIABLE INITIALIZATION
      MYEARS = 100
      NYEARS = 1

C     CHECK INPUT AND OUTPUT FILES
      CALL FILEIO
C     INPUT AND OUTPUT OF STATION_ID
      READ(11, 5010) STATION_ID
      WRITE(12, 6010) 'STN_ID', STATION_ID
5010  FORMAT(I4)
6010  FORMAT(A9, I9)
      REWIND(11)

C     FIND NUMBER OF YEARS IN RAINFALL DATA FILE
      DO 1020 I=1, MYEARS
       READ (11, 5020) RAINYEAR(I)
       IF (.NOT. EOF(11)) THEN
        NYEARS = NYEARS + 1
       ELSE
        GOTO 1050
       END IF
1020  CONTINUE
1050  YEARS=NYEARS
5020  FORMAT (7X,I4)
      REWIND(11)

C     GET DAILY RAINFALL DATA FILE
      DO 300, J=1, YEARS
      READ(11,5100) (RAINDATA(J,K), K=1,366)
300   CONTINUE
5100  FORMAT (11X, 366(1X,F6.2), 3X)

C     SORT OUT WAITING EVENTS FROM
      INDEX_WTEVT = 0
      DO 500, I= 1, YEARS
       DO 600, J = 1, 366
C     A ZERO RAIN-DAY
        IF (RAINDATA(I,J) .EQ. 0.00) THEN
C     A STARTING POINT OF WAITING EVENTS
         IF (RAINDATA(I,J-1) .NE. 0.00) THEN
C     TOTAL NUMBER OF WAITING EVENTS INCREASE BY ONE
          INDEX_WTEVT = INDEX_WTEVT + 1
C     FOR A NEW WAITING EVENT, ARRIVAL TIME INCREASE BY ONE
          NDAYS(INDEX_WTEVT)=NDAYS(INDEX_WTEVT) + 1
          GOTO 600
         ELSE
C     FOR A OLD WAITING EVENT, ARRIVAL TIME INCREASE BY ONE
          NDAYS(INDEX_WTEVT)=NDAYS(INDEX_WTEVT) + 1
          GOTO 600
         END IF
        ELSE
         GOTO 600
        END IF
600    CONTINUE
500   CONTINUE

C     FIND MAXIMUM ARRIVAL TIME
      DO 1610, I = 1, INDEX_WTEVT
       IF (MAX_ARRTIME .GE. NDAYS(I)) THEN
```

```
         GOTO 1610
        ELSE
         MAX_ARRTIME = NDAYS(I)
        END IF
1610   CONTINUE

C      FIND NUMBER OF WAITING EVENTS FOR EACH ARRIVAL TIME
       DO 1220, J = 1, MAX_ARRTIME
        DO I = 1, INDEX_WTEVT
         IF (J .EQ. NDAYS(I)) THEN
          N_RAIN(J) = N_RAIN(J) + 1
         END IF
        END DO
1220   CONTINUE

C      OUTPUT FILE TITLES
       WRITE(12, 6040) 'M_ARRTIME', MAX_ARRTIME
6040   FORMAT (A9, I9)
       WRITE(12, 6050) 'ARR_T', 'ECATF'

C      GENERATE NORMALIZED WAITING EVENTS
       DO 800, I = 1, MAX_ARRTIME
        N_RAIN_NORM(I) = FLOAT(N_RAIN(I)) / FLOAT(INDEX_WTEVT)
800    CONTINUE

C      GENERATE ECATF PARAMETERS
       DO 1710, I = 1, MAX_ARRTIME
        IF (I .EQ. 1) THEN
         ECATF_1(1) = N_RAIN_NORM(1)
         GOTO 1720
        END IF
        ECATF_1(I) = ECATF_1(I-1) + N_RAIN_NORM(I)
1720    WRITE(12, 6060) I, ECATF_1(I)
1710   CONTINUE

6050   FORMAT(A9, A9)
6060   FORMAT(I9, F9.4)

       CLOSE(11)
       CLOSE(12)
        END
```

A4.1.2 fileio.for

```
C      ECATFPG MODEL
C      FILEIO.FOR
C      CHECK INPUT AND OUTPUT FILES


       SUBROUTINE FILEIO

C      DEFINE VARIABLES
```

```
C     FILEIN: INPUT DAILY DATA FILE IDENTIFICATION NUMBER
      CHARACTER*4  FILEIN
C     FILEOUT: OUTPUT FILE NAME
      CHARACTER*11 FILEOUT
C     DAILY DATA FILE NAME
      CHARACTER*11 DPD
C     VARIABLE TO TAKE RESPONSE FROM USER
      CHARACTER*1 ANSWER1
C     LOGICAL VARIABLES TO CHECK INPUT AND OUTPUT FILES
      LOGICAL FLAGIN, FLAGOUT

C     ASK FOR THE STATION_ID
10    PRINT *, 'PLEASE ENTER STATION ID (4 DIGIT ONLY):'
      READ (*,5000) FILEIN
5000  FORMAT (A4)

C     CREATE INPUT FILE NAME FROM STATION_ID
      DPD = (FILEIN // 'D_2.TXT')

C     CHECK INPUT FILE STATUS
      INQUIRE (FILE=DPD, EXIST=FLAGIN)
      IF (FLAGIN .EQV. .TRUE.) THEN
       GOTO 20
      ELSE
       PRINT *, 'DPD FILE DOES NOT EXIST.'
       PRINT *, 'DO YOU WANT TO ENTER THE STATION ID AGAIN?'
       PRINT *, 'PRESS Y FOR YES, OR ANY OTHER KEYS TO QUIT,'
       PRINT *, 'THEN PRESS RETURN.'
       READ (*, 5030) ANSWER1
       IF ((ANSWER1 .EQ. 'Y') .OR. (ANSWER1 .EQ. 'y')) THEN
        GOTO 10
       ELSE
        STOP
       END IF
      END IF

C     IF CHECKING INPUT STATUS PASS, THEN OPEN THE FILE.
20    OPEN(UNIT=11,FILE=DPD,STATUS='OLD', ERR=20000)

C     ASK FOR OUTPUT FILE NAME
      FILEOUT = (FILEIN // 'D_3.TXT')
      PRINT *
      PRINT *
      PRINT *, 'OUTPUT FILE IS SAVED AS ', FILEOUT

C     CHECK OUTPUT FILE STATUS
      INQUIRE (FILE=FILEOUT, EXIST=FLAGOUT)
      IF (FLAGOUT .EQV. .TRUE.) THEN
       PRINT *, 'FILE ALREADY EXISTED. WANT TO REPLACE IT?'
       PRINT *, 'ENTER Y FOR YES, OR ANY OTHER KEYS TO QUIT,'
       PRINT *, 'THEN PRESS RETURN.'
       READ (*, 5030) ANSWER1
       IF ((ANSWER1 .EQ. 'Y') .OR. (ANSWER1 .EQ. 'y')) THEN
        GOTO 40
       ELSE
        STOP
       END IF
      ELSE
       GOTO 40
      END IF
```

```
5030  FORMAT(A1)

C     IF CHECKING STATUS PASS, THEN OPEN THE FILE.
40    OPEN(UNIT = 12, FILE = FILEOUT, ERR = 20000)

      GOTO 99999

C     ERROR HANDLER
20000 PRINT*, 'ERROR HAPPENS WHEN OPENING THE FILE.'
      GOTO 99999

99999 END
```

A4.2 ECATFG model input file_

The input file for ECATFPG model is actual historical daily rainfall data for each station. This demo example is part of file 1429d_2.txt for station 1429.

```
1429   1979   0.17   0.00   0.00   0.19   0.05   0.08   0.02   0.00
0.00   1.84   0.16   0.00   0.00   0.00   0.00   0.00   0.00   0.20
0.01   0.00   0.00   0.00   0.00   0.00   0.26   0.02   0.00   0.00
0.06   0.23   0.00   0.00   0.12   0.19   0.43   0.45   0.38   0.03
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.09   0.69   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.02   0.29   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.08   0.00   0.00   0.00   0.33   0.28   0.04   0.00
3.16   0.75   0.50   0.38   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.10   0.22   0.08   0.07   0.06   0.03   0.00   0.00   0.04
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.38
0.02   0.10   0.33   0.56   0.00   0.00   0.00   0.00   0.00   0.00
0.00   1.72   0.00   1.56   0.00   0.02   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.24   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.53   0.13   0.00   0.00   0.00   0.00   0.05
0.14   0.00   0.19   0.00   0.70   0.27   0.00   0.00   0.83   0.04
0.00   0.00   0.03   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.25   2.01
0.00   0.35   0.00   0.66   0.00   0.00   0.00   0.00   0.11   0.00
0.00   0.89   0.05   0.08   0.17   0.00   0.00   0.00   0.00   0.00
3.56   0.00   0.00   0.00   0.00   0.00   0.00   0.08   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.90   0.00   0.00   0.00   0.00
0.00   0.19   0.00   0.00   0.00   0.00   0.00   0.00   0.83   0.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.52
0.14   0.64   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.77   0.18   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.55   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.00   0.00   0.13   0.00   0.00   0.17   0.27   0.00   0.00
0.24   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
```

```
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.00
0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.33
0.00   0.00   0.00   0.00   0.00   1.29   0.00   0.00
1429   1980   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
0.00   0.04   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.25
0.06   0.06   0.17   0.24   0.00   0.00   0.00
……………………………
```

A4.3 ECATFG model output file

Output file from ECATFPG model is ECATFPG parameters for each station. This demo example is part of file 1429d_3.txt for station 1429.

```
STN_ID     1429
M_ARRTIME        64
    ARR_T    ECATF
        1    .1405
        2    .2508
        3    .3656
        4    .4547
        5    .5468
        .      . .
        .      . .
       58    .9985
       59    .9985
       60    .9985
       61    .9985
       62    .9985
       63    .9985
       64   1.0000
```

STN_ID: station identification number
M_ARRTIME: maximum arrival time
ARR_T: arrival time
ECATF: cumulative probability function values

A5. RDPG model source code and input/output files

A5.1 RDPG model FORTRAN source code

A5.1.1 main.for

```
C     RDPG MODEL
C     MAIN.FOR
C     CONTROL THE PROGRAM
```

```
C     DECLARES VARAIBLES

C     STATION_ID: STATION IDENTIFICATION NUMBER
      INTEGER STATION_ID
C     TOTAL_RAINS: TOATL NUMBER OF RAIN DAYS
      INTEGER TOTAL_RAINS
C     MDAYS: MAXIMUM NUMBER OF RAIN DAYS
      INTEGER MDAYS
C     INDEX: A COUNTER USED IN THIS PROGRAM
      INTEGER INDEX
C     RAINDATE: DATE OF THE RAIN EVENT
      CHARACTER*10, RAINDATE(1:3000)
C     RAIN_REALDATA: REAL (OR ACTUAL) RAINFALL DATA
      REAL RAIN_REALDATA(1:100)

C     COMMONLY USED VARIABLES IN FILES
      COMMON /COM_1/   RAIN_REALDATA
      COMMON /COM_11/  INDEX

C     INITIALIZE VARAIBLES
      MDAYS = 3650
      TOTAL_RAINS = 0

C     CALL FILEIO.FOR TO CHECK INPUT AND OUTPUT FILES
      CALL FILEIO

C     READ AND WRITE STATION IDENTIFICATION NUMBER
      READ (11, 5010) STATION_ID
      WRITE (12, 6010) 'STN ID', STATION_ID
      REWIND(11)

C     CALCULATE TOTAL NUMBER OF RAIN DAYS
      DO 200 J=1, MDAYS
       IF (.NOT. EOF(11)) THEN
       READ(11,5100) RAINDATE(J)
       ELSE
        GOTO 250
       END IF
200   CONTINUE
250   TOTAL_RAINS = J - 1
      REWIND (11)
5010  FORMAT(4X, I4)
5100  FORMAT(17X, A10)

C     OUTPUT FILE TITLE AND TOTAL NUMBER OF RAIN DAYS
      WRITE (12, 6020) 'T_RAINS', TOTAL_RAINS
      WRITE (*, *) 'TOTAL NUMBER OF RAINS ARE  ', TOTAL_RAINS
      WRITE (12, 6030) 'RAIN_NUM', 'RAIN_CTR', 'RAIN_DSP',
     +                 'RAIN_DRT', 'PK_RATE'

C     GENERATE PARAMTERS
      DO 300, I = 1, TOTAL_RAINS
       INDEX = I
       WRITE (*,*) STATION_ID, INDEX
       READ(11,5020) (RAIN_REALDATA(K), K=1,96)
       DO K = 1, 96
        RAIN_REALDATA(K) = 100.0 * RAIN_REALDATA(K)
       END DO
```

```
C     CALL SUBROUTINE PARA.FOR TO GENERATE PARAMTERS
       CALL PARA
500    CONTINUE
300   CONTINUE

5020  FORMAT (27X, 96(1X,F5.2), 8X)
6010  FORMAT (A9, I9)
6020  FORMAT (A9, I9)
6030  FORMAT(A9, A9, A9, A9, A9)

99999 END
```

A5.1.2 fileio.for

```
C     RDPG MODEL
C     FILEIO.FOR
C     CHECK INPUT AND OTPUT FILE


      SUBROUTINE FILEIO

C     DECLARE VARAIBLES

C     FILEIN: INPUT DAILY FILE INDENTIFICATION NUMBER
      CHARACTER*4  FILEIN
C     FILEOUT: OUTPUT FILE NAME
      CHARACTER*11 FILEOUT
C     FPD: OVERALL 15 MINUTE INPUT FILENAME
      CHARACTER*11 FPD
C     VARAIBLE TO TAKE RESPONSE FROM USER
      CHARACTER*1 ANSWER1
C     LOGICAL VARIABLE TO CHECK INPUT AND OUTPUT FILES
      LOGICAL FLAGIN, FLAGOUT

C     ASK FOR THE STATION_ID
10    PRINT *, 'PLEASE ENTER STATION ID (4 DIGIT ONLY):'
      READ (*,5000) FILEIN
5000  FORMAT (A4)

C     CREATE INPUT FILE NAME FROM STATION_ID
      FPD = (FILEIN // 'F_2.TXT')

C     CHECK INPUT FILE STATUS
      INQUIRE (FILE=FPD, EXIST=FLAGIN)
      IF (FLAGIN .EQV. .TRUE.) THEN
       GOTO 20
      ELSE
       PRINT *, 'FPD FILE DOES NOT EXIST.'
       PRINT *, 'DO YOU WANT TO ENTER THE STATION ID AGAIN?'
       PRINT *, 'PRESS Y FOR YES, OR ANY OTHER KEYS TO QUIT,'
       PRINT *, 'THEN PRESS RETURN.'
       READ (*, 5030) ANSWER1
       IF ((ANSWER1 .EQ. 'Y') .OR. (ANSWER1 .EQ. 'y')) THEN
        GOTO 10
```

```
       ELSE
        STOP
       END IF
      END IF

C     IF CHECKING STATUS PASS, THEN OPEN THE FILE.
20    OPEN(UNIT=11,FILE=FPD,STATUS='OLD', ERR=20000)

C     ASK FOR OUTPUT FILE NAME
      FILEOUT = (FILEIN // 'F_3.TXT')
      PRINT *
      PRINT *
      PRINT *, 'OUTPUT FILE IS SAVED AS ', FILEOUT

C     CHECK OUTPUT FILE STATUS
      INQUIRE (FILE=FILEOUT, EXIST=FLAGOUT)
      IF (FLAGOUT .EQV. .TRUE.) THEN
       PRINT *, 'FILE ALREADY EXISTED. WANT TO REPLACE IT?'
       PRINT *, 'ENTER Y FOR YES, OR ANY OTHER KEYS TO QUIT,'
       PRINT *, 'THEN PRESS RETURN.'
       READ (*, 5030) ANSWER1
       IF ((ANSWER1 .EQ. 'Y') .OR. (ANSWER1 .EQ. 'y')) THEN
        GOTO 40
       ELSE
        STOP
       END IF
      ELSE
       GOTO 40
      END IF
5030  FORMAT(A1)

C     IF CHECKING STATUS PASS, THEN OPEN THE FILE.
40    OPEN(UNIT = 12, FILE = FILEOUT, ERR = 20000)

      GOTO 99999

C     ERROR HANDLER
20000 PRINT*, 'ERROR HAPPENS WHEN OPENING THE FILE.'
      GOTO 99999

99999 END
```

A5.1.3 para.for

```
C     RDPG MODEL
C     PAPA.FOR
C     FIND INITIAL PARAMETER VALUES


      SUBROUTINE PARA

C     DECLARE VARAIBLES

C     P: RAIN-DAY PARAMETERS
      REAL P(1:4)
```

```
C     FTOL: TOLERANCE OF THE CALCULALTION
      REAL FTOL
C     FRET: GUESS OF THE MINIMUM VALUE OF THE FUNCTION
      REAL FRET
C     LIM_LOW, LIM_HIGH: RANGE OF RAINFALL DATA IN A DAY
      REAL LIM_LOW, LIM_HIGH
C     RAIN_REALDATA: REAL OR ACTUAL RAINFALL DATA
      REAL RAIN_REALDATA(1:100)
C     INDEX: A INDEX OF RAIN-DAY
      INTEGER INDEX

C     COMMONLY USED VARIABLES IN FILES
      COMMON /COM_1/   RAIN_REALDATA
      COMMON /COM_11/  INDEX

C     INITIALIZE VARIABLES
C     NUMBER OF PARAMETERS IN THE TARGET PARAMETER ARRAY
      N = 4
      FTOL = 1.0E-3
      FRET = 1.0E-3

C     P(1): TIME TO PEAK, P(2): RAIN DISPERSION COEFFICIENT
C     P(3): RAIN DURATION, P(4): PEAK RATE
      P(1) = 0.00
      P(2) = 0.01
      P(3) = 0.00
      P(4) = 0.00

C     FIND P(4) AND P(1)
      DO 820, K = 1, 96
       IF (P(4) .GE. RAIN_REALDATA(K)) THEN
        GOTO 820
       ELSE
        P(4) = RAIN_REALDATA(K)
        P(1) = K * 15.0
        GOTO 820
       END IF
820   CONTINUE

      DO J = 1, 96
       IF (RAIN_REALDATA(J) .NE. 0.00) THEN
        LIM_LOW = J
       GOTO 2100
       END IF
      END DO

2100  DO M = 96, 1, -1
       IF (RAIN_REALDATA(M) .NE. 0.00) THEN
        LIM_HIGH = M
       GOTO 2500
       END IF
      END DO

C     FIND P(3)
2500  IF ( (LIM_HIGH - LIM_LOW) .LE. 1.0 ) THEN
       P(3) = 15.0
      ELSE
       P(3) = (LIM_HIGH - LIM_LOW) * 15.0 / 2.0
      END IF
```

```
C     FIND FINAL P(1)
      IF ( (P(1) - P(3)/2) .LE. 0.00) THEN
       P(1) = 15.0
      ELSE
       P(1) = P(1) - (P(3) / 2)
      END IF

C     CALL QUASI-NEWTON ALGORITHM
      CALL DFPMIN(P,N,FTOL,ITER,FRET)

C     OUTPUT
      WRITE (12, 6040) INDEX, P(1), P(2), P(3), P(4)/100.0
6040  FORMAT(I9, F9.2, F9.2, F9.2, F9.4, F9.2)

      END
```

A5.1.4 dfpmin.for

```
C     RDPG MODEL
C     DFPMIN.FOR: FROM PRESS, ET AL., 1986, PAGE 310-311.
C     VARAIBLE METRIC METHODS OR QUASI-NEWTON METHOD


      SUBROUTINE DFPMIN(P,N,FTOL,ITER,FRET)

      PARAMETER (NMAX=50,ITMAX=200,EPS=1.E-10)
      DIMENSION P(N),HESSIN(NMAX,NMAX),XI(NMAX)
      DIMENSION G(NMAX),DG(NMAX),HDG(NMAX)
      REAL FP


      FP=FUNC(P)

      CALL DFUNC(P,G)

      DO 12 I=1,N
        DO 11 J=1,N
          HESSIN(I,J)=0.
11      CONTINUE
        HESSIN(I,I)=1.
        XI(I)=-G(I)
12    CONTINUE
      DO 24 ITER=1,ITMAX
        CALL LINMIN(P,XI,N,FRET)
        IF(2.*ABS(FRET-FP).LE.FTOL*(ABS(FRET)+ABS(FP)+EPS))
     +   RETURN
        FP=FRET
        DO 13 I=1,N
          DG(I)=G(I)
13      CONTINUE
        FRET=FUNC(P)
        CALL DFUNC(P,G)
        DO 14 I=1,N
          DG(I)=G(I)-DG(I)
```

```
14        CONTINUE
          DO 16 I=1,N
            HDG(I)=0.
            DO 15 J=1,N
              HDG(I)=HDG(I)+HESSIN(I,J)*DG(J)
15          CONTINUE
16        CONTINUE
          FAC=0.
          FAE=0.
          DO 17 I=1,N
            FAC=FAC+DG(I)*XI(I)
            FAE=FAE+DG(I)*HDG(I)
17        CONTINUE
C       ADDED CODE TO PREVENT DIVIDED-BY-ZERO
          IF (FAC .EQ. 0.00) THEN
           FAC = 1.0E-15
          END IF
          IF (FAE .EQ. 0.00) THEN
           FAE = 1.0E-15
          END IF
C       ADDED CODE ABOVE

          FAC=1./FAC
          FAD=1./FAE
          DO 18 I=1,N
            DG(I)=FAC*XI(I)-FAD*HDG(I)
18        CONTINUE
          DO 21 I=1,N
            DO 19 J=1,N
              HESSIN(I,J)=HESSIN(I,J)+FAC*XI(I)*XI(J)
     *          -FAD*HDG(I)*HDG(J)+FAE*DG(I)*DG(J)
19          CONTINUE
21        CONTINUE
          DO 23 I=1,N
            XI(I)=0.
            DO 22 J=1,N
              XI(I)=XI(I)-HESSIN(I,J)*G(J)
22          CONTINUE
23        CONTINUE
24      CONTINUE
        PAUSE 'too many iterations in DFPMIN'
        RETURN

        END
```

A5.1.5 library.for

```
C       RDPG MODEL
C       LIBRARY.FOR
C       STORE THE FUNCTION NAMED AS FUNC


        REAL FUNCTION FUNC(P)

        DIMENSION P(1:4)

        REAL TARGET

C       CALL MDLCLC.FOR TO CALCULATE FUNC VALLUE
```

```
      CALL MDLCLC(P, TARGET)
      FUNC = TARGET

      RETURN
      END
```

A5.1.6 dfunc.for

```
C     RDPG MODEL
C     DFUNC.FOR
C     GET GRADIENT G(I)


      SUBROUTINE DFUNC(P,G)

      REAL P(1:4), G(1:4)
      REAL X(1:4), X_DX(1:4)
      REAL TARGET
      REAL F_X
      REAL F_X_FORWARD(4), F_X_BACKWARD(4)

C     FUNCTION VALUE AT X
      DO I = 1, 4
       X(I) = P(I)
      END DO
      CALL MDLCLC(X, TARGET)
      F_X = TARGET

C     FUNCTION VALLUE AT X+DELTA_X
      DO I = 1, 4
       DELTA_X = P(I)/100.0
       IF (DELTA_X .EQ. 0.00) THEN
        DELTA_X = 0.001
       END IF
       DO J = 1, 4
        IF (J .EQ. I) THEN
         X_DX(J) = P(J) + DELTA_X
        ELSE
         X_DX(J) = P(J)
        END IF
       END DO
       CALL MDLCLC(X_DX, TARGET)
       F_X_FORWARD(I) = TARGET

C     FUNCTION VALLUE AT X+DELTA_X
       DO J = 1, 4
        IF (J .EQ. I) THEN
         X_DX(J) = P(J) - DELTA_X
        ELSE
         X_DX(J) = P(J)
        END IF
       END DO
       CALL MDLCLC(X_DX, TARGET)
       F_X_BACKWARD(I) = TARGET
```

```
C     PREVENT UNUSUAL CASE
       IF (DELTA_X .EQ. 0.00) THEN
        WRITE (*,*) 'DELTA_X IS 0.00. PRESS ANY KEY TO STOP.'
        PAUSE
        STOP
       END IF

C     GRADIENT ARRAY G(I) BY CENTRAL DIFFERENCE METHOD
       G(I) = (F_X_FORWARD(I) - F_X_BACKWARD(I)) / (2*DELTA_X)

      END DO

      END
```

A5.1.7 mdlclc.for

```
C     RDPG MODEL
C     MDLCLC.FOR
C     CALCULATE THE TARGET FUNCTION


      SUBROUTINE MDLCLC(X, TARGET)

C     DECLARE VARIABLES
C     X: 4 RAIN-DAY PARAMETERS
      REAL X(1:4)
C     RAIN_MODEL: MODEL RAINFALL DATA
      REAL RAIN_MODEL(1:100)
C     RAIN_REALDATA: REAL RAINFALL DATA
      REAL RAIN_REALDATA(1:100)
C     TARGET: TARGET FUNCTION
      REAL TARGET
C     VOLUME_MODEL,VOLUME_REALDATA: VOLUME OF MODEL & REAL DATA
      REAL VOLUME_MODEL, VOLUME_REALDATA
C     T: TIME, 15 MINUTE SPACED ON DAILY BASIS
      REAL T
C     V_DIFFERENCE: VOLUME DIFFERENCE B/W MODEL AND REAL DATA
      REAL*8 V_DIFFERENCE
C     TERM1, TERM2: TWO PARTS IN CONVOLUTION EQUATION
      REAL*8 TERM1, TERM2
C     Y1, Y2, Y3, Y4, Y5, Y6: MIDDLE RESULTS
      REAL*8 Y1, Y2, Y3, Y4, Y5, Y6
C     Y1, Y2, Y3, Y4, Y5, Y6: MIDDLE RESULTS
      REAL*8 Z1, Z2, Z3, Z4, Z5, Z6

C     COMMONLY USED VARAIBLES IN FILES
      COMMON /COM_1/  RAIN_REALDATA
      COMMON /COM_2/  RAIN_MODEL

C     X(1): TIME TO PEAK, X(2): RAIN DISPERSION COEFFICIENT
C     X(3): RAIN DURATION, X(4): PEAK RATE
```

```
C     INITIALIZE VARIABLES
      TARGET = 0.0000
      VOLUME_MODEL = 0.000
      VOLUME_REALDATA = 0.000

C     CONTROL RANGE OF PARAMETERS
      IF ( X(2) .LE. 0.01) THEN
       X(2) = 0.01
      END IF
      IF ( X(2) .GE. 1.0) THEN
       X(2) = 1.0
      END IF

      IF ( X(1) .LE. 15.0) THEN
       X(1) = 15.0
      END IF
      IF ( X(1) .GE. 1440.0) THEN
       X(1) = 1440.0
      END IF

      IF ( X(3) .LE. 15.0) THEN
       X(3) = 15.0
      END IF
      IF ( X(3) .GE. 1440.0) THEN
       X(3) = 1440.0
      END IF

      IF ( X(4) .LE. 0.001) THEN
       X(4) = 0.001
      END IF

C     BEGIN THE CALCULATION BASED ON CONVOLUTION EQUATION
      DO 2010, I = 1, 96
      T = I * 15.0

      Y1 = X(1) -  T
      Y2 = X(1) +  T
      Y3 = 2 * SQRT(X(2) * T)
      Y4 = EERFC(Y1/Y3)
      Y5 = EERFC(Y2/Y3)
      Y6 = EEXP((X(1)) / X(2))

      TERM1 = 0.5 * X(4) * (Y4 - Y6 * Y5)

      IF ((T - X(3)) .LE. 0.00) THEN
       TERM2 = 0.00
       GOTO 300
      ELSE
       Z1 = X(1) - (T - X(3))
       Z2 = X(1) + (T - X(3))
       Z3 = 2*SQRT(X(2)*(T - X(3)))
       Z4 = EERFC(Z1/Z3)
       Z5 = EERFC(Z2/Z3)
       Z6 = EEXP((X(1)) / X(2))
       TERM2 = 0.5 * X(4) * (Z4 - Z6 * Z5)
      END IF

300   IF ( (TERM1-TERM2) .LE. 1E-15 ) THEN
       RAIN_MODEL(I) = 1E-15
      ELSE
```

```
        RAIN_MODEL(I) = TERM1 - TERM2
       END IF

       VOLUME_MODEL = VOLUME_MODEL + RAIN_MODEL(I)
       VOLUME_REALDATA = VOLUME_REALDATA + RAIN_REALDATA(I)

2010   CONTINUE
C      IF MODEL DATA IS NOT GENERATED, STOP THE PROGRAM.
       IF (VOLUME_MODEL .EQ. 0.00) THEN
        WRITE (*,*) 'VOLUME_MODEL IS 0.00. PRESS ANY KEY TO STOP.'
        PAUSE
        STOP
       END IF
       V_DIFFERENCE = ABS(VOLUME_MODEL - VOLUME_REALDATA)
     +        / VOLUME_MODEL * 100

C      TARGET FUNCTION
       TARGET = V_DIFFERENCE

       RETURN

       END

C      CONDITIONAL ERROR FUCNTION
       REAL FUNCTION EERFC(Q1)
       REAL*8 Q1

       IF (Q1 .GE. 4.0) THEN
        EERFC = 0.00
        GOTO 400
       END IF
       IF (Q1 .LE. -4.0) THEN
        EERFC = 2.00
        GOTO 400
       END IF
       IF (Q1 .LT. 0.00) THEN
        EERFC = 2.00 - ERFC(-1.0*Q1)
        GOTO 400
       END IF
       IF ((Q1 .GE. 0.00) .AND. (Q1 .LT. 4.00)) THEN
        EERFC = ERFC(Q1)
        GOTO 400
       END IF

400    RETURN
       END

C      APPROXIMATE ERROR FUNCTION
       REAL FUNCTION ERFC(Q2)
       REAL A1, A2, A3, A4, A5, A6
       REAL *8 Q2, TEMP1, TEMP2

       A1 = 0.0705230784
       A2 = 0.0422820183
       A3 = 0.0092705272
       A4 = 0.0001520143
       A5 = 0.0002765672
       A6 = 0.0000430638

       TEMP1=1+(A1*Q2)+(A2*(Q2**2))+(A3*(Q2**3))
```

```
     +      +(A4*(Q2**4))+(A5*(Q2**5))+(A6*(Q2**6))
      IF (TEMP1 .EQ. 0.00) THEN
       TEMP1 = 1.0E-2
      END IF
      TEMP2= TEMP1**16
      ERFC = 1 / TEMP2

      RETURN
      END

C     CONDITIONAL EXPONENTIAL FUNCTION
      FUNCTION EEXP(Q3)
      REAL Q3

      IF (Q3 .LT. -100.0) THEN
       EEXP = 0.0000
       GOTO 500
      END IF
      IF (Q3 .GT. 85.0) THEN
       EEXP = EXP(85.0)
       GOTO 500
      END IF
      EEXP = EXP(Q3)
500   RETURN
      END
```

A5.1.8 linmin.for

```
C     RDPG MODEL
C     LINMIN.FOR: FROM PRESS, ET AL., 1986, P 300-301.
C     IMPLEMENT LINE MINIMIZATION


      SUBROUTINE LINMIN(P,XI,N,FRET)
      PARAMETER (NMAX=50,TOL=1.E-4)
      EXTERNAL F1DIM
      DIMENSION P(N),XI(N)
      COMMON /F1COM/ NCOM,PCOM(NMAX),XICOM(NMAX)

C     ADDED CODE BELOW TO CONTROL RANGE OF VARIABLES
      IF ( P(2) .LE. 0.01) THEN
       P(2) = 0.01
      END IF
      IF ( P(2) .GE. 1.0) THEN
       P(2) = 1.0
      END IF

      IF ( P(1) .LE. 15.0) THEN
       P(1) = 15.0
      END IF
      IF ( P(1) .GE. 1440.0) THEN
       P(1) = 1440.0
      END IF
```

```
      IF ( P(3) .LE. 15.0) THEN
       P(3) = 15.0
      END IF
      IF ( P(3) .GE. 1440.0) THEN
       P(3) = 1440.0
      END IF

      IF ( P(4) .LE. 0.001) THEN
       P(4) = 0.001
      END IF
C     ADDED CODE ABOVE

      NCOM=N
      DO 11 J=1,N
        PCOM(J)=P(J)
        XICOM(J)=XI(J)
11    CONTINUE
      AX=0.
      XX=1.
      BX=2.
      CALL MNBRAK(AX,XX,BX,FA,FX,FB,F1DIM)
      FRET=BRENT(AX,XX,BX,F1DIM,TOL,XMIN)
      DO 12 J=1,N
        XI(J)=XMIN*XI(J)
        P(J)=P(J)+XI(J)
12    CONTINUE

C     ADDED CODE BELOW TO CONTROL RANGE OF VARAIBLES
      IF ( P(2) .LE. 0.01) THEN
       P(2) = 0.01
      END IF
      IF ( P(2) .GE. 1.0) THEN
       P(2) = 1.0
      END IF
C     ADDED CODE ABOVE

      RETURN
      END


C     ADDED CODE FROM PRESS, ET AL, 1986, PAGE 301.
      FUNCTION F1DIM(X)
      PARAMETER (NMAX=50)
      COMMON /F1COM/ NCOM, PCOM(NMAX), XICOM(NMAX)
      DIMENSION XT(NMAX)
      DO J = 1, NCOM
       XT(J) = PCOM(J) + X * XICOM(J)
      END DO
      F1DIM = FUNC(XT)
      RETURN
      END
```

A5.1.9 mnbrak.for

```
C      RDPG MODEL
C      MNBRAK.FOR: FROM PRESS, ET AL., 1986, PAGE 281-282.
C      BRACKET THE MINIMUM IN THE FIRST PLACE

       SUBROUTINE MNBRAK(AX,BX,CX,FA,FB,FC,FUNC)
       PARAMETER (GOLD=1.618034, GLIMIT=100., TINY=1.E-20)
       FA=FUNC(AX)
       FB=FUNC(BX)
       IF(FB.GT.FA)THEN
         DUM=AX
         AX=BX
         BX=DUM
         DUM=FB
         FB=FA
         FA=DUM
       ENDIF
       CX=BX+GOLD*(BX-AX)
       FC=FUNC(CX)
1      IF(FB.GE.FC)THEN
         R=(BX-AX)*(FB-FC)
         Q=(BX-CX)*(FB-FA)

         IF (2.*SIGN(MAX(ABS(Q-R),TINY),Q-R) .EQ. 0.00) THEN
          U=BX-((BX-CX)*Q-(BX-AX)*R)/1.0E-15
         ELSE
           U=BX-((BX-CX)*Q-(BX-AX)*R)/
      +      (2.*SIGN(MAX(ABS(Q-R),TINY),Q-R))
         END IF

         ULIM=BX+GLIMIT*(CX-BX)
         IF((BX-U)*(U-CX).GT.0.)THEN
           FU=FUNC(U)
           IF(FU.LT.FC)THEN
             AX=BX
             FA=FB
             BX=U
             FB=FU
             GO TO 1
           ELSE IF(FU.GT.FB)THEN
             CX=U
             FC=FU
             GO TO 1
           ENDIF
           U=CX+GOLD*(CX-BX)
           FU=FUNC(U)
         ELSE IF((CX-U)*(U-ULIM).GT.0.)THEN
           FU=FUNC(U)
           IF(FU.LT.FC)THEN
             BX=CX
             CX=U
             U=CX+GOLD*(CX-BX)
             FB=FC
             FC=FU
             FU=FUNC(U)
           ENDIF
         ELSE IF((U-ULIM)*(ULIM-CX).GE.0.)THEN
           U=ULIM
           FU=FUNC(U)
         ELSE
```

```
          U=CX+GOLD*(CX-BX)
          FU=FUNC(U)
        ENDIF
        AX=BX
        BX=CX
        CX=U
        FA=FB
        FB=FC
        FC=FU
        GO TO 1
      ENDIF
      RETURN
      END
```

A5.1.10 brent.for

```
C     RDPG MODEL
C     BRENT.FOR: FROM PRESS, ET AL., 1986, PAGE 284-286.
C     DO PARABOLIC INTERPOLATION

      FUNCTION BRENT(AX,BX,CX,F,TOL,XMIN)

      PARAMETER (ITMAX=200,CGOLD=.3819660,ZEPS=1.0E-10)
      A=MIN(AX,CX)
      B=MAX(AX,CX)
      V=BX
      W=V
      X=V
      E=0.
      FX=F(X)
      FV=FX
      FW=FX
      DO 11 ITER=1,ITMAX
        XM=0.5*(A+B)
        TOL1=TOL*ABS(X)+ZEPS
        TOL2=2.*TOL1
        IF(ABS(X-XM).LE.(TOL2-.5*(B-A))) GOTO 3
        IF(ABS(E).GT.TOL1) THEN
          R=(X-W)*(FX-FV)
          Q=(X-V)*(FX-FW)
          P=(X-V)*Q-(X-W)*R
          Q=2.*(Q-R)
          IF(Q.GT.0.) P=-P
          Q=ABS(Q)
          ETEMP=E
          E=D
          IF(ABS(P).GE.ABS(.5*Q*ETEMP).OR.P.LE.Q*(A-X).OR.
     *        P.GE.Q*(B-X)) GOTO 1
          IF (Q .EQ. 0.00) THEN
           Q = 1.0E-15
          END IF
          D=P/Q
          U=X+D
          IF(U-A.LT.TOL2 .OR. B-U.LT.TOL2) D=SIGN(TOL1,XM-X)
```

```
            GOTO 2
          ENDIF
1         IF(X.GE.XM) THEN
            E=A-X
          ELSE
            E=B-X
          ENDIF
          D=CGOLD*E
2         IF(ABS(D).GE.TOL1) THEN
            U=X+D
          ELSE
            U=X+SIGN(TOL1,D)
          ENDIF
          FU=F(U)
          IF(FU.LE.FX) THEN
            IF(U.GE.X) THEN
              A=X
            ELSE
              B=X
            ENDIF
            V=W
            FV=FW
            W=X
            FW=FX
            X=U
            FX=FU
          ELSE
            IF(U.LT.X) THEN
              A=U
            ELSE
              B=U
            ENDIF
            IF(FU.LE.FW .OR. W.EQ.X) THEN
              V=W
              FV=FW
              W=U
              FW=FU
            ELSE IF(FU.LE.FV .OR. V.EQ.X .OR. V.EQ.W) THEN
              V=U
              FV=FU
            ENDIF
          ENDIF
11      CONTINUE
        PAUSE 'Brent exceed maximum iterations.'
3       XMIN=X
        BRENT=FX
        RETURN
        END
```

A5.2 RDPG model input file

The input file for RDPG model is actual historical 15-minute rainfall data for each station on daily basis. This demo example is part of file 0428f_2.txt for station 1429.

```
TX  0428  7  in  01/01/1984  0.01  0.02  0.03  0.04  0.05  0.06  0.07
0.08  0.09  0.10  0.09  0.08  0.07  0.01  0.03  0.08  0.01  0.04  0.08
0.03  0.05  0.08  0.04  0.02  0.10  0.20  0.03  0.03  0.05  0.06  0.90
0.30  0.04  0.20  0.00  0.03  0.00  0.00  0.20  0.00  0.00  0.03  0.00
0.00  0.03  0.00  0.00  0.00  0.80  0.00  0.00  0.00  0.30  0.00  0.00
0.20  0.00  0.00  0.00  0.10  0.00  0.00  0.05  0.00  0.00  0.03  0.00
0.00  0.50  0.00  0.00  0.40  0.00  0.00  0.04  0.00  0.00  0.04  0.00
0.00  0.40  0.00  0.00  0.01  0.00  0.00  0.40  0.00  0.50  0.00  0.90
0.00  0.04  0.00  0.02  0.00  0.01
TX  0428  7  in  01/02/1984  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.01  0.00  0.00  0.00  0.02  0.00  0.00  0.00
0.01  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.04
… … … … … …
```

A5.3 RDPG model output file

The output file for RDPG model is rain-day parameters for each station on daily basis. This demo example is part of file 0428f_2.txt for station 0428f_3.txt.

```
STN ID      428
  T_RAINS      898
 RAIN_NUM RAIN_CTR RAIN_DSP RAIN_DRT  PK_RATE
        1  1252.50      .01    15.00    .0100
        2   390.00      .01    59.93    .0100
        3  1095.00      .01   201.27    .0729
        4    90.00      .01    51.48    .1143
        5  1012.50      .01    15.00    .0100
         .      .         .       .        .
         .      .         .       .        .
         .      .         .       .        .
      894   795.00      .01    89.81    .0117
      895    45.00      .01   147.94    .0126
      896  1432.49      .01    15.01    .0218
      897    45.00      .01   378.99    .0722
      898   840.00      .01   116.56    .0572
```

STN ID: station identification number
T_RAINS: total number of rain-days
RAIN_NUM: rain number, index number of rain-day

RAIN_CTR: rain center, also called time to peak, which is the time that maximum precipitation occurs
RAIN_DSP: rain dispersion coefficient, which indicates the spread-out pattern of rainfall event
RAIN_DRT: rain duration, duration of rainfall event
PK_RATE: peak rate, maximum precipitation of a rainfall event