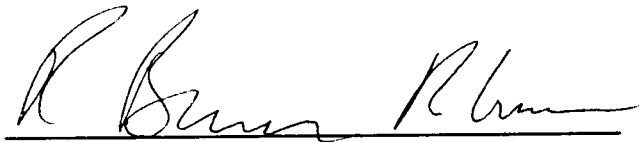


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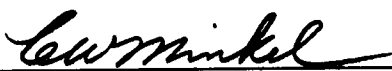
  
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SYNTHESIZING INSTANTANEOUS UNIT HYDROGRAPHS IN  
RURAL, UNGAGED WATERSHEDS WITH READILY AVAILABLE  
INFORMATION

A Thesis  
Presented for the  
Master of Science  
Degree  
The University of Tennessee, Knoxville

Kevin G. Klueh  
December, 1993

## ABSTRACT

A statistically based procedure was developed to estimate instantaneous unit hydrographs (IUHs) for rural, ungaged watersheds using data from Alabama, South Carolina, and Tennessee. This synthesized IUH may be used to construct a design storm hydrograph for a precipitation event of selected magnitude and duration.

One hundred and twenty-two watersheds were used in this research. The physical and hydrologic characteristics of these watersheds are diverse, with watershed areas ranging from 0.17 to 518 square miles and main stream channel slopes from 3 to 237 feet per mile. Each watershed was characterized by fourteen parameters including: watershed area, main stream channel length and slope, elevation, mean annual precipitation, forest cover, storage, and others. Multiple linear regression was employed to develop nine equations to predict points on the IUH of these watersheds. These nine points include the time to peak flow, peak flow, the time to base flow, and the times to 25- , 50- , and 75-percent of peak flow on the rising and falling limbs. This analysis concludes that each of the nine points may be determined with simple multiplicative predictive equations containing two independent parameters: watershed area, and main stream

channel slope.

Using the nine points these equations generate, one may readily construct the remaining portion of the IUH for an ungaged watershed. These predictive equations describe over 75 percent of the variation in an IUH, with standard errors ranging from 6.2 - 50.6 percent. Because the parameters needed for this technique are readily available either from topographic maps or other sources, this technique may be applied to ungaged watersheds in a relatively non-resource intensive manner.

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## I. INTRODUCTION

The hydraulic design of drainage and flood-control structures requires that they be designed to pass or contain the runoff resulting from a precipitation event of specified magnitude and duration. In many designs, a full design-storm hydrograph is needed as opposed to a simpler requirement of streamflow peak or total volume of runoff.

The development of a design storm hydrograph requires that streamflow be synthesized from either a precipitation event according to a chosen hydrologic modeling technique or developed from stream gaging records. In ungaged watersheds, historical records of precipitation and streamflow are unavailable for the calibration or testing of this chosen technique. Therefore, techniques to synthesize streamflow in ungaged watersheds must not be dependent upon gaged records of precipitation and streamflow but must incorporate other readily available information.

A literature search revealed deficiencies in current methodologies and a need for additional techniques to develop design-storm hydrographs for ungaged watersheds. To be most useful, these techniques should incorporate only readily available information so they may be applied in a non-resource intensive manner. An empirical

technique has been developed and is presented in this thesis which incorporates readily available watershed characteristics to predict the instantaneous unit hydrograph of a watershed. This instantaneous unit hydrograph may in turn be used to construct a design-storm hydrograph for a precipitation event with any magnitude and duration.

Development of empirical techniques to predict streamflow characteristics associated with a design storm has long been the subject of applied research. This work has resulted in a number of empirical equations to predict peak streamflow and total volume of runoff associated with a design storm. Following the initial research of Horton in the 1940's (Horton, 1945) who studied the role of geomorphologic characteristics on watershed development, researchers have used watershed characteristics as variables to predict streamflow response. Watershed characteristics generally used in these techniques include watershed area, slope, main stream channel length, and other measures of the physical and hydrologic characteristics of a watershed (Linsley, et.al., 1949), (Taylor and Schwarz, 1952), (Dalrymple and Tate, 1960), (Benson, 1962), (Chow, 1964), (Thomas and Benson, 1970), (Inman, 1986).

A disadvantage of many empirical techniques is the

inability to generate a total streamflow hydrograph. Because the design of many water resources structures requires the full streamflow hydrograph, most existing empirical techniques will not generate the needed information, and, therefore cannot be used. Other techniques have been developed however to provide the full design storm hydrograph.

The techniques with the most promise are the synthetic unit hydrograph models which incorporate watershed characteristics to predict a unit hydrograph. The unit hydrograph was first proposed by Sherman (Sherman, 1932) and has since found wide-ranging application for the estimation of design storm hydrographs. A unit hydrograph is defined as the direct runoff hydrograph resulting from a unit depth of excess precipitation produced by a storm of uniform intensity and specified duration at a specific site. The unit depth of precipitation excess is generally taken to equal one inch and is uniformly distributed over the entire watershed (Maidment, 1992). Unit hydrographs can be synthesized for ungaged drainage basins by relationships between parameters of a unit hydrograph model and the physical characteristics of the drainage basin (Maidment, 1992).

An important feature of the unit hydrograph is its specified time interval, which is taken as the duration of

precipitation excess that produces the unit hydrograph. In order to develop a technique which may be readily applied to determine design storm hydrographs of any duration, the author has chosen to focus on the instantaneous unit hydrograph. The instantaneous unit hydrograph is the unit hydrograph of runoff that would result if the one inch of precipitation excess were spread uniformly over an area in an instant (zero duration) and then allowed to run off (Viessman, et.al, 1989). As compared to the unit hydrograph, the instantaneous unit hydrograph is independent of the time duration of the precipitation event and therefore, may be considered a "finger print" or "template" of the runoff characteristics of a watershed. In other words, the instantaneous unit hydrograph describes hydrologic response as a function of watershed characteristics, unlike a unit hydrograph which is a function of watershed and precipitation characteristics.

This research presents an empirical technique which may be applied in a non-resource intensive manner to predict the instantaneous unit hydrograph of an ungaged, predominantly rural watershed. This technique is developed through statistical analyses of physical and hydrologic watershed characteristics. Nine predictive equations are presented, each capable of synthesizing one

point on the instantaneous unit hydrograph of a watershed. Each predictive equation incorporates readily available watershed characteristics as independent variables. The points on the instantaneous unit hydrograph developed with these nine equations may be used to develop a full instantaneous unit hydrograph which, in turn, may be used to construct a design-storm hydrograph for a precipitation event with any magnitude and duration. The precipitation event used to construct the design-storm hydrograph is considered to be spatially homogenous over the watershed.

One hundred and twenty-two rural watersheds located in the states of Alabama, South Carolina, and Tennessee are incorporated in this work. Because the data base includes watersheds of diverse physical and hydrologic characteristics, the developed predictive equations are not constrained by a number of limiting factors. The results of this analysis are examined to determine the role of watershed characteristics on the hydrologic response of a watershed.

## II. LITERATURE REVIEW

The following review of literature is divided into five sections. The first section focuses on unit hydrograph theory for the determination of design storm hydrographs. This discussion leads into instantaneous unit hydrograph theory and its suitability to this research. A detailed description of the procedure for constructing unit hydrographs and instantaneous unit hydrographs is not presented. Instead, the reader is referred to any of a number of introductory hydrology texts such as those listed in the reference section.

The third and fourth sections present two classes of models to determine hydrologic response: empirical equations and synthetic unit hydrograph techniques. These sections will focus only on models applicable to the study area of this research -- namely, non-urban watersheds of varying sizes located in the states of Alabama, South Carolina, and Tennessee. The empirical equations to be presented include models to determine the peak flow associated with a specific recurrence interval storm and the rational method, while the synthetic unit hydrograph techniques of Snyder, Espey, Clark, Nash, SCS, and the statewide dimensionless hydrographs of the U.S. Geological Survey (USGS) will also be presented. Non-statistically-

based and non-empirical hydrologic models which attempt to quantify all or most physical phenomena of a watershed through time-dependent deterministic equations are resource intensive to apply and, are therefore, outside the scope of this research and will not be discussed.

The final section provides a review of the statistical techniques and diagnostics with application to this research. A brief discussion of statistical terms will also be presented.

#### A. Unit Hydrograph Theory.

The unit hydrograph technique for converting precipitation events into stream hydrographs has gained wide acceptance since its original development by Sherman in 1932. Sherman defined the unit hydrograph as the hydrograph of surface runoff resulting from one unit of effective precipitation falling in a unit of time and produced uniformly in space and time over the entire catchment area (Sherman, 1942). Effective precipitation is that portion of total precipitation that is not confined or retained through infiltration, interception by vegetation or other surfaces, evaporation, or other processes, but instead is translated directly as runoff to

the watershed outlet. The standard depth of effective precipitation was taken by Sherman to equal one inch while the unit of time was a constant such as one hour.

In practice, unit hydrographs of durations other than one hour may be developed. These unit hydrographs are specified as "T"-hour unit hydrographs and are defined as the unit hydrograph resulting from a unit depth of effective rainfall falling in T hours over the catchment. This T-hour unit hydrograph may be represented graphically as a function of stream discharge and time. The volume of surface runoff is given by the area under the runoff hydrograph and is equivalent to a unit depth of effective precipitation distributed uniformly over the catchment multiplied by the catchment area.

The application of unit hydrograph theory is founded upon several assumptions. It assumes that a direct proportional relationship exists between surface runoff and the effective precipitation which produces this runoff. Although this assumption applies only to equal duration storms, it allows a user to construct hydrographs having design precipitation excess amounts of other than one inch. Therefore, two units of effective precipitation, each occurring simultaneously during the same T-hour period, will produce a surface-runoff hydrograph with ordinates twice the magnitude of the

ordinates for one of the T-hour unit hydrographs. Likewise, a hydrograph resulting from five units of precipitation excess in a one-hour duration may be constructed by multiplying the ordinates of a 1-hour unit hydrograph by five.

Similarly, unit hydrograph theory allows for the superposition of successive amounts of effective rainfall, each having the same T-hour duration, to construct a design storm hydrograph resulting from a variety of precipitation events. Therefore, if two successive amounts of effective rainfall,  $R_1$  and  $R_2$ , each of T-hour duration fall on a catchment, then the surface runoff hydrograph is the sum of the component hydrographs due to  $R_1$  and  $R_2$  separately, after the latter storm  $R_2$  is lagged by the T-hour duration (Shaw, 1988). This property of superposition extends to any number of effective precipitation blocks added in succession.

A third assumption of unit hydrograph theory states that the effective precipitation-runoff relationship does not change with time, i.e. that the same T-hour unit hydrograph always occurs whenever the unit of effective precipitation in T hours is applied. Using this assumption of invariance, once a T-hour unit hydrograph has been derived for a catchment area, it may be used to represent the response of the watershed whenever required

(Shaw, 1988).

These assumptions of unit hydrograph theory are not in total agreement with conceptual models, commonly accepted theory, and numerous empirical studies of hydrologic response. Hydrologic response is a function of antecedent conditions of a watershed (Shaw, 1988). Runoff from a watershed's surface will be generated more quickly when the storage capacities of the watershed were previously filled as compared to a watershed where storage capacities are not met. Likewise, precipitation falling on a watershed in the summer months may be more greatly influenced by vegetation than during the winter months when vegetation is not as prevalent. Unit hydrograph theory does not account for these varying antecedent conditions of the watershed but instead incorporates a linear conceptual representation of the rainfall-runoff relationship. In other words, the same quantity of runoff will be generated for a precipitation event regardless of the degree of saturation of the watershed, the time of year, or other antecedent conditions of the watershed. These factors may be significant when either one T-hour unit hydrograph is used to develop a hydrograph of duration other than the original T-hour duration or when two or more T-hour unit hydrographs are superimposed to generate a resultant hydrograph.

Another weakness of unit hydrograph theory is the assumption that effective rainfall is produced uniformly in a watershed over both space and time. The areal distribution of rainfall is rarely uniform because the intensity of storms vary both spatially and temporally. The consequent watershed response is, therefore, affected by storm movement over the catchment area. In addition, the season of the year is often a significant factor in the uniformity of a rainfall event. In the temperate climate of the southeastern United States, precipitation events during the winter months are generally long duration storms occurring over a broad geographical area, while during the summer months, precipitation events often occur sporadically in both space and time and affect more limited areas. However, for small- to medium-sized watersheds (up to a approximately 300 square miles), a significant rainfall event may extend over the whole catchment area and if the catchment is homogenous in composition, a fairly even distribution of effective rainfall may be produced (Shaw, 1988). Precipitation variations are also damped by the integrating reactions of the catchment, so the assumption of uniformity of effective rainfall over a selected period is less serious than might be first supposed (Shaw, 1988).

Despite these inconsistencies with generally accepted

principles of hydrologic response, unit hydrograph theory provides a simple means for design storm hydrograph development, and within limitations, has proven itself in practice. Once a T-hour unit hydrograph is derived for a catchment area, it may be used to represent the response of the catchment for many applications. The inherent simplicity of the unit hydrograph has been one of the major considerations for its use and focus of continued research.

#### **B. Instantaneous Unit Hydrograph Theory.**

A direct outgrowth of unit hydrograph theory is the instantaneous unit hydrograph (IUH). The IUH is the unit hydrograph that would result if one inch of effective precipitation were spread uniformly over the watershed in an instant of time and then allowed to run off (Schaake, 1965). A major advantage of the IUH is that it may be used to construct unit hydrographs of other than the derived duration (Viessman et. al., 1989). In contrast to a unit hydrograph of finite duration, the IUH is independent of the duration of rainfall excess (Chow, 1964).

An IUH may be synthesized from any T-hour unit

hydrograph according to a number of methods. A detailed description of these methods will not be presented here. Instead, the following short discussion will provide a brief description of IUH development while focusing on theory and practical aspects of the IUH as applied in this research.

The first step in the synthesis of an IUH is the development of an S-hydrograph which is the hydrograph of runoff generated by precipitation continuously applied over a watershed. This S-hydrograph is lagged by the interval  $\Delta t$  to develop a  $\Delta t$ -hour unit hydrograph according to the equation (Bras, 1990):

$$\Delta T\text{-hour Unit Hydrograph} = \frac{S(t) - S(t - \Delta t)}{\Delta t}$$

where:  $S(t)$  = flow ordinate of the S-hydrograph at time  $t$

As the time interval  $\Delta t$  becomes infinitesimally small, this equation defines the response function of a unit volume storm instantaneously occurring over the watershed area (Bras, 1990).

This response function is termed the instantaneous unit hydrograph and is expressed as (Chow, 1968):

$$IUH = \frac{dS}{dt}$$

where:  $dS/dt$  = change in flow with respect to time of the S-hydrograph.

Stated mathematically, the runoff rate at any time is given by the convolution integral (Chow, 1964):

$$Q(t) = \int_0^t u(t-t_d) I(t_d) dt_d$$

where:  $Q(t)$  = the output of the system at time  $t$ ;  
 $I(t_d)$  = the input to the system;  
 $u(t - t_d)$  = the response function of the IUH;  
 $t_d$  = dummy time variable of integration.

An IUH may be transformed to a unit hydrograph of any duration through the reverse of the previously described process. This transformation requires that flow ordinates of the IUH at the time duration of interest be averaged according to the formula (Viessman et. al., 1989):

$$Q_t (T\text{-hour Unit Hydrograph}) \approx \frac{1}{2} (IUH_t + IUH_{t-T})$$

Use of this approximation is allowed for small time intervals and permits direct calculation of a unit graph from an IUH, bypassing the normal S-hydrograph procedure (Viessman et. al., 1989).

Because an IUH is developed from an existing unit hydrograph, it is subject to the same limitations and possible weaknesses of unit hydrograph theory. An

advantage of the IUH in comparison with a unit hydrograph is that the IUH is independent of the duration of effective precipitation, thereby eliminating one variable in hydrograph analysis (Chow, 1964). Through elimination of the time variable, the IUH may be considered a "finger print" or "template" of hydrologic response. For these reasons, the IUH is considered to be better suited for the needs of theoretical investigations on the rainfall and runoff relationship in watersheds (Chow, 1964).

The advantage of the IUH to this research is that predictive equations may be developed to synthesize points on the IUH. These predictive equations are not constrained to a specified time duration as would be the case if equations were developed for a T-hour unit hydrograph. Instead, these equations are used as predictors of the ordinates of the IUH and are therefore broadly applicable.

#### **C. Empirical Methods to Determine Hydrologic Response of Specified Recurrence Interval Storms.**

Following the work of Horton (Horton, 1945) who studied the role of geomorphologic characteristics on watershed development, researchers have attempted to

correlate physical and meteorologic characteristics of a watershed to the peak streamflow associated with a precipitation event. The watershed characteristics generally used in this work include watershed area, watershed and main stream slope, main stream length, elevation, average annual precipitation, and other measures of the physical and hydrologic characteristics of a watershed. A number of simple, deterministic equations have been developed to predict peak streamflow resulting from a precipitation event. However, these empirical equations do not provide the user with a complete streamflow hydrograph. The following discussion provides the results of research on rural watersheds located in the states of Alabama, South Carolina, and Tennessee, aimed at the determination of the peak flow associated with specified recurrence interval storms.

# **1. Peak Flow for Specified Recurrence Interval Storms in Alabama.**

Regression equations were developed to relate watershed characteristics to peak streamflow of specified recurrence interval storms in rural watersheds in Alabama by the USGS (Olin and Atkins, 1985). Watersheds were partitioned geographically into six hydrologically

distinct areas and regression equations were developed with the following watershed characteristics: contributing watershed area; main channel slope; stream length; mean basin elevation; storage; mean annual precipitation; and the intensity of the 24-hour, 2-year storm. Storms of 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals were concluded to be most accurately approximated in five of the six hydrologic areas by watershed area as the sole predictive variable. This one parameter, multiplicative-type model was the chosen model for 85 percent of the area of Alabama.

For the remaining study watersheds, a two parameter, multiplicative-type model containing watershed area and percent of watershed area covered with storage reservoirs was the chosen predictive equation. The constant, 1, was added to each of the storage values of the watersheds to determine this equation. A constant was added in order for the mathematical functions incorporated in the model development to result in defined mathematical operations.

## **2. Peak Flow for Specified Recurrence Interval Storms in South Carolina.**

Similar flood frequency studies were undertaken by the USGS in South Carolina (Guimaraes and Bohman, 1992).

Watersheds were subdivided into four physiographic provinces and regression equations were developed to estimate peak flow associated with the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence interval storms, using the following watershed characteristics: drainage area; main channel slope; length of main channel; storage; and the variable length/slope<sup>1/2</sup>. The chosen equations were multiplicative-type models, each containing the single predictive variable watershed area. Standard errors of estimates for these models range from 23 to 53 percent.

### **3. Peak Flow for Specified Recurrence Interval Storms in Tennessee.**

Regression equations were developed to relate watershed characteristics to peak streamflow of specified recurrence interval storms in Tennessee by the USGS (Weaver and Gamble, 1993). Tennessee was subdivided into four areas, each concluded by Weaver and Gamble to be hydrologically distinct. Statistical regression was used to determine the peak flow associated with the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence interval storms as a function of the physical and hydrologic characteristics of two hundred and eighty one watersheds. The watershed characteristics used in the study included: contributing

watershed area; main channel slope; stream length; mean basin elevation; storage; mean annual precipitation; and the intensity of the 24-hour, 2-year storm. This study concluded that the best predictive equation to describe peak streamflow for each study area and for each recurrence interval storm incorporated watershed area as the single predictive variable. Standard error of estimates for these models range from 27 to 50 percent. It is noted that each of the 24 derived equations were one variable, multiplicative-type models as opposed to general linear models.

These three studies of watersheds located in Alabama, South Carolina, and Tennessee indicate that a one parameter multiplicative-type model incorporating drainage area of a watershed is the most useful empirical model to estimate peak streamflow of watersheds located in these states. This conclusion can be extended and compared to this research as a means for insight into possibly useful models for the prediction of the IUH. Of course, any conclusions from the three studies of peak flow for specified recurrence interval storms cannot be directly translated to prediction of an IUH because peak flow of a recurrence interval storm is not equivalent to points on an IUH. However, the similarities between the watershed characteristics used in these three studies indicate that

similar models may be developed in this thesis. If this is not the case, then the results of these studies should be questioned as to determine an underlying cause.

#### 4. Rational Method.

Another technique for determining peak streamflow associated with a specified recurrence interval storm is the Rational formula. The Rational formula was first introduced by Emil Kuichling in 1889 and is one of the earliest and most widely used methods for estimating peak runoff rates for small, urban watersheds (Kuichling, 1889). Although not explicitly an empirical technique, it is included in this discussion because it offers a relatively simple procedure for the determination of peak streamflow in rural watersheds.

According to the rational formula, peak streamflow is given by:

$$Q_p = CIA$$

where:  $Q_p$  = peak runoff rate (cfs);  
C = runoff coefficient;  
I = average rainfall intensity (inches/hour)  
lasting for a critical period of time,  $T_c$ ;  
 $T_c$  = time of concentration (hours);  
A = drainage area of the watershed (acres).

Application of the rational formula is a relatively

simple procedure involving estimation of the time of concentration, the runoff coefficient, and the average rainfall intensity from charts, equations, or intensity-duration-frequency curves available for the study area. The advantage of this technique is relative simplicity of application while giving consistent estimates of peak streamflow. Disadvantages of the method are numerous, however, and include difficulty in the estimation of the time of concentration and an inability to account for antecedent moisture and other abstractions of a watershed that affect hydrologic response. The Rational formula is considered a relatively inaccurate method for determining peak flow for other than very small, urban watersheds. In addition, the Rational formula will not provide the complete streamflow hydrograph.

#### D. Synthetic Unit Hydrograph Techniques.

As compared to empirical equations which may only be used to calculate the peak streamflow or total volume of runoff associated with a precipitation event, synthetic unit hydrograph techniques allow a user to compute a total design-storm hydrograph. These techniques are based on empirical expressions which relate physical and hydrologic

characteristics of the watershed to geometric aspects of the unit graphs (Gray, 1961). A number of synthetic unit hydrograph and synthetic instantaneous unit hydrograph techniques are available for the determination of a unit hydrograph or an IUH. The synthetic techniques of Snyder, Espey, Clark, Nash, SCS, and the USGS will be compared in an effort to provide background information for this study.

#### 1. Snyder Synthetic Unit Hydrograph Technique.

A synthetic unit hydrograph technique employed by the Army Corps of Engineers is founded on the work of Snyder (Snyder, 1938) and may be termed the Snyder synthetic unit hydrograph (Viessman et.al., 1989). In a study of watersheds located in the Appalachian highlands of the United States, and varying in size from 10 to 10,000 square miles ( $\text{mi}^2$ ), Snyder derived empirical relationships to describe a unit hydrograph (Chow et.al., 1988). The Snyder unit hydrograph technique allows for the determination of peak streamflow of a unit hydrograph, the unit hydrograph time widths at 50 and 75 percent of peak streamflow, the unit hydrograph duration, and the lag time. These points allow the user to determine a full unit hydrograph.

Snyder defined a unit hydrograph whose rainfall excess duration,  $T_R$ , is related to watershed lag time,  $T_L$ , by the expression:

$$T_R = \frac{T_L}{5.5}$$

Peak streamflow and watershed lag time of the standard unit hydrograph (in english units) are calculated as:

$$Q_p = \frac{640 C_p A}{T_L}$$

$$T_L = C_T (LL_c)^{0.3}$$

where:  $Q_p$  = Peak streamflow (cubic feet per second, (cfs));  
 $T_L$  = Watershed lag time which can be used to determine the time to peak of the unit hydrograph (hours);  
 $C_p$  = Coefficient accounting for flood wave and storage conditions;  
 $A$  = Watershed size ( $\text{mi}^2$ )  
 $C_T$  = Coefficient representing variations of watershed slopes and storage;  
 $L$  = Length of the main stream (miles);  
 $L_c$  = Distance from the outlet to a point on the stream nearest the centroid of the watershed area (miles).

Snyder then defined additional equations incorporating the above expressions to determine the time to the base and the widths of the unit hydrograph at 50- and 75-percent of peak flow. In addition, Snyder presents

an equation to determine lag time and peak discharge for other unit hydrograph durations. The seven points formed through the use of Snyder's equations can be plotted and a smooth curve drawn to represent the total unit hydrograph. As a means to ensure accuracy, the unit hydrograph shape and ordinates should be adjusted until the area beneath the curve is equivalent to one unit of direct runoff depth over the watershed area (Viessman et. al., 1989).

The correct choice of a representative lag time is a major difficulty to the application of the Snyder Technique. This technique assumes that lag time is a constant for a particular watershed and is not influenced by variations in rainfall intensity (Sabol, 1993). The validity of this assumption may be questioned on a conceptual basis since lag time should increase with a decrease in rainfall intensity (Sabol, 1993).

Another source of error in the application of the technique is the selection of representative values for the parameters  $C_t$  and  $C_p$ . The selection of these parameters requires considerable user judgement since these parameters are not physically-based. A range of parameter values presented as a function of geographic and hydrologic watershed characteristics are available to a prospective user of the Snyder unit hydrograph technique (Viessman et. al., 1989). However, the exact parameter

values must still be selected from this range. An alternative method for determination of  $C_t$  and  $C_p$  in an ungaged watershed is through extension of the Snyder technique to a similar, gaged watershed and transposing these parameter values to the ungaged watershed (Maidment, 1993). This requirement for a similar watershed may hinder application of the technique and is a possible source of error.

## 2. Espey 10-Minute Synthetic Unit Hydrograph.

Research by Espey, Altman, and Graves extended the work of Snyder through development of a set of regression equations to predict the seven points on the Snyder unit hydrograph. These equations were developed for the 10-minute unit hydrograph and incorporated watersheds located in eight states of the continental United States (Espey et. al., 1977). Unlike Snyder's study watersheds, these watersheds include impervious areas. Equations for this synthetic unit hydrograph are:

$$T_p = 3.1 L^{0.23} S^{-0.25} I^{-0.18} R^{1.57}$$

$$Q_p = (31,620) A^{0.96} T_p^{-1.07}$$

$$T_B = (125,890) A Q_p^{-0.95}$$

$$W_{50} = (16,220) A^{0.93} Q_p^{-0.92}$$

$$W_{75} = (3,240) A^{0.79} Q_p^{-0.78}$$

where:  $T_p$  = time to peak of the unit hydrograph (hours);  
 $Q_p$  = peak flow of the unit hydrograph (cfs);  
 $T_b$  = time base of the unit hydrograph (hours);  
 $W_{50}$  = width of hydrograph at 50 percent of  $Q_p$  (hours);  
 $W_{75}$  = width of hydrograph at 75 percent of  $Q_p$  (hours);  
 $L$  = main stream channel length (miles);  
 $S$  = main stream channel slope (feet/feet);  
 $I$  = impervious area ( $\text{mi}^2$ );  
 $R$  = dimensionless watershed conveyance factor which is a function of percent impervious area and roughness and may be determined through a nomograph developed by the authors;  
 $A$  = watershed drainage area ( $\text{mi}^2$ );

Although this technique is not directly applicable to this research since it considers urban watersheds, it was included in order to highlight a number of significant observations. These equations were developed through regression analysis of watershed characteristics as a means to predict several points on a unit hydrograph. The advantage of this technique to the Snyder Method is that five simple equations are provided from which a 10-minute unit hydrograph may be developed. The estimation of nonphysically-based parameters is not required and, therefore, the possibility of user errors are minimized. With the exception of the equation to calculate  $T_p$ , each

of these points may be determined with readily available watershed characteristics.  $T_p$  may also be calculated relatively easily through determination of Manning's roughness ( $n$ ) for the main channel and consulting a nomograph supplied by the authors.

The form of the equations and the parameters included in each equation are also of interest. The chosen equations are multiplicative as opposed to simple linear equations, while the watershed characteristics needed to define a unit hydrograph are length and slope of the main channel, contributing area of the watershed, percent impervious area, and Manning's  $n$ . Each of these variables, with the exception of percent impervious area and Manning's  $n$  are available to this research and have been used to develop regression equations to predict similar points on an IUH.

### 3. Clark's Time-Area Method.

A synthetic unit hydrograph technique that employs the instantaneous unit hydrograph was developed by Clark (Clark, 1945). In this technique, excess rainfall is translated from its point of entry in the watershed through the use of a time-area histogram for the watershed to the watershed outlet. The impact of watershed storage

on this translation is incorporated by routing the time-area histogram through a linear reservoir located at the watershed outlet. The linear reservoir has a storage coefficient,  $K$ , which is a measure of the temporary storage of rainfall excess on the watershed before it can drain to the outlet.

To implement the Time-Area Method, a watershed is subdivided into time contours (isochrones). The subareas are defined using travel times in increments equal to the time interval of the rainfall excess hyetograph and represent incremental runoff producing areas that have equal travel times to the watershed outlet (Baskar, 1988). Delineation into subareas allow the user to develop a time-area curve which represents the time it takes for runoff from subareas within a watershed to reach the outlet. The Time-Area Method specifies that the areas bounded by isochrones which lie close to the watershed outlet will contribute flow to the outlet more quickly than areas located farther away from the outlet and that all areas contribute runoff to the outlet at the time of concentration of the watershed. In order to develop a time history of runoff which is not disjointed, the user must subdivide the watershed into a number of isochrones.

The flow from each contributing area bounded by two isochrones is obtained by multiplying the mean intensity

of effective rainfall during the time interval by the area between the isochrones. Discharge per unit time to the watershed outlet may then be calculated as the summation of flow contributions from all subdivisions of the catchment. Discharge from the outlet is calculated after storage effects are taken into account with the storage coefficient. Application of this procedure provides the IUH for the watershed.

A major advantage of the Time-Area method over many other synthetic unit hydrograph techniques is that the hydrograph can be developed completely by relatively simple equations (Sabol, 1988). In addition, the hydrograph ordinates are calculated at selected time intervals of rainfall duration which computationally simplifies the convolution of the rainfall excess values with the unit hydrograph (Sabol, 1988). The use of the IUH as opposed to the finite duration unit hydrograph, is also an advantage since the IUH is independent of the duration of rainfall excess (Baskar, 1988).

However, application of the method is hindered by the requirement for the user to estimate the storage coefficient,  $K$ , and for the user to delineate the watershed into subareas of equal travel time.  $K$  may be determined by either of two methods: through approximation of  $K$  by the lag time of the watershed, or if

hydrograph data is available, by equating  $K$  to the value of flow divided by the slope of the hydrograph at the inflection point on the recession limb of the hydrograph. To delineate the watershed into subareas of equal travel time to the watershed, a user may incorporate a dimensionless time-area curve (U.S. Army Corps of Engineers, 1981) developed for this purpose.

Another disadvantage of the Time-Area Method is that the time base of the calculated watershed IUH is sometimes inaccurate due to shortcomings of the technique. Clark's Method often produces prolonged runoff because of the selection of  $K$  (Viessman et. al., 1989). The Time-Area method has probably not gained wide application possibly because of the difficulty in evaluating  $K$  from gaged records, and because of the lack of empirical procedures to estimate  $K$  for ungaged watersheds (Sabol, 1988).

#### **4. Nash's Synthetic IUH.**

One of the earliest and most popular methods to synthesize an IUH is through the Nash Synthetic IUH (Nash, 1957) technique (Smith et. al., 1993). The Nash synthetic IUH views a watershed as a series of  $N$  identical linear storage reservoirs, each having the same storage coefficient,  $K$  (Viessman et. al., 1989). The first

storage reservoir receives one inch of effective rainfall from the entire watershed in an instant of time (time = 0). This rainfall is translated to the next storage reservoir according to the diffusion effect of the storage coefficient. Water then passes through the rest of the  $N$  storage reservoirs, each providing the same diffusion effect. The Nash synthetic IUH therefore only requires two parameters to be specified, the number of reservoirs,  $N$ , and the storage coefficient,  $K$ .

Two distinct methods are available to approximate the parameters  $N$  and  $K$ : estimation from effective rainfall and runoff data of gaged watersheds (Singh, 1976), (Viessman et. al., 1989), (Boufadel et. al., 1993), (Smith et. al., 1993), in conjunction with the method of moments as proposed by Nash (Nash, 1957); and estimation with regression equations developed by other authors which incorporate watershed and storm characteristics (Rao et. al., 1972).

Similar to the Clark Time-Area method, a unit hydrograph of any duration may be constructed with the synthetic IUH of Nash. The disadvantage of this technique is the determination of the parameters  $N$  and  $K$  for an ungaged watershed.  $N$  and  $K$  may be determined at an ungaged watershed through regression equations which incorporate watershed characteristics as predictive

variables or through application of the technique to a similar gaged watershed and extension of these results to the ungaged watershed. However, equations are not available for all regions where the technique might be applied. Therefore, determination of Nash model parameters at an ungaged watershed may require the extension to a gaged watersheds.

#### **5. Soil Conservation Service Synthetic Unit Hydrograph Technique.**

The Soil Conservation Service (SCS) synthetic unit hydrograph technique is widely used and accepted by many regulatory bodies for the estimation of floods on small to medium-sized ungaged watersheds in the United States (Maidment, 1993). Incorporation of physical watershed characteristics and processes in a readily applicable format are two reasons for its general acceptance.

Application of the SCS technique involves the estimation of a runoff curve number,  $CN$ , which is a function of soil characteristics, cover condition, and the antecedent moisture condition of the land surface.  $CN$  may be selected from information provided by the SCS and other investigators. Potential retention,  $S$ , in the watershed may be may be calculated with  $CN$  according to (U.S. Soil

Conservation Service, 1972):

$$S = \frac{1000}{CN} - 10$$

Runoff volume may be determined through a graphical procedure developed by the SCS which relate runoff volume to cumulative rainfall and the runoff curve number or according to the formula (U.S. Soil Conservation Service, 1972):

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

where:     P = cumulative rainfall (inches);  
           S = potential retention of the watershed (inches).

Peak discharge,  $Q_p$ , and time to peak,  $T_p$ , for a storm event are determined according to the equations (U.S. Soil Conservation Service, 1972):

$$Q_p = \frac{484A}{T_p}$$

$$T_p = \frac{D}{2} + T_L$$

where:     A = drainage area of the watershed ( $\text{mi}^2$ );  
           D = duration of rainfall (hours);  
            $T_L$  = the lag time from the centroid of rainfall to peak discharge and may be determined from an SCS equation or another empirical equation incorporating watershed characteristics (hours).

A unit hydrograph for the watershed may then be synthesized by multiplying peak flow and time to peak by the respective ordinates of a dimensionless unit hydrograph developed by SCS.

The SCS method is a simple and direct method for synthesizing a design storm hydrograph. Inaccuracies may arise however during the selection of a representative lag time, curve number, and antecedent moisture condition of a watershed (Maidment, 1993). Numerous researchers have investigated the validity of the approach and found relatively poor results (Hawkins, 1980), (Howard, et. al., 1981), (Chen, 1982), (Steichen, 1983), (Wood and Blackburn, 1984).

The shape of the dimensionless unit hydrograph proposed by SCS may also be questioned. The SCS approximates the general curvilinear shape of hydrographs by a simple triangular approximation. This approximation may somewhat simplify construction of the hydrograph, but is not in agreement with accepted empirical data for hydrograph shape (Sheridan and Merkel, 1993). Other dimensionless unit hydrographs may be substituted for the triangular dimensionless unit hydrograph of SCS.

The SCS technique also uses a fixed relationship to describe the amount of runoff resulting from a rainfall event. The volume of runoff from the time of initiation

of runoff to the time of peak flow for the SCS dimensionless hydrograph is  $3/8$  of the total volume of runoff. For mountainous watersheds, this volumetric fraction may be expected to be greater than  $3/8$ , while for flat, swampy areas, it will probably be less (McCuen, 1989).

The SCS technique has a number of other useful characteristics. The SCS technique is applicable to watersheds of varying watershed characteristics, unlike the statewide dimensionless hydrographs of the U.S. Geological Survey (to be discussed in the following section) which are best suited for relatively homogenous watersheds (Bohman, 1990). In addition, a watershed may be divided into a number of subareas where unit hydrographs may be determined and combined with other subareas through routing procedures. This capability is especially useful to account for double peaks in runoff hydrographs such as would naturally occur as the result of tributary flow entering the main channel upstream of a basin outlet or from substantial changes in land use, soils, or physiography between the upstream and downstream areas of a watershed.

## 6. Statewide Dimensionless Hydrographs of the U.S. Geological Survey.

A dimensionless hydrograph was developed by the U.S. Geological Survey (USGS) to estimate a design-storm hydrograph for ungaged watersheds. This technique was developed for watersheds located in Georgia (Inman, 1986) and has since been extended to middle Tennessee (Robbins, 1986), Alabama (Olin et. al., 1988), east and west Tennessee (Gamble, 1989), South Carolina (Bohman, 1990), and Missouri (Becker, 1990). With the exception of western Tennessee watersheds, these studies conclude that a single dimensionless hydrograph is applicable to rural watersheds located in each of the study areas.

Application of the technique requires that the user determine peak flow for a specified recurrence interval storm and the lag time of the watershed. These quantities may be calculated with regression equations developed through these studies. Peak flow and lag time are then multiplied by the respective ordinate of the USGS dimensionless hydrograph to compute the streamflow hydrograph.

One advantage of the USGS dimensionless hydrograph is that it may be used to determine the hydrograph of runoff from a specified recurrence interval storm in a simple and non-resource intensive manner. The data requirements for

application include only those watershed characteristics needed to determine lag time and peak flow. In addition, the technique was found to be relatively accurate, with standard errors ranging between 20- and 40-percent along the predicted hydrograph. Therefore, this technique may be applied to ungaged watersheds in a relatively simple manner as a means to determine a full design-storm hydrograph.

With the exception of watersheds located in western Tennessee, a single dimensionless hydrograph may be applied to all watersheds located in the study area of this research. To apply the USGS dimensionless hydrograph, the user must only determine the watershed characteristics required in the predictive equations for peak flow and lag time. Table 1 presents the watershed characteristics required for application of the USGS dimensionless hydrograph to the study watersheds of this research.

As seen in Table 1, a design hydrograph may be described with a small number of watershed characteristics according to the USGS dimensionless hydrograph. Watershed area is the most common characteristic of each of these equations, while channel slope, channel length, and storage are also sometimes needed. Due to the similarity between these studies and the study of the author, it is

concluded that these watershed characteristics may be useful for determining the instantaneous unit hydrograph of a watershed.

Table 1: Watershed characteristics required as input to the USGS dimensionless hydrograph.

| Location                  | Lag Time               | Peak Flow        |
|---------------------------|------------------------|------------------|
| Alabama: 85% of state     | Area and Channel Slope | Area             |
| Alabama: 15% of state     | Area and Channel Slope | Area and Storage |
| South Carolina            | Area                   | Area             |
| East and Middle Tennessee | Channel Length         | Area             |
| West Tennessee            | Area                   | Area             |

#### E. Statistical Model Building.

The following section presents a review of the statistical techniques used to develop predictive equations for nine points on the IUH. The statistical diagnostics and multiple regression model forms included in this thesis are also described.

Multiple linear regression is a means to develop a predictive equation to relate a dependent variable,  $y$ , with a set of independent variables  $x_1, x_2, \dots, x_m$ . The

variability exhibited by  $y$  has two components: a systematic part and a random part. The systematic variation may be described as a function of the  $x$  variables while the random component takes into account the fact that the model does not exactly describe the behavior of the response (SAS, 1991). The resulting model which relates the dependent variable,  $y$ , to the independent variables,  $x_1, x_2, \dots, x_m$ , is called a regression equation.

In this thesis, two types of multiple regression model forms are incorporated: the general linear regression model, and the multiplicative regression model. The general linear regression model has the form:

$$y = B_0 + B_1X_1 + B_2X_2 + \dots + B_mX_m + E$$

while the multiplicative model is of the form:

$$y = (10^{B_0}) (X_1^{B_1}) (X_2^{B_2}) \dots (X_m^{B_m}) (10^E)$$

where:  $y$  = response or dependent variable;  
 $B_0, B_1, B_2, \dots, B_m$  = unknown parameters;  
 $X_1, X_2, \dots, X_m$  = independent variables;  
 $E$  = random error term.

Parameters for both models may be estimated by the technique known as linear, least squares. Least squares minimizes the sum of the squared differences between the actual values of the dependent variable and the values of the dependent variable predicted by the regression equation. Application of least squares regression

requires that dependent variables,  $y_i$ , and the corresponding independent variables,  $X_i$ , be known.

Development of the general linear regression model is direct process whereby independent and dependent variables are entered into a statistical analysis package for analysis by a linear, least squares regression algorithm. Development of the multiplicative model requires the preliminary step of taking the logarithms of both the dependent and independent variables before analysis.

Predictive equations may be selected with the statistical diagnostics coefficient of multiple determination ( $R^2$ ), standard error as measured by the coefficient of variation, T-test statistics of the model coefficients, Mallows'  $C_p$ , and the RSQUARE regression procedure of SAS (SAS, 1991). Collinearity, residual bias, normal probability plots, and outlier influence are also useful for this selection.

The coefficient of multiple determination measures the variation in the dependent variable accounted for by the model and is the ratio of the sum of squares for the model divided by the sum of squares for the corrected total (SAS, 1991). In general, the larger the value of  $R^2$ , the better the model's fit.

A correlation matrix may be developed between independent and dependent variables. The correlation

matrix presents  $R^2$  for each pair of variables included in the matrix. The correlation matrix provides a useful indication of variable correlation and a preliminary indication of collinearity.

The coefficient of variation describes the amount of variation in the population, and is 100 times the estimate of the standard deviation of the dependent variable, divided by the mean (SAS, 1991). The coefficient of variation is a preferred measure of standard error because it is dimensionless quantity. In general, the smaller the standard error, the better the model fit.

The T-test statistic of each of the model coefficients tests the hypothesis that a coefficient of the model is equal to zero. If the T-test indicates that a coefficient is zero, then the relationship between the independent variable and dependent variable cannot be considered linear and, therefore, the relationship is no stronger than what is likely to arise by chance (Helsel and Hirsch, 1992).

The RSQUARE regression procedure of SAS is incorporated in this thesis as a means to select a preliminary set of predictive equations. This method allows a user to select the optimum set of predictive equations according to chosen statistical diagnostics. Two common diagnostics used in this procedure are  $R^2$ ,

which was presented previously, and Mallows's  $C_p$ .

Mallow  $C_p$  is a measure of the total squared error for a predictive equation and is defined as (Mallows, 1973):

$$C_p = \frac{SSE(p)}{MSE} - (N - 2p) + 1$$

where:     MSE     =   the error mean square for the full  
                              model;  
           SSE(p) =   the error sum of squares for the  
                              subset model containing  $p$  independent  
                              variables, not including the  
                              intercept;  
           N       =   total sample size.

In application of the  $C_p$  criterion, one seeks to identify subsets of  $X$  variables for which the  $C_p$  value is small and  $C_p$  is near  $p$ . Sets of variables with small  $C_p$  have a small total mean squared error, and when  $C_p$  is also near  $p$ , the bias of the regression model is small (SAS, 1991).

Collinearity is the condition whereby at least one independent variable in a predictive equation is closely related to another. The presence of collinearity in a predictive equation is undesirable and therefore should be identified and removed from a predictive equation. An excellent statistical diagnostic for the identification of collinearity is the variance inflation factor (VIF) (Helsel and Hirsch, 1992). For an independent variable,  $i$ , VIF is defined as (Marquardt, 1970):

$$VIF_i = \frac{1}{1 - R_i^2}$$

where:  $R_i^2$  =  $R^2$  from a regression of the  $i$  independent variable on all of the other independent variables.

The ideal VIF is approximately equal to one. Serious collinearity is indicated when VIF is greater than ten (Helsel and Hirsch, 1992).

Residual plots of the residuals from the derived predictive equations as a function of the predicted values and other independent variables are also useful for model selection. Residuals as a function of predicted values give indication of curvature or heteroscedasticity (non-constant variance). Heteroscedasticity and curvature indicate that variable transformation may be required to provide a better fit to the data. Residual plots of the independent variables provides indication of possible bias as a function of the independent variables in the predictive equations. Normality of residuals may be determined with a normal probability plot. Residuals which depart from the normal distribution indicates that the various confidence intervals, prediction intervals, and T-tests will be inappropriate ((Helsel and Hirsch, 1992).

Outlier detection is another important consideration

for the development of predictive equations. Outliers are observations which may bias parameter estimates and make the resulting predictive equation less useful (SAS, 1991). A number of diagnostics are available for outlier detection, including studentized residuals, the hat diagonal, DFFITS, DFBETAS, and Cook's D. The reader is referred to the references included in this section for a detailed discussion of these diagnostics. Each of these diagnostics may be developed according to procedures provided in these references. The value of the diagnostic is then compared to available analysis criteria to determine if an observation excessively influences the predictive equation. Excessive influence may require the removal of the observation from the data set.

Following selection of a predictive equation, the PRESS statistic may be used for model validation. PRESS is defined as (Neter, et. al., 1990):

$$PRESS = \sum_{i=1}^n e(i)^2$$

where:  $e(i)$  = residual of the predicted value.  
 $(i)$  = symbolizes that the  $i$ 'th observation is left out of the computation

PRESS uses  $n-1$  observations to develop a predictive equation, then estimates the value of the observation left out, and then repeats the process for each observation (Helsel and Hirsch, 1992). Minimizing PRESS means that

the equation produces the least error when making new predictions (Helsel and Hirsch, 1992). To ensure validation, PRESS should be comparable in magnitude to the error sum of squares of the model (SAS, 1991).

The development of the multiplicative model form requires that the log of the independent and dependent variables of the model be taken. This transformation introduces bias when the variables are detransformed (Miller, 1984). A simple detransformation based on the antilogs results in a predicted value corresponding to the median rather than the mean value (Choquette, 1988). A correction factor to adjust for this transformation bias may be added to the predictive equation. This correction factor, C, is (Miller, 1984):

$$C = 10^{[0.5 (MSE)]}$$

where:     MSE     =   mean squared error of the predictive equation.

The development of predictive equations with regression therefore requires a number of statistical diagnostic tools and steps. Predictive equations should be chosen on the results of these tools and result in a model which agrees with theoretical considerations of the problem. For many applications, predictive equations

should be kept simple and parsimonious, and, therefore, should not include predictive variables which add relatively insignificant information to the model.

### III. METHODS AND MATERIALS

The following chapter is divided into two sections. The first section summarizes data collection and processing while the later section describes the development of predictive equations. The reader is referred to the preceding literature search for an explanation of the statistical terms and techniques presented in this section.

#### A. Data Collection and Development.

All instantaneous unit hydrographs presented in this report were developed from unit hydrographs previously synthesized by the USGS. Unit hydrographs were chosen from studies published by the USGS for application of the statewide dimensionless hydrograph of the USGS in Alabama (Olin and Atkins, 1988), South Carolina (Bohman, 1990), East and West Tennessee (Gamble, 1989), and Middle Tennessee (Robbins, 1986). Between five and ten T-hour unit hydrographs were developed by the respective authors for each watershed of these studies. An average unit hydrograph was also developed by the authors for the majority of these watersheds by aligning the peak

discharges of each unit hydrograph and averaging the ordinates. Each study incorporated the O'Donnell technique of harmonic analysis for unit hydrograph development (O'Donnell, 1960). In addition, computer algorithms developed by Ryan (Inman, 1986) were used to synthesize all unit hydrographs and average unit hydrographs in these studies.

The author retrieved these unit hydrographs and average unit hydrographs from the USGS. Unit hydrographs were available for every watershed in the study. However, average unit hydrographs were not available for watersheds located in Alabama and a number of watersheds in East Tennessee. The author therefore synthesized the remaining average unit hydrographs with the respective unit hydrographs for these study watersheds. To maintain repeatability, average unit hydrographs were constructed with the computer algorithm developed by Ryan (Inman, 1986). All unit hydrographs and average unit hydrographs incorporated in this research were developed with the same computer algorithms.

Following compilation of average unit hydrographs, the author synthesized an instantaneous unit hydrograph (IUH) for each study watershed. The S-hydrograph and lagging procedure was used for this synthesis (Chow, 1968), (Viessman et. al., 1989), (Bras, 1990). Nine

points located on each IUH were then determined. These nine points are summarized in Table 2.

These nine points compose the nine dependent variables of the regression analysis. A separate predictive equation is developed for each of these nine points.

Following compilation of the dependent variable set, the author retrieved watershed characteristics from the USGS Basin Characteristics File (U.S. Geological Survey, 1993) for each of the study watersheds. The basin characteristics file contains physical and meteorological watershed characteristics compiled by the USGS for watersheds located throughout the United States. A subset of watershed characteristics was chosen for the study watersheds which includes only those watershed characteristics available for each of the study watersheds. Table 3 lists the watershed characteristics which comprise this subset.

Three new independent variables were synthesized from this subset of available watershed characteristics. These predictive variables were included in this research because they were shown to be valid predictive variables of hydrologic response in other research (Choquette, 1988), (Olin and Atkins, 1988), (Gamble, 1989), and

Table 2: Dependent variable set for development of predictive equations.

| Point on IUH | Description of Point on IUH         |
|--------------|-------------------------------------|
| T25R         | Time to 25% Peak Flow, Rising Limb  |
| T50R         | Time to 50% Peak Flow, Rising Limb  |
| T75R         | Time to 75% Peak Flow, Rising Limb  |
| TPEAK        | Time to Peak Flow                   |
| T75F         | Time to 75% Peak Flow, Falling Limb |
| T50F         | Time to 50% Peak Flow, Falling Limb |
| T25F         | Time to 25% Peak Flow, Falling Limb |
| TBASE        | Time to Base Flow                   |
| QPEAK        | Peak Flow                           |

Table 3: Watershed characteristics available for study watersheds.

| Abbreviation | Watershed Characteristics                                                                                                                                          |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AREA         | Basin area including non-contributing areas, square miles.                                                                                                         |
| CONTD        | Basin area that contributes to surface runoff, square miles.                                                                                                       |
| ELEV         | Mean basin elevation measured from topographic maps by the transparent grid sampling method where 20 to 80 points in basin are sampled, feet above mean sea level. |
| FOREST       | Forested area as measured by the grid sampling method, percent of contributing drainage area.                                                                      |
| I24          | Precipitation intensity for 24-hour rainfall expected on the average of once each two years, inches.                                                               |
| LAT          | Latitude of stream-gaging station, decimal degrees.                                                                                                                |
| LENGTH       | Stream length measured along the main stream channel from the stream gage to the basin divide, miles.                                                              |
| LNG          | Longitude of stream-gaging station, decimal degrees.                                                                                                               |
| PRECIP       | Mean annual precipitation from the U.S. Weather Bureau series, "Climates of States", inches.                                                                       |
| SLOPE        | Slope of the main channel measured at points 10- and 85-percent of stream length upstream from stream gage, feet/mile.                                             |
| STORAGE      | Area of lakes, ponds, and swamps measured by the grid sampling method, in percent of contributing drainage area.                                                   |

(Bohman, 1990). Table 4 presents these additional watershed characteristics.

Table 4: Synthesized watershed characteristics.

| Abbreviation | Synthesized Independent Variables                               |
|--------------|-----------------------------------------------------------------|
| BS           | Basin shape factor ( $\text{LENGTH}^2/\text{AREA}$ )            |
| LS1          | Length-slope factor 1 ( $\text{LENGTH}/\text{SLOPE}$ )          |
| LS2          | Length-slope factor 2<br>( $\text{LENGTH}/\text{SLOPE}^{1/2}$ ) |

The eleven chosen watershed characteristics of Table 3 and the three synthesized watershed characteristics of Table 4 comprise the independent variable set for each of the nine dependent variables. The independent variables and the corresponding dependent variables were then compiled as an input file for regression analysis with the SAS statistical package (SAS Institute, 1989).

#### B. Preliminary Data Analysis.

Scatter plots were constructed for each of the dependent variables as a function of the independent

variables as a means to detect data input errors, outliers, and trends. All outliers were investigated for data input error and corrected where required. Data outliers were also examined to detect any departures from theoretically justifiable values. Scatter plots were then analyzed to determine trends in the data. Trend analysis is meant to highlight the presence of linear or nonlinear relationships between the dependent and independent variables, and the possibility of changing variance. This analysis provides insight into the need for variable transformation.

A correlation matrix of all independent and dependant variables was also developed to provide a further description of variable correlation and a preliminary indication of possible collinearity between independent variables.

### C. Multiple Regression with General Linear Regression Model and the Entire Data Set.

Multiple regression was used to determine predictive equations for each of the dependent variables with the general linear regression model of the form:

$$y = B_0 + B_1(\text{AREA}) + B_2(\text{BS}) + \dots + B_m(\text{STORAGE}) + E$$

where:  $y$  = response or dependent variable;  
 $B_0, B_1, B_2, \dots, B_m$  = unknown parameters;  
 $X_1, X_2, \dots, X_m$  = independent variables;  
 $E$  = random error term.

The SAS regression procedure, RSQUARE, with  $R^2$  and Mallow's  $C_p$  as diagnostics, was utilized to choose a subset of the most useful predictive equations for each of the nine dependent variables. The collinearity diagnostics VIF, and the variance proportion matrix, were included in this analysis to investigate collinearity between independent variables.

A subset of three to four predictive equations for each dependent variable was selected for further analysis. Selection of these subsets was made according to the  $R^2$ , and Mallow's  $C_p$  statistics in conjunction with collinearity diagnostics. Only those predictive equations which do not contain excessive collinearity were included in these subsets.

Separate regressions were made with each predictive equation included in these subsets. The ANOVA tables for these chosen predictive equations were compared as a means to select predictive equations with the most favorable  $R^2$ , coefficient of variation, and T-test statistics.

D. Multiple Regression with Multiplicative Model and Entire Data Set.

The base ten logarithms of the independent and dependent variables were taken in order to determine possibly useful predictive equations with the multiplicative model form. By taking the logarithms of the independent and dependent variables and entering these in a linear least squares regression analysis, predictive equations of the following multiplicative model form may be determined:

$$y = (10^{B_0}) (AREA_1^{B_1}) (BS_2^{B_2}) \dots (SLOPE_M^{B_M}) (10^E)$$

where:  $y$  = response or dependent variable;  
 $B_0, B_1, B_2, \dots, B_m$  = unknown parameters;  
 $X_1, X_2, \dots, X_m$  = independent variables;  
 $E$  = random error term.

Because the correlation matrix and the collinearity diagnostics incorporated in the multiple regression with the general linear model found extreme collinearity between the independent variables AREA and CONTDA, the independent variable CONTDA was dropped from this analysis. Motivation for the removal of CONTDA will be discussed in the section entitled "Discussion".

The independent variable STORAGE contains a large percentage of zero values. A zero value for STORAGE indicates a watershed does not include lakes, ponds, or

swamps. Since the logarithm of zero is undefined, STORAGE cannot directly be entered into the multiplicative regression analysis unless it is again transformed. A possibly useful transformation is the addition of a constant to the variable, such as 1 (Olin and Atkins, 1988) and (Sauer, et. al., 1983). A new variable STOR+1 was therefore defined as:

$$STOR+1 = \log_{10}(STORAGE + 1)$$

STOR+1 was included as an independent variable in all multiple regressions incorporating the multiplicative model form. Additional information concerning the independent variable STOR+1 is included in the section entitled "Discussion".

The independent variables AREA, ELEV, FOREST, I24, LAT, LENGTH, LNG PRECIP, SLOPE, and STOR+1, were entered into the SAS regression procedure, RSQUARE, with  $R^2$  and Mallow's  $C_p$  as diagnostics to determine the most favorable predictive equations according to the multiplicative model form. In addition, the collinearity diagnostics, VIF, and the variance proportion matrix, were included to test for significant collinearity between independent variables.

A subset of three to four predictive equations for each dependent variable was selected for further analysis. Selection of these subsets was made according to the  $R^2$

and Mallow's  $C_p$  statistics in conjunction with collinearity diagnostics. Only those models which do not contain excessive collinearity were included in these subsets.

Separate regressions were made with each model included in these subsets. The ANOVA tables were compared as a means to select the models with the best  $R^2$ , coefficient of variation, and T-test statistics.

#### **E. Multiplicative Model with Dependent Variables Divided by AREA.**

Each of the dependent variables for the time ordinates of IUH were divided by the independent variable AREA. Predictive equations were then developed with both the general linear model and the multiplicative model. The independent variables ELEV, FOREST, I24, LAT, LENGTH, LNG PRECIP, SLOPE, STORAGE, BS, LS1, and LS2 were included in the general linear model while the logged forms of the independent variables ELEV, FOREST, I24, LAT, LENGTH, LNG PRECIP, SLOPE, STOR+1, BS, LS1, and LS2 were included in the multiplicative model regressions. The SAS regression procedure, RSQUARE, with  $R^2$  and Mallow's  $C_p$  as diagnostics, was used to choose a subset of the most

useful predictive equations for each dependent variables.

A subset of three to four predictive equations for each dependent variable was selected for further analysis. Selection of these subsets was made according to the  $R^2$  and Mallows's  $C_p$  statistics in conjunction with collinearity diagnostics. Only those models which did not contain excessive collinearity were included in these subsets.

Separate regressions were made for each predictive equation in these subsets. The ANOVA tables were compared as a means to select the models with the most favorable  $R^2$ , coefficient of variation, and T-test statistics.

#### **F. Selection of Predictive Equations from Preliminary Analysis.**

The most favorable predictive equation for each dependent variable was selected from the results of the preceding investigations. The statistics  $R^2$ , coefficient of variation, and the T-test, were the basis for this decision. In addition, the author chose predictive equations based upon the purpose and goals of the research. These goals include a desire for the predictive equations to be possibly applicable outside of the study

area, while being simple, and non-resource intensive to apply. Finally, the chosen predictive equations were investigated to verify that each independent variable entered the equations in a theoretically justifiable manner.

Normal probability plots of the residuals from each of the chosen predictive equations were developed to investigate the distribution of residuals from the chosen models. The SAS outlier detection diagnostics, DFFITS, DFBETAS, and Cook's D were used to identify watersheds which strongly influence the regression results. Residual plots were also developed for each of the independent and dependent variables of the chosen models to determine the presence of residual bias.

One predictive equation for each of the nine dependent variables was chosen following comparison of the ANOVA tables, normal probability plots, outlier detection diagnostics, and the residual plots. In addition, a secondary set of predictive equations were chosen for further analysis according to the results of this investigation.

#### G. Development of Predictive Equations after Subdivision of Watersheds According to Residual Bias.

The chosen predictive equations were used to develop plots of model residuals as a function of the latitude and longitude of the study watersheds as a means to investigate possible geographical bias of the predictive equations. A bias was observed for the chosen predictive equations at the eastern boundary of the Blue Ridge Province of South Carolina. This bias was investigated by grouping all watersheds located east of the Blue Ridge Province into one subset and all remaining watersheds into a second subset.

Predictive equations were developed for each of the nine dependent variables for both subsets of watersheds. The SAS regression procedure, RSQUARE, with  $R^2$  and Mallow's  $C_p$  as diagnostics, was used to choose a subset of the most useful predictive equations for each dependent variable. Predictive equations were developed with the multiplicative model form and the logged forms of the independent variables AREA, ELEV, FOREST, I24, LAT, LENGTH, LNG, PRECIP, SLOPE, STOR+1, BS, LS1, and LS2. In addition, the collinearity diagnostics VIF and the variance proportion matrix were incorporated to test for significant collinearity.

A subset of two or more predictive equations for each dependent variable was selected for further analysis. Separate regressions were made with each model included in the two subsets. The ANOVA tables were compared as a means to select the models with the best  $R^2$ , coefficient of variation, and the T-test statistics. Only those models which did not contain excessive collinearity were considered for final selection.

A preliminary selection of the best predictive equations were selected from the results of this investigation. Normal probability plots of the residuals from each of the chosen predictive equations were developed to investigate the distribution of the residuals. The SAS outlier detection diagnostics, DFFITS, DFBETAS, and Cook's D were used to identify watersheds which strongly influence the regression results. Residual plots were developed for each of the independent and dependent variables of the chosen models to determine if residuals are geographically biased or are dependent upon any of the variables.

One predictive equation for each of the nine dependent variables and for each of the two subsets was chosen following comparison of the ANOVA tables, normal probability plots, outlier detection diagnostics, and the residual plots.

## H. Final Selection of Predictive Equations.

Predictive equations developed with the entire data set were compared to predictive equations developed with the subdivided data set. Final predictive equations were chosen according to  $R^2$ , standard error, and the T-test statistics. In addition, the selection was made based upon the author's discretion to meet the purpose of this research.

Following selection of the nine predictive equations, each model was validated with the PRESS statistic. A bias correction factor was then added to each chosen predictive model to correct for transformation bias.

As a means to investigate the accuracy of the chosen predictive equations, an IUH was generated for each watershed incorporated in this thesis and then compared to the measured IUH. These figures were then analyzed for trends as a means to indicate possibly shortcomings of the chosen predictive equations.

## IV. RESULTS

This section presents the results of the statistical analysis to synthesize predictive equations for nine points on the instantaneous unit hydrograph of rural watersheds located in Alabama, South Carolina, and Tennessee. Study watersheds are described in Part A. Part B presents the results of the preliminary statistical analysis of the data set. The chosen predictive equations developed with the general linear model and the results of the collinearity diagnostics are described in Part C. Part D presents the predictive equations developed with the multiplicative model. Predictive equations developed after dividing the time ordinates of the IUH by AREA are included in Part E. Part F lists the preliminary set of nine chosen predictive equations to synthesize the nine points on the IUH of a watershed. Part G presents the results of the statistical analysis after the data set is subdivided between watersheds located east of the Blue Ridge Province of South Carolina and the rest of the study area. Finally, part H presents the chosen predictive equations for each of the nine points on the IUH.

## A. Data Set Features.

One hundred and twenty two gaged watersheds, located in non-urban regions of the states of Alabama, South Carolina, and Tennessee, are incorporated in this thesis as a means to determine predictive equations for the nine points on the IUH. The location of these watersheds is presented in Figure 1. The name and gage number for each of the watersheds in Figure 1 are included as Appendix B. As is evident from this figure, study watersheds are located throughout the three states although the coastal boundaries of Alabama and South Carolina are not represented. In addition, Tennessee contains the greatest percentage of watersheds (61 percent), as compared to approximately 19 percent in Alabama and 20 percent in South Carolina.

Figures 2 - 11 present box and whiskers plots to summarize the range of watershed characteristics for the one hundred and twenty two watersheds while Figures 12 and 13 present additional box and whiskers plots to describe the range of the dependent variables TPEAK and QPEAK. Appendix B presents a listing of the values for each of the dependent and independent variables incorporated in this thesis.

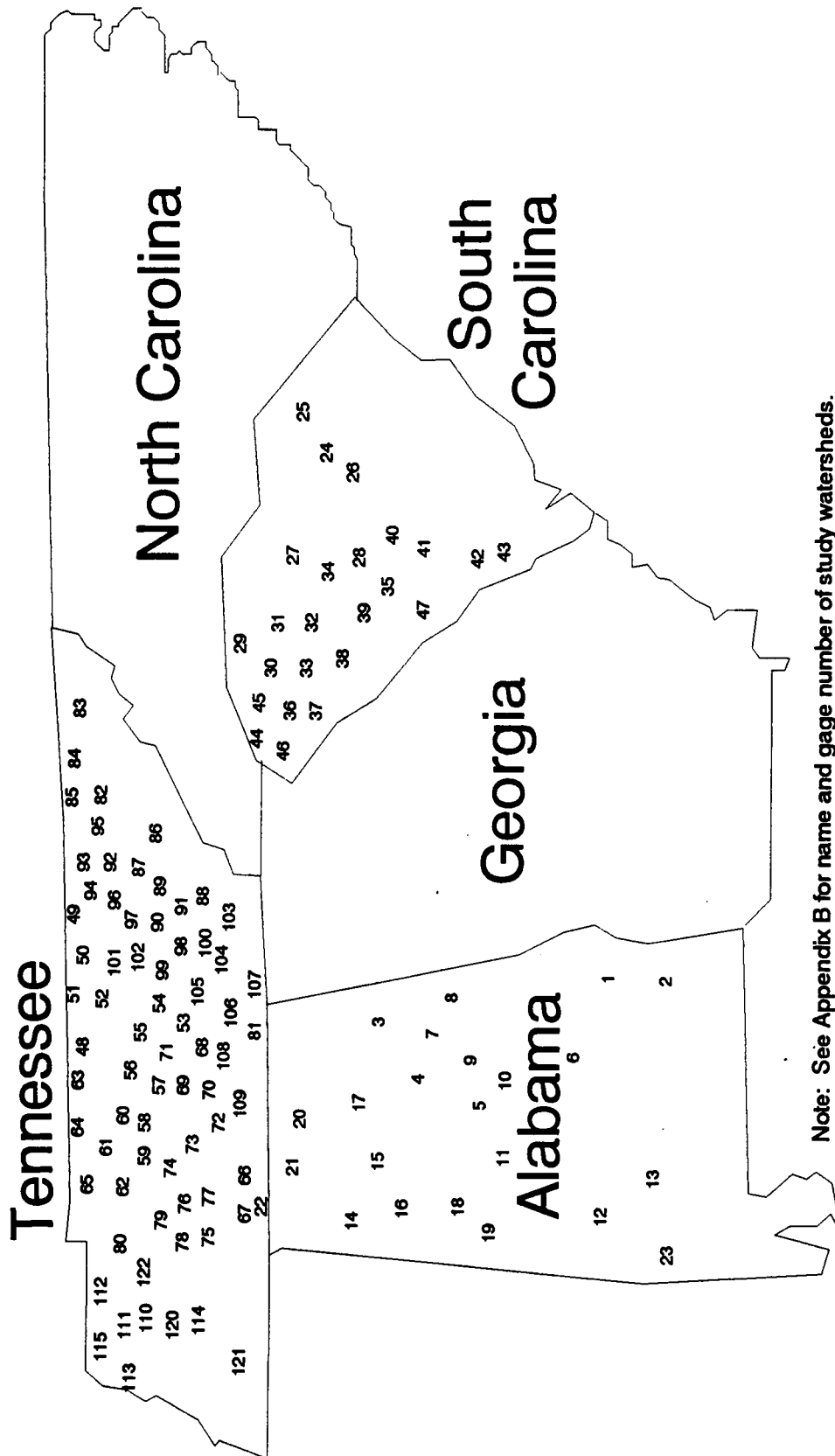


Figure 1. Location of study watersheds.

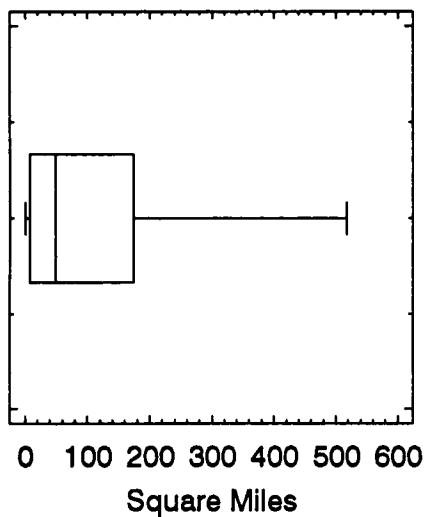


Figure 2. Watershed area.

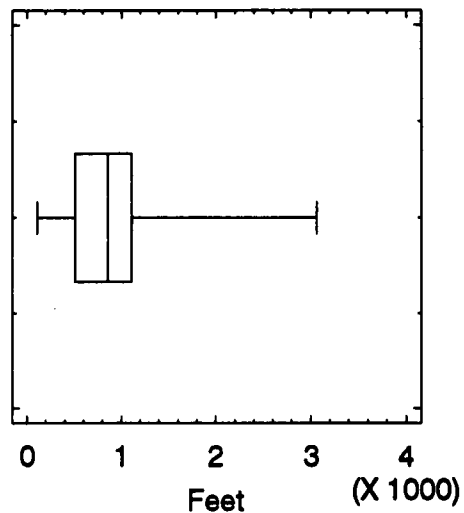


Figure 3. Watershed elevation.

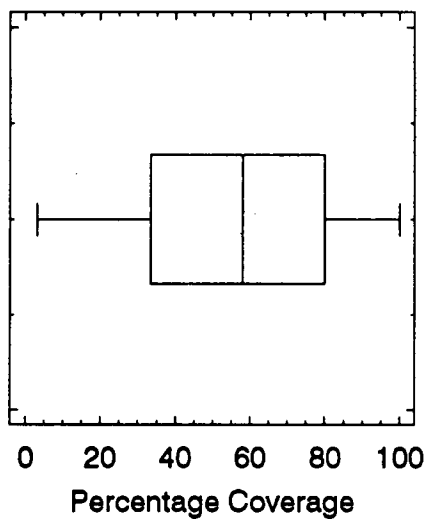


Figure 4. Forest cover.

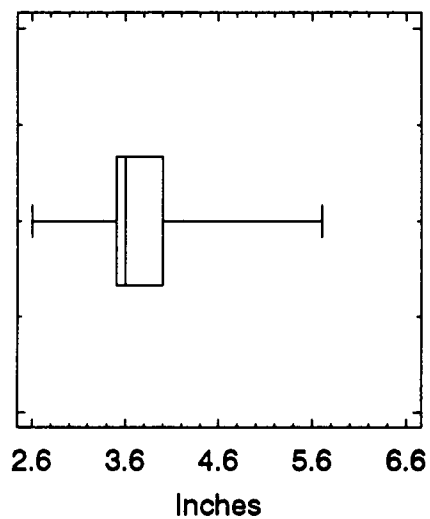


Figure 5. Precipitation intensity.

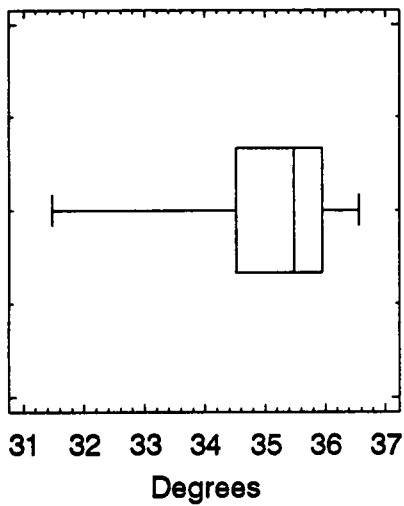


Figure 6. Latitude of gaging station.

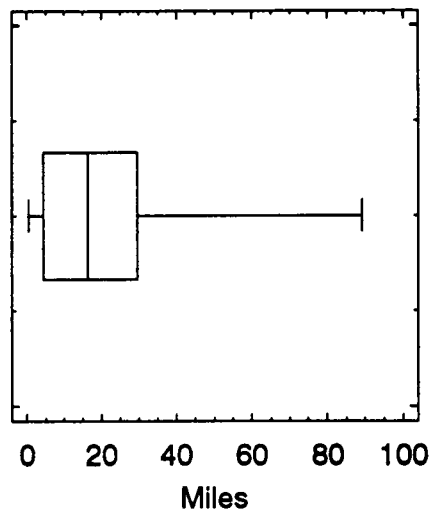


Figure 7. Main stream channel length.

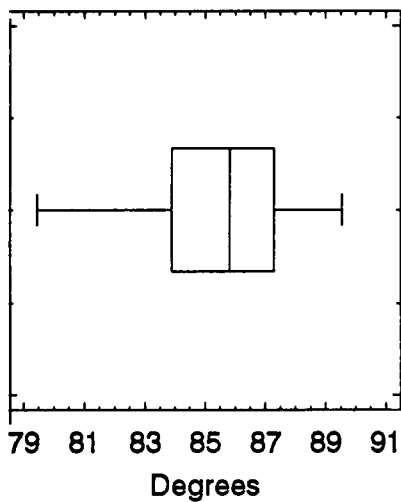


Figure 8. Longitude of gaging station.

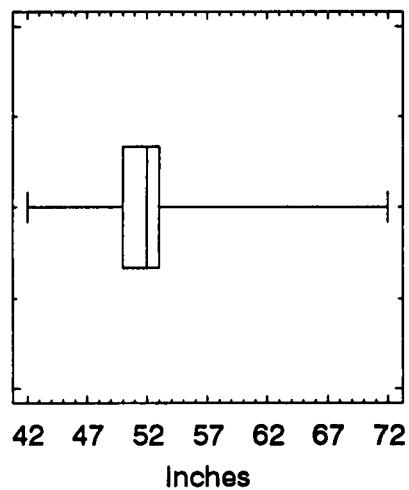


Figure 9. Mean annual precipitation

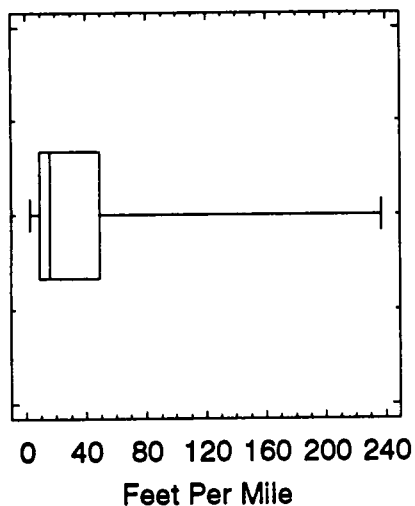


Figure 10. Main stream  
channel slope.

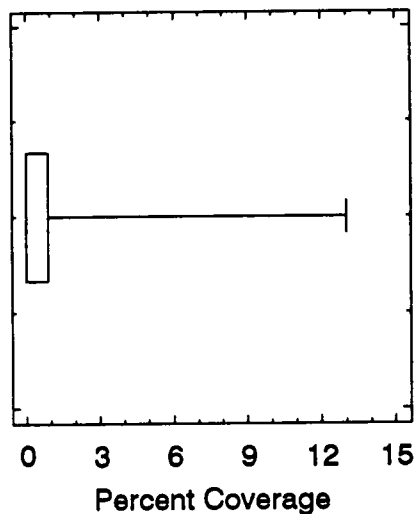


Figure 11. Storage coverage.

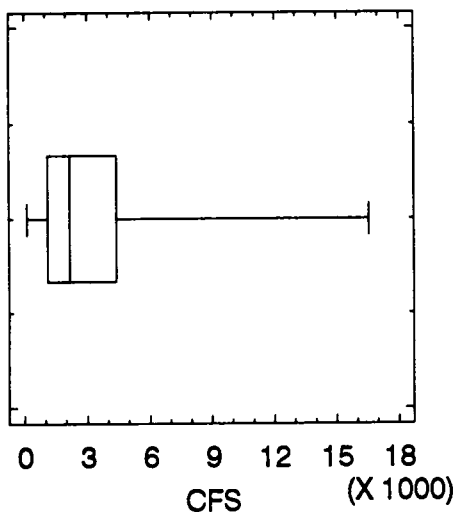


Figure 12. Streamflow peak.

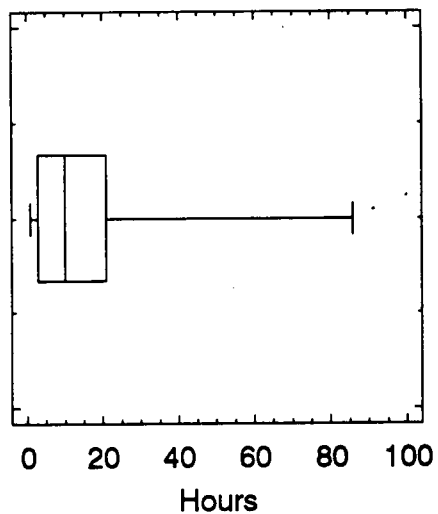


Figure 13. Time to peak  
streamflow.

The box and whiskers plots of Figures 2 - 13 graphically summarize the data characteristics of these variables. Asymmetric behavior and outliers may be detected from these plots. The central box of these figures covers the middle 50-percent of the data values between the 25- and 75-percent quartiles. The median value is described by the central line in the box while the "whiskers" extend to the maximum and minimum data values.

Figures 2 - 11 indicate the watersheds used to develop the predictive equations encompass a diverse range of physical and hydrologic watershed characteristics. Watershed area is seen to range from 0.17 to 518 square miles while main stream channel slope varies from 3.0 to 237 feet per mile. In addition, the elevation of the stream gaging stations range from 110 to 3060 feet while average annual precipitation varies from 42 to 72 inches. Of additional note is the presence of a number of zero values for the independent variable STORAGE. This observation is important for the application of the multiplicative model form to the determination of predictive equations.

## B. Preliminary Data Analysis.

Statistical analysis of the data began with the construction of scatter plots of the dependent and independent variables. Data from all watersheds was used in this analysis.

Scatter plots were analyzed for outliers, linear and nonlinear relationships, plus change of variance. All outliers were investigated to determine the possibility of a data input error and whether the outlier was theoretically justifiable. All data input errors were corrected. Only one watershed (station AL404400) contained outliers of note but it was retained in the data set since it was concluded to be theoretically justifiable. However, this watershed was noted as requiring possible further investigation with outlier detection diagnostics.

Scatter plots indicate the variables AREA, CONTDA, and LENGTH have approximately linear relationships with each of the nine dependent variables. In addition, variance is noted to increase with an increase in the magnitude for each of these independent variables. The variable SLOPE shows a distinct inverse relationship with the time and flow ordinates of the IUH. Variance is noted as remaining constant throughout this range.

The scatter plots of ELEV, STORAGE, FOREST, LAT, LNG, PRECIP, I24 were found to exhibit little if any relationship to the dependent variables. In addition, the independent variable STORAGE contains a large number of zero values.

Following preparation of scatter plots, a correlation matrix was developed to investigate correlation and as a preliminary indication of collinearity. Table 5 presents a correlation matrix of the independent variables and the dependent variables TPEAK and QPEAK. The other time ordinates of the IUH exhibit similar correlation as are noted for TPEAK and are not included in this summary. Table 5 indicates that TPEAK and QPEAK are most highly correlated with the independent variables AREA, CONTDA, LENGTH, LS1, and LS2. In addition, TPEAK is correlated with SLOPE.

The correlation matrices indicate that the independent variables AREA and CONTDA are the most highly correlated of all variables. The correlation coefficient for this pair of independent variables is found to equal 0.99, where exact correlation has a value of 1.0. A separate investigation of these two independent variables found that 118 of the 122 watersheds have identical values for AREA and CONTDA.

Table 5 also indicates that AREA and CONTDA are

Table 5: Correlation matrix.

|          | TPEAK | QPEAK | AREA  | CONTDATA | ELEV  | FOREST |
|----------|-------|-------|-------|----------|-------|--------|
| TPEAK    | 1.0   | 0.24  | 0.70  | 0.70     | 0.27  | 0.14   |
| QPEAK    | ----- | 1.00  | 0.73  | 0.73     | 0.26  | 0.02   |
| AREA     | ----- | ----- | 1.00  | 0.99     | 0.02  | 0.09   |
| CONTDATA | ----- | ----- | ----- | 1.00     | 0.02  | 0.09   |
| ELEV     | ----- | ----- | ----- | -----    | 1.00  | 0.33   |
| FOREST   | ----- | ----- | ----- | -----    | ----- | 1.00   |

Table 5: (continued)

|        | TPEAK | QPEAK | I24   | LAT   | LNG   | LENGTH |
|--------|-------|-------|-------|-------|-------|--------|
| TPEAK  | 1.00  | 0.24  | 0.01  | 0.09  | 0.22  | 0.64   |
| QPEAK  | ----- | 1.00  | 0.00  | 0.15  | 0.02  | 0.72   |
| I24    | ----- | ----- | 1.00  | 0.64  | 0.04  | 0.01   |
| LAT    | ----- | ----- | ----- | 1.00  | 0.17  | 0.07   |
| LNG    | ----- | ----- | ----- | ----- | 1.00  | 0.15   |
| LENGTH | ----- | ----- | ----- | ----- | ----- | 1.00   |

Table 5: (continued)

|         | TPEAK | QPEAK | LNG   | PRECIP | SLOPE | STORAGE |
|---------|-------|-------|-------|--------|-------|---------|
| TPEAK   | 1.00  | 0.24  | 0.22  | 0.21   | 0.49  | 0.48    |
| QPEAK   | ----- | 1.00  | 0.02  | 0.18   | 0.27  | 0.06    |
| LNG     | ----- | ----- | 1.00  | 0.13   | 0.06  | 0.44    |
| PRECIP  | ----- | ----- | ----- | 1.00   | 0.37  | 0.30    |
| SLOPE   | ----- | ----- | ----- | -----  | 1.00  | 0.19    |
| STORAGE | ----- | ----- | ----- | -----  | ----- | 1.00    |

Table 5: (continued)

|       | TPEAK | QPEAK | BS    | LS1   | LS2  |
|-------|-------|-------|-------|-------|------|
| TPEAK | 1.00  | 0.24  | 0.27  | 0.66  | 0.68 |
| QPEAK | ----- | 1.00  | 0.26  | 0.44  | 0.56 |
| BS    | ----- | ----- | 1.00  | 0.50  | 0.57 |
| LS1   | ----- | ----- | ----- | 1.00  | 0.98 |
| LS2   | ----- | ----- | ----- | ----- | 1.00 |

Table 5: (continued)

|        | LENGTH | PRECIP | SLOPE | STORAGE | BS   | LS1  | LS2  |
|--------|--------|--------|-------|---------|------|------|------|
| AREA   | 0.89   | 0.04   | 0.42  | 0.28    | 0.31 | 0.82 | 0.87 |
| CONTD  | 0.89   | 0.04   | 0.42  | 0.28    | 0.31 | 0.82 | 0.87 |
| ELEV   | 0.11   | 0.53   | 0.42  | 0.32    | 0.16 | 0.13 | 0.08 |
| FOREST | 0.06   | 0.34   | 0.29  | 0.05    | 0.06 | 0.17 | 0.15 |
| I24    | 0.01   | 0.55   | 0.18  | 0.09    | 0.07 | 0.00 | 0.00 |
| LAT    | 0.07   | 0.06   | 0.03  | 0.22    | 0.10 | 0.04 | 0.04 |
| LNG    | 0.15   | 0.13   | 0.05  | 0.44    | 0.19 | 0.06 | 0.02 |

highly correlated with the independent variables LENGTH, LS1, and LS2. LENGTH and SLOPE are also noted to be correlated with LS1 and LS2. This result is justifiable since both LS1 and LS2 are functions of LENGTH and SLOPE. As a final note, SLOPE is found to be somewhat correlated with AREA, CONTD, and LENGTH.

### C. Multiple Regression with General Linear Regression Model and the Entire Data Set.

Multiple regression was used to determine the most favorable predictive equations for each of the dependent variables with the general linear regression model of the form:

$$Y = B_0 + B_1(\text{AREA}) + B_2(\text{BS}) + \dots + B_m(\text{STORAGE}) + E$$

where:  $Y$  = response or dependent variable;  
 $B_0, B_1, B_2, \dots, B_m$  = unknown parameters;  
 $X_1, X_2, \dots, X_m$  = independent variables;  
 $E$  = random error term.

The SAS regression procedure, RSQUARE, with  $R^2$  and Mallow's  $C_p$  as diagnostics, was used to choose predictive equations. The collinearity diagnostics, VIF, and the variance proportion matrix, were included to test for significant collinearity among independent variables.

The results of this analysis indicate that a

predictive equation for each of the dependent variables requires the inclusion of at least three independent variables. In some instances, four independent variables are required. This conclusion is warranted by the large values for the Mallows's  $C_p$  test statistic.

The multiple correlation coefficient,  $R^2$ , for the best three parameter predictive equations for the time ordinates of the IUH range from 0.49 to 0.73 while standard errors range from 51 - 81 percent. These predictive equations generally include the independent variables AREA, SLOPE, and STORAGE, or AREA, SLOPE, and LNG. The best three parameter predictive equations for QPEAK contains the independent variables AREA, ELEV, and STORAGE and has an  $R^2$  of 0.65 and a standard error of 55 percent.

Results of the collinearity diagnostics indicate the independent variables AREA and CONTDA have a large degree of collinearity. As indicated previously, AREA and CONTDA were found to contain identical values for 118 of the 122 watersheds. The four remaining watersheds were noted to differ by a relatively small amount. As will be explained in the section of this thesis entitled "Discussion", CONTDA was dropped from the data set and AREA was retained for each of the following analyses.

**D. Multiple Regression with Multiplicative Model and Entire Data Set.**

The base-10 logarithms of the independent and dependent variables were taken in order to determine the most favorable predictive equations with the multiplicative model:

$$y = (10^{B_0}) (AREA_1^{B_1}) (BS_2^{B_2}) \dots (SLOPE_M^{B_M}) (10^E)$$

where:  $y$  = response or dependent variable;  
 $B_0, B_1, B_2, \dots, B_m$  = unknown parameters;  
 $X_1, X_2, \dots, X_m$  = independent variables;  
 $E$  = random error term.

The independent variable CONTDA was dropped from this analysis. In addition, the independent variable STORAGE was modified by the addition of the constant 1 to each value before the base-10 logarithm were taken. As noted in the part D of the Methods and Materials section of this thesis, STORAGE contains a large percentage of zero values, thereby resulting in an undefined quantity when the log is taken. Modification by the addition of 1 was made to allow the logarithm of STORAGE to be mathematically defined. Therefore, the independent variable STOR+1 was used in this analysis as a replacement for STORAGE. Please refer to the section of this thesis entitled "Discussion" for further information regarding this transformation.

The multiplicative model form with the independent variables AREA, ELEV, FOREST, I24, LAT, LENGTH, LNG PRECIP, SLOPE, STOR+1, BS, LS1, and LS2 was analyzed with the RSQUARE SAS regression procedure with  $R^2$  and Mallow's  $C_p$  as diagnostics to determine a subset of the most favorable predictive equations for each of the dependent variables. An ANOVA table for each predictive equation was developed for these subsets.

Table 6 presents a concise listing of the independent variables for each of the chosen predictive equations that comprise this preliminary subset of predictive equations. Only those models which do not contain an excessive amount of collinearity are included in this table. Coefficients are not specified for the models since this is only a preliminary subset of predictive equations. Included in Table 6 are the statistical diagnostics, coefficient of multiple determination,  $R^2$ , and the standard error as measured by the coefficient of variation.

Comparison of the predictive equations listed in Table 6 with the three parameter predictive equations developed with the general linear model form finds the multiplicative models are generally much more accurate predictors of the IUH. For the time ordinates of the IUH,  $R^2$  is seen to improve from the range of 0.49 - 0.73 in the general linear models to a range of 0.73 - 0.85 in the

Table 6: Subset of predictive equations developed with the multiplicative model form.

| Predictive Variables       | R <sup>2</sup> | Standard Error, Percent |
|----------------------------|----------------|-------------------------|
| T25R = AREA                | 0.73           | 53.0                    |
| T25R = AREA SLOPE          | 0.75           | 50.6                    |
| T25R = LS2 STOR+1          | 0.75           | 50.7                    |
| T25R = AREA SLOPE FOREST   | 0.76           | 49.7                    |
| T50R = AREA                | 0.76           | 36.4                    |
| T50R = AREA SLOPE          | 0.80           | 33.7                    |
| T50R = LS2 STOR+1          | 0.80           | 33.3                    |
| T50R = AREA SLOPE FOREST   | 0.81           | 32.9                    |
| T75R = AREA                | 0.78           | 30.4                    |
| T75R = AREA SLOPE          | 0.82           | 27.6                    |
| T75R = LS2 STOR+1          | 0.82           | 27.2                    |
| T75R = AREA SLOPE FOREST   | 0.83           | 26.8                    |
| TPEAK = AREA               | 0.79           | 25.4                    |
| TPEAK = AREA SLOPE         | 0.84           | 22.4                    |
| TPEAK = LS2 STOR+1         | 0.84           | 22.0                    |
| TPEAK = AREA SLOPE FOREST  | 0.85           | 21.6                    |
| T75F = AREA                | 0.80           | 21.8                    |
| T75F = AREA SLOPE          | 0.85           | 19.1                    |
| T75F = LS2 STOR+1          | 0.86           | 18.3                    |
| T75F = AREA SLOPE STORAGE  | 0.87           | 18.0                    |
| T50F = AREA                | 0.81           | 20.1                    |
| T50F = AREA SLOPE          | 0.85           | 17.9                    |
| T50F = LS2 STOR+1          | 0.87           | 16.8                    |
| T50F = AREA SLOPE STORAGE  | 0.87           | 16.6                    |
| T25F = AREA                | 0.81           | 17.9                    |
| T25F = AREA SLOPE          | 0.85           | 16.3                    |
| T25F = LS2 STOR+1          | 0.86           | 15.5                    |
| T25F = AREA SLOPE STORAGE  | 0.87           | 15.3                    |
| TBASE = AREA               | 0.81           | 12.7                    |
| TBASE = AREA SLOPE         | 0.83           | 11.7                    |
| TBASE = LS2 STOR+1         | 0.83           | 11.8                    |
| TBASE = AREA SLOPE STORAGE | 0.83           | 11.7                    |
| QPEAK = AREA               | 0.73           | 6.8                     |
| QPEAK = AREA SLOPE         | 0.78           | 6.2                     |
| QPEAK = AREA STOR+1        | 0.78           | 6.1                     |
| QPEAK = AREA SLOPE STORAGE | 0.81           | 5.8                     |

multiplicative models. The standard error as described with the coefficient of variation decreases from 51 - 81 percent in the general linear models to 6.2 - 53 percent in the two parameter multiplicative models. For the predictive equations to synthesize peak flow,  $R^2$  is noted to improve somewhat from 0.73 with the three parameter general linear model form, to 0.78 with the best two parameter multiplicative model. The standard error is also noted to decrease from 51 to 6.2 percent. In addition, the predictive equations developed with the multiplicative models show little statistical improvement between the two parameter models and the three parameter models. Therefore, the two parameter multiplicative models are the most statistically significant predictive equations to meet the goals of this research.

The collinearity diagnostics VIF and the variance proportion matrix were used to detect significant collinearity in the independent variables. Excessive collinearity between the independent variables LS1, LS2, LENGTH, and AREA resulted in the exclusion of a predictive equation containing these independent variables in the same equation.

#### E. Multiplicative Model with Dependent Variables Divided by AREA.

Predictive equations were developed with the general linear model and the multiplicative model after each of the dependent variables of the time ordinates of the IUH were divided by the independent variable AREA. Motivation for the division of the time ordinates of the IUH by AREA are presented in the section of this thesis entitled "Discussion". The SAS regression procedure, RSQUARE, with  $R^2$  and Mallow's  $C_p$  as diagnostics, was used to choose a subset of the best predictive models for further analysis.

Table 7 presents a concise listing of the independent variables for each of the chosen predictive equations that compose this preliminary subset of models. Each of these predictive equations incorporate the multiplicative model since these predictive equations were found to be preferable to models developed with the general linear model. Coefficients are not specified for the predictive equations since this is only a preliminary subset of predictive equations. The statistical diagnostics coefficient of multiple determination,  $R^2$ , standard error as measured by the coefficient of variation are included in Table 7.

Comparison of Table 7 to the results of earlier

Table 7: Subset of predictive equations developed with the multiplicative model after division of time ordinates by AREA.

| Predictive Variables  | R <sup>2</sup> | Standard Error, Percent |
|-----------------------|----------------|-------------------------|
| T25R = LENGTH         | 0.64           | 28.8                    |
| T25R = LENGTH SLOPE   | 0.66           | 28.3                    |
| T50R = LENGTH         | 0.66           | 33.1                    |
| T50R = LENGTH SLOPE   | 0.68           | 32.1                    |
| T75R = LENGTH         | 0.67           | 36.5                    |
| T75R = SLOPE LENGTH   | 0.70           | 34.9                    |
| TPEAK = LENGTH        | 0.68           | 43.8                    |
| TPEAK = LENGTH SLOPE  | 0.72           | 41.2                    |
| T75F = LENGTH         | 0.68           | 54.3                    |
| T75F = LENGTH SLOPE   | 0.73           | 50.7                    |
| T50F = LENGTH         | 0.68           | 66.4                    |
| T50F = LENGTH SLOPE   | 0.72           | 62.4                    |
| T50F = LENGTH STOR+1  | 0.71           | 89.5                    |
| T25F = LENGTH         | 0.69           | 93.0                    |
| T25F = LENGTH SLOPE   | 0.72           | 89.0                    |
| T25F = LENGTH STOR+1  | 0.71           | 89.5                    |
| TBASE = LENGTH        | 0.75           | 131.7                   |
| TBASE = LENGTH SLOPE  | 0.75           | 131.9                   |
| TBASE = LENGTH FOREST | 0.76           | 131.8                   |

analyses finds division of the time ordinates by AREA does not improve the regression results. With the exception of the T25R and T50R predictive equations, division by AREA increases the standard error of the predictive equations. In addition, standard error is noted to increase with respect to the time ordinates of the IUH for the predictive equations developed by division of the time ordinates of the IUH by AREA.

#### F. Preliminary Selection of Predictive Equations.

Results of the preceding investigations indicate the multiplicative model without division of the time ordinates of the IUH by AREA, is the preferred model form. Two subsets of the best predictive equations are included in Tables 8 and 9. These subsets comprise the preliminary sets of selected predictive equations to define nine points on the IUH of watersheds located in the study area. Table 8 presents the primary set of predictive equations while Table 9 documents a secondary list of predictive equations. With the exception of 75- , 50- , and 25- percent of peak flow on the falling limb of the IUH, Tables 8 and 9 contain the same predictive equations. At these points, the primary set of predictive equations

Table 8: Primary set of predictive equations.

| Predictive Equations                                            | R <sup>2</sup> | Std.<br>Error,<br>Percent |
|-----------------------------------------------------------------|----------------|---------------------------|
| T25R = 1.8467 AREA <sup>0.4027</sup> SLOPE <sup>-0.2851</sup>   | 0.75           | 50.6                      |
| T50R = 3.2779 AREA <sup>0.3952</sup> SLOPE <sup>-0.3275</sup>   | 0.80           | 33.7                      |
| T75R = 4.5930 AREA <sup>0.3916</sup> SLOPE <sup>-0.3541</sup>   | 0.82           | 27.6                      |
| TPEAK = 6.9904 AREA <sup>0.3876</sup> SLOPE <sup>-0.3818</sup>  | 0.84           | 22.4                      |
| T75F = 9.2598 AREA <sup>0.3934</sup> SLOPE <sup>-0.3843</sup>   | 0.85           | 19.1                      |
| T50F = 10.2731 AREA <sup>0.4045</sup> SLOPE <sup>-0.3657</sup>  | 0.85           | 17.9                      |
| T25F = 10.7920 AREA <sup>0.4245</sup> SLOPE <sup>-0.3195</sup>  | 0.85           | 16.3                      |
| TBASE = 14.9555 AREA <sup>0.4599</sup> SLOPE <sup>-0.1337</sup> | 0.83           | 11.7                      |
| QPEAK = 112.2018 AREA <sup>0.5604</sup> SLOPE <sup>0.3057</sup> | 0.78           | 6.2                       |

Table 9: Secondary set of predictive equations.

| Predictive Equations                                            | R <sup>2</sup> | Std.<br>Error,<br>Percent |
|-----------------------------------------------------------------|----------------|---------------------------|
| T25R = 1.8467 AREA <sup>0.4027</sup> SLOPE <sup>-0.2851</sup>   | 0.75           | 50.6                      |
| T50R = 3.2779 AREA <sup>0.3952</sup> SLOPE <sup>-0.3275</sup>   | 0.80           | 33.7                      |
| T75R = 4.5930 AREA <sup>0.3916</sup> SLOPE <sup>-0.3541</sup>   | 0.82           | 27.6                      |
| TPEAK = 6.9904 AREA <sup>0.3876</sup> SLOPE <sup>-0.3818</sup>  | 0.84           | 22.4                      |
| T75F = 5.3753 LS2 <sup>0.6473</sup> STOR+1 <sup>0.3694</sup>    | 0.86           | 18.3                      |
| T50F = 6.5058 LS2 <sup>0.6465</sup> STOR+1 <sup>0.3944</sup>    | 0.87           | 16.8                      |
| T25F = 8.4840 LS2 <sup>0.6462</sup> STOR+1 <sup>0.3741</sup>    | 0.86           | 15.5                      |
| TBASE = 14.9555 AREA <sup>0.4599</sup> SLOPE <sup>-0.1337</sup> | 0.83           | 11.7                      |
| QPEAK = 112.2018 AREA <sup>0.5604</sup> SLOPE <sup>0.3057</sup> | 0.78           | 6.2                       |

contain the two predictive variables AREA and SLOPE, while for the secondary set, the predictive variables are LS2 and STOR+1.

With the exception of the predictive equation for T25R in the primary set of predictive equations as listed in Table 8, the T-test statistics for each of the independent variables of these equations have a probability of exceedance of less than 0.0001. This exceedance probability meets the criteria for acceptance as a predictive equation for this research. The T-test of the intercept term of the predictive equation for T25R was found to have a probability of exceedance of 0.104, indicating that the intercept has a 10.4 percent chance of being statistically insignificant. This predictive equation was retained in this subset in order that the predictive equations would be consistent and parsimonious. This point will be discussed further in the section of this thesis entitled "Discussion".

A number of the predictive equations listed in the secondary set of predictive equations presented in Table 9 contain the independent variable STOR+1. Comparison of Table 8 to Table 9 finds the predictive equations containing STOR+1 have smaller standard errors and larger  $R^2$  than the respective models listed in Table 8. If considered exclusively on these criteria, the predictive

equations listed in Table 9 would be the most accurate and therefore would be the preferred predictive equations. Additional considerations must be taken into account before the final predictive equations are selected. These considerations will be discussed in the Discussion section of this thesis.

Each of the chosen predictive equations were investigated to verify that independent variables entered the equations in a theoretically justifiable manner. In the primary set of predictive equations, the time ordinates of the IUH include the independent variables AREA raised to a positive exponent and SLOPE raised to a negative exponent. For the peak flow of the IUH, both AREA and SLOPE contained positive exponents. In the secondary set of equations, the exponents of the independent variables LS2 and STOR+1 are positive. The sign of each of these exponents are theoretically justified. The rationale for this conclusion will be presented in the section of this thesis entitled "Discussion".

Normal probability plots of the residuals from each of the chosen predictive equations in Tables 8 and 9 were developed to investigate the distribution of the residuals. Normal probability plots indicate the residuals from both predictive equation sets are normally

distributed. Therefore the T-test and other diagnostics listed previously can be considered relevant.

The SAS outlier detection diagnostics, DFFITS, DFBETAS, and Cook's D were used to test for the presence of observations which strongly influence the regression results for both sets of predictive equations. Although data was found to influence the regression, these diagnostics did not indicate excessive influence which would require additional analysis. Therefore, the regression results may be considered accurate.

Residual plots were developed for each of the independent and dependent variables of the chosen models to determine the presence of residual bias. Figures 14 - 17 present plots of residuals from the predictive equations for TPEAK and QPEAK as a function of the independent variables AREA and SLOPE. Figures 14 - 17 do not indicate the presence of residual bias. Residual plots of the remaining independent variables from both the primary and secondary sets of predictive equations also do not indicate bias.

Residuals were also plotted as a function of watershed location to investigate the presence of geographical bias. Residuals were noted to be geographically biased for the primary set of predictive equations. The residuals from the time ordinates of the

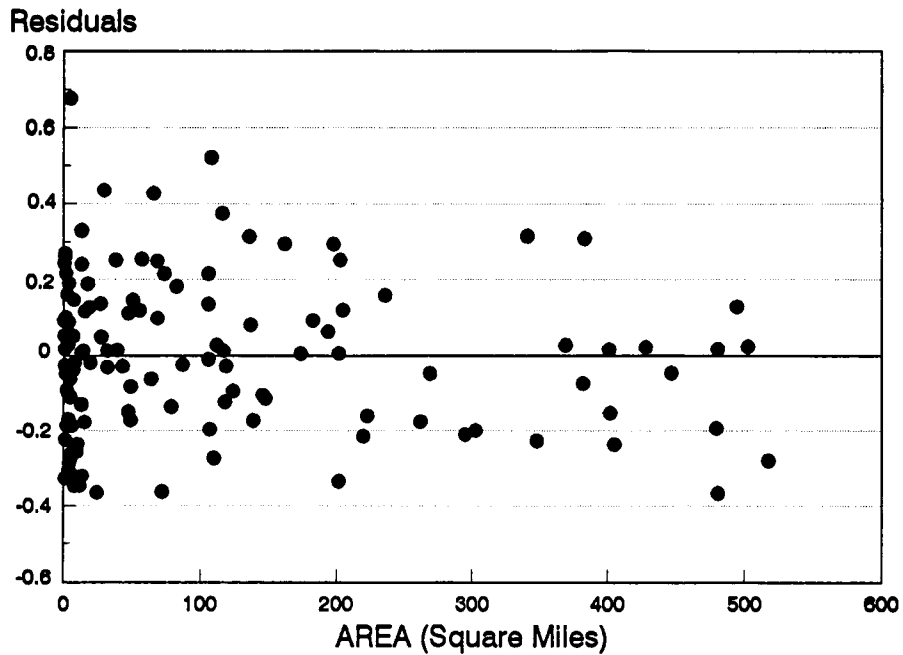


Figure 14. Residuals vs. AREA for predictive equation to determine TPEAK.

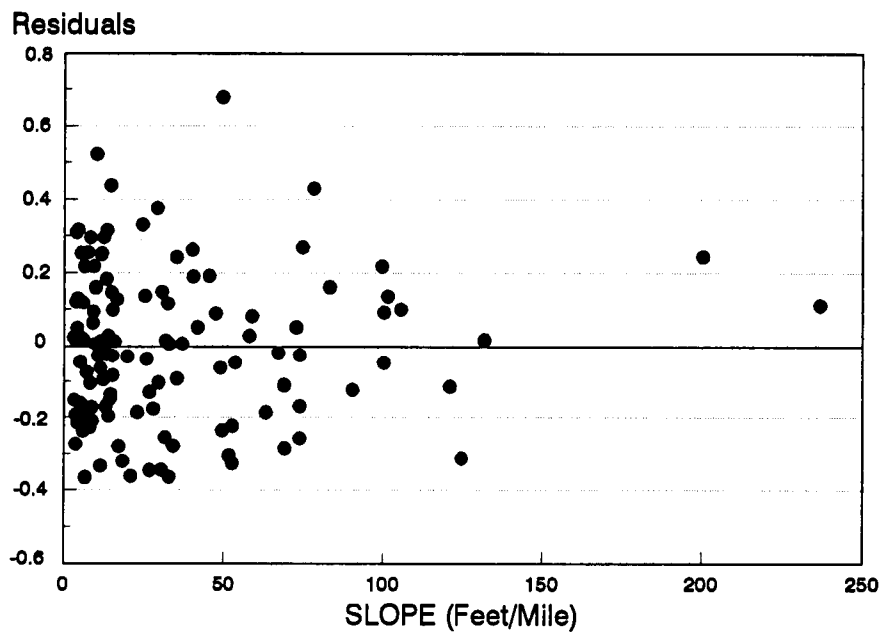


Figure 15. Residuals vs. SLOPE for predictive equation to determine TPEAK.

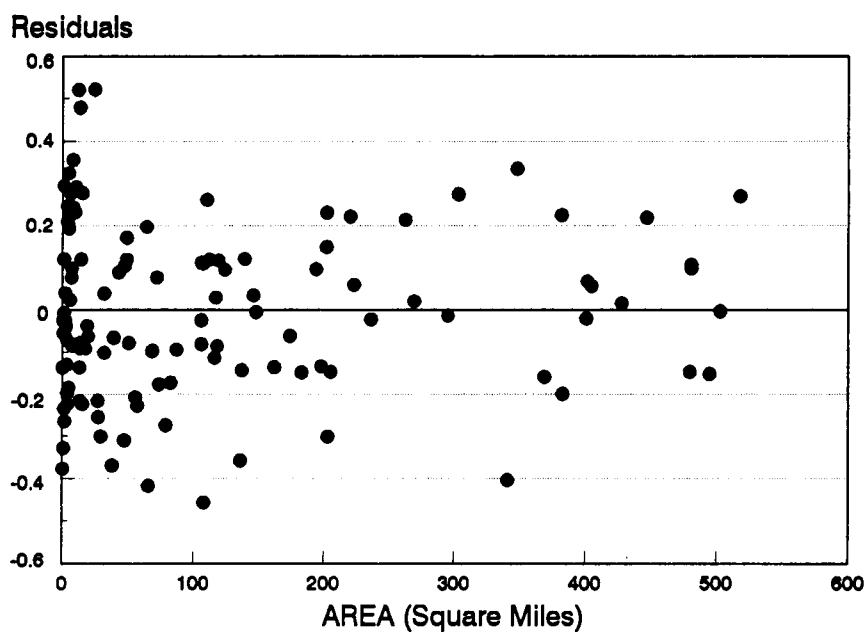


Figure 16. Residuals vs. AREA for predictive equation to determine QPEAK.

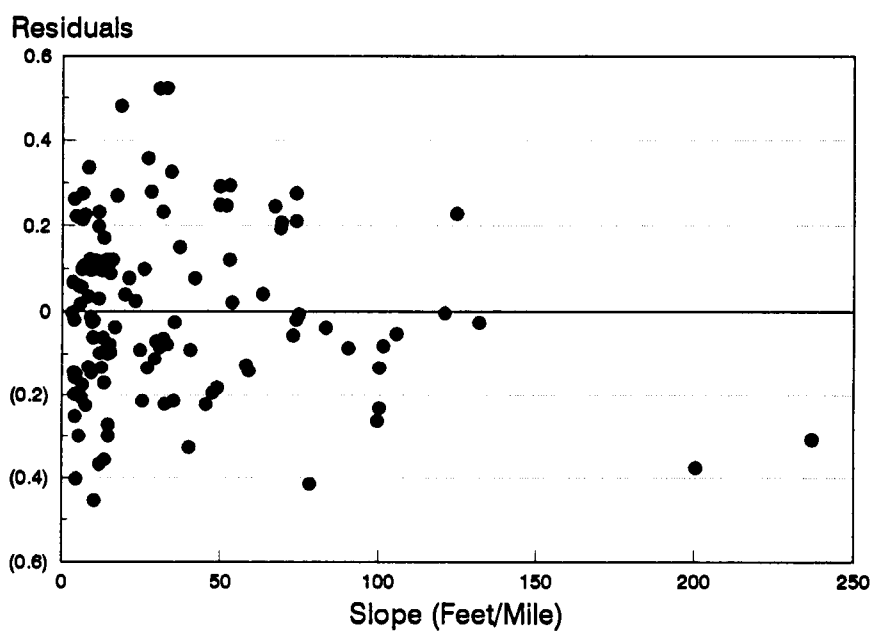


Figure 17. Residuals vs. SLOPE for predictive equation to determine QPEAK.

IUH for the secondary set of predictive equations which include the variable STOR+1 were not found to be geographically biased. However, the predictive equation for peak flow in the secondary set of equations contains the same variables as the primary set and therefore was found to contain geographical bias. The geographical residual bias identified in the primary set of predictive equations is investigated in the following section.

#### **G. Development of Predictive Equations after Subdivision of Watersheds According to Residual Bias.**

The predictive equation to synthesize TPEAK in the primary set of predictive equations and listed in Table 8 was found to consistently over-predict peak streamflow in watersheds located east of the Blue Ridge Province in South Carolina. Likewise, the chosen predictive equations for the time ordinates of the IUH were noted to underestimate the actual time ordinates of the IUH in this geographical area. The Blue Ridge Province of South Carolina is the mountainous area in the western corner of South Carolina and is presented in Figure 18. This geographical bias was investigated by grouping all watersheds located east of the Blue Ridge Province into

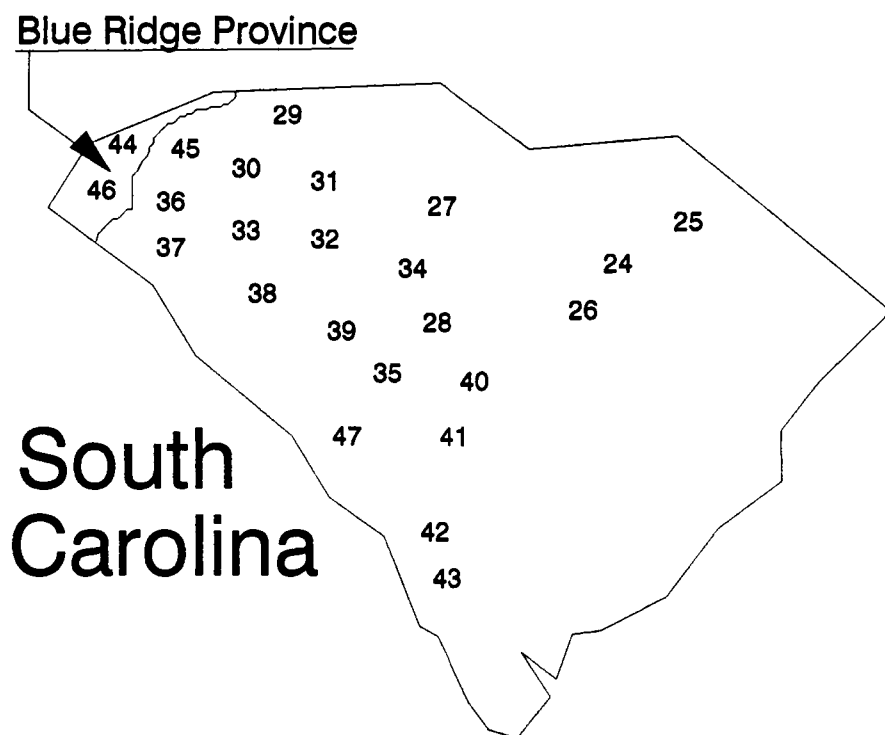


Figure 18. Blue Ridge Province of South Carolina.

one subset and all remaining watersheds into a second subset. Predictive equations were developed for both watershed subsets and for each of the nine dependent variables with the multiplicative model form. The logged forms of the independent variables AREA, ELEV, FOREST, I24, LAT, LENGTH, LNG PRECIP, SLOPE, STOR+1, BS, LS1, and LS2 were included in this analysis.

One predictive equation for each of the nine dependent variables and for each of the two watershed subsets was chosen following comparison of the ANOVA tables, normal probability plots, outlier detection diagnostics, and residual plots. These predictive equations are listed in Tables 10 and 11.

Residual plots of the predictive equations listed in Tables 10 and 11 show no major occurrence of geographical bias. Comparison of these two sets of equations with the primary set of predictive equations listed in Table 8 indicate a number of notable features. The set of predictive equations developed for watersheds located in the Blue Ridge province of South Carolina and west in the states of Alabama and Tennessee and listed in Table 11 contain the same independent variables as noted for the primary set of predictive equations. The coefficient of multiple determination,  $R^2$ , is seen to improve following subdivision, while the standard errors are seen to

Table 10: Predictive equations for watersheds located in the Blue Ridge Province of South Carolina and the states of Alabama and Tennessee.

| Predictive Equations                                            | R <sup>2</sup> | Std. Error, Percent |
|-----------------------------------------------------------------|----------------|---------------------|
| T25R = 1.9249 AREA <sup>0.5013</sup>                            | 0.76           | 60.2                |
| T50R = 2.7784 AREA <sup>0.3884</sup> SLOPE <sup>-0.2890</sup>   | 0.82           | 35.9                |
| T75R = 4.1429 AREA <sup>0.3788</sup> SLOPE <sup>-0.3286</sup>   | 0.84           | 28.7                |
| TPEAK = 6.0688 AREA <sup>0.3777</sup> SLOPE <sup>-0.3484</sup>  | 0.85           | 23.3                |
| T75F = 8.3407 AREA <sup>0.3769</sup> SLOPE <sup>-0.3588</sup>   | 0.86           | 19.8                |
| T50F = 9.5367 AREA <sup>0.3839</sup> SLOPE <sup>-0.3467</sup>   | 0.86           | 18.6                |
| T25F = 9.9129 AREA <sup>0.4077</sup> SLOPE <sup>-0.2987</sup>   | 0.85           | 17.2                |
| TBASE = 13.9412 AREA <sup>0.4621</sup> SLOPE <sup>-0.1209</sup> | 0.82           | 13.1                |
| QPEAK = 118.0592 AREA <sup>0.5803</sup> SLOPE <sup>0.2931</sup> | 0.81           | 6.1                 |

Table 11: Predictive equations for watersheds located east of the Blue Ridge Province of South Carolina.

| Predictive Equations                                                   | R <sup>2</sup> | Std. Error, Percent |
|------------------------------------------------------------------------|----------------|---------------------|
| T25R = 192,796.9 LENGTH <sup>0.6403</sup> PRECIP <sup>-3.0866</sup>    | 0.51           | 28.2                |
| T50R = 409,166.4 LENGTH <sup>0.7507</sup> PRECIP <sup>-3.2550</sup>    | 0.62           | 20.3                |
| T75R = 431,916.7 LENGTH <sup>0.7875</sup> PRECIP <sup>-3.2361</sup>    | 0.66           | 17.4                |
| TPEAK = 1,424,295.2 LENGTH <sup>0.7199</sup> PRECIP <sup>-3.3963</sup> | 0.73           | 13.0                |
| T75F = 747,480.7 LENGTH <sup>0.6549</sup> PRECIP <sup>-3.0923</sup>    | 0.71           | 11.4                |
| T50F = 2.7720 LS2 <sup>0.4787</sup> STOR+1 <sup>0.4428</sup>           | 0.69           | 10.6                |
| T25F = 12.4108 LS2 <sup>0.4514</sup> STOR+1 <sup>0.4265</sup>          | 0.69           | 9.5                 |
| TBASE = 67.3597 AREA <sup>0.3558</sup> ELEV <sup>-0.1951</sup>         | 0.64           | 5.4                 |
| QPEAK = 11.8495 AREA <sup>0.5476</sup> ELEV <sup>0.4334</sup>          | 0.74           | 4.4                 |

increase. This increase in standard error indicates that the predictive equations developed after subdivision will be less useful than the chosen set of predictive equations without subdivision for predicting the nine points on the IUH.

Comparison of the predictive equations developed for watersheds located east of the Blue Ridge Province in South Carolina, Table 10, with the chosen set of predictive equations finds a different set of chosen predictive equations. The independent variables LENGTH and PRECIP are the preferred independent variables for the rising limb of the IUH and T75F on the falling limb of the IUH. The two variable predictive equation containing LS2 and STOR+1, and the two variable predictive equation containing AREA and ELEV are the preferred model forms for the remaining points on the IUH. In addition, the chosen predictive equations for T50F and T25F contain the independent variables LS2 and STOR+1 which are the same independent variables as found in the secondary set of chosen predictive equations.

#### H. Chosen Predictive Equations.

The final chosen predictive equations for each point

on the IUH was made upon comparison of the primary and secondary sets of predictive equations listed in Tables 8 and 9 with the predictive equations developed after subdivision of the watersheds according to geographical bias. The primary set of predictive equations was chosen to be the best set of predictive equations for the purpose of this research.

Validation of this chosen set of predictive equations was made with the PRESS statistic. The PRESS statistic was found to be only slightly larger than the error sum of squares for each of the chosen predictive equations. Therefore, the chosen set of predictive equations are concluded to be validated.

A bias correction factor was added to each chosen predictive model to correct for transformation bias. The final chosen predictive equations for each point on the IUH are presented in Table 12. The bias correction factor is added as the final term to each of these equations.

The final set of predictive equations were used to generate instantaneous unit hydrographs for each of the 122 study watersheds. The predicted and measured points on the IUH for each of the 122 study watersheds are included in Appendix C.

Each predicted IUH was compared to the actual IUH used in the development of the predictive equations.

Table 12: Chosen predictive equations.

| Predictive Equations                                                 | R <sup>2</sup> | Std.<br>Error,<br>Percent |
|----------------------------------------------------------------------|----------------|---------------------------|
| T25R = 1.847 AREA <sup>0.403</sup> SLOPE <sup>-0.285</sup> (1.080)   | 0.75           | 50.6                      |
| T50R = 3.278 AREA <sup>0.395</sup> SLOPE <sup>-0.328</sup> (1.065)   | 0.80           | 33.7                      |
| T75R = 4.593 AREA <sup>0.392</sup> SLOPE <sup>-0.354</sup> (1.058)   | 0.82           | 27.6                      |
| TPEAK = 6.990 AREA <sup>0.388</sup> SLOPE <sup>-0.382</sup> (1.053)  | 0.84           | 22.4                      |
| T75F = 9.260 AREA <sup>0.393</sup> SLOPE <sup>-0.384</sup> (1.049)   | 0.85           | 19.1                      |
| T50F = 10.273 AREA <sup>0.405</sup> SLOPE <sup>-0.366</sup> (1.050)  | 0.85           | 17.9                      |
| T25F = 10.792 AREA <sup>0.424</sup> SLOPE <sup>-0.320</sup> (1.050)  | 0.85           | 16.3                      |
| TBASE = 14.956 AREA <sup>0.460</sup> SLOPE <sup>-0.134</sup> (1.047) | 0.83           | 11.7                      |
| QPEAK = 112.202 AREA <sup>0.560</sup> SLOPE <sup>0.306</sup> (1.050) | 0.78           | 6.2                       |

Three typical examples of instantaneous unit hydrographs synthesized with the chosen predictive equations are compared to the actual measured instantaneous unit hydrographs. These comparisons are presented in Figures 19 - 21. Note that straight lines are drawn in these figures to connect the points on the IUH. As will be presented in the section of this thesis entitled "Discussion", points should be connected with smooth, curvilinear lines for application of this technique.

Figure 19 presents the predicted and measured IUH for station 185000 of South Carolina. This figure typifies a set of IUHs which show very close agreement with the measured IUH. This figure indicates that the predicted IUH closely approximates the measured IUH at each of the nine points on the IUH. Approximately 38 percent of the 122 watersheds of the study were noted to be similar to this figure. Figure 20 compares the measured and predicted IUHs at station 420400 in Tennessee. This figure is typical of another set of IUHs which show relatively close agreement with the measured IUH, although the time to peak streamflow is not defined accurately. The shape of the predicted IUH in Figure 20 closely approximates the measured IUH. Approximately 37 percent of the 122 watersheds are similar to this figure. Figure 21 identifies the remaining set of IUH's which show poorer

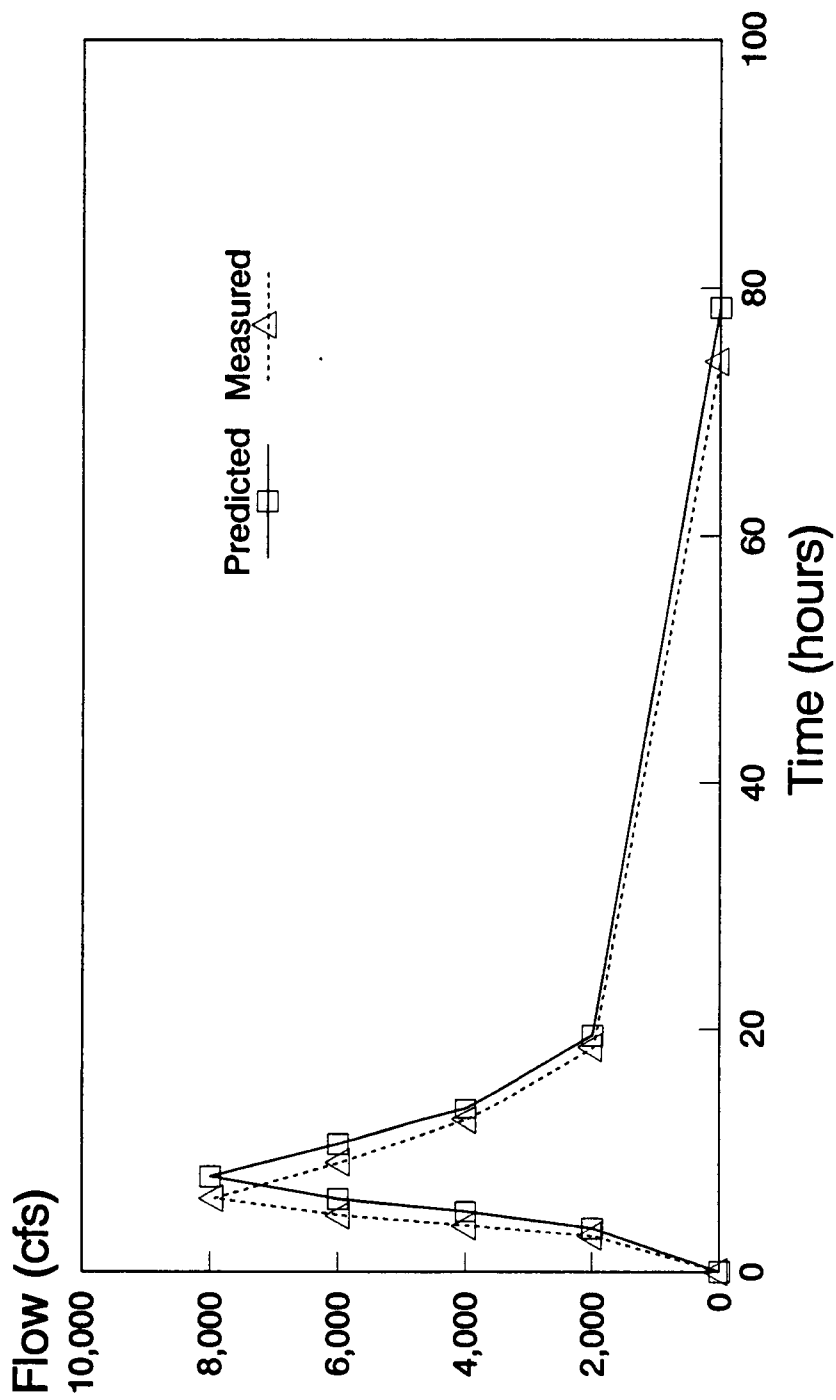


Figure 19. Predicted and measured IUH for SC185000.

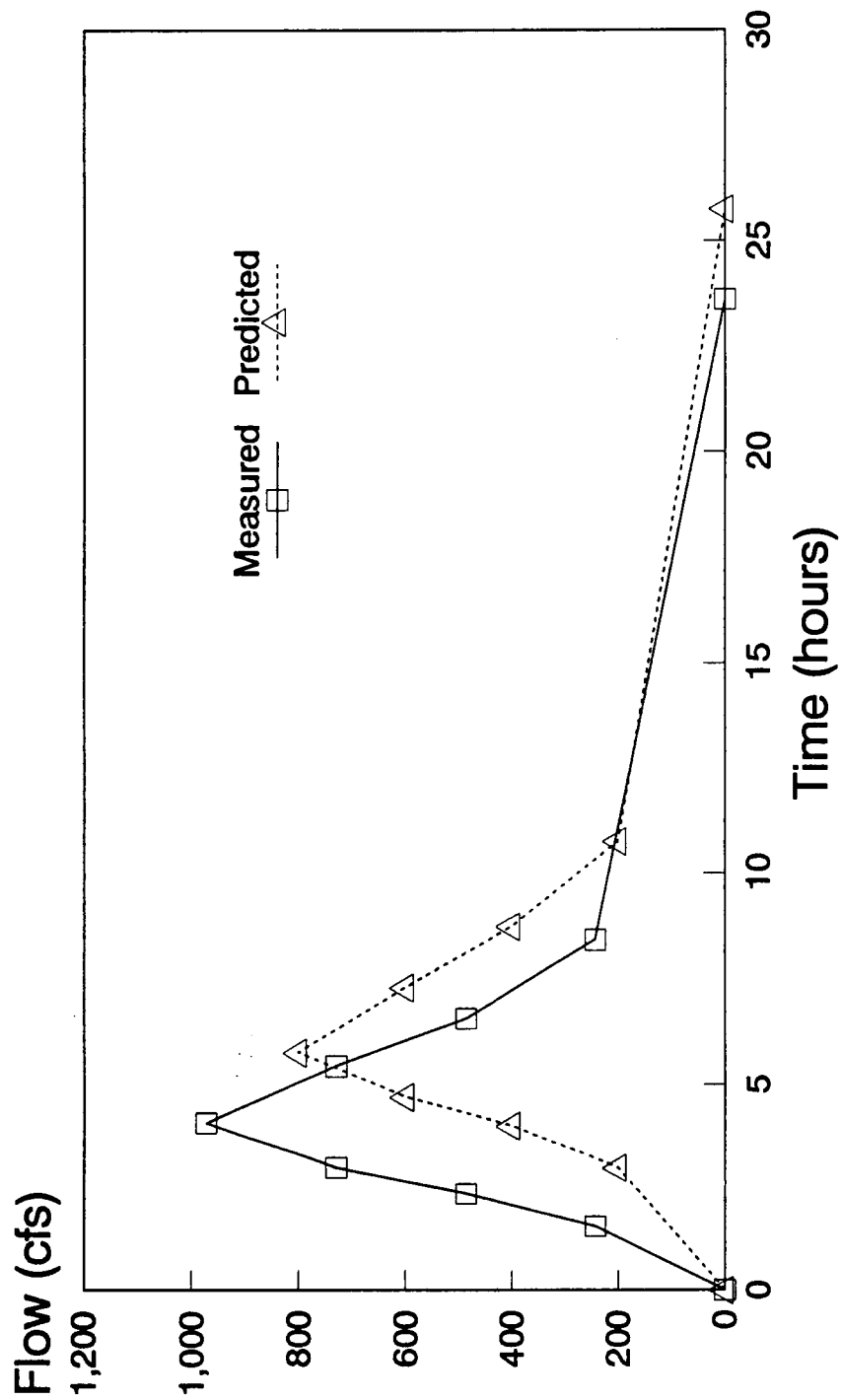


Figure 20. Predicted and measured IUH for TN420400.

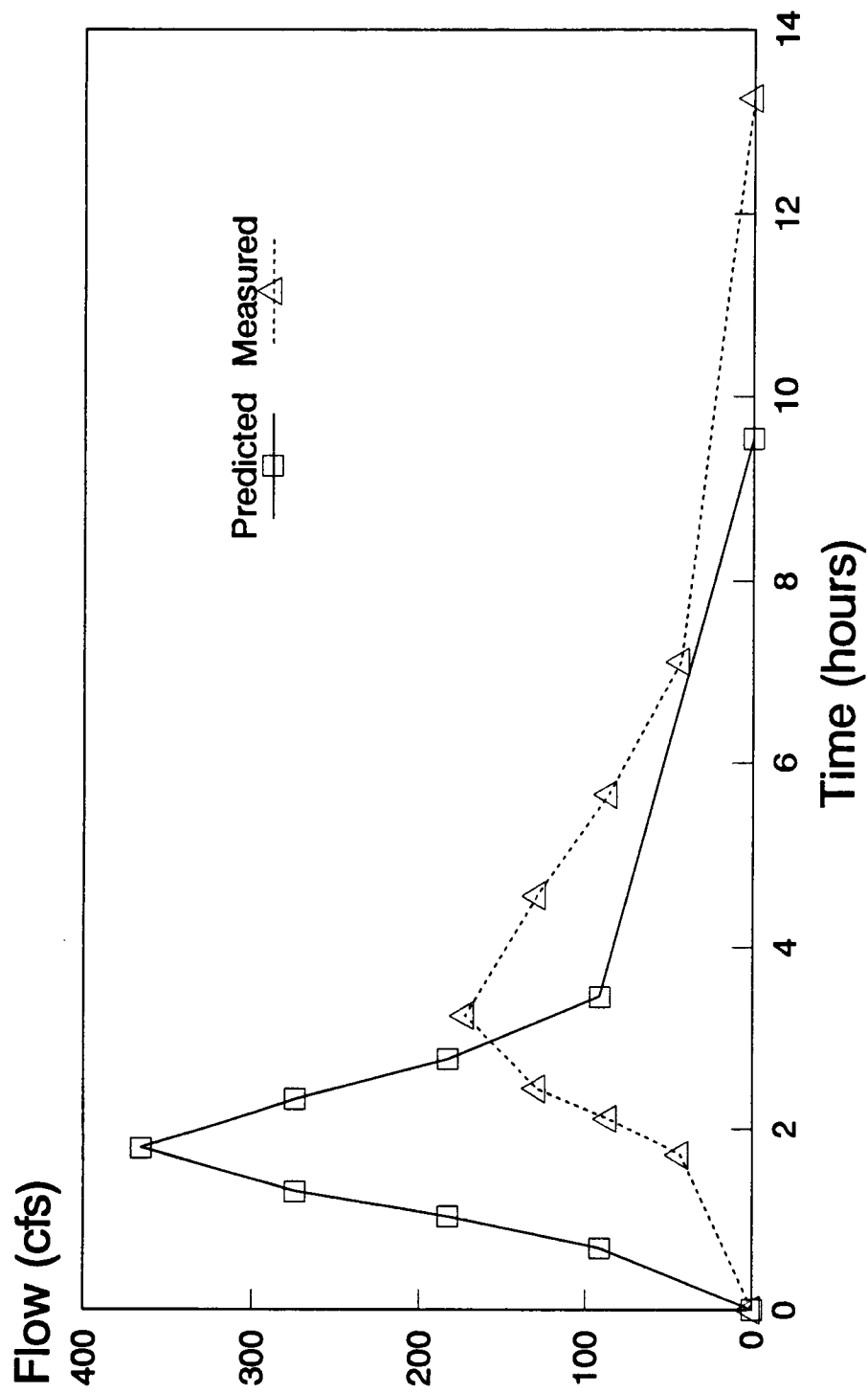


Figure 21. Predicted and measured IUH for TN539100.

agreement with the measured IUH. Note that streamflow peak is underestimated by nearly 100-percent and the shape of the two IUH's differ considerably. Approximately 26 percent of all hydrographs are similar to this figure.

## V. DISCUSSION

### A. Data Set Features.

#### 1. Watershed Characteristics.

One hundred and twenty two watersheds, located in the states of Alabama, South Carolina, and Tennessee were used to develop predictive equations for nine points on an IUH. The physical and hydrologic characteristics of these predominantly rural watersheds are noted to vary considerably. As a concise summary of this variation, Table 13 presents the upper and lower limits of each for each of these watershed characteristics.

Finite ranges exist for each independent variable incorporated in this study. These limits are considered the limiting boundaries for the application of the predictive equations in Alabama, South Carolina, and Tennessee.

The chosen predictive equations may be applied to watersheds having characteristics which lie outside the limits of Table 13. In these cases, the goodness of the chosen predictive equations may be in question.

It is envisioned that the chosen predictive equations may be applied to watersheds having physical and hydrologic characteristics within the ranges of Table 13,

Table 13: Upper and lower range of watershed characteristics.

| Watershed Characteristic | Range                   |
|--------------------------|-------------------------|
| AREA                     | 0.17 - 518 square miles |
| ELEV                     | 110 - 3060 feet         |
| FOREST                   | 3.2 - 100 percent       |
| I24                      | 2.6 - 5.7 inches        |
| LAT                      | 31.47 - 36.56 degrees   |
| LENGTH                   | 0.56 - 89.2 miles       |
| LNG                      | 79.44 - 89.54 degrees   |
| PRECIP                   | 42 - 72 inches          |
| SLOPE                    | 3.03 - 237 feet/mile    |
| STORAGE                  | 0 - 13 percent          |

but located outside of the states of Alabama, South Carolina, and Tennessee. Extension to watersheds located outside of the study area must be made with caution, however, due to the extrapolative nature of this extension. In these cases, the goodness of the chosen predictive equations may be in question.

It is also concluded that application of the predictive equations in the mountainous regions of East Tennessee must be made with caution. The vast majority of watersheds incorporated in this research are not subject to orographic effects that are common in this mountainous area. Because orographic effects may result in significant changes to hydrologic response, application to these watersheds should be made with caution.

## **2. Instantaneous Unit Hydrographs.**

Each of the instantaneous unit hydrographs incorporated in this research were synthesized from unit hydrographs developed by the USGS for application of the Statewide Dimensionless Hydrograph of the USGS to middle Tennessee (Robbins, 1986), east and west Tennessee (Gamble, 1989), Alabama (Olin et. al., 1988), and South Carolina (Bohman, 1990). As described in the section of this thesis entitled "Methods and Materials", each of the

unit hydrographs and average unit hydrographs in these studies were developed with the same procedure and computer algorithm. Average unit hydrographs not available from the USGS data base were synthesized by the author with the same procedure. After compilation of average unit hydrographs for each of the 122 study watersheds, the author synthesized instantaneous unit hydrographs according to S-hydrograph and lagging procedures (Bras, 1990).

As a means to verify the development of the remaining average unit hydrographs, the author generated average unit hydrographs for thirty watersheds and compared these to the respective average unit hydrograph developed by the USGS. Watersheds used in this verification step were evenly distributed between South Carolina, east and west Tennessee, and middle Tennessee. Average unit hydrographs in Alabama were not available and could not be verified. Only minor differences, considered insignificant by the author, were noted in this comparison. Therefore, all average unit hydrographs were developed with the same procedure and were judged adequate for this research.

All instantaneous unit hydrographs incorporated in this thesis were also verified for accuracy. In theory, the volume of runoff associated with the average unit hydrograph should be equivalent to the volume of runoff

associated with the instantaneous unit hydrograph. The volume of runoff from either hydrograph is equivalent to the area under the hydrograph. Results of this verification step found that the volume associated with the instantaneous unit hydrographs differed from the volume associated with the average unit hydrographs by no greater than three percent. These errors are considered acceptable for this research.

The accuracy of unit hydrographs developed by the USGS could not be verified. These unit hydrographs are, therefore, a possible source of error. Possible errors include an inaccurate unit hydrograph synthesis technique, and errors resulting from the choice of storm events for unit hydrograph synthesis. Because unit hydrographs were developed by the USGS with a technique which has been widely employed by the agency for at least ten years, it is concluded that these unit hydrographs are reasonably accurate.

The second possible source of error is also of concern. Unit hydrographs were developed with storm events selected from two decades of gaging records. Unit hydrographs may, therefore, have been developed to describe watershed conditions at different times than when watershed characteristics were measured. In other words, predictive equations may have been developed with

dependent and independent variables measured at different times.

The magnitude of this error may be addressed only through a general analysis because data incorporated in this work does not indicate its date of origin. Of the fourteen independent parameters used to predict the IUH, only the variables CONTDA, FOREST, and STORAGE may possibly be subject to this error because the percentage of forest cover, storage, and contributing drainage area in a rural watershed may change over time through the impact of changing land usage. The remaining independent variables, AREA, BS, CONTDA, ELEV, I24, LAT, LENGTH, LNG, LS1, LS2, PRECIP, and SLOPE are constants in rural watersheds and are therefore not subject to this possible error. According to the purpose of this research, which aims to develop a method which is simple and non-resource intensive to apply, possible errors of this nature are acceptable. These errors must be accepted because watershed characteristics in the future will always differ from those incorporated in this research.

User selection of storm events to develop unit hydrographs is another possible source of error. Unit hydrographs were gathered from four separate studies. The possibility exists that storm events were selected for unit hydrograph development according to criteria which

differed between studies. The magnitude of this error is difficult to address. Although criteria for selection of storm events to synthesize unit hydrographs is a relatively standard procedure, it does require considerable user selection. It is concluded that unit hydrographs incorporated in this research may contain bias associated with the selection of storm events for unit hydrograph synthesis. This bias is considered minimal for two reasons: predictive equations were developed which are theoretically reasonable and comparable to the results of studies to determine streamflow peak for recurrence interval storms in the states of Alabama (Olin and Atkins, 1988), South Carolina (Bohman, 1990), and Tennessee (Gamble, 1989) and (Robbins, 1986); and unit hydrographs used in this thesis were developed and reviewed by professional hydrologists of the USGS.

#### **B. Preliminary Data Analysis.**

The correlation matrix listed previously in Table 5, and the collinearity diagnostics included in the development of predictive equations found the independent variables AREA (area of the watershed above the stream gauge and including non-contributing areas) and CONTDA

(area of the watershed above the stream gauge which contributes surface runoff) are the most highly correlated of all variables. A further examination of these two variables determined that of the 122 watersheds of the study, 118 watersheds have identical values for AREA and CONTDA. Therefore, AREA and CONTDA may be effectively considered identical. This high degree of correlation means that excessive collinearity will exclude the use of AREA and CONTDA from the same predictive equation. It was therefore decided that one of these variables should be discarded from the independent variable set.

CONTDA was discarded from the independent variable set in favor of retaining AREA because the author believes the determination of CONTDA is subject to a greater amount of user selection and possible error than required for the determination of AREA. In addition, AREA is more widely available than CONTDA. For these reasons, CONTDA was not used as an independent variable for the development of predictive equations.

A large degree of collinearity was noted between other pairs of independent variables, including: LS1 and LS2; LS2 and LENGTH; LS1 and LENGTH; LS1 and AREA; and LS2 and AREA. The high degree of collinearity between these pairs of independent variables dictates that predictive equations may not be chosen which include these pairs of

variables.

The independent variable STORAGE (area of lakes, ponds, and swamps measured by the grid sampling method) was found to contain a number of zero values. In past regional analysis work of the USGS, a constant has been added to the independent variable STORAGE in order to specify a mathematically definable quantity for inclusion in a multiplicative regression model (Sauer, et. al., 1983), (Olin and Atkins, 1988). The constant, 1, was added to each of the values of STORAGE for each watershed in this research in agreement with past work of the USGS. As will be presented in the following discussions, constants other than 1 were also added to STORAGE as a means to investigate the effects of this variable transformation.

#### C. Multiple Regression with General Linear Regression Model and the Entire Data Set.

The predictive equations developed with the general linear regression model were noted to be less useful than predictive equations developed with the multiplicative model. This conclusion is in agreement with a number of other studies which have correlated hydrologic watershed

response with watershed characteristics (Espey, et. al., 1977), (Sauer, 1983), (Inman, 1986), (Robbins, 1986), (Olin et. al., 1988), (Gamble, 1989), (Bohman, 1990), (Becker, 1990), and others.

#### **D. Multiple Regression with Multiplicative Model and Entire Data Set.**

Two sets of predictive equations were developed from this analysis. These equation sets are listed previously in Tables 8 and 9. The predictive equations listed in these tables are noted to be much more statistically significant than the predictive equations developed with the general linear model form.

#### **E. Multiplicative Model with Dependent Variables Divided by AREA.**

The time ordinates of the IUH were divided by AREA in the attempt to provide a scaling factor for describing hydrologic response. AREA was chosen as the scaling factor because it was found to be highly correlated to the time ordinates of the IUH. AREA is a useful scaling

factor because travel time to the watershed outlet is highly dependent on the size of the watershed; i.e., as watershed area becomes large, the travel time to the outlet increases. In addition, division of the time ordinates of the IUH by AREA removes AREA as an independent variable and therefore may provide an extra degree of freedom to the predictive equations.

Predictive equations developed with AREA as a scaling factor are presented in Table 7. Comparison to predictive equations developed with the multiplicative model form without scaling finds the statistical significance of the predictive equations are not improved.

The possibility exists that AREA raised to a power may be more useful scaling factor. Possibly useful power functions may be hypothesized from the results of the predictive equations developed with the multiplicative models listed in Table 8. Table 8 shows that the exponent of AREA ranges from 0.38 to 0.45 along the time ordinates of the IUH. This relationship is not constant but instead changes as a function of the time ordinate of the IUH. Predictive equations developed with AREA and other independent variables found that the exponent of AREA changes from the range listed above. It is concluded that little advantage will be gained by dividing the time ordinates of the IUH by AREA.

## **F. Preliminary Selection of Predictive Equations.**

Two sets of predictive equations were chosen after comparison of the preceding analyses. These equations are presented in Tables 8 and 9. The primary set of predictive equations contain the independent variables AREA and SLOPE for each point on the IUH. The secondary set of predictive equations are the same as those of the primary set except for the points at 75-, 50-, and 25-percent of peak flow on the falling limb of the IUH. At these points, the predictive equations contain the independent variables LS2 and STOR+1.

Both sets of chosen predictive equations are concluded to be justified on the basis of the independent variables incorporated in the models and the sign of the exponents of these variables. The primary set of predictive equations contain the independent variables AREA and SLOPE for each point on the IUH. From a conceptual standpoint, both AREA and SLOPE are highly influential to the runoff characteristics of a watershed. As watershed size increases, the amount of precipitation translated as streamflow to the watershed outlet will increase. Watershed size will also strongly influence the timing of runoff because travel time to the watershed outlet is highly dependent upon the length of the path of

runoff, which, in turn, is highly correlated with watershed area (Gray, 1961). Therefore, as watershed size is increased, the most remote regions of the watershed will contribute surface runoff to the watershed outlet over a longer period of time than a comparable, smaller watershed. According to this conceptual model, the exponent of AREA in the predictive equation should be positive for the time and flow ordinates of the IUH. This hypothesis was verified in the predictive equations.

Inclusion of the independent variable SLOPE in the predictive equations to define time and flow ordinates of the IUH is also theoretically justified on a conceptual basis. Travel time to a watershed outlet and the quantity of flow reaching the outlet are dependent on the slope of a watershed. Runoff in watersheds of relatively small slope will more likely be retained in surface water bodies or be subject to watershed abstractions through infiltration and evaporation as contrasted to comparable watersheds of greater slope. This conclusion may be extended to the slope of the main stream channel, which is the independent variable incorporated in this thesis. Slope of a watershed is highly correlated with slope of the main stream channel (Gray, 1961). Therefore, from a conceptual basis, inclusion of SLOPE in predictive equations to define the time and flow ordinates of an IUH

is theoretically justified. According to this conceptual model, SLOPE should be inversely proportional to the time ordinates of the IUH and should have a direct proportional relationship to the flow ordinate. These hypotheses were verified by the predictive equations.

The secondary set of predictive equations listed in Table 9 contain the two independent variables LS2 and STOR+1 for the times to 75-, 50-, and 25-percent of peak flow on the falling limb of the IUH. The remaining predictive equations are those contained in the primary set of predictive equations.

The inclusion of STOR+1 as a predictive variable for the falling limb of the IUH is in agreement with conceptual models of hydrologic response. The recession limb of a hydrograph represents the withdrawal of water from storage after all inflow to the channel has ceased (Chow, 1964). Withdrawal of water from storage occurs from either storage in water bodies or other ground surface conditions of the watershed. From this conceptual framework, storage should have a direct proportional relationship to the timing of flow on the recession limb of the hydrograph. This hypothesis is verified by the positive exponents of STOR+1 in the predictive equations.

The inclusion of LS2 in this subset of secondary equations follows the conceptual model presented for the

independent variable AREA. LS2 and AREA are highly correlated ( $R^2 = 0.87$ ). Due to this high correlation, LS2 may be considered a surrogate variable for AREA and should have a direct proportional relationship to the time ordinates of the IUH. This hypothesis was noted for the three predictive equations which incorporate LS2 and STOR+1.

The T-test of the intercept term of the predictive equation for time to 25-percent of peak flow on the rising limb of the IUH for both sets of predictive equations was found to have a probability of exceedance of 0.104, indicating that this equation has a 10.4 percent chance of being statistically insignificant. The second choice of a predictive equation for this point contains the single independent variable, AREA. The ANOVA table for this one parameter model found that each of the independent variables would be statistically significant with a probability of exceedance of 0.0001. The one variable predictive equation was not chosen however because of the possibility of inconsistent predictive capability. The two parameter equation was therefore retained in order that the predictive equations would be consistent and parsimonious throughout the IUH.

#### **G. Development of Predictive Equations after Subdivision of Watersheds According to Residual Bias.**

The predictive equation to synthesize TPEAK in the primary set of predictive equations was found to consistently over-predict peak streamflow in watersheds located east of the Blue Ridge Province in South Carolina. Likewise, the chosen predictive equations for the time ordinates of the IUH were noted to underestimate the actual time ordinates of the IUH in this geographical area. This geographical bias was investigated by development of predictive equations for watersheds located east of the Blue Ridge Province and development of predictive equations for the remaining watersheds.

The results of this investigation indicate that improvement in the predictive capability of the IUH may be gained with separate predictive equations for watersheds located east of the Blue Ridge province of South Carolina. However, this improvement is only noted for a small subset of the watersheds used in the study. Statistical gains in the predictive capability for the remaining 101 watersheds are not noted to improve. It is concluded, therefore, that predictive equations developed for the entire data set are the chosen models to meet the scope of this research.

## H. Final Selection of Predictive Equations.

The chosen models to predict nine points on the IUH of a watershed are presented in Table 12. Each predictive equation contains the two independent variables AREA and SLOPE. These models have been corrected for transformation bias and are statistically significant according to the diagnostics presented in this table.

These results indicate that a number of independent variables were not found to be statistically significant for predicting points on the IUH of rural watersheds located in the states of Alabama, South Carolina, and Tennessee. These variables include: ELEV, FOREST, I24, LAT, LENGTH, LNG, PRECIP, BS, and LS.

Results of the correlation matrix, the scatter plots, and the development of predictive equations conclude that the independent variable FOREST (percentage of area which is forested) has little if any correlation to the nine points on the IUH. This conclusion is somewhat contrary to conceptual models of hydrologic response which suggest that forest cover is an important factor in the timing and quantity of streamflow in a watershed.

The results of this thesis do not necessarily invalidate these generally held views. Instead, the data base used in this thesis may explain the reasons for the

relative insignificance of FOREST. Data used for FOREST was gathered from the Basin Characteristics File of the USGS. The date when this data was compiled is unknown. In addition, it is highly probable that forest cover for the 122 watersheds of the study was measured at widely differing times. Therefore, the actual forest cover when the dependent variables were determined may be much different than the forest cover used in the development of the predictive equations. This time dependent error can be considered significant only for FOREST; other watershed characteristics used in this thesis are not as transient.

Another consideration centers on the type of forests in the study area. Forests in Alabama are generally coniferous while those in Tennessee are often deciduous. Therefore, the type of forest cover may play an important role in runoff characteristics in a watershed. No information was available concerning the type of forests in the study watersheds.

The independent variables LAT and LNG were also not included in the chosen predictive equations. The purpose of the thesis and the discretion of the author are reasons underlying this result. LAT and LNG were both found to be useful parameters in a number of predictive equations. These equations were not chosen because an attempt was made to use only physically-based parameters to describe

the IUH. The use of LAT and LNG might result in significant errors if the chosen predictive equations were used outside of the study area. It is concluded that LAT and LNG may be surrogate variables for other watershed characteristics not incorporated in this thesis. These surrogate variables may be related to soil conditions and watershed cover.

Comparisons of three examples of IUHs synthesized with the chosen predictive equations were compared to the measured IUHs in Figures 19 - 21. These figures provide three sets of typical results. Figure 19 presents a predicted IUH which closely approximates the measured IUH. Figure 20 presents predicted IUHs which follow the general shape of the measured IUH but either underestimate or overestimate the time to streamflow peak. Figure 21 presents a synthesized IUH which is in poor agreement with the measured IUH.

These three sets of examples are characteristic of the results of this thesis. A general discussion of the reasons for either agreement or disagreement with the measured IUH cannot be offered. As indicated previously, bias as a function of each of the thirteen independent variables in the predictive equations were analyzed. This investigation did not find bias as a function of the independent variable set.

Bias was noted for a subset of models located in South Carolina. However, further analysis of the predicted and measured IUHs for South Carolina watersheds does not conclude that IUHs for these watersheds are much less accurately predicted than IUHs synthesized for watersheds located in Alabama or Tennessee.

Comparison of predicted IUHs with measured IUHs finds that predictive equations define points on an IUH which follow the theoretical shape of an IUH. Past synthetic unit hydrograph techniques such as the Snyder synthetic unit hydrograph technique and Espey's 10-minute unit hydrograph determined width relationships for the unit hydrograph at 50- and 75-percent of peak flow. Width relationships are not required in this technique because the shape of the predicted IUH did not vary from the theoretical IUH shape.

Predictive equations developed in this thesis are founded on unit hydrograph theory. As indicated previously, a number of assumptions of unit hydrograph theory are not in total agreement with conceptual models, commonly accepted theory, and numerous empirical studies of hydrologic response. Unit hydrograph theory assumes that effective rainfall is produced uniformly in a watershed over both space and time. In large watersheds, this assumption is generally not valid. In addition, unit

hydrograph theory does not account for varying antecedent conditions of a watershed but instead incorporates a linear conceptual representation of the rainfall-runoff relationship. This factor may be significant when an IUH developed with the predictive equations is used to generate a design storm hydrograph. In conclusion, a user of these predictive equations must address the limitations of unit hydrograph theory in the modeling effort.

#### I. Application of the Predictive Equations.

Each of the nine chosen predictive equations listed in Table 12 may be applied to rural, ungaged watersheds in the states of Alabama, South Carolina, and Tennessee as a means to synthesize an IUH for the watershed. Application of this technique may be made according to the following five steps.

1. Choose the watershed of interest, either a gaged or ungaged rural watershed located in Alabama, South Carolina, or Tennessee.
2. Determine AREA (watershed area, in square miles, above the point of interest) and SLOPE (slope of the

main channel, in feet per mile, measured at points 10- and 85-percent of stream length upstream from the point of interest). A topographic map, the USGS basin characteristics file, or another source of watershed information may be used.

3. Enter these values into each of the nine predictive equations listed in Table 12 to determine nine points on the IUH of the watershed.
4. Sketch the full IUH by connecting the points. Smooth, curvilinear lines should be drawn.
5. Transform the derived IUH to a design storm hydrograph according to commonly used unit hydrograph construction techniques.

## VI. SUMMARY AND CONCLUSIONS

Predictive equations were developed to calculate nine points on the instantaneous unit hydrograph of rural watersheds located in the states of Alabama, South Carolina, and Tennessee. These nine points allow the user to synthesize an entire instantaneous unit hydrograph for either a gaged or ungaged watershed in this region. The synthesized instantaneous unit hydrograph may be transformed to a unit hydrograph for a precipitation event of any magnitude and duration, which in turn may be used to construct a design storm hydrograph. The data set incorporated in this thesis included physical and hydrologic watershed characteristics and instantaneous unit hydrographs for 122 rural, gaged watersheds located in the states of Alabama, South Carolina, and Tennessee.

The conclusions of this thesis are listed as follows.

1. Nine predictive equations are presented, each capable of synthesizing one point on the instantaneous unit hydrograph of an ungaged, rural watersheds located in the states of Alabama, South Carolina, and Tennessee.
2. These nine equations contain two independent variables: watershed area, and main stream channel slope.

3. These predictive equations indicate that a two variable predictive equation may describe over 75 percent of the variation in an IUH, with standard errors ranging from 6.2 - 50.6 percent.
4. These predictive equations are subject to the constraints and assumptions of unit hydrograph theory.
5. It is envisioned that these predictive equations are applicable to rural watersheds located outside of the study area with physical and hydrologic watershed characteristics similar to those incorporated in this research.

## LIST OF REFERENCES

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- Becker, L.D., 1990. "Simulation of Flood Hydrographs for Small Basins in Missouri". U.S. Geological Survey Water Resources Investigations Report 90-4045.
- Baskar, N.R. 1988. "Projection of Urbanization Effects on Runoff Using Clark Instantaneous Unit Hydrograph Parameters". Water Resources Bulletin, Vol 24, No. 1.
- Bohman, L.R., 1990. "Determination of Flood Hydrographs for Streams in South Carolina: Volume 1. Simulation of Flood Hydrographs for Rural Watersheds in South Carolina". U.S. Geological Survey Water Resources Investigations Report 89-4087.
- Boufadel, M.C., Buchberger, S.G., 1993. "Robust Method to Generate Multiple Unit Hydrographs". Proceedings of the Symposium of the American Society of Civil Engineers, Hydraulics Division, July, 1993.
- Chen, C.L., 1982. "An Evaluation of the Mathematical and Physical Significance of the Soil Conservation Service Curve Number Procedure for Estimating Runoff Volume". In V.P. Singh, ed., Rainfall-Runoff Relationship, Proceedings of the International Symposium on Rainfall-Runoff Modeling, Water Resources Publication, Littleton, Colorado, pp. 387-415.
- Choquette, A.F., 1988. "Regionalization of Peak Discharges for Streams in Kentucky". U.S. Geological Survey Water-Resources Investigations Report 87-420.
- Chow, V.T., 1964. Handbook of Applied Hydrology. McGraw Hill Publishers.
- Chow, Ven Te. 1962. "Hydrologic Determination of Waterway Areas for the Design of Drainage Structures in Small Drainage Basins". University of Illinois Engineering Experiment Station Bulletin 462.
- Chow, V.T., Maidment, D.R. and Mays, L.W., 1988. Applied Hydrology, McGraw-Hill Publishers.
- Clark, C.O. "Storage and the Unit Hydrograph". ASCE Transactions (110), pp. 1419-1446, 1945.

- Dalrymple and Tate, 1960. Flood-frequency Analysis. U.S. Geological Survey Water-Supply Paper 1543-A.
- Espey, W.H., Jr., Altman, D.G., and Graves, C.B., 1977. "Nomographs for Ten-minute Unit Hydrographs for Small Urban Watersheds". Technical Memorandum Number 32, Urban Water Resources Research Program, American Society of Civil Engineers.
- Gamble, C.R., 1988. "Techniques for Simulating Flood Hydrographs and Estimating Flood Volumes for Ungaged Basins in East and West Tennessee". U.S. Geological Survey Water Resources Investigations Report 89-4076.
- Gray, Don M., 1961. "Interrelationships of Watershed Characteristics". Journal of Geophysical Research, 66 (1).
- Guimaraes, W.B., Bohman, L.R., 1992. "Techniques for Estimating Magnitude and Frequency of Floods in South Carolina, 1988". U.S. Geological Survey Water-Resources Investigations Report 91-4157.
- Hawkins, R.H., 1980. "Infiltration and Curve Numbers: Some Pragmatic and Theoretical Relationships". Proceedings Symposium Watershed Management 1980, Boise, Idaho, Volume II, ASCE, pp. 925-937.
- Helsel, D.R., Hirsch, R.M., 1992. Statistical Methods in Water Resources. Elsevier Publishers.
- Horton, R.E., 1945. "Erosional Development of Streams and their Drainage Basins; Hydrophysical Approach to Quantitative Morphology". Bulletin Geological Society of America, 56, 275-370.
- Howard, K.M., and Meadows, M.E., 1981. "A Comparison of Four Synthetic Unit Hydrograph Techniques". Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, University of Kentucky, Lexington, Kentucky.
- Inman, E.J., 1986. "Simulation of Flood hydrographs for Georgia Streams". U.S. Geological Survey Water Resources Investigations Report 86-4004.
- Kuichling, E., 1989. "The Relation Between the Rainfall and the Discharge of Sewers in Populous Districts". Transactions ASCE, 20.

- Linsley, R.K., Jr., Kohler, M.A., and Paulhus, J.L.N., 1949. Applied Hydrology. McGraw-Hill Book Company.
- Maidment, D. R., editor., 1992. Handbook of Hydrology. McGraw-Hill, Inc.
- Mallows, C.P., 1973. "Some Comments on  $C(p)$ ". *Technometrics*, 15, 661-675.
- Marquardt, D.W., 1970. "Generalized Inverses, Ridge Regression, Biased Linear Estimation, and Nonlinear Estimation". *Technometrics* 12, 591-612.
- McCuen, R.H., 1989. "Calibration of Hydrologic Models for Maryland". Maryland Department of Transportation, Report Number FHWA/MD-91/03.
- Miller, D.M., 1984. "Reducing Transformation Bias in Curve Fitting". *American Statistician*, Volume 38, Number 2, pp. 124-126.
- Nash, J.E., 1957. "The Form of the Instantaneous Unit Hydrograph". *International Association of Hydrologic Sciences*, Publication 45, 114-118.
- Neter, J., Wasserman, W., Kutner, M.H., 1990. Applied Linear Statistical Models. Third Edition. Irwin Publishers.
- O'Donnell, T., 1960. "Instantaneous Unit Hydrograph Derivation by Harmonic Analysis". *Commission of Surface Waters*, Publication 51, *International Association of Scientific Hydrology*, p. 546-557.
- Olin, D.A. and Atkins, J.B., 1988. "Estimating Flood Hydrographs and Volumes for Alabama Streams". U.S. Geological Survey Water Resources Investigations Report 88-404.
- Olin, D.A., 1985. "Magnitude and Frequency of Floods in Alabama". U.S. Geological Survey Water-Resources Investigations Report 84-4191.
- Rao, R.A., Delleur, J.W., and Sarma, B., 1972. "Conceptual Hydrologic Models for Urbanizing Basins". *Proceedings ASCE, Journal of the Hydraulic Division*, July, 1972.
- Robbins, C.H., 1986. "Techniques for Simulating Flood Hydrographs and Estimating Flood Volumes for Ungaged

Basins in Central Tennessee". U.S. Geological Survey Water Resources Investigations Report 86-4192.

Sabol, G.V., 1993. "Lag Relations for Semi-arid Regions and Urban Areas". Proceedings of the Symposium of the American Society of Civil Engineers, Hydraulics Division, July, 1993.

Sabol, G.V., 1988. "Clark Unit Hydrograph and R-parameter Estimation". Journal of Hydraulic Engineering, Volume 114, No. 1.

SAS Institute, 1991. SAS/STAT Users' Guide. Version 6, Fourth Edition, Volume 2.

SAS Institute, 1989. SAS Proprietary Software Release 6.08. SAS Institute Inc., Cary, NC.

SAS Institute, 1991. SAS System for Regression, Second Edition.

Sauer, V.B., Thomas, W.O., Stricker, V.A., and Wilson, K.V., 1983. "Flood Characteristics of Urban Watersheds in the United States". U.S. Geological Survey Water-Supply Paper 2207.

Sherman, L. K., 1932. "Streamflow from Rainfall by the Unit-graph Method". Engineering news Record, Volume 108, pp. 501-505.

Sherman, L.K., 1942. "The Unit Hydrograph Method," Chapter XI E of Hydrology, ed. O.E. Meinzer, pp. 514 - 525.

Shaw, E. M., 1988. Hydrology in Practice, Second Edition. Chapman and Hall Publishers.

Shaake, J. C. Jr., 1965. "Synthesis of the Inlet Hydrograph". Technical Report Number 3, Department of Sanitary Engineering and Water Resources, The Johns Hopkins University, Baltimore, MD.

Sheridan, J.M., Merkel, W.H., 1993. "Determining Design Unit Hydrographs for Small Watersheds". In Proceedings of the Federal Interagency Workshop on Hydrologic Modeling Demands for the 90's. U.S. Geological Survey Water-Resources Investigations Report 93-4018, pp. 8-42 - 8-49.

Singh, V.P., 1976. "Unit hydrograph, a Comparative

- Study". Water Resources Bulletin, 12(2), 381-396.
- Smith, R. A., Mesa, O.J., and Ramirez, S., 1993. "Estimation and Regionalization Procedures of Nash's Instantaneous Unit Hydrograph". Proceedings of the Symposium of the American Society of Civil Engineers, Hydraulics Division, July, 1993.
- Snyder, F.F., 1938. "Synthetic Unit Graphs". Transactions American Geophysical Union, 19, pp. 447-454.
- Steichen, J.M., 1983. "Field Verification of Runoff Curve Numbers for Fallow Rotations". Journal of Soil Water Conservation, Volume 38, Number 6, pp. 496-499.
- Taylor, A.B. and Schwarz, H.E., 1952. "Unit Hydrograph Lag and Peak Flow Related to Basin Characteristics". Transactions of American Geophysical Union, 33.
- Thomas, D.A., Benson, M.A., 1970. "Generalization of Streamflow Characteristics From Drainage-Basin Characteristics". U.S. Geological Survey Water-Supply Paper 1975.
- U.S. Army Corps of Engineers, 1981. "Flood Hydrograph Package HEC-1". The Hydrologic Engineering Center, U.S. Army Corps of Engineers.
- U.S. Geological Survey, 1993. "Basin Characteristics File" U.S. Geological Survey, Reston, Virginia.
- U.S. Soil Conservation Service, 1972. National Engineering Handbook, Section 4, Hydrology, U.S. Department of Agriculture.
- Viessman, W., Lewis, G. L., and Knapp, J. W., 1989. Introduction to Hydrology, Third Edition. Harper and Row, Publishers.
- Weaver, J.D., Gamble, C.R., 1993. "Flood Frequency of Streams in Rural Basins of Tennessee", U.S. Geological Survey Water-Resources Investigations Report 92-4165.
- Wood, M.K., and Blackburn, W.H., 1984. "An Evaluation of the Hydrologic Soil Groups as Used in the SCS Runoff Method on Rangelands". Water Resources Bulletin, Volume 20, pp. 379-389.

## APPENDIXES

APPENDIX A. GLOSSARY OF TERMS.

## APPENDIX A. GLOSSARY OF TERMS.

|                |                                                                                                                                                                                                                     |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AREA           | = Basin area including non-contributing areas, square miles.                                                                                                                                                        |
| BS             | = Basin shape ( $\text{LENGTH} \times \text{LENGTH} / \text{AREA}$ ), dimensionless.                                                                                                                                |
| CONTD          | = Basin area that contributes to surface runoff, square miles.                                                                                                                                                      |
| ELEV           | = Mean basin elevation measured from topographic maps by transparent grid sampling method where 20 to 80 points in basin were sampled, feet above mean sea level.                                                   |
| FOREST         | = Forested area as measured by the grid sampling method, percent of contributing drainage area.                                                                                                                     |
| IUH            | = Instantaneous unit hydrograph defined as the unit hydrograph that would result if one inch of effective precipitation were spread uniformly over the watershed in an instant of time and then allowed to run off. |
| I24            | = Precipitation intensity for 24-hour rainfall expected on the average of once each two years, inches.                                                                                                              |
| LAT            | = Latitude of stream-gaging station, decimal degrees.                                                                                                                                                               |
| LENGTH         | = Stream length measured along the channel from the gauge to the basin divide, miles.                                                                                                                               |
| LNG            | = Longitude of stream-gaging station, decimal degrees.                                                                                                                                                              |
| LS1            | = Length slope factor ( $\text{LENGTH} / \text{SLOPE}$ ), miles/feet/mile                                                                                                                                           |
| LS2            | = Second length slope factor ( $\text{LENGTH} / \text{SLOPE}^{1/2}$ ), miles/(feet/mile) <sup>1/2</sup>                                                                                                             |
| PRECIP         | = Mean annual precipitation from the U.S. Weather Bureau series, "Climates of States"; I24 = precipitation intensity for 24-hour rainfall expected on the average once each 2 years, inches.                        |
| QPEAK          | = Peak flow, cubic feet per second.                                                                                                                                                                                 |
| R <sup>2</sup> | = Coefficient of multiple determination.                                                                                                                                                                            |
| SLOPE          | = Slope of the main channel measured at points 10- and                                                                                                                                                              |

85-percent of stream length upstream from gauge,  
feet/mile.

STORAGE = Area of lakes, ponds, and swamps measured by the grid  
sampling method, in percent of contributing drainage  
area.

T25R = Time to 25% of peak flow on the rising limb, hours.

T50R = Time to 50% of peak flow on the rising limb, hours.

T75R = Time to 75% of peak flow on the rising limb, hours.

TPEAK = Time to peak flow, hours.

T75F = Time to 75% of peak flow on the falling limb, hours.

T50F = Time to 50% of peak flow on the falling limb, hours.

T25F = Time to 25% of peak flow on the falling limb, hours.

TBASE = Time to base flow, hours.

USGS = United States Geological Survey, Department of the  
Interior.

APPENDIX B. WATERSHED STATIONS AND  
IDENTIFICATION.

APPENDIX B. Watershed Stations and Identification.

| NO. | Station Number | Watershed Description                           |
|-----|----------------|-------------------------------------------------|
| 1   | AL 02342933    | South Fork Cowikee Creek near Batesville        |
| 2   | AL 02343300    | Abbie Creek near Haleburg                       |
| 3   | AL 02399800    | Little Terrapin Creek near Borden Springs       |
| 4   | AL 02404400    | Choccolocco Creek at Jackson Shoal near Lincoln |
| 5   | AL 02407900    | Paint Creek near Marble Valley                  |
| 6   | AL 02410000    | Paterson Creek near Central                     |
| 7   | AL 02412320    | Elder Creek near Dempsey                        |
| 8   | AL 02413400    | Wedowee Creek above Wedowee                     |
| 9   | AL 02414800    | Harbuck Creek near Hackneyville                 |
| 10  | AL 02417400    | Stearns Creek near Seman                        |
| 11  | AL 02424010    | Sandy Creek near Centreville                    |
| 12  | AL 02427013    | Caine Creek near Safford                        |
| 13  | AL 02428300    | Tallatchee Creek near Vredenburgh               |
| 14  | AL 02437800    | Barn Creek near Hackleburg                      |
| 15  | AL 02450200    | Dorsey Creek near Arkadelphia                   |
| 16  | AL 02453900    | Cheatham Creek near Carbon Hill                 |
| 17  | AL 02455000    | Locust Fork near Cleveland                      |
| 18  | AL 02464000    | North River near Samantha                       |
| 19  | AL 02465205    | Jay Creek near Coker                            |
| 20  | AL 03575830    | Indian Creek near Madison                       |
| 21  | AL 03576250    | Limesone Creek near Athens                      |
| 22  | AL 03585380    | West Fork Anderson Creek near Lexington         |
| 23  | AL 02469735    | Souwilpa Creek at Bolinger                      |

|    |             |                                                |
|----|-------------|------------------------------------------------|
| 24 | SC 02130900 | Black Creek near McBee                         |
| 25 | SC 02131150 | Catfish Canal near Sellers                     |
| 26 | SC 02135500 | Black River near Gable                         |
| 27 | SC 02147500 | Rocky Creek at Great Falls                     |
| 28 | SC 02148300 | Colonels Creek near Leesburg                   |
| 29 | SC 02154500 | North Pacolet River at Fingerville             |
| 30 | SC 02157500 | Middle Tyger River near Lyman                  |
| 31 | SC 02158000 | North Tyger River near Moore                   |
| 32 | SC 02158500 | South Tyger River near Reidville               |
| 33 | SC 02159000 | South Tyger River near Woodruff                |
| 34 | SC 02160000 | Fairforest Creek near Union                    |
| 35 | SC 02162010 | Cedar Creek near Blythewood                    |
| 36 | SC 02162500 | Saluda River near Greenville                   |
| 37 | SC 02163000 | Saluda River near Pelzer                       |
| 38 | SC 02165000 | Reedy River near Ware Shoals                   |
| 39 | SC 02165200 | South Rabon Creek near Gray Court              |
| 40 | SC 02169550 | Congaree Creek at Cayce                        |
| 41 | SC 02172500 | South Fork Edisto River near<br>Montmorenci    |
| 42 | SC 02175500 | Salkehatchie River near Miley                  |
| 43 | SC 02176500 | Coosawhatchie River near Hampton               |
| 44 | SC 02184500 | Whitewater River at Jocassee                   |
| 45 | SC 02185000 | Keowee River near Jocassee                     |
| 46 | SC 02185200 | Little River near Walhalla                     |
| 47 | SC 02197300 | Upper Three Runs near New Ellenton             |
| 48 | TN 03313600 | W. Fork Drakes Crk. Trib near<br>Fountain Head |
| 49 | TN 03408500 | New River at New River                         |
| 50 | TN 03414500 | E. Fork Obey River near Jamestown              |
| 51 | TN 03416000 | Wolf River near Brydstown                      |
| 52 | TN 03418000 | Roaring River near Hilham                      |

|    |             |                                             |
|----|-------------|---------------------------------------------|
| 53 | TN 03420360 | Mud Creek near Summitville                  |
| 54 | TN 03420400 | Mud Creek near Summitville                  |
| 55 | TN 03426800 | East Fork Stones River at Woodbury          |
| 56 | TN 03427500 | East Fork Stones River near Lascassas       |
| 57 | TN 03427830 | Short Creek Trib., near Christiana          |
| 58 | TN 03427840 | Short Creek near Christiana                 |
| 59 | TN 03430400 | Mill Creek at Nolensville                   |
| 60 | TN 03431000 | Mill Creek near Antioch                     |
| 61 | TN 03431520 | Claylick Creek at Lickton                   |
| 62 | TN 03431700 | Richland Crk. at Charlotte Ave at Nashville |
| 63 | TN 03435030 | Red River near Portland                     |
| 64 | TN 03435600 | Mill Branch near White House                |
| 65 | TN 03436700 | Yellow Creek near Shiloh                    |
| 66 | TN 03588400 | Chisholm Creek at Westpoint                 |
| 67 | TN 03588500 | Shoal Creek at Iron City                    |
| 68 | TN 03596000 | Duck River below Manchester                 |
| 69 | TN 03597300 | Wartrace Creek above Bell Buckle            |
| 70 | TN 03597400 | Wartrace Creek near Bell Buckle             |
| 71 | TN 03597450 | Kelly Creek Trib. near Bell Buckle          |
| 72 | TN 03598000 | Duck River near Shelbyville                 |
| 73 | TN 03600500 | Big Bigby Creek at Sandy Hook .             |
| 74 | TN 03602500 | Piney River at Vernon                       |
| 75 | TN 03604000 | Buffalo River near Flatwoods                |
| 76 | TN 03604070 | Coon Creek Trib. near Hohenwald             |
| 77 | TN 03604080 | Hugh Hollow Branch near Hohenwald           |
| 78 | TN 03604090 | Coon Creek above Chop Hollow                |
| 79 | TN 03604100 | Coon Creek near Hohenwald                   |
| 80 | TN 03605555 | Trace Creek above Denver                    |

|     |             |                                          |
|-----|-------------|------------------------------------------|
| 81  | TN 03568500 | Chattanooga Creek near Flintstone, GA    |
| 82  | TN 03467000 | Lick Creek at Mohawk                     |
| 83  | TN 03485500 | Doe River at Elizabethton                |
| 84  | TN 03486225 | Powder Branch near Johnson City          |
| 85  | TN 03491000 | Big Creek near Rogersville               |
| 86  | TN 03497300 | Little River above Townsend              |
| 87  | TN 03498500 | Little River near Maryville              |
| 88  | TN 03518500 | Tellico River at Tellico Plains          |
| 89  | TN 03519610 | Baker Creek Trib. near Binfield          |
| 90  | TN 03519630 | Griffitts Branch near Greenback          |
| 91  | TN 03519650 | Little Baker Creek near Greenback        |
| 92  | TN 03535000 | Bullrun Creek near Halls Crossroads      |
| 93  | TN 03535140 | South Fork Beaver Creek at Harbison      |
| 94  | TN 03535160 | Beaver Creek near Halls Crossroads       |
| 95  | TN 03535180 | Willow Fold near Halls Crossroads        |
| 96  | TN 03538225 | Poplar Creek near Oak Ridge              |
| 97  | TN 03538250 | East Fork Poplar Creek Oak Ridge         |
| 98  | TN 03538900 | Self Creek near Big Lick                 |
| 99  | TN 03539100 | Byrd Creek near Crossville               |
| 100 | TN 03539600 | Daddys Creek near Hebbertsburg           |
| 101 | TN 03539800 | Obed River near Lancing                  |
| 102 | TN 03543500 | Sewee Creek near Decatur                 |
| 103 | TN 03556000 | Turtletown Creek at Turtletown           |
| 104 | TN 03565300 | South Chestuee Creek near Benton         |
| 105 | TN 03565500 | Oostanaula Creek near Sanford            |
| 106 | TN 03566420 | Wolftever Creek near Ooltewah            |
| 107 | TN 03567500 | South Chickamauga Creek near Chickamauga |
| 108 | TN 03571000 | Sequatchie River near Whitwell           |
| 109 | TN 03578000 | Elk River near Pelham                    |

|     |             |                                           |
|-----|-------------|-------------------------------------------|
| 110 | TN 07024300 | Beaver Creek at Huntingdon                |
| 111 | TN 07024500 | South Fork Obion River near Greenfield    |
| 112 | TN 07025500 | North Fork Obion River near Union City    |
| 113 | TN 07026500 | Reelfoot Creek near Samburg               |
| 114 | TN 07027500 | South Fork Forked Deer River near Jackson |
| 115 | TN 07028500 | North Fork Forked Deer River near Trenton |
| 116 | TN 07028930 | Turkey Creek at Medina                    |
| 117 | TN 07028935 | Turkey Creek Tributary near Medina        |
| 118 | TN 07028940 | Turkey Creek near Medina                  |
| 119 | TN 07028950 | Turkey Creek near Fairview                |
| 120 | TN 07029000 | Middle Fork Forked Deer River near Alamo  |
| 121 | TN 07030500 | Wolf River at Rossville                   |
| 122 | TN 03606500 | Big Sandy River at Bruceton               |

APPENDIX C. DEPENDENT AND INDEPENDENT VARIABLE  
VALUES.

# APPENDIX C. Dependent and Independent Variables Values.

| STATION | T25R    | T50R    | T75R    | TPEAK | T75F    |
|---------|---------|---------|---------|-------|---------|
| 24300   | 6.2179  | 9.1814  | 14.115  | 22    | 30.208  |
| 24500   | 36.5122 | 60.3614 | 73.3695 | 86    | 101.972 |
| 25500   | 3.9086  | 9.484   | 15.5007 | 30    | 70.355  |
| 26500   | 3.7457  | 7.7889  | 9.8916  | 14    | 16.908  |
| 27500   | 14.3353 | 25.1754 | 36.9113 | 60    | 81.262  |
| 28500   | 8.155   | 16.04   | 22.02   | 30    | 38.46   |
| 28930   | 0.8217  | 1.1274  | 1.3927  | 1.75  | 2.414   |
| 28935   | 0.3528  | 0.5207  | 0.6353  | 0.75  | 1.173   |
| 28940   | 0.7693  | 1.0452  | 1.3677  | 2     | 2.781   |
| 28950   | 1.6236  | 1.9521  | 2.291   | 3     | 3.845   |
| 29000   | 11.3483 | 14.6868 | 20.997  | 44    | 71.795  |
| 30500   | 24.7188 | 34.7002 | 43.9509 | 54    | 74.361  |
| 130900  | 8.0916  | 34.4853 | 46.6785 | 59    | 72.153  |
| 131150  | 5.4137  | 7.5572  | 9.9636  | 16.5  | 27.716  |
| 135500  | 14.4318 | 23.3106 | 32.0734 | 45    | 63.23   |
| 147500  | 9.5227  | 15.7842 | 20.696  | 27    | 34.131  |
| 148300  | 6.8974  | 10.3193 | 13.3734 | 20    | 32.7    |
| 154500  | 12.2419 | 21.2282 | 24.8331 | 29    | 32.35   |
| 157500  | 14.0571 | 18.289  | 20.3671 | 25    | 31.374  |
| 158000  | 19.8714 | 24.957  | 30.8855 | 38    | 48.146  |
| 158500  | 21.2305 | 23.7777 | 26.6656 | 30    | 34.362  |
| 159000  | 6.5879  | 12.5528 | 16.639  | 22    | 29.875  |
| 160000  | 6.1661  | 11.4039 | 15.8998 | 28    | 43.923  |
| 162010  | 2.5789  | 3.8308  | 4.6514  | 8     | 10.246  |
| 162500  | 5.2335  | 8.2694  | 11.5078 | 17    | 29.663  |
| 163000  | 6.1448  | 9.8471  | 13.2651 | 21    | 34.509  |
| 165000  | 14.3129 | 22.3541 | 27.848  | 35    | 44.557  |
| 165200  | 12.7992 | 15.5465 | 17.2793 | 25.5  | 30.236  |
| 169550  | 13.7523 | 22.2821 | 27.1059 | 36    | 50.559  |
| 172500  | 26.8735 | 35.4412 | 40.3397 | 48    | 59.982  |
| 175500  | 17.9839 | 29.8557 | 49.0739 | 79    | 119.687 |
| 176500  | 18.3497 | 24.7274 | 30.6774 | 52    | 72.286  |
| 184500  | 1.388   | 2.5013  | 3.555   | 5     | 8.2332  |
| 185000  | 2.9104  | 3.7163  | 4.58    | 6     | 8.9376  |
| 185200  | 1.6035  | 2.5772  | 3.4656  | 5     | 8.694   |
| 197300  | 4.6736  | 6.1964  | 7.9005  | 14    | 22.3842 |
| 313600  | 0.5465  | 0.745   | 0.9003  | 1.25  | 1.5241  |
| 342933  | 7.2263  | 10.1747 | 12.3627 | 17    | 21.2199 |
| 343300  | 3.9891  | 5.742   | 11.0495 | 17    | 21.5298 |
| 399800  | 2.5809  | 3.6449  | 4.6792  | 7     | 10.976  |
| 404400  | 6.9336  | 9.6637  | 11.8544 | 16    | 23.693  |
| 407900  | 1.2557  | 2.294   | 3.167   | 5     | 7.0644  |
| 408500  | 12.4844 | 17.4259 | 20.8529 | 28    | 34.3804 |
| 410000  | 0.9926  | 1.3592  | 1.597   | 2     | 2.4042  |

|        |        |         |         |      |         |
|--------|--------|---------|---------|------|---------|
| 412320 | 1.2435 | 1.8806  | 2.153   | 2.5  | 3.3136  |
| 413400 | 2.3117 | 2.7659  | 3.1529  | 4    | 4.8171  |
| 414500 | 7.6314 | 9.9971  | 11.4483 | 14   | 16.6486 |
| 414800 | 1.9193 | 2.2288  | 2.4524  | 3    | 3.518   |
| 416000 | 8.1929 | 10.9615 | 13.1537 | 16   | 20.7088 |
| 417400 | 1.8902 | 2.1401  | 2.3378  | 2.75 | 3.0879  |
| 418000 | 2.7181 | 4.8388  | 6.8361  | 10   | 16.8543 |
| 420360 | 0.5548 | 0.9621  | 1.4261  | 2    | 2.7304  |
| 420400 | 2.972  | 4.0152  | 4.7017  | 5.75 | 7.2874  |
| 424010 | 0.5534 | 0.7968  | 0.9453  | 1.25 | 1.5077  |
| 426800 | 3.0193 | 4.3534  | 5.3527  | 8    | 10.0697 |
| 427013 | 1.1032 | 1.4367  | 1.8485  | 2.75 | 3.3923  |
| 427500 | 7.3312 | 11.1463 | 13.8063 | 20   | 25.8168 |
| 427830 | 0.3151 | 0.4581  | 0.6036  | 0.75 | 1.0189  |
| 427840 | 0.9032 | 1.1022  | 1.2675  | 1.5  | 2.0738  |
| 428300 | 5.6416 | 8.1872  | 9.7769  | 12   | 14.2861 |
| 430400 | 1.3236 | 1.5586  | 1.7597  | 2.25 | 2.6832  |
| 431000 | 4.9686 | 7.2445  | 8.9105  | 12   | 13.8257 |
| 431520 | 0.5363 | 0.6998  | 0.8617  | 1.25 | 1.5396  |
| 431700 | 1.4742 | 1.845   | 2.1486  | 2.75 | 3.1634  |
| 435030 | 2.211  | 2.6762  | 3.0769  | 3.75 | 4.6479  |
| 435600 | 0.5933 | 0.7712  | 0.9216  | 1.25 | 1.6141  |
| 436700 | 6.1239 | 8.5322  | 10.6565 | 14   | 18.4884 |
| 437800 | 4.4467 | 6.0585  | 7.0435  | 8.5  | 11.2285 |
| 450200 | 1.0557 | 2.5679  | 3.2427  | 4    | 7.3318  |
| 453900 | 1.1783 | 1.7149  | 2.0298  | 2.5  | 3.4843  |
| 455000 | 7.5204 | 13.0929 | 16.4482 | 20   | 26.6507 |
| 464000 | 8.5133 | 11.0461 | 14.497  | 21   | 31.9127 |
| 465205 | 1.3898 | 1.9559  | 2.4817  | 3.25 | 4.2376  |
| 467000 | 8.717  | 12.5909 | 15.1486 | 20   | 24.1474 |
| 469736 | 0.7548 | 1.286   | 2.3969  | 4    | 5.1673  |
| 485500 | 4.7087 | 6.2864  | 7.7192  | 12   | 15.9784 |
| 486225 | 0.2518 | 0.5143  | 0.713   | 1    | 1.4828  |
| 491000 | 3.4011 | 4.9673  | 6.3837  | 8    | 11.7811 |
| 497300 | 6.2835 | 7.537   | 8.7735  | 10   | 13.3897 |
| 498500 | 3.5186 | 6.2205  | 7.9067  | 12   | 15.6132 |
| 518500 | 2.2818 | 3.4508  | 4.693   | 6    | 9.6854  |
| 519610 | 0.3341 | 0.6685  | 0.8875  | 1.25 | 1.9485  |
| 519630 | 0.2539 | 0.5098  | 0.7935  | 1.25 | 1.7433  |
| 519650 | 0.5971 | 1.3204  | 1.7413  | 2.5  | 3.444   |
| 535000 | 4.2619 | 7.6668  | 10.8372 | 16   | 20.3037 |
| 535140 | 0.2519 | 0.5037  | 0.71    | 1    | 1.5576  |
| 535160 | 4.3431 | 5.6577  | 6.1686  | 7    | 8.7219  |
| 535180 | 0.9662 | 1.4395  | 1.682   | 2.5  | 3.2302  |
| 538225 | 6.6121 | 10.604  | 14.4416 | 22   | 29.2591 |
| 538250 | 2.0205 | 3.6212  | 5.3485  | 8    | 11.9106 |
| 538900 | 0.9848 | 1.804   | 2.6519  | 4.25 | 5.7753  |
| 539100 | 1.6972 | 2.1158  | 2.4439  | 3.25 | 4.5579  |
| 539600 | 6.5062 | 8.7142  | 10.8534 | 14   | 19.1697 |
| 539800 | 6.4604 | 8.3537  | 9.9848  | 14   | 18.1396 |

|        |         |         |         |      |         |
|--------|---------|---------|---------|------|---------|
| 543500 | 4.544   | 7.6763  | 11.9653 | 18   | 22.336  |
| 556000 | 1.4994  | 3.4189  | 5.4761  | 10   | 13.4268 |
| 565300 | 2.5056  | 5.303   | 7.1503  | 10   | 11.9817 |
| 565500 | 6.9025  | 12.328  | 17.657  | 28   | 33.3801 |
| 566420 | 3.1155  | 4.8237  | 6.3148  | 10   | 11.675  |
| 567500 | 13.6769 | 17.432  | 26.6094 | 40   | 51.9429 |
| 568500 | 9.6099  | 11.8514 | 13.5273 | 16   | 21.6317 |
| 571000 | 11.9059 | 19.7007 | 24.2475 | 32   | 44.8231 |
| 575830 | 4.1408  | 7.3057  | 7.9852  | 9.25 | 13.7902 |
| 576250 | 4.0498  | 8.8603  | 12.3335 | 17   | 21.0543 |
| 578000 | 10.437  | 12.462  | 14.1482 | 18   | 24.2942 |
| 585380 | 1.2709  | 1.6956  | 2.18    | 2.75 | 4.0409  |
| 588400 | 4.6071  | 6.2519  | 7.4704  | 10   | 11.9815 |
| 588500 | 8.8059  | 13.4662 | 15.5474 | 18   | 22.9112 |
| 596000 | 2.6492  | 5.2357  | 7.4105  | 10   | 14.6094 |
| 597300 | 7.0165  | 9.1562  | 10.8311 | 14   | 16.7885 |
| 597400 | 1.0505  | 1.3047  | 1.6155  | 2.5  | 3.3278  |
| 597450 | 0.3368  | 0.5068  | 0.6507  | 1    | 1.2445  |
| 598000 | 16.1748 | 20.4734 | 27.5155 | 40   | 50.2319 |
| 600500 | 3.5368  | 4.6639  | 5.5515  | 8    | 9.1545  |
| 602500 | 3.0803  | 4.7115  | 6.0791  | 10   | 13.3337 |
| 604000 | 20.6793 | 28.3033 | 31.4837 | 36   | 44.1017 |
| 604070 | 0.4742  | 0.638   | 0.8039  | 1.25 | 1.7865  |
| 604080 | 0.7181  | 1.1488  | 1.4271  | 1.75 | 2.2423  |
| 604090 | 0.5062  | 0.8293  | 1.0559  | 1.5  | 1.8218  |
| 604100 | 1.073   | 1.4697  | 1.7394  | 2.25 | 2.6788  |
| 605555 | 2.7685  | 4.3261  | 5.5061  | 8    | 9.793   |
| 606500 | 10.9267 | 24.8971 | 32.2192 | 44   | 58.4433 |

| STATION | T50F    | T25F    | TBASE | QPEAK   | AREA |
|---------|---------|---------|-------|---------|------|
| 24300   | 38.93   | 49.727  | 138   | 1145.22 | 55.5 |
| 24500   | 125.728 | 161.928 | 348   | 2997.34 | 383  |
| 25500   | 93.237  | 110.102 | 220   | 3786.81 | 480  |
| 26500   | 20.186  | 30.263  | 90    | 4271.53 | 110  |
| 27500   | 100.478 | 124.556 | 282   | 3996.74 | 495  |
| 28500   | 44.28   | 53.35   | 162   | 1467.11 | 73.5 |
| 28930   | 2.772   | 3.38    | 11    | 1674.71 | 4.75 |
| 28935   | 1.489   | 1.88    | 5.5   | 775     | 1.08 |
| 28940   | 3.163   | 3.677   | 8     | 2219.85 | 7.87 |
| 28950   | 4.229   | 4.668   | 11.25 | 3529.08 | 13.3 |
| 29000   | 88.855  | 109.55  | 204   | 3232.36 | 369  |
| 30500   | 93.571  | 117.341 | 288   | 5109.27 | 503  |
| 130900  | 85.326  | 108.271 | 180   | 1101.52 | 108  |
| 131150  | 36.023  | 45.011  | 71    | 616.98  | 27.4 |
| 135500  | 77.594  | 94.111  | 142   | 4600.63 | 401  |
| 147500  | 37.585  | 41.595  | 105   | 5263.5  | 194  |
| 148300  | 41.898  | 51.935  | 76    | 786.59  | 38.1 |
| 154500  | 37.393  | 43.236  | 90    | 3482.38 | 116  |
| 157500  | 35.626  | 40.596  | 113   | 2028.15 | 68.3 |

|        |         |         |       |         |      |
|--------|---------|---------|-------|---------|------|
| 158000 | 54.807  | 64.531  | 125   | 3071.7  | 162  |
| 158500 | 40.988  | 57.034  | 126   | 2861.84 | 106  |
| 159000 | 40.346  | 55.82   | 94    | 3520.18 | 174  |
| 160000 | 52.175  | 60.891  | 130   | 2914.55 | 183  |
| 162010 | 11.525  | 13.382  | 53    | 3234.19 | 48.9 |
| 162500 | 43.174  | 56.808  | 112   | 5147.21 | 295  |
| 163000 | 48.336  | 65.757  | 128   | 6403.74 | 405  |
| 165000 | 50.014  | 59.682  | 113   | 4591.4  | 236  |
| 165200 | 34.911  | 43.423  | 77.75 | 851.7   | 29.5 |
| 169550 | 64.066  | 79.235  | 134   | 1711.01 | 136  |
| 172500 | 69.041  | 83.984  | 167   | 3038.8  | 198  |
| 175500 | 152.691 | 185.86  | 258   | 1832.62 | 341  |
| 176500 | 90.587  | 114.589 | 213   | 1838.79 | 203  |
| 184500 | 11.5402 | 16.7443 | 55    | 2547.52 | 47.3 |
| 185000 | 12.4962 | 18.4682 | 74    | 7925.37 | 148  |
| 185200 | 11.9922 | 17.8807 | 74    | 3738.86 | 72   |
| 197300 | 27.9061 | 34.7278 | 76    | 2423.46 | 87   |
| 313600 | 1.8678  | 2.4256  | 8.5   | 388.88  | 0.95 |
| 342933 | 24.3214 | 28.9767 | 53    | 4653.7  | 112  |
| 343300 | 28.0476 | 40.0562 | 61    | 3780.86 | 146  |
| 399800 | 14.3933 | 19.2606 | 33    | 900.93  | 15.4 |
| 404400 | 39.3551 | 69.5103 | 146   | 8183.3  | 481  |
| 407900 | 8.5206  | 10.7222 | 34    | 1136.76 | 12.7 |
| 408500 | 39.0117 | 44.4189 | 114   | 9590.25 | 382  |
| 410000 | 2.7784  | 3.572   | 15.75 | 1561.01 | 4.91 |
| 412320 | 4.34    | 6.1074  | 14.5  | 346.3   | 1.79 |
| 413400 | 5.873   | 7.232   | 22.5  | 1235.25 | 6.87 |
| 414500 | 18.4922 | 21.8478 | 100   | 9356.54 | 202  |
| 414800 | 3.9529  | 4.8496  | 17.75 | 2285.95 | 7.97 |
| 416000 | 23.3351 | 29.6562 | 80    | 4273.97 | 106  |
| 417400 | 3.4522  | 4.233   | 14.5  | 472.4   | 1.27 |
| 418000 | 21.6219 | 29.9746 | 86    | 1568.81 | 78.7 |
| 420360 | 3.2895  | 4.4188  | 14    | 499.48  | 2.28 |
| 420400 | 8.7176  | 10.7609 | 25.75 | 800.96  | 7.3  |
| 424010 | 1.8223  | 2.3921  | 6.75  | 272.48  | 0.59 |
| 426800 | 12.9328 | 17.0612 | 90    | 2170.44 | 39.1 |
| 427013 | 3.7355  | 4.1444  | 13.75 | 691.94  | 2.69 |
| 427500 | 30.0855 | 37.703  | 96    | 7333.97 | 262  |
| 427830 | 1.1645  | 1.4196  | 6     | 124.58  | 0.17 |
| 427840 | 2.4455  | 2.9516  | 10    | 1379.74 | 3.54 |
| 428300 | 15.886  | 18.0913 | 40    | 1027.35 | 13.2 |
| 430400 | 2.977   | 3.5099  | 13    | 4269.99 | 12   |
| 431000 | 15.4861 | 17.99   | 58    | 3832.44 | 64   |
| 431520 | 1.8977  | 2.719   | 12.25 | 1463.29 | 4.13 |
| 431700 | 3.5369  | 4.4679  | 13.75 | 6500.99 | 24.3 |
| 435030 | 5.2749  | 6.3997  | 22.25 | 2699.7  | 15.1 |
| 435600 | 2.0289  | 2.6996  | 11.75 | 1335.42 | 3.5  |
| 436700 | 21.0447 | 30.4692 | 98    | 4495.89 | 124  |
| 437800 | 13.8042 | 18.0231 | 39.5  | 858.89  | 13.1 |
| 450200 | 8.8329  | 13.5275 | 50    | 945     | 13   |

|        |         |         |       |         |      |
|--------|---------|---------|-------|---------|------|
| 453900 | 4.5981  | 6.2642  | 11    | 574.85  | 4.7  |
| 455000 | 32.9894 | 44.9001 | 62    | 9169.73 | 303  |
| 464000 | 40.0433 | 55.4439 | 105   | 4417.25 | 223  |
| 465205 | 5.1894  | 7.5387  | 29.75 | 481.12  | 3.65 |
| 467000 | 31.2766 | 41.6683 | 144   | 5970.75 | 220  |
| 469736 | 6.0234  | 7.2404  | 11    | 1154.48 | 7.25 |
| 485500 | 22.1714 | 33.5471 | 96    | 4425.38 | 137  |
| 486225 | 1.8346  | 2.3991  | 9.25  | 2019.74 | 4.88 |
| 491000 | 13.8953 | 18.0424 | 102   | 2801.14 | 47.3 |
| 497300 | 18.389  | 27.8186 | 86    | 5222.12 | 106  |
| 498500 | 19.9351 | 29.3229 | 104   | 9140.73 | 269  |
| 518500 | 12.2267 | 20.7926 | 88    | 5295.7  | 118  |
| 519610 | 2.4694  | 3.0832  | 9.25  | 663.52  | 2.1  |
| 519630 | 2.6219  | 4.1805  | 12    | 331.93  | 1.46 |
| 519650 | 4.8052  | 6.6945  | 14.75 | 554.26  | 3.65 |
| 535000 | 23.9318 | 30.9801 | 104   | 2208.14 | 68.5 |
| 535140 | 1.8529  | 2.2837  | 7     | 559.87  | 1.23 |
| 535160 | 10.4369 | 13.3408 | 22    | 1518.58 | 14.1 |
| 535180 | 4.3264  | 5.9398  | 12    | 557.12  | 3.23 |
| 538225 | 35.2915 | 43.6819 | 140   | 1971.23 | 82.5 |
| 538250 | 13.3768 | 15.4566 | 74    | 1122.46 | 19.5 |
| 538900 | 7.4927  | 10.2155 | 19.5  | 454.68  | 3.8  |
| 539100 | 5.6547  | 7.1163  | 13.25 | 172.26  | 1.1  |
| 539600 | 22.7899 | 37.6748 | 104   | 4557.92 | 139  |
| 539800 | 22.998  | 34.7432 | 144   | 16546.8 | 518  |
| 543500 | 25.1345 | 30.2005 | 84    | 3656.46 | 117  |
| 556000 | 15.8714 | 20.7207 | 48    | 1162.4  | 26.9 |
| 565300 | 14.5156 | 21.765  | 76    | 1395.31 | 31.8 |
| 565500 | 38.6718 | 49.4704 | 134   | 1187.59 | 57   |
| 566420 | 13.2503 | 15.7547 | 56    | 1257.47 | 18.8 |
| 567500 | 60.1725 | 77.7774 | 136   | 5882.54 | 428  |
| 568500 | 25.093  | 34.0879 | 132   | 1932.19 | 50.6 |
| 571000 | 63.9558 | 89.7865 | 150   | 5441.69 | 402  |
| 575830 | 17.2496 | 21.7687 | 34.25 | 3007.39 | 49   |
| 576250 | 25.9505 | 31.683  | 76    | 4413.38 | 119  |
| 578000 | 30.384  | 42.9423 | 180   | 1701.08 | 65.6 |
| 585380 | 5.449   | 7.7234  | 19.5  | 838.5   | 5.92 |
| 588400 | 13.6565 | 16.9216 | 84    | 2602.16 | 43   |
| 588500 | 26.5438 | 32.3646 | 122   | 12268.8 | 348  |
| 596000 | 17.0881 | 21.6667 | 114   | 4444.1  | 107  |
| 597300 | 19.7664 | 25.8275 | 148   | 1616.06 | 4.99 |
| 597400 | 3.942   | 5.0284  | 18.75 | 1956.79 | 9.59 |
| 597450 | 1.4907  | 1.8909  | 5.75  | 394.51  | 0.73 |
| 598000 | 56.5808 | 66.7942 | 188   | 7806.57 | 481  |
| 600500 | 10.466  | 12.7785 | 50    | 1402.13 | 17.5 |
| 602500 | 16.0272 | 21.561  | 102   | 7900.82 | 202  |
| 604000 | 52.7612 | 60.4063 | 192   | 9341.35 | 447  |
| 604070 | 2.3768  | 3.288   | 7.5   | 163.56  | 0.51 |
| 604080 | 2.618   | 3.4172  | 7     | 522.71  | 1.52 |
| 604090 | 2.1348  | 2.8574  | 9.5   | 2157.7  | 6.02 |

|        |         |         |       |         |      |
|--------|---------|---------|-------|---------|------|
| 604100 | 3.1152  | 4.1806  | 15.25 | 2650.73 | 10.1 |
| 605555 | 11.3462 | 13.9447 | 74    | 2131.63 | 31.9 |
| 606500 | 73.5825 | 92.8786 | 198   | 2365.22 | 205  |

| STATION | CONTRDA | SLOPE | LENGTH | ELEV | STORAGE |
|---------|---------|-------|--------|------|---------|
| 24300   | 55.5    | 6.02  | 11.8   | 450  | 0       |
| 24500   | 383     | 3.81  | 37.4   | 410  | 3.51    |
| 25500   | 480     | 3.65  | 44.5   | 430  | 9.58    |
| 26500   | 110     | 3.72  | 24.3   | 400  | 0       |
| 27500   | 495     | 4.27  | 37.2   | 480  | 1.06    |
| 28500   | 73.5    | 6.42  | 16     | 390  | 0       |
| 28930   | 4.75    | 34.32 | 3.5    | 480  | 0.42    |
| 28935   | 1.08    | 52.8  | 1.8    | 470  | 0       |
| 28940   | 7.87    | 26.93 | 4.56   | 470  | 0.54    |
| 28950   | 13.3    | 18.48 | 6.78   | 450  | 0.62    |
| 29000   | 369     | 3.86  | 47.3   | 420  | 2.04    |
| 30500   | 503     | 3.03  | 58.9   | 490  | 0.02    |
| 130900  | 108     | 10.2  | 29.7   | 410  | 2.6     |
| 131150  | 27.4    | 4.1   | 13     | 110  | 10      |
| 135500  | 401     | 3.7   | 27.9   | 200  | 13      |
| 147500  | 194     | 9     | 27.4   | 490  | 0.9     |
| 148300  | 38.1    | 11.8  | 10.6   | 300  | 8.4     |
| 154500  | 116     | 29.1  | 31.2   | 1200 | 1.2     |
| 157500  | 68.3    | 11.7  | 22.8   | 980  | 2.1     |
| 158000  | 162     | 12.4  | 26.6   | 880  | 1.9     |
| 158500  | 106     | 9.3   | 32.6   | 880  | 1.7     |
| 159000  | 174     | 9.7   | 49.6   | 790  | 1.5     |
| 160000  | 183     | 9.2   | 39.3   | 620  | 1.3     |
| 162010  | 48.9    | 13.1  | 16.5   | 430  | 1       |
| 162500  | 295     | 8.9   | 46.4   | 1380 | 2.1     |
| 163000  | 405     | 6     | 64.2   | 1240 | 1.8     |
| 165000  | 236     | 9.9   | 54.3   | 840  | 1.3     |
| 165200  | 29.5    | 14.6  | 17.2   | 750  | 0.3     |
| 169550  | 136     | 13.4  | 14.6   | 350  | 2.5     |
| 172500  | 198     | 8.2   | 31.7   | 480  | 3.6     |
| 175500  | 341     | 4.4   | 43.9   | 205  | 9.4     |
| 176500  | 203     | 5.3   | 19.8   | 120  | 10.2    |
| 184500  | 47.3    | 237   | 14.8   | 2460 | 0.9     |
| 185000  | 148     | 121   | 24.5   | 2550 | 1.1     |
| 185200  | 72      | 21    | 14.5   | 1290 | 0.2     |
| 197300  | 87      | 13.1  | 10.8   | 375  | 1.5     |
| 313600  | 0.95    | 73.92 | 1.55   | 790  | 0       |
| 342933  | 112     | 13.9  | 19.2   | 358  | 0       |
| 343300  | 146     | 8.2   | 24.4   | 332  | 1       |
| 399800  | 15.4    | 32.4  | 9.53   | 1020 | 0       |
| 404400  | 481     | 6.7   | 49.3   | 600  | 0       |
| 407900  | 12.7    | 33    | 7.35   | 640  | 0       |
| 408500  | 382     | 7.06  | 46.2   | 1800 | 0       |
| 410000  | 4.91    | 69    | 3.6    | 550  | 1       |

|        |      |        |       |      |      |
|--------|------|--------|-------|------|------|
| 412320 | 1.79 | 99.7   | 2.88  | 1057 | 0    |
| 413400 | 6.87 | 41.8   | 5.9   | 1200 | 0    |
| 414500 | 196  | 37     | 37.6  | 1720 | 0.1  |
| 414800 | 7.97 | 67.2   | 4.5   | 860  | 0    |
| 416000 | 106  | 12.3   | 23.4  | 1300 | 0    |
| 417400 | 1.27 | 74.8   | 2.22  | 650  | 0    |
| 418000 | 51.6 | 14.6   | 20.1  | 1110 | 0.04 |
| 420360 | 2.28 | 35.38  | 2.46  | 1100 | 0.05 |
| 420400 | 7.3  | 30.62  | 4.05  | 1090 | 0.15 |
| 424010 | 0.59 | 72.9   | 1.4   | 500  | 0    |
| 426800 | 39.1 | 31.85  | 9     | 960  | 0    |
| 427013 | 2.69 | 83.3   | 2.6   | 875  | 0    |
| 427500 | 262  | 6.36   | 39.2  | 800  | 0    |
| 427830 | 0.17 | 100.32 | 0.56  | 870  | 0    |
| 427840 | 3.54 | 73.92  | 4.58  | 940  | 0    |
| 428300 | 13.2 | 24.5   | 5.5   | 212  | 0    |
| 430400 | 12   | 30.58  | 4.34  | 740  | 0.12 |
| 431000 | 64   | 11.4   | 17    | 660  | 0    |
| 431520 | 4.13 | 69.26  | 4.45  | 730  | 0.09 |
| 431700 | 24.3 | 32.97  | 7.9   | 600  | 0    |
| 435030 | 15.1 | 27.98  | 6.7   | 860  | 0    |
| 435600 | 3.5  | 51.74  | 3.52  | 840  | 0.13 |
| 436700 | 124  | 12.3   | 25.7  | 670  | 0    |
| 437800 | 13.1 | 35.2   | 6.25  | 724  | 0    |
| 450200 | 13   | 26.8   | 6.84  | 582  | 0    |
| 453900 | 4.7  | 49     | 3.98  | 510  | 0    |
| 455000 | 303  | 6.4    | 58.4  | 880  | 0    |
| 464000 | 223  | 5.2    | 34.5  | 440  | 0    |
| 465205 | 3.65 | 47.5   | 2.94  | 260  | 0    |
| 467000 | 220  | 4.21   | 50.4  | 1380 | 0    |
| 469736 | 7.25 | 25.8   | 4.4   | 252  | 0    |
| 485500 | 137  | 58.9   | 28.4  | 2950 | 0    |
| 486225 | 3.48 | 124.83 | 3.87  | 1780 | 0    |
| 491000 | 47.3 | 14.4   | 20.1  | 1470 | 0    |
| 497300 | 106  | 101.5  | 23.85 | 3060 | 0    |
| 498500 | 269  | 53.6   | 42.7  | 1960 | 0.06 |
| 518500 | 118  | 90.5   | 27.8  | 2350 | 0    |
| 519610 | 2.1  | 63.36  | 2.22  | 1050 | 0    |
| 519630 | 1.46 | 100.32 | 1.19  | 970  | 4.16 |
| 519650 | 3.65 | 29.57  | 4.07  | 990  | 0    |
| 535000 | 68.5 | 15.2   | 26.4  | 1200 | 0    |
| 535140 | 1.23 | 52.8   | 1.72  | 1190 | 0    |
| 535160 | 14.1 | 15.84  | 6.78  | 1210 | 0    |
| 535180 | 3.23 | 58.08  | 4.58  | 1200 | 0.27 |
| 538225 | 82.5 | 13.22  | 20.2  | 1120 | 0    |
| 538250 | 19.5 | 12.87  | 12.65 | 910  | 0    |
| 538900 | 3.8  | 45.41  | 3.67  | 1910 | 1.05 |
| 539100 | 1.1  | 40.13  | 1.66  | 1890 | 0    |
| 539600 | 139  | 8.65   | 39.6  | 1810 | 0.5  |
| 539800 | 518  | 17.2   | 56.3  | 1680 | 0.16 |

|        |      |        |       |      |      |
|--------|------|--------|-------|------|------|
| 543500 | 117  | 11.5   | 22.7  | 900  | 0    |
| 556000 | 26.9 | 25.3   | 10.5  | 1790 | 0    |
| 565300 | 31.8 | 14.3   | 10.6  | 840  | 0    |
| 565500 | 57   | 7.49   | 40.5  | 940  | 0    |
| 566420 | 18.8 | 16.58  | 7.8   | 900  | 0    |
| 567500 | 428  | 5.58   | 46.2  | 950  | 0    |
| 568500 | 50.6 | 14.9   | 17    | 1375 | 0    |
| 571000 | 384  | 3.29   | 89.2  | 1390 | 0    |
| 575830 | 49   | 15.2   | 16.7  | 760  | 1    |
| 576250 | 119  | 10.6   | 26.5  | 800  | 0    |
| 578000 | 65.6 | 78.3   | 15.5  | 1660 | 0    |
| 585380 | 5.92 | 23     | 5.75  | 810  | 0    |
| 588400 | 43   | 15.13  | 18.94 | 870  | 0    |
| 588500 | 348  | 8.16   | 44.1  | 850  | 0    |
| 596000 | 107  | 13.9   | 24.8  | 1090 | 0.16 |
| 597300 | 4.99 | 49.63  | 4.2   | 1045 | 0    |
| 597400 | 9.59 | 31.68  | 6.08  | 1030 | 0    |
| 597450 | 0.73 | 132    | 1.7   | 1030 | 0    |
| 598000 | 481  | 6.11   | 74    | 990  | 0.07 |
| 600500 | 17.5 | 40.4   | 7.1   | 930  | 0    |
| 602500 | 202  | 11.5   | 24.6  | 740  | 0.03 |
| 604000 | 447  | 5.08   | 71.1  | 860  | 0.02 |
| 604070 | 0.51 | 200.48 | 0.87  | 870  | 0    |
| 604080 | 1.52 | 105.6  | 2.16  | 830  | 0    |
| 604090 | 6.02 | 73.92  | 3.14  | 840  | 0    |
| 604100 | 10.1 | 49.63  | 5.23  | 810  | 0    |
| 605555 | 31.9 | 19.76  | 20.3  | 650  | 0    |
| 606500 | 205  | 3.73   | 28.9  | 510  | 0.1  |

| STATION | FOREST | LAT    | LNG    | PRECIP | I24 |
|---------|--------|--------|--------|--------|-----|
| 24300   | 42.9   | 35.999 | 88.434 | 50     | 3.5 |
| 24500   | 18.2   | 36.118 | 88.811 | 51     | 3.5 |
| 25500   | 21.4   | 36.4   | 88.995 | 49     | 3.5 |
| 26500   | 26.7   | 36.442 | 89.296 | 49     | 3.5 |
| 27500   | 48.3   | 35.594 | 88.814 | 52     | 4.1 |
| 28500   | 13.5   | 35.98  | 88.926 | 52     | 3.8 |
| 28930   | 13.8   | 35.807 | 88.802 | 52     | 3.5 |
| 28935   | 4.4    | 35.793 | 88.791 | 52     | 3.5 |
| 28940   | 12.3   | 35.794 | 88.81  | 52     | 3.5 |
| 28950   | 14.1   | 35.769 | 88.833 | 52     | 3.5 |
| 29000   | 25     | 35.851 | 89.067 | 52     | 3.8 |
| 30500   | 36.8   | 35.054 | 89.541 | 53     | 4   |
| 130900  | 80     | 34.52  | 80.18  | 46     | 3.7 |
| 131150  | 40     | 34.28  | 79.44  | 45     | 4.2 |
| 135500  | 50     | 33.9   | 80.17  | 44     | 3.7 |
| 147500  | 58     | 34.56  | 80.92  | 44     | 3.5 |
| 148300  | 92     | 34.01  | 80.73  | 48     | 3.7 |
| 154500  | 79     | 35.12  | 81.99  | 52     | 4   |
| 157500  | 50     | 34.94  | 82.13  | 52     | 4.5 |

|        |      |        |        |    |      |
|--------|------|--------|--------|----|------|
| 158000 | 46   | 34.8   | 81.97  | 52 | 4    |
| 158500 | 65   | 34.88  | 82.09  | 56 | 4.5  |
| 159000 | 58   | 34.76  | 81.94  | 52 | 4    |
| 160000 | 44   | 34.68  | 81.69  | 46 | 3.5  |
| 162010 | 88   | 34.2   | 81.1   | 46 | 3.6  |
| 162500 | 89   | 34.84  | 82.48  | 64 | 4.5  |
| 163000 | 74   | 34.67  | 82.47  | 60 | 4.5  |
| 165000 | 24   | 34.44  | 82.18  | 52 | 4    |
| 165200 | 62   | 34.52  | 82.16  | 49 | 3.5  |
| 169550 | 84   | 33.94  | 81.08  | 44 | 3.7  |
| 172500 | 55   | 33.74  | 80.96  | 44 | 3.5  |
| 175500 | 35   | 32.99  | 81.05  | 44 | 3.7  |
| 176500 | 59   | 32.84  | 81.13  | 44 | 4    |
| 184500 | 95   | 34.97  | 82.94  | 72 | 5.7  |
| 185000 | 96   | 34.96  | 82.91  | 72 | 5.5  |
| 185200 | 91   | 34.84  | 82.98  | 70 | 5    |
| 197300 | 79   | 33.38  | 81.62  | 44 | 3.7  |
| 313600 | 22.5 | 36.559 | 86.457 | 51 | 3.4  |
| 342933 | 5    | 32.017 | 85.296 | 52 | 4.4  |
| 343300 | 60   | 31.47  | 85.16  | 53 | 4.7  |
| 399800 | 95   | 33.915 | 85.466 | 52 | 3.8  |
| 404400 | 3.2  | 33.548 | 86.097 | 54 | 4.03 |
| 407900 | 90   | 33.039 | 86.425 | 54 | 4.3  |
| 408500 | 90   | 36.386 | 84.555 | 54 | 3.3  |
| 410000 | 84   | 32.682 | 86.128 | 52 | 4.45 |
| 412320 | 100  | 33.463 | 85.776 | 52 | 4    |
| 413400 | 70   | 33.332 | 85.361 | 52 | 4    |
| 414500 | 92   | 36.416 | 85.026 | 53 | 3.3  |
| 414800 | 90   | 33.119 | 85.945 | 54 | 4.1  |
| 416000 | 88.9 | 36.56  | 85.073 | 53 | 3.4  |
| 417400 | 90   | 32.715 | 86.089 | 52 | 4.3  |
| 418000 | 51.3 | 36.341 | 85.426 | 54 | 3.6  |
| 420360 | 32.7 | 35.603 | 86.026 | 51 | 3.6  |
| 420400 | 29.7 | 35.623 | 86     | 51 | 3.6  |
| 424010 | 100  | 32.883 | 86.997 | 54 | 4.4  |
| 426800 | 69.2 | 35.828 | 86.077 | 53 | 3.5  |
| 427013 | 10   | 32.295 | 87.339 | 54 | 4.6  |
| 427500 | 33.9 | 35.918 | 86.334 | 53 | 3.6  |
| 427830 | 63.2 | 35.677 | 86.363 | 52 | 3.5  |
| 427840 | 46.3 | 35.693 | 86.364 | 52 | 3.5  |
| 428300 | 90   | 31.799 | 87.305 | 56 | 4.8  |
| 430400 | 62.2 | 35.959 | 86.675 | 47 | 3.5  |
| 431000 | 36.4 | 36.082 | 86.681 | 47 | 3.5  |
| 431520 | 72   | 36.301 | 86.81  | 47 | 3.4  |
| 431700 | 15   | 36.151 | 86.854 | 48 | 3.5  |
| 435030 | 13.3 | 36.557 | 86.571 | 48 | 3.3  |
| 435600 | 10.6 | 36.448 | 86.715 | 48 | 3.3  |
| 436700 | 69.6 | 36.349 | 87.539 | 50 | 3.5  |
| 437800 | 75   | 34.167 | 87.783 | 55 | 3.8  |
| 450200 | 75   | 33.953 | 87.004 | 54 | 3.9  |

|        |      |        |        |      |      |
|--------|------|--------|--------|------|------|
| 453900 | 100  | 33.891 | 87.45  | 54   | 4    |
| 455000 | 20   | 34.024 | 86.574 | 53   | 3.9  |
| 464000 | 85   | 33.479 | 87.597 | 53   | 4.2  |
| 465205 | 75   | 33.225 | 87.697 | 54   | 4.2  |
| 467000 | 42.9 | 36.201 | 83.048 | 42   | 3.3  |
| 469736 | 75   | 31.772 | 88.328 | 58   | 4.8  |
| 485500 | 64.9 | 36.344 | 82.21  | 50   | 2.6  |
| 486225 | 34.5 | 36.317 | 82.278 | 46   | 2.6  |
| 491000 | 58.1 | 36.426 | 82.952 | 44   | 3    |
| 497300 | 100  | 35.664 | 83.711 | 70   | 3.5  |
| 498500 | 73.7 | 35.786 | 83.884 | 59   | 3.5  |
| 518500 | 98   | 35.362 | 84.279 | 64   | 3.5  |
| 519610 | 27.3 | 35.699 | 84.046 | 51   | 3.5  |
| 519630 | 37.5 | 35.698 | 84.104 | 51   | 3.5  |
| 519650 | 32.4 | 35.656 | 84.104 | 51   | 3.5  |
| 535000 | 61.8 | 36.114 | 83.988 | 48   | 3.4  |
| 535140 | 33.3 | 36.114 | 83.854 | 49   | 3.4  |
| 535160 | 41.4 | 36.083 | 83.907 | 49   | 3.4  |
| 535180 | 44.7 | 36.1   | 83.907 | 49   | 3.4  |
| 538225 | 67.5 | 35.999 | 84.34  | 56   | 3.5  |
| 538250 | 24.2 | 35.966 | 84.358 | 52   | 3.5  |
| 538900 | 86.7 | 35.798 | 85.042 | 52   | 3.6  |
| 539100 | 67.3 | 35.894 | 85.061 | 51   | 3.6  |
| 539600 | 83.2 | 35.998 | 84.823 | 52   | 3.5  |
| 539800 | 90.4 | 36.081 | 84.671 | 52   | 3.5  |
| 543500 | 31   | 35.581 | 84.748 | 53   | 3.5  |
| 556000 | 70.4 | 35.132 | 84.344 | 58   | 3.5  |
| 565300 | 39.4 | 35.167 | 84.716 | 53   | 3.5  |
| 565500 | 22.6 | 35.327 | 84.705 | 53   | 3.5  |
| 566420 | 51.2 | 35.062 | 85.066 | 53   | 3.5  |
| 567500 | 52.2 | 35.014 | 85.207 | 54   | 4    |
| 568500 | 73.1 | 34.97  | 85.33  | 52.5 | 3.5  |
| 571000 | 73.8 | 35.206 | 85.497 | 56   | 3.5  |
| 575830 | 10   | 34.697 | 86.7   | 49   | 3.66 |
| 576250 | 20   | 34.752 | 86.823 | 50   | 3.8  |
| 578000 | 84.6 | 35.297 | 85.87  | 58   | 3.5  |
| 585380 | 15   | 34.973 | 87.285 | 52   | 3.7  |
| 588400 | 45.4 | 35.134 | 87.529 | 55   | 3.8  |
| 588500 | 33.3 | 35.024 | 87.579 | 54   | 3.8  |
| 596000 | 55.2 | 35.471 | 86.122 | 52   | 3.5  |
| 597300 | 41   | 35.629 | 86.356 | 52   | 3.5  |
| 597400 | 46.7 | 35.606 | 86.352 | 52   | 3.5  |
| 597450 | 31.2 | 35.609 | 86.32  | 52   | 3.5  |
| 598000 | 29.9 | 35.48  | 86.499 | 53   | 3.5  |
| 600500 | 71.1 | 35.489 | 87.233 | 52   | 3.7  |
| 602500 | 66.7 | 35.871 | 87.501 | 50   | 3.6  |
| 604000 | 63.3 | 35.496 | 87.833 | 53   | 3.8  |
| 604070 | 92.5 | 35.569 | 87.667 | 52   | 3.8  |
| 604080 | 97.4 | 35.583 | 87.677 | 52   | 3.8  |
| 604090 | 95.9 | 35.589 | 87.686 | 52   | 3.8  |

|        |      |        |        |    |     |
|--------|------|--------|--------|----|-----|
| 604100 | 99.3 | 35.606 | 87.712 | 52 | 3.8 |
| 605555 | 48.6 | 36.052 | 87.907 | 51 | 3.4 |
| 606500 | 43.5 | 36.039 | 88.228 | 52 | 3.4 |

| STATION | Q25R<br>Measured | Q25R<br>Predicted | T25R<br>Measured | T25R<br>Predicted |
|---------|------------------|-------------------|------------------|-------------------|
| 24300   | 286.31           | 461.06            | 6.2179           | 5.5799            |
| 24500   | 749.33           | 1183.34           | 36.5122          | 13.8396           |
| 25500   | 946.7            | 1325.42           | 3.9086           | 15.3434           |
| 26500   | 1067.88          | 583.88            | 3.7457           | 8.431             |
| 27500   | 999.18           | 1414.73           | 14.3353          | 14.8552           |
| 28500   | 366.78           | 550.37            | 8.155            | 6.1347            |
| 28930   | 418.68           | 197.98            | 0.8217           | 1.2622            |
| 28935   | 193.75           | 98.48             | 0.3528           | 0.6148            |
| 28940   | 554.96           | 243.95            | 0.7693           | 1.6576            |
| 28950   | 882.27           | 291.75            | 1.6236           | 2.2797            |
| 29000   | 808.09           | 1163.53           | 11.3483          | 13.583            |
| 30500   | 1277.32          | 1285.36           | 24.7188          | 16.4876           |
| 130900  | 275.38           | 786.66            | 8.0916           | 6.2774            |
| 131150  | 154.24           | 276.04            | 5.4137           | 4.6852            |
| 135500  | 1150.16          | 1203.36           | 14.4318          | 14.2162           |
| 147500  | 1315.88          | 1051.27           | 9.5227           | 8.2361            |
| 148300  | 196.65           | 458.74            | 6.8974           | 3.9582            |
| 154500  | 870.6            | 1128.19           | 12.2419          | 4.7915            |
| 157500  | 507.04           | 634.59            | 14.0571          | 5.0193            |
| 158000  | 767.92           | 1048.09           | 19.8714          | 6.9906            |
| 158500  | 715.46           | 756.79            | 21.2305          | 6.3966            |
| 159000  | 880.05           | 1012.01           | 6.5879           | 7.7165            |
| 160000  | 728.64           | 1024.3            | 6.1661           | 7.9945            |
| 162010  | 808.55           | 544.73            | 2.5789           | 4.2482            |
| 162500  | 1286.8           | 1325.05           | 5.2335           | 9.7817            |
| 163000  | 1600.94          | 1402.82           | 6.1448           | 12.4355           |
| 165000  | 1147.85          | 1207.99           | 14.3129          | 8.6736            |
| 165200  | 212.92           | 424.21            | 12.7992          | 3.3604            |
| 169550  | 427.75           | 973.02            | 13.7523          | 6.3726            |
| 172500  | 759.7            | 1033.53           | 26.8735          | 8.5275            |
| 175500  | 458.15           | 1158.67           | 17.9839          | 12.676            |
| 176500  | 459.7            | 917.15            | 18.3497          | 9.7548            |
| 184500  | 636.88           | 1295.83           | 1.388            | 1.836             |
| 185000  | 1981.34          | 1999.37           | 2.9104           | 3.5208            |
| 185200  | 934.72           | 781.63            | 1.6035           | 4.3396            |
| 197300  | 605.87           | 752.3             | 4.6736           | 5.3577            |
| 313600  | 97.22            | 101.58            | 0.5465           | 0.5304            |
| 342933  | 1163.43          | 882.54            | 7.2263           | 5.832             |
| 343300  | 945.22           | 871.32            | 3.9891           | 7.5428            |
| 399800  | 225.23           | 376.04            | 2.5809           | 2.0606            |
| 404400  | 2045.82          | 1597.75           | 6.9336           | 12.9146           |
| 407900  | 284.19           | 339.44            | 1.2557           | 1.8968            |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 408500 | 2397.56 | 1426.84 | 12.4844 | 11.5956 |
| 410000 | 390.25  | 249.7   | 0.9926  | 1.0483  |
| 412320 | 86.57   | 158.75  | 1.2435  | 0.6286  |
| 413400 | 308.81  | 258.59  | 2.31167 | 1.3844  |
| 414500 | 2339.14 | 1656.77 | 7.63141 | 5.5944  |
| 414800 | 571.49  | 324.94  | 1.91926 | 1.2837  |
| 416000 | 1068.49 | 824.33  | 8.19289 | 5.9065  |
| 417400 | 118.1   | 119.96  | 1.89016 | 0.5942  |
| 418000 | 392.2   | 735.17  | 2.71814 | 4.9891  |
| 420360 | 124.87  | 132.45  | 0.55478 | 0.9311  |
| 420400 | 200.24  | 243.26  | 2.97203 | 1.5504  |
| 424010 | 68.12   | 77.46   | 0.55337 | 0.4396  |
| 426800 | 542.61  | 630.55  | 3.01934 | 3.0136  |
| 427013 | 172.98  | 188.79  | 1.1032  | 0.7796  |
| 427500 | 1833.49 | 1118.78 | 7.3312  | 10.2629 |
| 427830 | 31.14   | 42.52   | 0.3151  | 0.2432  |
| 427840 | 344.94  | 212.3   | 0.9032  | 0.901   |
| 428300 | 256.84  | 316.67  | 5.6416  | 2.0972  |
| 430400 | 1067.5  | 321.25  | 1.3236  | 1.8946  |
| 431000 | 958.11  | 607.04  | 4.9686  | 4.9259  |
| 431520 | 365.82  | 226.89  | 0.5363  | 0.9767  |
| 431700 | 1625.25 | 488.15  | 1.4742  | 2.4639  |
| 435030 | 674.92  | 355.61  | 2.211   | 2.1317  |
| 435600 | 333.85  | 189.15  | 0.5933  | 0.9929  |
| 436700 | 1123.97 | 900.05  | 6.1239  | 6.2916  |
| 437800 | 214.72  | 352.27  | 4.4467  | 1.8856  |
| 450200 | 236.25  | 322.71  | 1.0557  | 2.0317  |
| 453900 | 143.71  | 219.45  | 1.1783  | 1.1355  |
| 455000 | 2292.43 | 1216.07 | 7.5204  | 10.8623 |
| 464000 | 1104.31 | 961.13  | 8.5133  | 10.1862 |
| 465205 | 120.28  | 188.66  | 1.3898  | 1.0347  |
| 467000 | 1492.69 | 894.21  | 8.717   | 10.7596 |
| 469736 | 288.62  | 229.96  | 0.7548  | 1.6234  |
| 485500 | 1106.34 | 1536.39 | 4.7087  | 4.1906  |
| 486225 | 504.93  | 298.3   | 0.2518  | 0.8831  |
| 491000 | 700.28  | 550.36  | 3.4011  | 4.0802  |
| 497300 | 1305.53 | 1571.55 | 6.2835  | 3.2361  |
| 498500 | 2285.18 | 2178.65 | 3.5186  | 5.6489  |
| 518500 | 1323.93 | 1611.38 | 2.2818  | 3.4912  |
| 519610 | 165.88  | 151.15  | 0.3341  | 0.7629  |
| 519630 | 82.98   | 141.89  | 0.2539  | 0.5781  |
| 519650 | 138.57  | 163.21  | 0.5971  | 1.1844  |
| 535000 | 552.04  | 688.58  | 4.2619  | 4.6639  |
| 535140 | 139.97  | 105.93  | 0.2519  | 0.6479  |
| 535160 | 379.64  | 287.58  | 4.3431  | 2.4388  |
| 535180 | 139.28  | 187.34  | 0.9662  | 0.9301  |
| 538225 | 492.81  | 732.28  | 6.6121  | 5.2307  |
| 538250 | 280.62  | 323.66  | 2.0205  | 2.9485  |
| 538900 | 113.67  | 190.33  | 0.9848  | 1.0652  |
| 539100 | 43.07   | 91.49   | 1.6972  | 0.6698  |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 539600 | 1139.48 | 861.62  | 6.5062  | 7.2832  |
| 539800 | 4136.7  | 2221.93 | 6.4604  | 10.1697 |
| 543500 | 914.12  | 853.49  | 4.544   | 6.2651  |
| 556000 | 290.6   | 476.57  | 1.4994  | 2.7681  |
| 565300 | 348.83  | 439.64  | 2.5056  | 3.4841  |
| 565500 | 296.9   | 500.33  | 6.9025  | 5.2995  |
| 566420 | 314.37  | 342.63  | 3.1155  | 2.703   |
| 567500 | 1470.64 | 1415.17 | 13.6769 | 12.9811 |
| 568500 | 483.05  | 577.56  | 9.6099  | 4.1519  |
| 571000 | 1360.42 | 1162.54 | 11.9059 | 14.7151 |
| 575830 | 751.85  | 570.72  | 4.1408  | 4.0753  |
| 576250 | 1103.34 | 840.43  | 4.0498  | 6.4563  |
| 578000 | 425.27  | 1109.4  | 10.437  | 2.8722  |
| 585380 | 209.63  | 198.18  | 1.2709  | 1.546   |
| 588400 | 650.54  | 529.69  | 4.6071  | 3.8715  |
| 588500 | 3067.2  | 1415.52 | 8.8059  | 10.7167 |
| 596000 | 1111.03 | 860.24  | 2.6492  | 5.7257  |
| 597300 | 404.02  | 227.83  | 7.0165  | 1.159   |
| 597400 | 489.2   | 286.41  | 1.0505  | 1.7137  |
| 597450 | 98.63   | 104.64  | 0.3368  | 0.4044  |
| 598000 | 1951.64 | 1553.35 | 16.1748 | 13.2585 |
| 600500 | 350.53  | 432.16  | 3.5368  | 2.0372  |
| 602500 | 1975.2  | 1159.04 | 3.0803  | 7.8062  |
| 604000 | 2335.34 | 1409.01 | 20.6793 | 13.5685 |
| 604070 | 40.89   | 97.26   | 0.4742  | 0.3107  |
| 604080 | 130.68  | 147.42  | 0.7181  | 0.579   |
| 604090 | 539.43  | 285.87  | 0.5062  | 1.1158  |
| 604100 | 662.68  | 338.22  | 1.073   | 1.5396  |
| 605555 | 532.91  | 486.19  | 2.7685  | 3.1813  |
| 606500 | 591.31  | 828.29  | 10.9267 | 10.8251 |

| STATION | Q50R<br>Measured | Q50R<br>Predicted | T50R<br>Measured | T50R<br>Predicted |
|---------|------------------|-------------------|------------------|-------------------|
| 24300   | 572.61           | 922.11            | 9.1814           | 8.9034            |
| 24500   | 1498.67          | 2366.68           | 60.3614          | 22.1895           |
| 25500   | 1893.41          | 2650.84           | 9.484            | 24.6034           |
| 26500   | 2135.76          | 1167.76           | 7.7889           | 13.6596           |
| 27500   | 1998.37          | 2829.46           | 25.1754          | 23.657            |
| 28500   | 733.56           | 1100.75           | 16.04            | 9.7412            |
| 28930   | 837.36           | 395.97            | 1.1274           | 1.9057            |
| 28935   | 387.5            | 196.96            | 0.5207           | 0.9217            |
| 28940   | 1109.93          | 487.91            | 1.0452           | 2.5189            |
| 28950   | 1764.54          | 583.49            | 1.9521           | 3.5061            |
| 29000   | 1616.18          | 2327.06           | 14.6868          | 21.7722           |
| 30500   | 2554.64          | 2570.72           | 34.7002          | 26.6385           |
| 130900  | 550.76           | 1573.33           | 34.4853          | 9.7455            |
| 131150  | 308.49           | 552.08            | 7.5572           | 7.6393            |
| 135500  | 2300.31          | 2406.72           | 23.3106          | 22.8138           |
| 147500  | 2631.75          | 2102.55           | 15.7842          | 12.7978           |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 148300 | 393.29  | 917.49  | 10.3193 | 6.1554  |
| 154500 | 1741.19 | 2256.38 | 21.2282 | 7.1112  |
| 157500 | 1014.08 | 1269.18 | 18.289  | 7.774   |
| 158000 | 1535.85 | 2096.18 | 24.957  | 10.7303 |
| 158500 | 1430.92 | 1513.58 | 23.7777 | 9.971   |
| 159000 | 1760.09 | 2024.01 | 12.5528 | 11.9621 |
| 160000 | 1457.28 | 2048.61 | 11.4039 | 12.4163 |
| 162010 | 1617.09 | 1089.46 | 3.8308  | 6.5648  |
| 162500 | 2573.6  | 2650.1  | 8.2694  | 15.1585 |
| 163000 | 3201.87 | 2805.64 | 9.8471  | 19.5494 |
| 165000 | 2295.7  | 2415.99 | 22.3541 | 13.4033 |
| 165200 | 425.85  | 848.43  | 15.5465 | 5.1888  |
| 169550 | 855.51  | 1946.05 | 22.2821 | 9.7623  |
| 172500 | 1519.4  | 2067.06 | 35.4412 | 13.3009 |
| 175500 | 916.31  | 2317.34 | 29.8557 | 20.2177 |
| 176500 | 919.39  | 1834.31 | 24.7274 | 15.4968 |
| 184500 | 1273.76 | 2591.67 | 2.5013  | 2.5098  |
| 185000 | 3962.69 | 3998.73 | 3.7163  | 4.9095  |
| 185200 | 1869.43 | 1563.25 | 2.5772  | 6.5538  |
| 197300 | 1211.73 | 1504.61 | 6.1964  | 8.2433  |
| 313600 | 194.44  | 203.17  | 0.745   | 0.7847  |
| 342933 | 2326.85 | 1765.09 | 10.1747 | 8.9335  |
| 343300 | 1890.43 | 1742.64 | 5.742   | 11.7921 |
| 399800 | 450.46  | 752.08  | 3.6449  | 3.0911  |
| 404400 | 4091.65 | 3195.5  | 9.6637  | 20.1814 |
| 407900 | 568.38  | 678.87  | 2.294   | 2.8472  |
| 408500 | 4795.12 | 2853.68 | 17.4259 | 18.1116 |
| 410000 | 780.51  | 499.4   | 1.3592  | 1.536   |
| 412320 | 173.15  | 317.51  | 1.8806  | 0.9138  |
| 413400 | 617.62  | 517.18  | 2.7659  | 2.067   |
| 414500 | 4678.27 | 3313.55 | 9.9971  | 8.1841  |
| 414800 | 1142.97 | 649.88  | 2.2288  | 1.8763  |
| 416000 | 2136.99 | 1648.65 | 10.9615 | 9.0984  |
| 417400 | 236.2   | 239.92  | 2.1401  | 0.8767  |
| 418000 | 784.41  | 1470.34 | 4.8388  | 7.6467  |
| 420360 | 249.74  | 264.89  | 0.9621  | 1.4118  |
| 420400 | 400.48  | 486.51  | 4.0152  | 2.3444  |
| 424010 | 136.24  | 154.91  | 0.7968  | 0.653   |
| 426800 | 1085.22 | 1261.1  | 4.3534  | 4.4922  |
| 427013 | 345.97  | 377.59  | 1.4367  | 1.1385  |
| 427500 | 3666.99 | 2237.55 | 11.1463 | 16.1471 |
| 427830 | 62.29   | 85.05   | 0.4581  | 0.3597  |
| 427840 | 689.87  | 424.6   | 1.1022  | 1.3196  |
| 428300 | 513.67  | 633.34  | 8.1872  | 3.1872  |
| 430400 | 2135    | 642.51  | 1.5586  | 2.8545  |
| 431000 | 1916.22 | 1214.08 | 7.2445  | 7.6416  |
| 431520 | 731.65  | 453.78  | 0.6998  | 1.4328  |
| 431700 | 3250.5  | 976.3   | 1.845   | 3.6805  |
| 435030 | 1349.85 | 711.22  | 2.6762  | 3.2181  |
| 435600 | 667.71  | 378.31  | 0.7712  | 1.4766  |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 436700 | 2247.95 | 1800.11 | 8.5322  | 9.6802  |
| 437800 | 429.44  | 704.54  | 6.0585  | 2.822   |
| 450200 | 472.5   | 645.41  | 2.5679  | 3.0763  |
| 453900 | 287.42  | 438.9   | 1.7149  | 1.6888  |
| 455000 | 4584.87 | 2432.14 | 13.0929 | 17.0669 |
| 464000 | 2208.62 | 1922.25 | 11.0461 | 16.1837 |
| 465205 | 240.56  | 377.32  | 1.9559  | 1.5439  |
| 467000 | 2985.38 | 1788.43 | 12.5909 | 17.2503 |
| 469736 | 577.24  | 459.91  | 1.286   | 2.473   |
| 485500 | 2212.69 | 3072.78 | 6.2864  | 6.0283  |
| 486225 | 1009.87 | 596.59  | 0.5143  | 1.2619  |
| 491000 | 1400.57 | 1100.73 | 4.9673  | 6.2814  |
| 497300 | 2611.06 | 3143.11 | 7.537   | 4.5578  |
| 498500 | 4570.37 | 4357.29 | 6.2205  | 8.1173  |
| 518500 | 2647.85 | 3222.76 | 3.4508  | 4.9372  |
| 519610 | 331.76  | 302.29  | 0.6685  | 1.1292  |
| 519630 | 165.96  | 283.78  | 0.5098  | 0.8414  |
| 519650 | 277.13  | 326.42  | 1.3204  | 1.8032  |
| 535000 | 1104.07 | 1377.16 | 7.6668  | 7.1437  |
| 535140 | 279.93  | 211.85  | 0.5037  | 0.9703  |
| 535160 | 759.29  | 575.15  | 5.6577  | 3.7738  |
| 535180 | 278.56  | 374.68  | 1.4395  | 1.3773  |
| 538225 | 985.61  | 1464.57 | 10.604  | 8.048   |
| 538250 | 561.23  | 647.32  | 3.6212  | 4.5915  |
| 538900 | 227.34  | 380.65  | 1.804   | 1.5919  |
| 539100 | 86.13   | 182.99  | 2.1158  | 1.0157  |
| 539600 | 2278.96 | 1723.24 | 8.7142  | 11.3648 |
| 539800 | 8273.4  | 4443.86 | 8.3537  | 15.2601 |
| 543500 | 1828.23 | 1706.98 | 7.6763  | 9.6712  |
| 556000 | 581.2   | 953.15  | 3.4189  | 4.1785  |
| 565300 | 697.65  | 879.28  | 5.303   | 5.3815  |
| 565500 | 593.79  | 1000.65 | 12.328  | 8.3763  |
| 566420 | 628.74  | 685.26  | 4.8237  | 4.1654  |
| 567500 | 2941.27 | 2830.34 | 17.432  | 20.4614 |
| 568500 | 966.09  | 1155.12 | 11.8514 | 6.3793  |
| 571000 | 2720.84 | 2325.08 | 19.7007 | 23.7318 |
| 575830 | 1503.69 | 1141.44 | 7.3057  | 6.2578  |
| 576250 | 2206.69 | 1680.86 | 8.8603  | 9.9995  |
| 578000 | 850.54  | 2218.8  | 12.462  | 4.105   |
| 585380 | 419.25  | 396.37  | 1.6956  | 2.3702  |
| 588400 | 1301.08 | 1059.38 | 6.2519  | 5.952   |
| 588500 | 6134.4  | 2831.04 | 13.4662 | 16.6479 |
| 596000 | 2222.05 | 1720.49 | 5.2357  | 8.7737  |
| 597300 | 808.03  | 455.65  | 9.1562  | 1.722   |
| 597400 | 978.39  | 572.81  | 1.3047  | 2.5824  |
| 597450 | 197.25  | 209.28  | 0.5068  | 0.5848  |
| 598000 | 3903.28 | 3106.69 | 20.4734 | 20.8001 |
| 600500 | 701.06  | 864.32  | 4.6639  | 3.0246  |
| 602500 | 3950.41 | 2318.08 | 4.7115  | 12.0006 |
| 604000 | 4670.67 | 2818.02 | 28.3033 | 21.4657 |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 604070 | 81.78   | 194.51  | 0.638   | 0.4426  |
| 604080 | 261.35  | 294.85  | 1.1488  | 0.8407  |
| 604090 | 1078.85 | 571.74  | 0.8293  | 1.6277  |
| 604100 | 1325.36 | 676.44  | 1.4697  | 2.2754  |
| 605555 | 1065.81 | 972.37  | 4.3261  | 4.8466  |
| 606500 | 1182.61 | 1656.58 | 24.8971 | 17.4541 |

| STATION | Q75R<br>Measured | Q75R<br>Predicted | T75R<br>Measured | T75R<br>Predicted |
|---------|------------------|-------------------|------------------|-------------------|
| 24300   | 858.92           | 1383.17           | 14.115           | 11.7259           |
| 24500   | 2248.01          | 3550.02           | 73.3695          | 29.3757           |
| 25500   | 2840.11          | 3976.26           | 15.5007          | 32.5819           |
| 26500   | 3203.65          | 1751.64           | 9.8916           | 18.1762           |
| 27500   | 2997.55          | 4244.19           | 36.9113          | 31.195            |
| 28500   | 1100.33          | 1651.12           | 22.02            | 12.7945           |
| 28930   | 1256.03          | 593.95            | 1.3927           | 2.4179            |
| 28935   | 581.25           | 295.45            | 0.6353           | 1.1623            |
| 28940   | 1664.89          | 731.86            | 1.3677           | 3.2106            |
| 28950   | 2646.81          | 875.24            | 2.291            | 4.5053            |
| 29000   | 2424.27          | 3490.59           | 20.997           | 28.8171           |
| 30500   | 3831.95          | 3856.08           | 43.9509          | 35.4456           |
| 130900  | 826.14           | 2359.99           | 46.6785          | 12.6264           |
| 131150  | 462.73           | 828.12            | 9.9636           | 10.19             |
| 135500  | 3450.47          | 3610.09           | 32.0734          | 30.2206           |
| 147500  | 3947.62          | 3153.82           | 20.696           | 16.601            |
| 148300  | 589.94           | 1376.23           | 13.3734          | 7.9741            |
| 154500  | 2611.78          | 3384.57           | 24.8331          | 8.9583            |
| 157500  | 1521.11          | 1903.76           | 20.3671          | 10.0521           |
| 158000  | 2303.77          | 3144.28           | 30.8855          | 13.8102           |
| 158500  | 2146.38          | 2270.37           | 26.6656          | 12.951            |
| 159000  | 2640.14          | 3036.02           | 16.639           | 15.4922           |
| 160000  | 2185.91          | 3072.91           | 15.8998          | 16.1001           |
| 162010  | 2425.64          | 1634.2            | 4.6514           | 8.4733            |
| 162500  | 3860.41          | 3975.14           | 11.5078          | 19.6394           |
| 163000  | 4802.81          | 4208.46           | 13.2651          | 25.5655           |
| 165000  | 3443.55          | 3623.98           | 27.848           | 17.3303           |
| 165200  | 638.77           | 1272.64           | 17.2793          | 6.6902            |
| 169550  | 1283.26          | 2919.07           | 27.1059          | 12.5465           |
| 172500  | 2279.1           | 3100.58           | 40.3397          | 17.295            |
| 175500  | 1374.46          | 3476.01           | 49.0739          | 26.6744           |
| 176500  | 1379.09          | 2751.46           | 30.6774          | 20.3832           |
| 184500  | 1910.64          | 3887.5            | 3.555            | 3.0003            |
| 185000  | 5944.03          | 5998.1            | 4.58             | 5.9501            |
| 185200  | 2804.15          | 2344.88           | 3.4656           | 8.3422            |
| 197300  | 1817.59          | 2256.91           | 7.9005           | 10.6177           |
| 313600  | 291.66           | 304.75            | 0.9003           | 0.9812            |
| 342933  | 3490.28          | 2647.63           | 12.3627          | 11.4781           |
| 343300  | 2835.65          | 2613.96           | 11.0495          | 15.35             |
| 399800  | 675.7            | 1128.12           | 4.6792           | 3.9113            |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 404400 | 6137.47 | 4793.25 | 11.8544 | 26.2986 |
| 407900 | 852.57  | 1018.31 | 3.167   | 3.6034  |
| 408500 | 7192.69 | 4280.52 | 20.8529 | 23.5882 |
| 410000 | 1170.76 | 749.11  | 1.597   | 1.9128  |
| 412320 | 259.72  | 476.26  | 2.153   | 1.131   |
| 413400 | 926.44  | 775.77  | 3.1529  | 2.6054  |
| 414500 | 7017.41 | 4970.32 | 11.4483 | 10.224  |
| 414800 | 1714.46 | 974.81  | 2.4524  | 2.3341  |
| 416000 | 3205.48 | 2472.98 | 13.1537 | 11.7304 |
| 417400 | 354.3   | 359.89  | 2.3378  | 1.0947  |
| 418000 | 1176.61 | 2205.51 | 6.8361  | 9.8245  |
| 420360 | 374.61  | 397.34  | 1.4261  | 1.7945  |
| 420400 | 600.72  | 729.77  | 4.7017  | 2.9789  |
| 424010 | 204.36  | 232.37  | 0.9453  | 0.8182  |
| 426800 | 1627.83 | 1891.65 | 5.3527  | 5.6677  |
| 427013 | 518.95  | 566.38  | 1.8485  | 1.4138  |
| 427500 | 5500.48 | 3356.33 | 13.8063 | 21.1166 |
| 427830 | 93.43   | 127.57  | 0.6036  | 0.4489  |
| 427840 | 1034.8  | 636.9   | 1.2675  | 1.6423  |
| 428300 | 770.51  | 950.02  | 9.7769  | 4.0652  |
| 430400 | 3202.49 | 963.76  | 1.7597  | 3.6206  |
| 431000 | 2874.33 | 1821.12 | 8.9105  | 9.8899  |
| 431520 | 1097.47 | 680.68  | 0.8617  | 1.7852  |
| 431700 | 4875.74 | 1464.45 | 2.1486  | 4.6473  |
| 435030 | 2024.77 | 1066.83 | 3.0769  | 4.0881  |
| 435600 | 1001.56 | 567.46  | 0.9216  | 1.8551  |
| 436700 | 3371.92 | 2700.16 | 10.6565 | 12.4734 |
| 437800 | 644.16  | 1056.81 | 7.0435  | 3.565   |
| 450200 | 708.75  | 968.12  | 3.2427  | 3.9146  |
| 453900 | 431.14  | 658.35  | 2.0298  | 2.1226  |
| 455000 | 6877.3  | 3648.21 | 16.4482 | 22.3041 |
| 464000 | 3312.94 | 2883.38 | 14.497  | 21.2902 |
| 465205 | 360.84  | 565.97  | 2.4817  | 1.9438  |
| 467000 | 4478.06 | 2682.64 | 15.1486 | 22.822  |
| 469736 | 865.86  | 689.87  | 2.3969  | 3.1566  |
| 485500 | 3319.03 | 4609.16 | 7.7192  | 7.449   |
| 486225 | 1514.8  | 894.89  | 0.713   | 1.5469  |
| 491000 | 2100.85 | 1651.09 | 6.3837  | 8.0881  |
| 497300 | 3916.59 | 4714.66 | 8.7735  | 5.5563  |
| 498500 | 6855.55 | 6535.94 | 7.9067  | 10.0309 |
| 518500 | 3971.78 | 4834.14 | 4.693   | 6.0348  |
| 519610 | 497.64  | 453.44  | 0.8875  | 1.4137  |
| 519630 | 248.95  | 425.67  | 0.7935  | 1.042   |
| 519650 | 415.7   | 489.62  | 1.7413  | 2.299   |
| 535000 | 1656.1  | 2065.74 | 10.8372 | 9.173   |
| 535140 | 419.9   | 317.78  | 0.71    | 1.223   |
| 535160 | 1138.93 | 862.73  | 6.1686  | 4.8681  |
| 535180 | 417.84  | 562.01  | 1.682   | 1.7256  |
| 538225 | 1478.42 | 2196.85 | 14.4416 | 10.3657 |
| 538250 | 841.85  | 970.98  | 5.3485  | 5.9488  |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 538900 | 341.01  | 570.98  | 2.6519  | 2.0065  |
| 539100 | 129.2   | 274.48  | 2.4439  | 1.2901  |
| 539600 | 3418.44 | 2584.86 | 10.8534 | 14.7754 |
| 539800 | 12410.1 | 6665.8  | 9.9848  | 19.3892 |
| 543500 | 2742.34 | 2560.47 | 11.9653 | 12.4866 |
| 556000 | 871.8   | 1429.72 | 5.4761  | 5.3114  |
| 565300 | 1046.48 | 1318.92 | 7.1503  | 6.9406  |
| 565500 | 890.69  | 1500.98 | 17.657  | 10.9669 |
| 566420 | 943.1   | 1027.89 | 6.3148  | 5.3612  |
| 567500 | 4411.91 | 4245.51 | 26.6094 | 26.8044 |
| 568500 | 1449.14 | 1732.67 | 13.5273 | 8.2048  |
| 571000 | 4081.27 | 3487.62 | 24.2475 | 31.5345 |
| 575830 | 2255.54 | 1712.16 | 7.9852  | 8.0452  |
| 576250 | 3310.03 | 2521.29 | 12.3335 | 12.9378 |
| 578000 | 1275.81 | 3328.2  | 14.1482 | 5.0476  |
| 585380 | 628.88  | 594.55  | 2.18    | 3.0369  |
| 588400 | 1951.62 | 1589.07 | 7.4704  | 7.6566  |
| 588500 | 9201.6  | 4246.56 | 15.5474 | 21.6061 |
| 596000 | 3333.08 | 2580.73 | 7.4105  | 11.2747 |
| 597300 | 1212.05 | 683.48  | 10.8311 | 2.1632  |
| 597400 | 1467.59 | 859.22  | 1.6155  | 3.2751  |
| 597450 | 295.88  | 313.93  | 0.6507  | 0.7208  |
| 598000 | 5854.93 | 4660.04 | 27.5155 | 27.1711 |
| 600500 | 1051.6  | 1296.49 | 5.5515  | 3.803   |
| 602500 | 5925.61 | 3477.12 | 6.0791  | 15.4637 |
| 604000 | 7006.01 | 4227.03 | 31.4837 | 28.1857 |
| 604070 | 122.67  | 291.77  | 0.8039  | 0.5402  |
| 604080 | 392.03  | 442.27  | 1.4271  | 1.0395  |
| 604090 | 1618.27 | 857.61  | 1.0559  | 2.0218  |
| 604100 | 1988.05 | 1014.66 | 1.7394  | 2.8511  |
| 605555 | 1598.72 | 1458.56 | 5.5061  | 6.1973  |
| 606500 | 1773.92 | 2484.87 | 32.2192 | 23.1717 |

| STATION | QPEAK<br>Measured | QPEAK<br>Predicted | TPEAK<br>Measured | TPEAK<br>Predicted |
|---------|-------------------|--------------------|-------------------|--------------------|
| 24300   | 1145.22           | 1844.22            | 22                | 16.7031            |
| 24500   | 2997.34           | 4733.36            | 86                | 42.0508            |
| 25500   | 3786.81           | 5301.67            | 30                | 46.6536            |
| 26500   | 4271.53           | 2335.52            | 14                | 26.1673            |
| 27500   | 3996.74           | 5658.92            | 60                | 44.4682            |
| 28500   | 1467.11           | 2201.49            | 30                | 18.1723            |
| 28930   | 1674.71           | 791.93             | 1.75              | 3.3145             |
| 28935   | 775               | 393.93             | 0.75              | 1.5837             |
| 28940   | 2219.85           | 975.82             | 2                 | 4.4219             |
| 28950   | 3529.08           | 1166.98            | 3                 | 6.2569             |
| 29000   | 3232.36           | 4654.13            | 44                | 41.2425            |
| 30500   | 5109.27           | 5141.43            | 54                | 51.0073            |
| 130900  | 1101.52           | 3146.66            | 59                | 17.6772            |
| 131150  | 616.98            | 1104.17            | 16.5              | 14.7125            |

|        |         |         |      |         |
|--------|---------|---------|------|---------|
| 135500 | 4600.63 | 4813.45 | 45   | 43.2875 |
| 147500 | 5263.5  | 4205.1  | 27   | 23.2677 |
| 148300 | 786.59  | 1834.98 | 20   | 11.1657 |
| 154500 | 3482.38 | 4512.76 | 29   | 12.1788 |
| 157500 | 2028.15 | 2538.35 | 25   | 14.0456 |
| 158000 | 3071.7  | 4192.37 | 38   | 19.1987 |
| 158500 | 2861.84 | 3027.16 | 30   | 18.1796 |
| 159000 | 3520.18 | 4048.02 | 22   | 21.6781 |
| 160000 | 2914.55 | 4097.22 | 28   | 22.5572 |
| 162010 | 3234.19 | 2178.93 | 8    | 11.8184 |
| 162500 | 5147.21 | 5300.19 | 17   | 27.4884 |
| 163000 | 6403.74 | 5611.28 | 21   | 36.1302 |
| 165000 | 4591.4  | 4831.98 | 35   | 24.2066 |
| 165200 | 851.7   | 1696.85 | 25.5 | 9.3222  |
| 169550 | 1711.01 | 3892.09 | 36   | 17.4167 |
| 172500 | 3038.8  | 4134.11 | 48   | 24.301  |
| 175500 | 1832.62 | 4634.67 | 79   | 38.0496 |
| 176500 | 1838.79 | 3668.61 | 52   | 28.9862 |
| 184500 | 2547.52 | 5183.34 | 5    | 3.8622  |
| 185000 | 7925.37 | 7997.47 | 6    | 7.7679  |
| 185200 | 3738.86 | 3126.51 | 5    | 11.4663 |
| 197300 | 2423.46 | 3009.22 | 14   | 14.775  |
| 313600 | 388.88  | 406.33  | 1.25 | 1.3252  |
| 342933 | 4653.7  | 3530.18 | 17   | 15.9299 |
| 343300 | 3780.86 | 3485.29 | 17   | 21.5947 |
| 399800 | 900.93  | 1504.17 | 7    | 5.3448  |
| 404400 | 8183.3  | 6391    | 16   | 37.0271 |
| 407900 | 1136.76 | 1357.75 | 5    | 4.9254  |
| 408500 | 9590.25 | 5707.36 | 28   | 33.1935 |
| 410000 | 1561.01 | 998.81  | 2    | 2.5715  |
| 412320 | 346.3   | 635.01  | 2.5  | 1.5112  |
| 413400 | 1235.25 | 1034.37 | 4    | 3.5467  |
| 414500 | 9356.54 | 6627.1  | 14   | 13.7764 |
| 414800 | 2285.95 | 1299.75 | 3    | 3.134   |
| 416000 | 4273.97 | 3297.3  | 16   | 16.339  |
| 417400 | 472.4   | 479.85  | 2.75 | 1.4764  |
| 418000 | 1568.81 | 2940.68 | 10   | 13.6357 |
| 420360 | 499.47  | 529.79  | 2    | 2.4651  |
| 420400 | 800.96  | 973.03  | 5.75 | 4.0894  |
| 424010 | 272.48  | 309.82  | 1.25 | 1.1077  |
| 426800 | 2170.44 | 2522.2  | 8    | 7.7196  |
| 427013 | 691.94  | 755.18  | 2.75 | 1.8953  |
| 427500 | 7333.97 | 4475.1  | 20   | 29.8471 |
| 427830 | 124.57  | 170.09  | 0.75 | 0.6054  |
| 427840 | 1379.74 | 849.2   | 1.5  | 2.2065  |
| 428300 | 1027.35 | 1266.69 | 12   | 5.6018  |
| 430400 | 4269.99 | 1285.02 | 2.25 | 4.9605  |
| 431000 | 3832.44 | 2428.16 | 12   | 13.8325 |
| 431520 | 1463.29 | 907.57  | 1.25 | 2.4013  |
| 431700 | 6500.99 | 1952.6  | 2.75 | 6.3359  |

|        |         |         |      |         |
|--------|---------|---------|------|---------|
| 435030 | 2699.7  | 1422.44 | 3.75 | 5.6097  |
| 435600 | 1335.42 | 756.62  | 1.25 | 2.5173  |
| 436700 | 4495.89 | 3600.22 | 14   | 17.3629 |
| 437800 | 858.89  | 1409.08 | 8.5  | 4.8636  |
| 450200 | 945     | 1290.83 | 4    | 5.3812  |
| 453900 | 574.85  | 877.8   | 2.5  | 2.8813  |
| 455000 | 9169.73 | 4864.27 | 20   | 31.5016 |
| 464000 | 4417.25 | 3844.51 | 21   | 30.2807 |
| 465205 | 481.12  | 754.63  | 3.25 | 2.6435  |
| 467000 | 5970.75 | 3576.86 | 20   | 32.6517 |
| 469736 | 1154.48 | 919.83  | 4    | 4.3541  |
| 485500 | 4425.38 | 6145.55 | 12   | 9.924   |
| 486225 | 2019.74 | 1193.19 | 1    | 2.0457  |
| 491000 | 2801.14 | 2201.46 | 8    | 11.253  |
| 497300 | 5222.12 | 6286.22 | 10   | 7.2991  |
| 498500 | 9140.73 | 8714.59 | 12   | 13.3626 |
| 518500 | 5295.7  | 6445.52 | 6    | 7.9495  |
| 519610 | 663.52  | 604.59  | 1.25 | 1.9115  |
| 519630 | 331.93  | 567.56  | 1.25 | 1.3931  |
| 519650 | 554.26  | 652.83  | 2.5  | 3.1679  |
| 535000 | 2208.14 | 2754.31 | 16   | 12.7243 |
| 535140 | 559.87  | 423.71  | 1    | 1.6656  |
| 535160 | 1518.58 | 1150.3  | 7    | 6.7881  |
| 535180 | 557.11  | 749.35  | 2.5  | 2.3349  |
| 538225 | 1971.23 | 2929.13 | 22   | 14.4237 |
| 538250 | 1122.46 | 1294.64 | 8    | 8.3321  |
| 538900 | 454.68  | 761.31  | 4.25 | 2.7316  |
| 539100 | 172.26  | 365.97  | 3.25 | 1.7712  |
| 539600 | 4557.92 | 3446.47 | 14   | 20.7596 |
| 539800 | 16546.8 | 8887.73 | 14   | 26.5862 |
| 543500 | 3656.46 | 3413.95 | 18   | 17.4178 |
| 556000 | 1162.4  | 1906.3  | 10   | 7.2916  |
| 565300 | 1395.31 | 1758.56 | 10   | 9.6738  |
| 565500 | 1187.59 | 2001.31 | 28   | 15.5259 |
| 566420 | 1257.47 | 1370.52 | 10   | 7.4576  |
| 567500 | 5882.54 | 5660.68 | 40   | 37.9491 |
| 568500 | 1932.19 | 2310.23 | 16   | 11.4015 |
| 571000 | 5441.69 | 4650.16 | 32   | 45.3165 |
| 575830 | 3007.39 | 2282.88 | 9.25 | 11.175  |
| 576250 | 4413.38 | 3361.72 | 17   | 18.0867 |
| 578000 | 1701.08 | 4437.61 | 18   | 6.6916  |
| 585380 | 838.5   | 792.74  | 2.75 | 4.2057  |
| 588400 | 2602.16 | 2118.76 | 10   | 10.6421 |
| 588500 | 12268.8 | 5662.08 | 18   | 30.2938 |
| 596000 | 4444.1  | 3440.98 | 10   | 15.6504 |
| 597300 | 1616.06 | 911.3   | 14   | 2.9346  |
| 597400 | 1956.79 | 1145.62 | 2.5  | 4.4868  |
| 597450 | 394.51  | 418.57  | 1    | 0.959   |
| 598000 | 7806.57 | 6213.39 | 40   | 38.3535 |
| 600500 | 1402.13 | 1728.65 | 8    | 5.1624  |

|        |         |         |      |         |
|--------|---------|---------|------|---------|
| 602500 | 7900.82 | 4636.16 | 10   | 21.5233 |
| 604000 | 9341.35 | 5636.04 | 36   | 40.0017 |
| 604070 | 163.56  | 389.02  | 1.25 | 0.7115  |
| 604080 | 522.71  | 589.69  | 1.75 | 1.3876  |
| 604090 | 2157.7  | 1143.48 | 1.5  | 2.7106  |
| 604100 | 2650.73 | 1352.88 | 2.25 | 3.8567  |
| 605555 | 2131.63 | 1944.75 | 8    | 8.5605  |
| 606500 | 2365.22 | 3313.16 | 44   | 33.2731 |

| STATION | Q75F<br>Measured | Q75F<br>Predicted | T75F<br>Measured | T75F<br>Predicted |
|---------|------------------|-------------------|------------------|-------------------|
| 24300   | 858.92           | 1383.17           | 30.208           | 22.5522           |
| 24500   | 2248.01          | 3550.02           | 101.972          | 57.4835           |
| 25500   | 2840.11          | 3976.26           | 70.355           | 63.8662           |
| 26500   | 3203.65          | 1751.64           | 16.908           | 35.514            |
| 27500   | 2997.55          | 4244.19           | 81.262           | 60.8617           |
| 28500   | 1100.33          | 1651.12           | 38.46            | 24.5721           |
| 28930   | 1256.03          | 593.95            | 2.414            | 4.3925            |
| 28935   | 581.25           | 295.45            | 1.173            | 2.0786            |
| 28940   | 1664.89          | 731.86            | 2.781            | 5.8809            |
| 28950   | 2646.81          | 875.24            | 3.845            | 8.3546            |
| 29000   | 2424.27          | 3490.59           | 71.795           | 56.3645           |
| 30500   | 3831.95          | 3856.08           | 74.361           | 69.8776           |
| 130900  | 826.14           | 2359.99           | 72.153           | 23.9287           |
| 131150  | 462.73           | 828.12            | 27.716           | 19.802            |
| 135500  | 3450.47          | 3610.09           | 63.23            | 59.1942           |
| 147500  | 3947.62          | 3153.82           | 34.131           | 31.6137           |
| 148300  | 589.94           | 1376.23           | 32.7             | 15.0175           |
| 154500  | 2611.78          | 3384.57           | 32.35            | 16.4497           |
| 157500  | 1521.11          | 1903.76           | 31.374           | 18.9556           |
| 158000  | 2303.77          | 3144.28           | 48.146           | 26.0371           |
| 158500  | 2146.38          | 2270.37           | 34.362           | 24.6118           |
| 159000  | 2640.14          | 3036.02           | 29.875           | 29.4298           |
| 160000  | 2185.91          | 3072.91           | 43.923           | 30.6362           |
| 162010  | 2425.64          | 1634.2            | 10.246           | 15.9144           |
| 162500  | 3860.41          | 3975.14           | 29.663           | 37.4406           |
| 163000  | 4802.81          | 4208.46           | 34.509           | 49.3505           |
| 165000  | 3443.55          | 3623.98           | 44.556           | 32.9192           |
| 165200  | 638.77           | 1272.64           | 30.236           | 12.5129           |
| 169550  | 1283.26          | 2919.07           | 50.559           | 23.5918           |
| 172500  | 2279.1           | 3100.58           | 59.982           | 33.0293           |
| 175500  | 1374.46          | 3476.01           | 119.687          | 51.9602           |
| 176500  | 1379.09          | 2751.46           | 72.286           | 39.4456           |
| 184500  | 1910.64          | 3887.5            | 8.233            | 5.1625            |
| 185000  | 5944.03          | 5998.1            | 8.9376           | 10.4698           |
| 185200  | 2804.15          | 2344.88           | 8.694            | 15.457            |
| 197300  | 1817.59          | 2256.91           | 22.3842          | 19.9626           |
| 313600  | 291.66           | 304.75            | 1.5241           | 1.7366            |
| 342933  | 3490.28          | 2647.63           | 21.2199          | 21.5515           |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 343300 | 2835.65 | 2613.96 | 21.5298 | 29.2989 |
| 399800 | 675.7   | 1128.12 | 10.976  | 7.1329  |
| 404400 | 6137.47 | 4793.25 | 23.693  | 50.6122 |
| 407900 | 852.57  | 1018.31 | 7.0644  | 6.5655  |
| 408500 | 7192.69 | 4280.52 | 34.3804 | 45.3055 |
| 410000 | 1170.76 | 749.11  | 2.4042  | 3.4026  |
| 412320 | 259.72  | 476.26  | 3.3136  | 1.9861  |
| 413400 | 926.44  | 775.77  | 4.8171  | 4.7081  |
| 414500 | 7017.41 | 4970.32 | 16.6486 | 18.6567 |
| 414800 | 1714.46 | 974.81  | 3.518   | 4.1589  |
| 416000 | 3205.48 | 2472.98 | 20.7088 | 22.1045 |
| 417400 | 354.3   | 359.89  | 3.0879  | 1.9378  |
| 418000 | 1176.61 | 2205.51 | 16.8543 | 18.4075 |
| 420360 | 374.61  | 397.34  | 2.7304  | 3.2527  |
| 420400 | 600.72  | 729.77  | 7.2874  | 5.4346  |
| 424010 | 204.36  | 232.37  | 1.5077  | 1.4476  |
| 426800 | 1627.83 | 1891.65 | 10.0697 | 10.3587 |
| 427013 | 518.95  | 566.38  | 3.3923  | 2.4979  |
| 427500 | 5500.48 | 3356.33 | 25.8168 | 40.6591 |
| 427830 | 93.43   | 127.57  | 1.0189  | 0.7848  |
| 427840 | 1034.8  | 636.9   | 2.0738  | 2.9136  |
| 428300 | 770.51  | 950.02  | 14.2861 | 7.4744  |
| 430400 | 3202.49 | 963.76  | 2.6832  | 6.6114  |
| 431000 | 2874.33 | 1821.12 | 13.8257 | 18.6623 |
| 431520 | 1097.47 | 680.68  | 1.5396  | 3.1742  |
| 431700 | 4875.74 | 1464.45 | 3.1634  | 8.4777  |
| 435030 | 2024.77 | 1066.83 | 4.6479  | 7.4883  |
| 435600 | 1001.56 | 567.46  | 1.6141  | 3.3268  |
| 436700 | 3371.92 | 2700.16 | 18.4884 | 23.5113 |
| 437800 | 644.16  | 1056.81 | 11.2285 | 6.4833  |
| 450200 | 708.75  | 968.12  | 7.3318  | 7.1778  |
| 453900 | 431.14  | 658.35  | 3.4843  | 3.8148  |
| 455000 | 6877.3  | 3648.21 | 26.6507 | 42.9487 |
| 464000 | 3312.94 | 2883.38 | 31.9127 | 41.2317 |
| 465205 | 360.84  | 565.97  | 4.2376  | 3.4951  |
| 467000 | 4478.06 | 2682.64 | 24.1474 | 44.4801 |
| 469736 | 865.86  | 689.87  | 5.1673  | 5.7886  |
| 485500 | 3319.03 | 4609.16 | 15.9784 | 13.3938 |
| 486225 | 1514.8  | 894.89  | 1.4828  | 2.7028  |
| 491000 | 2100.85 | 1651.09 | 11.7811 | 15.1466 |
| 497300 | 3916.59 | 4714.66 | 13.3897 | 9.8231  |
| 498500 | 6855.55 | 6535.94 | 15.6132 | 18.1098 |
| 518500 | 3971.78 | 4834.14 | 9.6854  | 10.7081 |
| 519610 | 497.64  | 453.44  | 1.9485  | 2.5173  |
| 519630 | 248.95  | 425.67  | 1.7433  | 1.8287  |
| 519650 | 415.7   | 489.62  | 3.444   | 4.1934  |
| 535000 | 1656.1  | 2065.74 | 20.3037 | 17.1616 |
| 535140 | 419.9   | 317.78  | 1.5576  | 2.1877  |
| 535160 | 1138.93 | 862.73  | 8.7219  | 9.0706  |
| 535180 | 417.84  | 562.01  | 3.2302  | 3.0833  |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 538225 | 1478.42 | 2196.85 | 29.2591 | 19.4815 |
| 538250 | 841.85  | 970.98  | 11.9106 | 11.1605 |
| 538900 | 341.01  | 570.98  | 5.7753  | 3.6129  |
| 539100 | 129.2   | 274.48  | 4.5579  | 2.3265  |
| 539600 | 3418.44 | 2584.86 | 19.1697 | 28.154  |
| 539800 | 12410.1 | 6665.8  | 18.1396 | 36.2713 |
| 543500 | 2742.34 | 2560.47 | 22.336  | 23.5816 |
| 556000 | 871.8   | 1429.72 | 13.4268 | 9.7687  |
| 565300 | 1046.48 | 1318.92 | 11.9817 | 12.9912 |
| 565500 | 890.69  | 1500.98 | 33.3801 | 20.9547 |
| 566420 | 943.1   | 1027.89 | 11.675  | 9.9807  |
| 567500 | 4411.91 | 4245.51 | 51.9429 | 51.8609 |
| 568500 | 1449.14 | 1732.67 | 21.6317 | 15.3512 |
| 571000 | 4081.27 | 3487.62 | 44.8231 | 61.9878 |
| 575830 | 2255.54 | 1712.16 | 13.7902 | 15.0427 |
| 576250 | 3310.03 | 2521.29 | 21.0543 | 24.4946 |
| 578000 | 1275.81 | 3328.2  | 24.2942 | 8.9863  |
| 585380 | 628.88  | 594.55  | 4.0409  | 5.5863  |
| 588400 | 1951.62 | 1589.07 | 11.9815 | 14.3146 |
| 588500 | 9201.6  | 4246.56 | 22.9112 | 41.3103 |
| 596000 | 3333.08 | 2580.73 | 14.6094 | 21.1678 |
| 597300 | 1212.05 | 683.48  | 16.7885 | 3.8866  |
| 597400 | 1467.59 | 859.22  | 3.3278  | 5.9717  |
| 597450 | 295.88  | 313.93  | 1.2445  | 1.2529  |
| 598000 | 5854.93 | 4660.04 | 50.2319 | 52.4373 |
| 600500 | 1051.6  | 1296.49 | 9.1545  | 6.8909  |
| 602500 | 5925.61 | 3477.12 | 13.3337 | 29.2327 |
| 604000 | 7006.01 | 4227.03 | 44.1017 | 54.6926 |
| 604070 | 122.67  | 291.77  | 1.7865  | 0.9266  |
| 604080 | 392.03  | 442.27  | 2.2423  | 1.8216  |
| 604090 | 1618.27 | 857.61  | 1.8218  | 3.5903  |
| 604100 | 1988.05 | 1014.66 | 2.6788  | 5.1289  |
| 605555 | 1598.72 | 1458.56 | 9.793   | 11.4871 |
| 606500 | 1773.92 | 2484.87 | 58.4433 | 45.3216 |

| STATION | Q50F<br>Measured | Q50F<br>Predicted | T50F<br>Measured | T50F<br>Predicted |
|---------|------------------|-------------------|------------------|-------------------|
| 24300   | 572.61           | 922.11            | 38.93            | 27.0503           |
| 24500   | 1498.67          | 2366.68           | 125.728          | 69.8494           |
| 25500   | 1893.41          | 2650.84           | 93.237           | 77.7382           |
| 26500   | 2135.76          | 1167.76           | 20.186           | 42.5403           |
| 27500   | 1998.37          | 2829.46           | 100.478          | 74.323            |
| 28500   | 733.56           | 1100.75           | 44.28            | 29.6007           |
| 28930   | 837.36           | 395.97            | 2.772            | 5.2951            |
| 28935   | 387.5            | 196.96            | 1.489            | 2.4846            |
| 28940   | 1109.93          | 487.91            | 3.163            | 7.0972            |
| 28950   | 1764.54          | 583.49            | 4.229            | 10.0709           |
| 29000   | 1616.18          | 2327.06           | 88.855           | 68.4779           |
| 30500   | 2554.64          | 2570.72           | 93.571           | 84.8055           |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 130900 | 550.76  | 1573.33 | 85.326  | 29.1997 |
| 131150 | 308.49  | 552.08  | 36.023  | 23.3981 |
| 135500 | 2300.31 | 2406.72 | 77.594  | 71.9256 |
| 147500 | 2631.75 | 2102.55 | 37.585  | 38.7393 |
| 148300 | 393.29  | 917.49  | 41.898  | 18.1635 |
| 154500 | 1741.19 | 2256.38 | 37.393  | 20.4846 |
| 157500 | 1014.08 | 1269.18 | 35.626  | 23.0723 |
| 158000 | 1535.85 | 2096.18 | 54.807  | 32.0322 |
| 158500 | 1430.92 | 1513.58 | 40.988  | 29.9754 |
| 159000 | 1760.09 | 2024.01 | 40.346  | 36.0697 |
| 160000 | 1457.28 | 2048.61 | 52.175  | 37.5324 |
| 162010 | 1617.09 | 1089.46 | 11.525  | 19.3394 |
| 162500 | 2573.6  | 2650.1  | 43.174  | 46.0843 |
| 163000 | 3201.87 | 2805.64 | 48.336  | 60.5129 |
| 165000 | 2295.7  | 2415.99 | 50.014  | 40.4987 |
| 165200 | 425.85  | 848.43  | 34.911  | 15.1511 |
| 169550 | 855.51  | 1946.05 | 64.066  | 29.0092 |
| 172500 | 1519.4  | 2067.06 | 69.041  | 40.4131 |
| 175500 | 916.31  | 2317.34 | 152.691 | 63.2254 |
| 176500 | 919.39  | 1834.31 | 90.587  | 47.887  |
| 184500 | 1273.76 | 2591.67 | 11.54   | 6.6181  |
| 185000 | 3962.69 | 3998.73 | 12.4962 | 13.4244 |
| 185200 | 1869.43 | 1563.25 | 11.9922 | 19.0308 |
| 197300 | 1211.73 | 1504.61 | 27.9061 | 24.4147 |
| 313600 | 194.44  | 203.17  | 1.8678  | 2.0859  |
| 342933 | 2326.85 | 1765.09 | 24.3214 | 26.4613 |
| 343300 | 1890.43 | 1742.64 | 28.0476 | 35.7274 |
| 399800 | 450.46  | 752.08  | 14.3933 | 8.7026  |
| 404400 | 4091.65 | 3195.5  | 39.3551 | 62.3066 |
| 407900 | 568.38  | 678.87  | 8.5206  | 7.996   |
| 408500 | 4795.12 | 2853.68 | 39.0117 | 55.6851 |
| 410000 | 780.51  | 499.4   | 2.7784  | 4.157   |
| 412320 | 173.15  | 317.51  | 4.34    | 2.4158  |
| 413400 | 617.62  | 517.18  | 5.873   | 5.7199  |
| 414500 | 4678.27 | 3313.55 | 18.4922 | 23.4813 |
| 414800 | 1142.97 | 649.88  | 3.9529  | 5.1059  |
| 416000 | 2136.99 | 1648.65 | 23.3351 | 27.062  |
| 417400 | 236.2   | 239.92  | 3.4522  | 2.3356  |
| 418000 | 784.41  | 1470.34 | 21.6219 | 22.5331 |
| 420360 | 249.74  | 264.89  | 3.2895  | 3.8914  |
| 420400 | 400.48  | 486.51  | 8.7176  | 6.5688  |
| 424010 | 136.24  | 154.91  | 1.8223  | 1.7291  |
| 426800 | 1085.22 | 1261.1  | 12.9328 | 12.7659 |
| 427013 | 345.97  | 377.59  | 3.7355  | 3.042   |
| 427500 | 3666.99 | 2237.55 | 30.0855 | 49.6685 |
| 427830 | 62.29   | 85.05   | 1.1645  | 0.9301  |
| 427840 | 689.87  | 424.6   | 2.4455  | 3.5511  |
| 428300 | 513.67  | 633.34  | 15.886  | 9.0564  |
| 430400 | 2135    | 642.51  | 2.977   | 8.0354  |
| 431000 | 1916.22 | 1214.08 | 15.4861 | 22.6878 |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 431520 | 731.65  | 453.78  | 1.8977  | 3.8707  |
| 431700 | 3250.5  | 976.3   | 3.5369  | 10.3993 |
| 435030 | 1349.85 | 711.22  | 5.2749  | 9.1093  |
| 435600 | 667.71  | 378.31  | 2.0289  | 4.0275  |
| 436700 | 2247.95 | 1800.11 | 21.0447 | 28.8345 |
| 437800 | 429.44  | 704.54  | 13.8042 | 7.908   |
| 450200 | 472.5   | 645.41  | 8.8329  | 8.7101  |
| 453900 | 287.42  | 438.9   | 4.5981  | 4.6287  |
| 455000 | 4584.87 | 2432.14 | 32.9894 | 52.5565 |
| 464000 | 2208.62 | 1922.25 | 40.0433 | 50.0899 |
| 465205 | 240.56  | 377.32  | 5.1894  | 4.2265  |
| 467000 | 2985.38 | 1788.43 | 31.2766 | 53.8163 |
| 469736 | 577.24  | 459.91  | 6.0234  | 6.974   |
| 485500 | 2212.69 | 3072.78 | 22.1714 | 16.9306 |
| 486225 | 1009.87 | 596.59  | 1.8346  | 3.3384  |
| 491000 | 1400.57 | 1100.73 | 13.8953 | 18.432  |
| 497300 | 2611.06 | 3143.11 | 18.389  | 12.5075 |
| 498500 | 4570.37 | 4357.29 | 19.9351 | 23.0239 |
| 518500 | 2647.85 | 3222.76 | 12.2267 | 13.6216 |
| 519610 | 331.76  | 302.29  | 2.4694  | 3.0417  |
| 519630 | 165.96  | 283.78  | 2.6219  | 2.2196  |
| 519650 | 277.13  | 326.42  | 4.8052  | 5.0265  |
| 535000 | 1104.07 | 1377.16 | 23.9318 | 20.9913 |
| 535140 | 279.93  | 211.85  | 1.8529  | 2.6188  |
| 535160 | 759.29  | 575.15  | 10.4369 | 10.9097 |
| 535180 | 278.56  | 374.68  | 4.3264  | 3.7374  |
| 538225 | 985.61  | 1464.57 | 35.2915 | 23.8163 |
| 538250 | 561.23  | 647.32  | 13.3768 | 13.4199 |
| 538900 | 227.34  | 380.65  | 7.4927  | 4.3672  |
| 539100 | 86.13   | 182.99  | 5.6547  | 2.7673  |
| 539600 | 2278.96 | 1723.24 | 22.7899 | 34.3467 |
| 539800 | 8273.4  | 4443.86 | 22.998  | 45.4793 |
| 543500 | 1828.23 | 1706.98 | 25.1345 | 28.866  |
| 556000 | 581.2   | 953.15  | 15.8714 | 11.9376 |
| 565300 | 697.65  | 879.28  | 14.5156 | 15.7373 |
| 565500 | 593.79  | 1000.65 | 38.6718 | 25.244  |
| 566420 | 628.74  | 685.26  | 13.2503 | 12.0531 |
| 567500 | 2941.27 | 2830.34 | 60.1725 | 63.5444 |
| 568500 | 966.09  | 1155.12 | 25.093  | 18.7067 |
| 571000 | 2720.84 | 2325.08 | 63.9558 | 75.1578 |
| 575830 | 1503.69 | 1141.44 | 17.2496 | 18.331  |
| 576250 | 2206.69 | 1680.86 | 25.9505 | 29.9438 |
| 578000 | 850.54  | 2218.8  | 30.384  | 11.3263 |
| 585380 | 419.25  | 396.37  | 5.449   | 6.7008  |
| 588400 | 1301.08 | 1059.38 | 13.6565 | 17.417  |
| 588500 | 6134.4  | 2831.04 | 26.5438 | 50.8587 |
| 596000 | 2222.05 | 1720.49 | 17.0881 | 25.9769 |
| 597300 | 808.03  | 455.65  | 19.7664 | 4.7201  |
| 597400 | 978.39  | 572.81  | 3.942   | 7.2446  |
| 597450 | 197.25  | 209.28  | 1.4907  | 1.5168  |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 598000 | 3903.28 | 3106.69 | 56.5808 | 64.4428 |
| 600500 | 701.06  | 864.32  | 10.466  | 8.4539  |
| 602500 | 3950.41 | 2318.08 | 16.0272 | 36.0014 |
| 604000 | 4670.67 | 2818.02 | 52.7612 | 66.9295 |
| 604070 | 81.78   | 194.51  | 2.3768  | 1.126   |
| 604080 | 261.35  | 294.85  | 2.618   | 2.2141  |
| 604090 | 1078.85 | 571.74  | 2.1348  | 4.4019  |
| 604100 | 1325.36 | 676.44  | 3.1152  | 6.2779  |
| 605555 | 1065.81 | 972.37  | 11.3462 | 13.9996 |
| 606500 | 1182.61 | 1656.58 | 73.5825 | 54.6682 |

| STATION | Q25F<br>Measured | Q25F<br>Predicted | T25F<br>Measured | T25F<br>Predicted |
|---------|------------------|-------------------|------------------|-------------------|
| 24300   | 286.31           | 461.06            | 49.727           | 33.455            |
| 24500   | 749.33           | 1183.34           | 161.928          | 87.903            |
| 25500   | 946.7            | 1325.42           | 110.102          | 98.078            |
| 26500   | 1067.88          | 583.88            | 30.263           | 52.161            |
| 27500   | 999.18           | 1414.73           | 124.556          | 94.51             |
| 28500   | 366.78           | 550.37            | 53.35            | 36.925            |
| 28930   | 418.68           | 197.98            | 3.38             | 6.758             |
| 28935   | 193.75           | 98.48             | 1.88             | 3.141             |
| 28940   | 554.96           | 243.95            | 3.677            | 9.048             |
| 28950   | 882.27           | 291.75            | 4.668            | 12.75             |
| 29000   | 808.09           | 1163.53           | 109.55           | 86.165            |
| 30500   | 1277.32          | 1285.36           | 117.341          | 106.176           |
| 130900  | 275.38           | 786.66            | 108.271          | 37.499            |
| 131150  | 154.24           | 276.04            | 45.011           | 28.031            |
| 135500  | 1150.16          | 1203.36           | 94.111           | 90.476            |
| 147500  | 1315.88          | 1051.27           | 41.595           | 50.045            |
| 148300  | 196.65           | 458.74            | 51.935           | 23.001            |
| 154500  | 870.6            | 1128.19           | 43.236           | 27.653            |
| 157500  | 507.04           | 634.59            | 40.596           | 29.548            |
| 158000  | 767.92           | 1048.09           | 64.531           | 41.848            |
| 158500  | 715.46           | 756.79            | 57.034           | 38.317            |
| 159000  | 880.05           | 1012.01           | 55.82            | 46.657            |
| 160000  | 728.64           | 1024.3            | 60.891           | 48.4788           |
| 162010  | 808.55           | 544.73            | 13.382           | 24.7313           |
| 162500  | 1286.8           | 1325.05           | 56.808           | 60.0027           |
| 163000  | 1600.94          | 1402.82           | 65.757           | 77.8563           |
| 165000  | 1147.85          | 1207.99           | 59.682           | 52.755            |
| 165200  | 212.92           | 424.21            | 43.423           | 19.2772           |
| 169550  | 427.75           | 973.02            | 79.235           | 37.9019           |
| 172500  | 759.7            | 1033.53           | 83.984           | 52.0043           |
| 175500  | 458.15           | 1158.67           | 185.86           | 79.9131           |
| 176500  | 459.7            | 917.15            | 114.589          | 60.4208           |
| 184500  | 636.88           | 1295.83           | 16.744           | 9.6694            |
| 185000  | 1981.34          | 1999.37           | 18.4682          | 19.4511           |
| 185200  | 934.72           | 781.63            | 17.8807          | 25.0664           |
| 197300  | 605.87           | 752.3             | 34.7278          | 31.5827           |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 313600 | 97.22   | 101.58  | 2.4256  | 2.6711  |
| 342933 | 1163.43 | 882.54  | 28.9767 | 34.4975 |
| 343300 | 945.22  | 871.32  | 40.0562 | 45.696  |
| 399800 | 225.23  | 376.04  | 19.2606 | 11.3403 |
| 404400 | 2045.82 | 1597.75 | 69.5103 | 80.8512 |
| 407900 | 284.19  | 339.44  | 10.7222 | 10.3883 |
| 408500 | 2397.56 | 1426.84 | 44.4189 | 72.1016 |
| 410000 | 390.25  | 249.7   | 3.572   | 5.4831  |
| 412320 | 86.57   | 158.75  | 6.1074  | 3.1766  |
| 413400 | 308.81  | 258.59  | 7.232   | 7.4214  |
| 414500 | 2339.14 | 1656.77 | 21.8478 | 32.4096 |
| 414800 | 571.49  | 324.94  | 4.8496  | 6.7919  |
| 416000 | 1068.49 | 824.33  | 29.6562 | 35.0433 |
| 417400 | 118.1   | 119.96  | 4.233   | 3.0099  |
| 418000 | 392.2   | 735.17  | 29.9746 | 29.2366 |
| 420360 | 124.87  | 132.45  | 4.4188  | 4.9011  |
| 420400 | 200.24  | 243.26  | 10.7609 | 8.4112  |
| 424010 | 68.12   | 77.46   | 2.3921  | 2.1918  |
| 426800 | 542.61  | 630.55  | 17.0612 | 16.934  |
| 427013 | 172.98  | 188.79  | 4.1444  | 3.9992  |
| 427500 | 1833.49 | 1118.78 | 37.703  | 63.5218 |
| 427830 | 31.14   | 42.52   | 1.4196  | 1.1672  |
| 427840 | 344.94  | 212.3   | 2.9516  | 4.6684  |
| 428300 | 256.84  | 316.67  | 18.0913 | 11.6141 |
| 430400 | 1067.5  | 321.25  | 3.5099  | 10.3911 |
| 431000 | 958.11  | 607.04  | 17.99   | 28.9827 |
| 431520 | 365.82  | 226.89  | 2.719   | 5.0888  |
| 431700 | 1625.25 | 488.15  | 4.4679  | 13.6862 |
| 435030 | 674.92  | 355.61  | 6.3997  | 11.7855 |
| 435600 | 333.85  | 189.15  | 2.6996  | 5.2068  |
| 436700 | 1123.97 | 900.05  | 30.4692 | 37.4556 |
| 437800 | 214.72  | 352.27  | 18.0231 | 10.3112 |
| 450200 | 236.25  | 322.71  | 13.5275 | 11.213  |
| 453900 | 143.71  | 219.45  | 6.2642  | 6.0043  |
| 455000 | 2292.43 | 1216.07 | 44.9001 | 67.43   |
| 464000 | 1104.31 | 961.13  | 55.4439 | 63.2631 |
| 465205 | 120.28  | 188.66  | 7.5387  | 5.4471  |
| 467000 | 1492.69 | 894.21  | 41.6683 | 67.2907 |
| 469736 | 288.62  | 229.96  | 7.2404  | 8.8584  |
| 485500 | 1106.34 | 1536.39 | 33.5471 | 23.6916 |
| 486225 | 504.93  | 298.3   | 2.3991  | 4.5253  |
| 491000 | 700.28  | 550.36  | 18.0424 | 23.6585 |
| 497300 | 1305.53 | 1571.55 | 27.8186 | 17.8566 |
| 498500 | 2285.18 | 2178.65 | 29.3229 | 32.5128 |
| 518500 | 1323.93 | 1611.38 | 20.7926 | 19.3857 |
| 519610 | 165.88  | 151.15  | 3.0832  | 3.9291  |
| 519630 | 82.98   | 141.89  | 4.1805  | 2.9076  |
| 519650 | 138.57  | 163.21  | 6.6945  | 6.3376  |
| 535000 | 552.04  | 688.58  | 30.9801 | 27.2114 |
| 535140 | 139.97  | 105.93  | 2.2837  | 3.3188  |

|        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 535160 | 379.64  | 287.58  | 13.3408 | 13.7295 |
| 535180 | 139.28  | 187.34  | 5.9398  | 4.8499  |
| 538225 | 492.81  | 732.28  | 43.6819 | 30.7889 |
| 538250 | 280.62  | 323.66  | 15.4566 | 16.8357 |
| 538900 | 113.67  | 190.33  | 10.2155 | 5.6213  |
| 539100 | 43.07   | 91.49   | 7.1163  | 3.4551  |
| 539600 | 1139.48 | 861.62  | 37.6748 | 43.9956 |
| 539800 | 4136.7  | 2221.93 | 34.7432 | 61.7366 |
| 543500 | 914.12  | 853.49  | 30.2005 | 37.3367 |
| 556000 | 290.6   | 476.57  | 20.7207 | 15.551  |
| 565300 | 348.83  | 439.64  | 21.765  | 20.0338 |
| 565500 | 296.9   | 500.33  | 49.4704 | 31.5547 |
| 566420 | 314.37  | 342.63  | 15.7547 | 15.288  |
| 567500 | 1470.64 | 1415.17 | 77.7774 | 81.5726 |
| 568500 | 483.05  | 577.56  | 34.0879 | 24.0815 |
| 571000 | 1360.42 | 1162.54 | 89.7865 | 94.0348 |
| 575830 | 751.85  | 570.72  | 21.7687 | 23.6045 |
| 576250 | 1103.34 | 840.43  | 31.683  | 38.5982 |
| 578000 | 425.27  | 1109.4  | 42.9423 | 15.8251 |
| 585380 | 209.63  | 198.18  | 7.7234  | 8.4321  |
| 588400 | 650.54  | 529.69  | 16.9216 | 22.3644 |
| 588500 | 3067.2  | 1415.52 | 32.3646 | 66.1717 |
| 596000 | 1111.03 | 860.24  | 21.6667 | 33.8352 |
| 597300 | 404.02  | 227.83  | 25.8275 | 6.1337  |
| 597400 | 489.2   | 286.41  | 5.0284  | 9.3418  |
| 597450 | 98.63   | 104.64  | 1.8909  | 1.9846  |
| 598000 | 1951.64 | 1553.35 | 66.7942 | 83.2676 |
| 600500 | 350.53  | 432.16  | 12.7785 | 11.1577 |
| 602500 | 1975.2  | 1159.04 | 21.561  | 47.0762 |
| 604000 | 2335.34 | 1409.01 | 60.4063 | 85.6201 |
| 604070 | 40.89   | 97.26   | 3.288   | 1.4914  |
| 604080 | 130.68  | 147.42  | 3.4172  | 2.9096  |
| 604090 | 539.43  | 285.87  | 2.8574  | 5.8485  |
| 604100 | 662.68  | 338.22  | 4.1806  | 8.2737  |
| 605555 | 532.91  | 486.19  | 13.9447 | 18.0915 |
| 606500 | 591.31  | 828.29  | 92.8786 | 67.8786 |

| STATION | QBASE<br>Measured | QBASE<br>Predicted | TBASE<br>Measured | TBASE<br>Predicted |
|---------|-------------------|--------------------|-------------------|--------------------|
| 24300   | 0                 | 0                  | 138               | 74.592             |
| 24500   | 0                 | 0                  | 348               | 192.776            |
| 25500   | 0                 | 0                  | 220               | 215.096            |
| 26500   | 0                 | 0                  | 90                | 108.962            |
| 27500   | 0                 | 0                  | 282               | 213.632            |
| 28500   | 0                 | 0                  | 162               | 84.15              |
| 28930   | 0                 | 0                  | 11                | 19.082             |
| 28935   | 0                 | 0                  | 5.5               | 9.116              |
| 28940   | 0                 | 0                  | 8                 | 24.863             |
| 28950   | 0                 | 0                  | 11.25             | 33.283             |

|        |   |   |       |         |
|--------|---|---|-------|---------|
| 29000  | 0 | 0 | 204   | 189.173 |
| 30500  | 0 | 0 | 288   | 225.317 |
| 130900 | 0 | 0 | 180   | 94.413  |
| 131150 | 0 | 0 | 71    | 56.758  |
| 135500 | 0 | 0 | 142   | 197.664 |
| 147500 | 0 | 0 | 105   | 125.685 |
| 148300 | 0 | 0 | 76    | 57.342  |
| 154500 | 0 | 0 | 90    | 84.804  |
| 157500 | 0 | 0 | 113   | 75.083  |
| 158000 | 0 | 0 | 125   | 110.833 |
| 158500 | 0 | 0 | 126   | 94.768  |
| 159000 | 0 | 0 | 94    | 118.359 |
| 160000 | 0 | 0 | 130   | 121.997 |
| 162010 | 0 | 0 | 53    | 63.423  |
| 162500 | 0 | 0 | 112   | 152.63  |
| 163000 | 0 | 0 | 128   | 186.137 |
| 165000 | 0 | 0 | 113   | 135.796 |
| 165200 | 0 | 0 | 77.75 | 49.546  |
| 169550 | 0 | 0 | 134   | 101.21  |
| 172500 | 0 | 0 | 167   | 128.459 |
| 175500 | 0 | 0 | 258   | 179.264 |
| 176500 | 0 | 0 | 213   | 137.751 |
| 184500 | 0 | 0 | 55    | 42.407  |
| 185000 | 0 | 0 | 74    | 78.398  |
| 185200 | 0 | 0 | 74    | 71.139  |
| 197300 | 0 | 0 | 76    | 82.663  |
| 313600 | 0 | 0 | 8.5   | 8.215   |
| 342933 | 0 | 0 | 53    | 92.112  |
| 343300 | 0 | 0 | 61    | 111.665 |
| 399800 | 0 | 0 | 33    | 33.029  |
| 404400 | 0 | 0 | 146   | 198.506 |
| 407900 | 0 | 0 | 34    | 30.153  |
| 408500 | 0 | 0 | 114   | 177.3   |
| 410000 | 0 | 0 | 15.75 | 17.648  |
| 412320 | 0 | 0 | 14.5  | 10.563  |
| 413400 | 0 | 0 | 22.5  | 22.023  |
| 414500 | 0 | 0 | 100   | 105.986 |
| 414800 | 0 | 0 | 17.75 | 22.129  |
| 416000 | 0 | 0 | 80    | 91.29   |
| 417400 | 0 | 0 | 14.5  | 9.374   |
| 418000 | 0 | 0 | 86    | 77.802  |
| 420360 | 0 | 0 | 14    | 13.56   |
| 420400 | 0 | 0 | 25.75 | 23.609  |
| 424010 | 0 | 0 | 6.75  | 6.611   |
| 426800 | 0 | 0 | 90    | 50.813  |
| 427013 | 0 | 0 | 13.75 | 13.049  |
| 427500 | 0 | 0 | 96    | 151.169 |
| 427830 | 0 | 0 | 6     | 3.575   |
| 427840 | 0 | 0 | 10    | 15.043  |
| 428300 | 0 | 0 | 40    | 31.94   |

|        |   |   |       |         |
|--------|---|---|-------|---------|
| 430400 | 0 | 0 | 13    | 29.677  |
| 431000 | 0 | 0 | 58    | 73.125  |
| 431520 | 0 | 0 | 12.25 | 16.29   |
| 431700 | 0 | 0 | 13.75 | 40.642  |
| 435030 | 0 | 0 | 22.25 | 33.38   |
| 435600 | 0 | 0 | 11.75 | 15.696  |
| 436700 | 0 | 0 | 98    | 98.118  |
| 437800 | 0 | 0 | 39.5  | 30.323  |
| 450200 | 0 | 0 | 50    | 31.338  |
| 453900 | 0 | 0 | 11    | 18.106  |
| 455000 | 0 | 0 | 62    | 161.486 |
| 464000 | 0 | 0 | 105   | 144.2   |
| 465205 | 0 | 0 | 29.75 | 16.186  |
| 467000 | 0 | 0 | 144   | 147.41  |
| 469736 | 0 | 0 | 11    | 24.08   |
| 485500 | 0 | 0 | 96    | 83.31   |
| 486225 | 0 | 0 | 9.25  | 16.257  |
| 491000 | 0 | 0 | 102   | 61.675  |
| 497300 | 0 | 0 | 86    | 68.842  |
| 498500 | 0 | 0 | 104   | 115.062 |
| 518500 | 0 | 0 | 88    | 73.44   |
| 519610 | 0 | 0 | 9.25  | 12.078  |
| 519630 | 0 | 0 | 12    | 9.61    |
| 519650 | 0 | 0 | 14.75 | 17.245  |
| 535000 | 0 | 0 | 104   | 72.599  |
| 535140 | 0 | 0 | 7     | 9.677   |
| 535160 | 0 | 0 | 22    | 34.901  |
| 535180 | 0 | 0 | 12    | 14.895  |
| 538225 | 0 | 0 | 140   | 80.57   |
| 538250 | 0 | 0 | 74    | 41.654  |
| 538900 | 0 | 0 | 19.5  | 16.588  |
| 539100 | 0 | 0 | 13.25 | 9.536   |
| 539600 | 0 | 0 | 104   | 108.393 |
| 539800 | 0 | 0 | 144   | 181.058 |
| 543500 | 0 | 0 | 84    | 96.394  |
| 556000 | 0 | 0 | 48    | 44.122  |
| 565300 | 0 | 0 | 76    | 51.43   |
| 565500 | 0 | 0 | 134   | 73.338  |
| 566420 | 0 | 0 | 56    | 39.595  |
| 567500 | 0 | 0 | 136   | 192.788 |
| 568500 | 0 | 0 | 132   | 63.328  |
| 571000 | 0 | 0 | 150   | 201.023 |
| 575830 | 0 | 0 | 34.25 | 62.233  |
| 576250 | 0 | 0 | 76    | 98.213  |
| 578000 | 0 | 0 | 180   | 57.159  |
| 585380 | 0 | 0 | 19.5  | 22.277  |
| 588400 | 0 | 0 | 84    | 58.641  |
| 588500 | 0 | 0 | 122   | 166.602 |
| 596000 | 0 | 0 | 114   | 90.198  |
| 597300 | 0 | 0 | 148   | 18.58   |

|        |   |   |       |         |
|--------|---|---|-------|---------|
| 597400 | 0 | 0 | 18.75 | 26.644  |
| 597450 | 0 | 0 | 5.75  | 6.735   |
| 598000 | 0 | 0 | 188   | 200.968 |
| 600500 | 0 | 0 | 50    | 34.01   |
| 602500 | 0 | 0 | 102   | 123.913 |
| 604000 | 0 | 0 | 192   | 199.162 |
| 604070 | 0 | 0 | 7.5   | 5.401   |
| 604080 | 0 | 0 | 7     | 9.723   |
| 604090 | 0 | 0 | 9.5   | 19.204  |
| 604100 | 0 | 0 | 15.25 | 25.697  |
| 605555 | 0 | 0 | 74    | 49.324  |
| 606500 | 0 | 0 | 198   | 145.029 |

## VITA

Kevin G. Klueh was born in Pittsburgh, Pennsylvania on November 25, 1963. He attended primary and secondary schools in Oak Ridge, Tennessee before entering the University of Tennessee, Knoxville in 1982. He received the Bachelor of Science Degree in Engineering Science and Mechanics in December 1986. Following employment as an environmental engineer for four years, he again entered the University of Tennessee in June, 1991. He is scheduled to receive the Master of Science Degree in Civil and Environmental Engineering in December, 1993.